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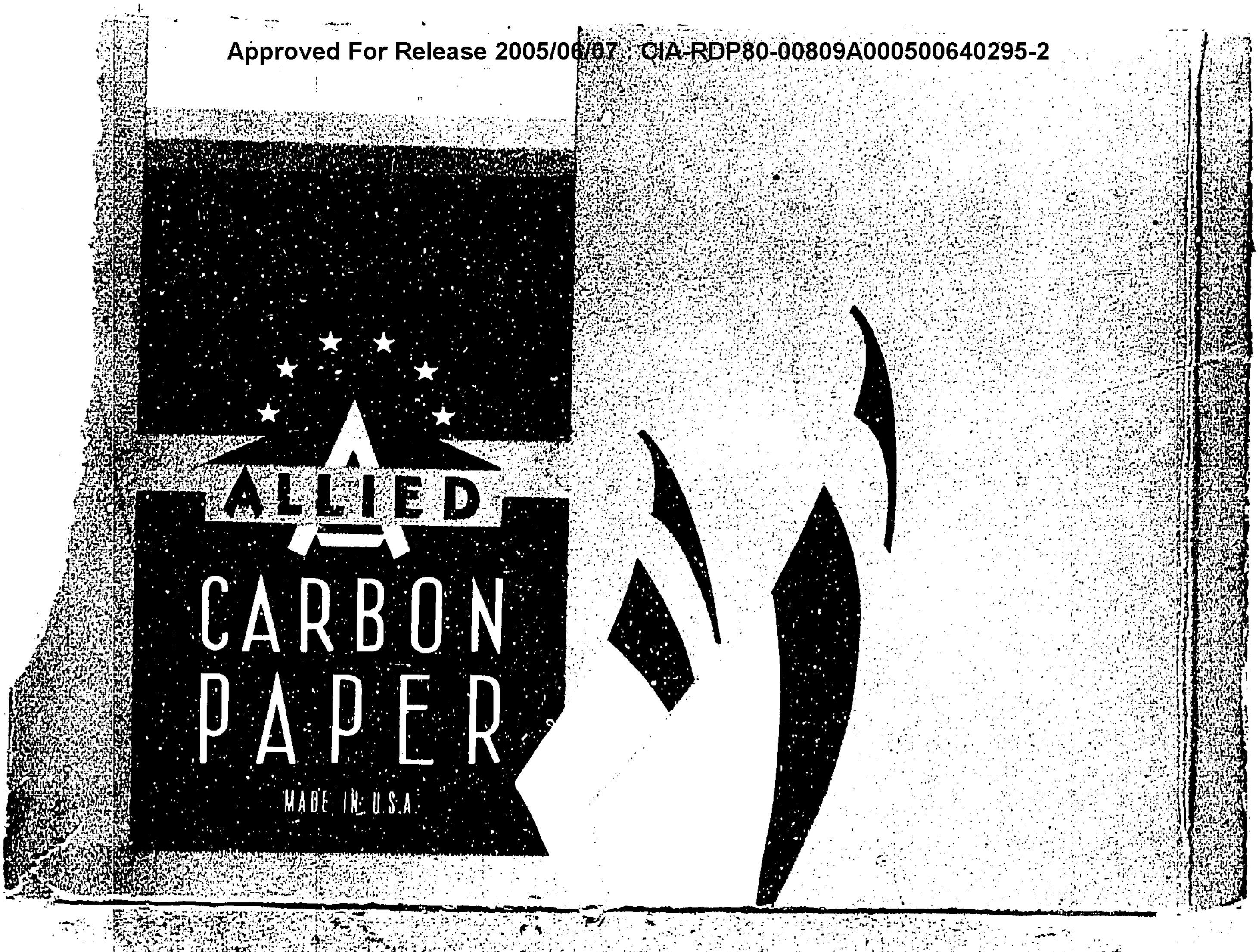
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# ORGANISATION SYSTÉMATIQUE DES OBSERVATIONS CONCERNANT LA DISPONIBILITÉ ET L'UTILISATION DE L'ÉNERGIE ÉOLIENNE POUR LA PRODUCTION DE L'ÉLECTRICITÉ

## CENTRALES AÉRO-ÉLECTRIQUES

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Le développement que les études et les réalisations dans le domaine de l'utilisation de l'énergie éolienne ont atteint soit en Italie qu'à l'étranger, rend toujours plus urgente et nécessaire une étude statistique de la disponibilité des ressources éoliennes en Italie: cette étude devrait avoir un but scientifique, mais en même temps pratique pour la recherche préliminaire sur les emplacements favorables à l'installation des centrales aéro-électriques. Elle devrait aussi servir de base pour évaluer l'intégration des ressources hydrauliques avec celle du vent, les premières étant toujours plus insuffisantes par rapport à l'augmentation continuelle des besoins industriels.

Dans l'étude des questions concernant l'utilisation de l'énergie du vent on aura recours à certaines formules et définitions fondamentales, qui ont été généralement adoptées pour les calculs et les études des aménagements éoliques.

En ce qui concerne la puissance, on peut considérer fondamentale la formule théorique indiquée par le Prof. Betz (1) pour la puissance

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(1) — Betz — Windenergie und ihre Ausnutzung in Windmühlen — Göttingen 1926.

maxima pouvant être atteinte par un moteur a vent du type normal à pales ayant un diamètre D et pour un vitesse V du vent en m/sec:

$$P_{\max} = \frac{V^3}{27} \cdot \frac{\pi D^2}{4} \text{ en kg/m/sec} = 0{,}000285\, V^3 D^2 \text{ en kW}$$

Dans cette formule on ajoute en général un coefficient $\alpha$ donné par le rapport de la densité de l'air dans les conditions d'utilisation à celle de l'air à 15° C et 760 mm.

Selon le type de la construction du moteur à vent, on doit tenir compte de pertes de rendement du 20 jusqu'au 30%, auxquelles on doit ajouter d'autres pertes dues aux transmissions et aux engrenages jusqu'au générateur; par conséquent, pour obtenir pour un moteur à vent, le maximum de puissance effectivement utilisable il est d'usage d'employer généralement un coéfficient de rendement total du 65%, qui doit être appliqué à la formule précédente.

### *Le réseau des observations anémologiques existant actuellement en Italie*

Une enquète préliminaire sur une trentaine de stations du Ministère de la Défense en Italie a déjà été développée par l'A. dans un autre mémoire (2) au sujet de la vitesse du vent sur le sol et à des hauteurs de 75 et 150 m au dessus du sol; ces vitesses avaient été enregistrées soit par des anémographes soit par des lectures directes toutes les deux heures pour les premières ou par des ballons sondes pour les deuxièmes.

De toutes ces observations on avait déduit certains renseignements assez intéressants concernant le régime des vents sur les plaines des différentes régions de l'Italie; il était par contre évident que pour une étude complète, étendue à toutes les zones montagneuses, conduite selon les critères ci-dessus, on n'aurait pu se borner à recueillir seulement les données de certaines stations du Service Météorologique de l'Aeronautique, qui pouvaient disposer des moyens d'observations en question.

Pour augmenter, par conséquent, le nombre des stations d'observation et surtout les placer à une plus grande hauteur au dessus du niveau de la mer pour arriver à celle des zones de montagne où l'on supposait favorable l'utilisation de l'énergie éolienne, il fallait se contenter d'une plus petite précision et continuité des données en tenant compte seulement des données des stations du Service susdit qui pouvaient être considerées comme le plus petit dénominateur commun auquel toutes les autres devaient se référer: ceci avait le but de rendre homogène la statistique et comparables entre eux les résultats.

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(2) — R. Vezzani — Il problema italiano dell'utilizzazione del vento — "Annali dei Lavori Pubblici". Fasc. 3, 1942.

Ceci établi, il ne serait pas à exclure comme point de départ la fréquence de la vitesse déduite des observations directes sur le vent qui se font trois fois par jour à des heures fixes, c'est à dire, selon une convention internationale, à 8 h., à 14 h. et à 19 h., en étendant moitié de chaque côté les valeurs mêmes des fréquences dans l'intervalle de temps compris entre les observations en question. De cette façon, on pourra obtenir une homogénéité de la statistique, et avoir des résultats comparables ce qui est, du reste, le but réel de ces recherches, n'étant pas tant la valeur absolue des vitesses du vent, pouvant toujours être vérifiée plus tard, qui intéresse, mais plutôt leur valeur relative qui permet de choisir l'emplacement pour le montage d'un aéromoteur.

On obtient ainsi les durées des différentes vitesses du vent, subdivisées, pour facilité d'élaboration, en degrés, soit par ex: de 0 à 2,5 m/sec, calme; de 2,6 à 3,5 m/sec, 1er degré; de 3,6 à 5,5 m/sec, 2me degré; de 5,6 à 8,5 m/sec, 3me degré; de 8,6 à 12,5 m/ sec, 4me degré; au dessus de 12,6 m/sec, 5me degré. Sur la base de ces données on pourra tracer le diagramme des durées des différentes vitesses du vent.

Dans un système d'axes orthogonaux on reporte les vitesses du vent selon les ordonnées et sur les abscisses le nombre des heures de leur durée ou bien la période en pour cent de l'intervalle c' est à dire de l'année, du mois ou du trimestre correspondant. Sil'on relie entre eux les l'année, du mois ou du trimestre correspondant. Si l'on relie entre eux les points du milieu de chaque gradin des vitesses, on obtiendra une courbe continue dont les propriétés sont bien connues. L'abscisse d'un point quelconque D (fig. 1) auquel correspond l'ordonnée OQ relative à la vitesse V représente la durée en heures de cette vitesse dans l'intervalle choisi.

Dans le mémoire de l'utilisation du vent déjà cité on a reporté les courbes de la durée des vitesses pour les 32 stations d'observation au sol et à la cote 75 et 150 m au dessus du sol pendant l'intervalle d'un an et cela pour les années 1938, 1939 et 1940. L'allure de ces courbes est assez uniforme, sauf vers le point terminal des plus grandes vitesses; la superposition ou presque des courbes se référant à différentes années est assez caractéristique, exception faite pour leur extrémité, ainsi que le rehaussement progressif de ces mêmes courbes lorsqu'on passe à la cote 75 m et à la cote 150 m au dessus du sol.

Des courbes de durée on pourra passer facilement, pour un certain diamètre du moteur à vent, aux courbes des puissances et à celles de la production d'énergie dans le temps voulu, seulement si on introduit les valeurs des vitesses dans la formule précitée, qui donne la puissance du moteur à vent d'un diamètre fixé. Ces mêmes courbes de durée sont donc toutes particulières pour chaque endroit et donnent les puissances utilisables et la production d'énergie dans un temps déterminé pour cette localité et selon un certain diamètre du moteur à vent.

Si, d'autre part, on convenait de tracer pour chaque localité où se trouve une station d'observation, cette même courbe en se basant sur un seul point de celle-ci, étant donné l'analogie et l'uniformité qui existent entre ces courbes selon ce qui est indiqué dans le mémoire déjà cité, l'erreur qui en résulterait, tout en étant inférieure ou du même ordre de celle qui pourrait se produire dans la préparation du travail, serait limitée à la dernière partie de ces courbes; ceci n'a pas grande importance du fait que cette erreur se rapporte à des vitesses du vent trop fortes pour être utilisables.

On pourra donc caractériser chaque localité où il existe une station d'observation, selon la valeur de la vitesse du vent soufflant par exemple, pour une période moyenne par an; en faisant ainsi il est certain qu'on pourra tracer avec une aproximation suffisante la courbe de la durée des vitesses du vent durant l'année et pour toutes les localités ayant des stations d'observation. En reliant entre eux les points d'égale vitesse du vent pour une durée de temps moyenne, on obtiendra une série de courbes d'égale vitesse, qui pourront montrer la distribution de l'énergie éolienne sur une certaine région; en même temps ces courbes auront un fondement scientifique assez sûr pour arriver à calculer facilement l'énergie qu'on pourra produire durant un an avec un moteur à vent dont les pales ont un diamètre déterminé.

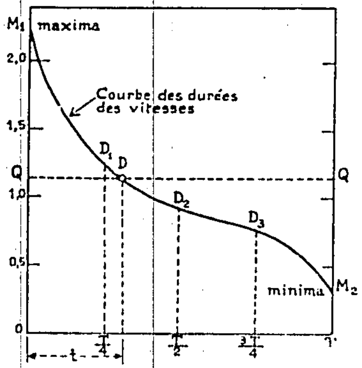

Fig. 1 — Courbe des durées des vitesses du vent.

Dans cette étude on n'a par tenu compte de la direction du vent, car on a supposé que le moteur utilisé, à axe horizontal, pourra toujours se placer automatiquement dans la position perpendiculaire à la direction du vent, dont il serait cependant indépendant s'il était à axe vertical.

Si le premier type de moteur demande des organes rotatifs assez coûteux dont l'entretien est difficile, le deuxième type par contre se prête seulement à fournir des puissances modérées. Il s'ensuit que, si on veut envisager des aménagements éoliens de grande puissance, il conviendra de ne pas tenir compte de ces types de moteurs et choisir par contre d'autres solutions pour lesquelles on puisse compter sur l'orientation du vent selon une ou deux directions en sens contraire ou bien selon un groupe de directions comprises dans un étroit secteur de l'horizon.

Dans ce cas, l'installation par exemple de tubes Venturi dans cette direction sera toujours possible: en montant l'équipement fixe du moteur a vent et du génerateur dans l'étranglement du tube, on pourra augmenter considérablement la vitesse du vent.

Avec ces appareillages brévetés, qui font l'objet de la deuxième partie de ce rapport, il sera aussi possible de déterminer en aval du moteur à vent des dépressions qui consentent d'augmenter la vitesse du courant d'air et par conséquent la puissance de l'installation. De ce fait on peut déduire l'importance que, peut avoir la connaissance de la direction du vent pour établir l'orientation fixe du moteur.

En outre dans un Pays comme l'Italie, dont l'orographie est tellement accidentée, les directions des vents dominants dépendent dans une large mesure de l'effect de canalisation d'air dans les vallées, ou de la séparation des bassins par les chaines de montagnes; ainsi, pour arriver à une représentation la plus complète possible de la distribution des vents dans une certaine région il est indispensable de connaitre la direction dominante de ceux-ci, étant donné aussi le petit nombre des stations d'observation existantes.

Pour cette recherche la détermination des directions du vent et la lecture directe de la vitesse faites à des heures fixes dans les Stations de Service Météorologique de l'Aéronautique a une grande utilité; cette détermination se fait normalement pour les huit directions de l'horizon et sur cette base il est possible, par les moyens connus, de déterminer les directions des vents dominants pendant la période d'observation.

### *Achèvement des mesures anemologiques au moyen du réseau des observations météorologiques de la pression*

Avec les données recueillies dans les stations d'observation existantes et dans celles qu'il sera possible d'installer à l'avenir, on pourra tracer les courbes isotachies de durée moyenne dans l'année pour la direction dominante du vent et passer ensuite à la recherche des localités de montagne où l'appareil précité du tube Venturi pourrait être installé pour utiliser les directions constantes du vent determinées, soit par l'engouffrement dans les vallées ou dans les gorges des montagnes, soit par le déséquilibre de la pression sur des bassins séparés par des chaînes montagneuses, soit enfin par d'autres phénomènes caractéristiques des hautes vallées, des lacs ou de la mer, comme par ex: les forts courants d'air nocturnes causés par la présence de glaciers, et les courants d'air se formant au débouché des courants froids de l'hinterland sur les côtes de la mer ou des lacs. On a ainsi la possibilité de procéder parallèlement avec la statistique des ressources hydrauliques, étant donné que même dans ce cas on pourrait procéder à l'étude des projets d'utilisation de l'énergie éolienne dans des localités bien définies, des dimensions du moteur à vent et du nombre des groupes aéromoteurs générateurs de types peu variables, de façon à pouvoir établir à peu près la quantité de l'énergie éolienne productible.

S'il s'agissait de l'énergie nécessaire pour l'intégration de l'énergie hydraulique déjà existante, une étude du régime des vents durant les différents mois de l'année se rendrait nécessaire: cette étude, établie sur les fréquences des vitesses, serait mise en rapport avec le régime des précipitations atmosphériques et par conséquent aussi des débits et de l'emmagasinement des réservoirs.

Ceci dit il est évident que, pour arriver aux résultats prévus, il serait indispensable de pouvoir disposer d'un réseau de stations d'observation très serré et distribué d'une façon uniforme sur toute la région.

Mais en Italie le réseau météorologique de l'Aéronautique est bien loin de présenter ces caractéristiques, étant surtout orienté vers les zones en plaine des aéroports et des côtes marines où il se sert des observations faites par les sémaphores de la Marine; exceptionnellement sur quelques pas de montagne ou sur quelques sommets spéciaux il existe des stations isolées.

Il faut donc avoir recours, du moins à présent, à certains procédés se basant sur plusieurs rapports existant entre la direction et la vitesse du vent d'un côté et la distribution des variables physiques, de l'autre à fin d'étudier le régime des vents au moyen de ces dernières.

### *Comparaison entre le vent gradient et le vent observé*

Les définitions en météorologie du vent géostrophique et du vent gradient sont bien connues. Lorsque le gradient de pression est compensé par la force de déviation le vent prend le nom de vent géostrophique, qui souffle le long des isobares avec une haute pression à droite de la direction du mouvement (hemisphère boréal); en outre la vitesse du vent géostrophique est proportionnelle directement au gradient de pression et inversement à la distance entre les isobares. On devra tenir compte aussi du fait que le vent géostrophique dérive de l'admission que le terme d'accélération soit négligeable; ceci s'avère lorsque les isobares sont rectilignes et parallèles et lorsque le gradient de pression ne varie pas. Si le parcours du vent a une courbure dans le même sens que les isobares, anticycloniques ou cycloniques, alors le vent prend le nom de gradient.

Le vent gradient n'ayant aucune composante radiale peut se considérer comme un véritable vent au dessus de la couche de friction, lorsque les isobares ne sont pas divergentes ou convergentes dans une mesure appréciable.

Une comparaison détaillée du vent gradient avec le vent observé a

Une comparaison détaillée du vent gradient avel le vent observé a été faite par Gold (3); cet auteur trouva que pour une hauteur de 500 m au dessus du sol la direction du vent se trouvait presqu'exactement le long des isobares au niveau de la mer, tandis que la vitesse se trouvait légèrement au dessous du vent gradient calculé.

Des recherches successives ont montré que l'influence du frottement de surface sur la terre-ferme peut être encore observée à grande hauteur, mais la différence entre le vent gradient et les vents observés est trop petite pour avoir une signification quelconque entre 500 m et 1.000 m au dessus du sol.

Lorsque les isobares sont rectilignes et leur courbure est petite, la courbure du parcours est négligeable et le vent géostrophique peut être considéré avec une bonne approximation comme le vent véritable dans la partie supérieure de la couche de frottement et au dessus de celle-ci.

Lorsque les systèmes de pression sont stationnaires, ou presque, la courbure du parcours peut différer considérablement de la courbure des isobares; on devra alors avoir soin d'employer le terme soit de vent géostrophique, soit de vent gradient, comme évaluation approximative du vent véritable au dessus de la couche qui peut être influencée par le frottement d'une façon appréciable et dans laquelle les vents observés diffèrent sensiblement du vent géostrophique calculé ou du vent gradient. Sur la terre-ferme les conditions varient sensiblement à cause des variations de la rugosité du sol: il est généralement reconnu que le rapport de la vitesse du vent observé et celle du vent géostrophique varie selon la direction du vent. En mer ces conditions sont assez simples et l'analyse des cartes du temps ont montré que le rapport entre le vent observé et le vent géostrophique est approximativement de 2 à 3. La direction du vent observé en mer est en général de 15° à 30° à gauche des isobares (dans l'hémisphère boréal). Ceci s'applique aux conditions des hautes et moyennes latitudes où la courbure des isobares est telle que le vent est essentiellement géostrophique. Sur les latitudes tropicales et subtropicales le contrôle géostrophique est faible et les vents observés peuvent être de nature Eulérienne ou anti-triptyque. Dans ces cas il n'existe aucune relation simple entre le gradient de pression et le vent.

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(3) — E. Gold — Barometric gradient and wind force — "Met. Office" n. 190 — London.

Le rapport entre le gradient de pression et les vents observés a une grande importance, soit pour le tracé des isobares en mer, où les observations de pression sont rares, soit pour les prévisions des déplacements des masses d'air et des fronts. On attire d'autre part l'attention sur le fait que le rapport entre le vent observé et le gradient de pression est sensiblement modifié et peut devenir fictif lorsque le gradient de pression change rapidement. Ceci est dû au fait que le mouvement ne survient pas entre des forces en équilibre. Dans ces conditions le mouvement tend à s'adapter au gradient de pression; mais l'équilibre est incomplet et il en résulte une composante de la vitesse le long du gradient isallobarique.

L'équation du vent gradient peut avoir seulement les solutions suivantes ayant une signification physique:

$$V_{gr} = \frac{1}{2} \lambda r \left( 1 - \sqrt{1 - \frac{4 V_{gs}}{r}} \right) \text{ courbure anti-cyclonique}$$

$$V_{gi} = \frac{1}{2} \lambda r \left( \sqrt{1 + \frac{4 V_{gs}}{r}} - 1 \right) \text{ courbure cyclonique}$$

où $\lambda$ représente le terme $2\omega \sin \varphi$ (où $\omega$ est la vitesse angulaire du disque tournant à la latitude $\varphi$) et r est le rayon de courbure.

*Echelle du vent géostrophique*

Les rapports entre vent et pression indiqués dans les équations ci-dessus peuvent être transportés sur une feuille de celluloïde en tenant compte de la projection et de l'échelle de la carte du temps. Il convient donc de transformer les variables en unités convenables.

En premier lieu la vitesse du vent peut être transformée en unité Beaufort comme on a fait dans la table I.

La vitesse du vent géostrophique est donnée par:

$$V_{gs} = \frac{1}{\rho \lambda} \quad \frac{\partial p}{\partial n}$$

où $\rho$ indique la densité de l'air et $\frac{\partial p}{\partial n}$ le gradient de pression.

En employant le système d'unités: mètre, tonnes, seconde, p devra être exprimé en centibar et $\rho$ en tonnes par m³. Si les isobares sont tracées pour chaque 5 millibar (995, 1000, 1005) on peut poser:

$$\frac{\partial p}{\partial n} = \frac{0{,}5}{H}$$

où H représente la distance entre deux isobares voisines. Puisque $\rho = p/RT$ et $\lambda = 2\,\omega \sin \varphi$, dans l'équation précèdente on a :

$$H = \frac{RT}{p} \quad \frac{1}{4\,\omega \sin \varphi\, V_{gs}} \qquad \text{(mètres)}$$

En partant de cette formule on peut calculer la distance entre les isobares voisines qui correspondent aux vitesses équivalentes indiquées dans le tableau I. Ainsi à chaque valeur de H correspond un certain vent géostrophique (qui varie selon T, p et $\varphi$) et vice-versa.

Les variations qui dépendent de T et de p sont en conséquence aussi faibles qu'il suffit dans de nombreux cas d'adopter des valeurs moyennes de ces variables. Le rapport entre H et $V_{gs}$ (pour p = 1.000 millibars et T = 283° K) est donnée par le tableau I et les corrections pour les variations de p et T sont indiquées dans le tableau II ci dessous.

### TABLEAU I

**Rapport entre le gradient de pression (0,5/4), le vent géostrophique ($V_{gs}$) et le déplacement géostrophique pour 6 heures (D) lorsque p = 1.000 $M_b$ et T = 283° K (tab. I)**

| Limites des numéros de Beaufort | Vert géostroph. | $21.600\ V_{gs} = D$ déplacement géostroph. en 6 h | Valeurs correspondantes de H (km) pour différentes latitudes | | | |
|---|---|---|---|---|---|---|
| | m/s | km | 40° | 50° | 60° | 70° |
| 2-3 | 3,4 | 75 | 1.280 | 1.080 | 945 | 875 |
| 3-4 | 5,3 | 120 | 825 | 690 | 610 | 565 |
| 4-5 | 7,5 | 160 | 580 | 490 | 430 | 400 |
| 5-6 | 9,9 | 215 | 440 | 370 | 325 | 300 |
| 6-7 | 12,5 | 270 | 350 | 295 | 255 | 240 |
| 7-8 | 15,3 | 335 | 280 | 240 | 210 | 195 |
| 8-9 | 18,3 | 390 | 240 | 200 | 175 | 165 |
| 9-10 | 21,6 | 465 | 200 | 170 | 150 | 140 |
| 10-11 | 25,2 | 542 | 175 | 145 | 130 | 120 |
| 11-12 | 29,1 | 625 | 150 | 125 | 110 | 105 |

### TABLEAU II

Corrections pour cent des tableaux I et III pour les variations de T (°C) et p ($M_b$) (tab. II).

| T / p | 10° C | 0° C | 10° C | 20° C |
|---|---|---|---|---|
| 1.040 | — 11 | — 7 | — 4 | 0 |
| 1.020 | — 8 | — 5 | — 2 | 2 |
| 1.000 | — 6 | — 4 | 0 | 3 |
| 980 | — 4 | — 2 | 2 | 6 |
| 960 | — 2 | 0 | 1 | 8 |

Pour l'emploi sur des cartes du temps il convient quelquefois remplacer $V_g$ par la distance D que l'air pourrait parcourir pendant 6 heures si le vent était strictement géostrophique.

On trouve alors que:

$$D = 21.600\ V_g \qquad \text{(mètres)}$$

On a expliqué ci-dessus que la vitesse du vent en mer sur une latitude moyenne ou haute où le contrôle géostrophique est plus marqué, est assez voisine au 2/3 du vent géostrophique. On peut donc écrire $V = 2/3\ V_g$: cette valeur substituée dans l'équation du vent gradient donne:

$$H = \frac{RT}{p} \quad \frac{1}{6\,\omega \sin \varphi\, V}$$

De cette équation s'ensuit que, lorsque la direction et la vitesse du vent sont observées en mer, le gradient de pression dans le voisinage d'un navire peut être déduit du vent observé. Les valeurs correspondantes de H et de V sont indiquées dans le tableau III pour T = 283° K et p = 1.000 $M_b$. Les influences dues aux variations de pression et de température sont faibles et peuvent être corrigées à l'aide du tableau II.

Les formules ci-dessus s'appliquent lorsque le contrôle géostrophique est prévalent, lorsque la courbure du parcous n'est pas tellement grande et lorsque la distribution de la pression ne change pas rapidement. Si la courbure du parcours est considérable, le vent gradient devra être employé à la place du vent géostrophique. Sur les hautes et moyennes latitudes la courbure du parcours est souvent tellement petite que le terme cyclostrophique est négligeable.

Le tableau suivant montre le rapport entre le vent gradient et le vent géostrophique selon les différentes courbures cycloniques à des latitudes différentes. Lorsque la courbure est anti-cyclonique, la vitesse du vent est rarement très forte et le rayon de courbure est généralement grand. La différence entre le vent géostrophique et le vent gradient est alors assez petite.

### TABLEAU III

Rapport entre le vent géostrophique et le vent gradient (courbure cyclonique)

| Vent géostrophique m/sec | Latitude degrés | Vent gradient m/sec | | | |
|---|---|---|---|---|---|
| | | r = 10000 km | r = 1.000 km | r = 500 km | r = 200 km |
| 10 | 10 | 10 | 8 | 7 | 5 |
| | 20 | 10 | 9 | 8 | 6 |
| | 40 | 10 | 9 | 8 | 7 |
| | 70 | 10 | 9 | 9 | 8 |
| 20 | 10 | 19 | 13 | 11 | 8 |
| | 20 | 19 | 15 | 13 | 10 |
| | 40 | 19 | 17 | 15 | 12 |
| | 70 | 19 | 18 | 16 | 13 |
| 30 | 10 | 26 | 18 | 14 | 10 |
| | 20 | 28 | 21 | 18 | 13 |
| | 40 | 29 | 24 | 21 | 16 |
| | 70 | 29 | 25 | 23 | 18 |
| 50 | 10 | 43 | 25 | 20 | 14 |
| | 20 | 46 | 31 | 25 | 18 |
| | 40 | 47 | 36 | 30 | 23 |
| | 70 | 48 | 39 | 33 | 26 |
| 70 | 10 | 57 | 33 | 24 | 16 |
| | 20 | 62 | 39 | 31 | 22 |
| | 40 | 65 | 47 | 38 | 28 |
| | 70 | 66 | 55 | 43 | 32 |

Ces données concernant le rapport entre le gradient de pression et le vent peuvent être rapportés sur une feuille de celluloïde selon ce qui est indiqué dans la fig. 2. En faisant ainsi il est nécessaire de tenir compte de la projection et de l'échelle de la planche du temps. L'organisation météorologique internationale a recommandé trois projections conformes (orthomorphiques) dont la projection conique conforme Lambert est conseillée, pour les moyennes latitudes, le cône intersectant la sphère à 30° et 60°.

L'échelle de ces cartes est une fonction de la latitude et on en a tenu compte pour la construction de la fig. 2.

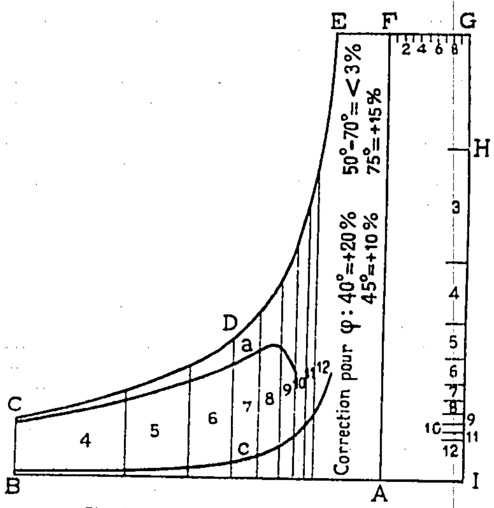

Fig. 2 — L'échelle du vent géostrophique.

La construction de l'échelle du vent peut être indiquée selon ce qui suit: les distances entre les isobares voisines sont reportées le long de l'échelle A-B. Les numéros entre les lignes verticales indiquent le vent géostrophique, à savoir les numéros de Beaufort, qui correspondent aux distances mesurées entre les isobares voisines. Les distances verticales de la ligne A B à la courbe C D E indiquent les distances que l'air aurait parcouru en 6 heures si le vent avait été strictement géostrophique. Ces valeurs sont indiquées sur le premier tableau. Les corrections pour la courbure du parcours peuvent être calculées selon ce qui est indiqué pour la courbe C (courbure cyclonique) et pour la courbe A (courbure anti-cyclonique). Les données nécessaires sont fournies par le dernier tableau ou par l'équation:

$$H = \frac{RT}{p} \frac{1}{4 \omega \sin \varphi V}$$

Ainsi, lorsque le rayon de courbure cyclonique est de 800 km, la distance que l'air pourrait parcourir avec une vitesse du vent gradient en 6 heures est indiquée par la distance entre la courbe c et la courbe C D E. Si la courbure était anti-cyclonique l'air se déplacerait plus rapidement du vent géostrophique de la quantité indiquée par les lignes entre la courbe a et la courbe C D E. Un nombre suffisant de ces courbes de correction peut être tracé sur le graphique. On doit remarquer que les grandes courbures cycloniques par vents forts sont rares. En météorologie on démontre que lorsqu'on calcule le déplacement des fronts et des masses d'air, il est préférable de choisir des points sur la carte où la courbure du parcours est si petite que les corrections sont de grandeur négligeable. Le diagramme est construit pour 60° de latitude mais à cause de l'influence combinée des variations de latitude sur le vent géostrophique et sur l'échelle de la carte, le diagramme est valable avec une exactitude suffisante pour un vaste champ de $\varphi$ sur les moyennes latitudes. Les corrections de latitude qui devraient être appliquées aux distances parcourues en 6 heures sont indiquées dans le graphique.

La partie de l'échelle du vent géostrophique à gauche de la ligne A F peut être employée pour déterminer le vent approximatif au sommet de la couche de frottement et le déplacement des fronts des masses d'air, selon ce qui sera indiqué par la suite. La partie sur la gauche du diagramme sert pour deux autres buts. L'échelle I H est calculée avec l'équation précitée qui donne le rapport entre le vent observé (représentatif) sur la mer et le gradient de pression. Les données sont rapportées dans le tableau III. Par exemple si un navire observe un vent de la force 7 de l'échelle de Beaufort, la distance le long de I H de I à l'interval indiqué par 7 indiquera la distance approximative entre les isobares en proximité du navire. Ce rapport est particulièrement utile pour tracer les isobares en mer lorsque les observations sont peu nombreuses. L'échelle I H peut aussi être employée pour déterminer la force approximative du vent d'après les isobares lorsque les observations sont peu nombreuses.

Les applications de l'échelle du vent géostrophique décrite ci-dessus ne sont pas valables sur les latitudes tropicales ou subtropicales, où l'équilibre géostrophique est moins rigide, ni même pour les moyennes et hautes latitudes où la vitesse du vent est faible. Cependant lorsque les isobares sont tracées avec un certain fondement, on peut faire un large usage de l'échelle des vents au nord de 35°, par ex. lorsque la force du vent est supérieure au numéro 4 de Beaufort.

L'échelle indiqué par F G dans la fig. 2 est employée pour corriger les tendances barométriques observées sur le navire.

### *L'organisation et l'élaboration de la statistique des ressources éoliennes.*

D'après ce qui a été exposé ci-dessus il est à présent facile de déduire les critères pour le tracement des courbes d'égale vitesse de durée moyenne dans l'année. Il est d'abord nécessaire d'établir que ces courbes doivent en premier lieu être considerées comme courbes d'intégration de la vitesse du vent sur toutes les directions de l'horizon. Cette première recherche, selon ce qui a été dit, devrait servir comme représentation relative de l'énergie du vent disponible dans les différentes régions: il n'y aurait donc aucune raison de se préocuper des directions, d'autant plus que, surtout pour les zones en plaine, on pourra avoir recours à des installations aéro-électriques pouvant s'orienter selon les vents et par conséquent pouvant fonctionner pour chaque direction des courants d'air.

On devra toutefois renoncer à cette simplification lorsqu'on passera à une étude plus complète de ce problème dans une zone montagneuse où certainement l'importance de l'orientation des courants d'air, due à la conformation particulière du système orographique, se fera sentir d'autant plus fortement lorsque la construction d'installations fixes selon le nouveau type cité ci-dessus, sera préférée à l'emploi d'un moteur à vent orientable du type normal. Dans ce cas il semble indispensable de tracer pour chaque localité les courbes d'égale vitesse pour la direction ou le groupe de directions utilisables pour des installations fixes orientées en tenant compte de la morphologie locale. Celle-ci est donc une recherche qu'on devra faire en même temps soit sur les directions du vent dominant soit sur la conformation orographique de la localité; par ce fait on pourra arriver au double résultat de pouvoir choisir les endroits où il convient de construire les aménagements aero-électriques et en même temps, de pouvoir fixer leur puissance d'une façon analogue à ce qui a été fait par la statistique des ressources hydrauliques.

Dans le cas où les données anémologiques disponibles pour les différentes localités aient été déduites des observations barométriques selon le procédé précité, il est presque inutile de mentionner la nécessité de tenir compte des déviations, communiquées aux courants d'air sur les grandes directions ainsi déterminées par les caractéristiques orographiques de la région, étant évident que, par ex., en présence de vallées, de gorges ou de cols le long des sommets des montagnes, le vent sera dirigé vers une ou deux directions obligées.

On pourra ensuite passer à l'examen des critères économiques de l'installation des moteurs à vent et de l'intégration des ressources hydrauliques de la région en ayant soin d'établir toutes les corrections indiquées, pour le passage des valeurs du vent calculé sur la base de la pression aux valeurs du vent réel, compte tenu aussi des formules suivantes pour la détermination de la correction de la vitesse du vent due au frottement.

Hellman a exprimé l'augmentation de la vitesse du vent en hauteur, d'après des mesures faites à Nauen et à Postdam, avec les formules suivantes:

pour les hauteurs moyennes: $\frac{V}{V_0} = \sqrt[5]{\frac{h}{h_0}}$

et pour les hauteurs entre 16 et 500 m: $V = 2{,}7 \sqrt[5]{h}$

Grosse de Brême a indiqué pour ce cas la formule:

$$V = 2{,}91 \, . \, h^{0{,}19}$$

F. Bradke donne par contre la formule:

$$V = 1{,}2 + 1{,}79 \, h^{0{,}246}$$

tandis que dans la même publication (Meteorologische Zeitschrift 1928) V. Làska donne:

$$\log V_x = \log V_1 \left( 1 + \frac{x-1}{10} \right)$$

où $\log V_1 = 0{,}5333$

H. Bouguards indique la formule:

$$V = V_1 \sqrt[6]{h + \left(\frac{\log h}{0{,}715}\right) 24}$$

Au Service Meteorologique de l'Aviation on trouve les cartes des isobares pour chaque 5 et même 3 mb, pour chaque jour et même pour 12 h ou bien pour 6 h et cela pour une période qui va de 15 à 20 ans selon les différentes stations. En se basant sur ces cartes il sera possible de recueillir les données qui intéressent la vitesse et la direction du vent pour intégrer d'abord lescourbes d'égale vitesse et en deuxième lieu les études spécifiques pour des installations aéro-électriques particulières. L'approximation qu'on peut atteindre avec ces données dans le domaine de la statistique des ressources éoliennes est comparable à celle établie par le recensement des ressources hydrauliques: en tous cas, étant donné l'impossibilité de recouvrir le territoire national d'un réseau d'appareils très coûteux et d'un entretien difficile comme les anémographes, ce système est le seul qui puisse être envisagé à l'état actuel des observations et même pour un avenir prochain.

Etant donné que le but de la statistique même est l'orientation des recherches définitives pour l'emplacement des installations aéro-électriques et pour l'évaluation et le calcul à large approximation de l'énergie qu'elles pourraient produire, il semble indispensable d'en fixer les bases dès à présent sans attendre des perfectionnements difficiles à réaliser; il faudra de même en commencer l'étude pour les régions qui intéressent plus spécialement telles que l'Italie centrale et meridionale et les îles.

Un procédé assez simple pour établir l'étude des données anémologiques calculées sur la base des données de la pression déduites des cartes isobariques pourrait être par ex. le suivant:

On reporte sur une feuille de papier transparent le plan des points pour lesquels il intéresse de connaître le régime des vents dans la même échelle des cartes; on applique successivement cette feuille sur chaque carte d'un jour en marquant pour chaque point le gradient de la pression et la direction des isobares correspondantes sur un tableau spécial se référant au jour et à l'heure de chaque carte. En portant sur ces tableaux les corrections de la vitesse et de la direction du vent déjà mentionnées on pourra établir d'autres tableaux sur lesquels on aura indiqué pour chaque point les vitesses et la direction du vent corrigées, ainsi que tous les jours et les heures relatives, pareillement à ce qui a été obtenu pour les stations d'observations réelles. Il sera alors possible de tracer au moyen du procédé indiqué ci-dessus les courbes d'égale vitesse de durée moyenne dans l'année, d'abord pour toutes les directions de la même région et ainsi de suite, après une étude soignée des directions dominantes pour les emplacements choisis pour les installations aéro-électriques, les courbes d'égale vitesse de ces directions. Sur la base de ces dernières courbes on pourra alors établir la puissance productible par les aéro-moteurs d'un certain diamètre des pales et ensuite la puissance complète de l'installation comprenant un certain nombre de ces aéro-moteurs.

En tenant compte de la nature du sol, des difficultés de transport, etc.; on pourra se faire une idée du prix de revient des travaux de terrassement, de la maçonnerie et du béton armé nécessaire pour la partie fixe de l'installation, tandis que pour la machinerie, les moteurs à vent, les générateurs électriques, etc. on pourra avoir recours aux données standardisées d'usage normal.

## II PARTIE

### 4-2. *Centrales aéro-électriques*

En exposant librement à l'air un tube Venturi la différence des pressions sur la section antérieure et sur la section étranglée intérieure $p_a - p_i$ est obtenue par des expériences et indiquée par l'équation:

$$p_a - p_i = K \frac{\rho}{2} Va^2 = Kq$$

où $V_a$ représente la vitesse du vent à l'extérieur, $\rho$ la densité de l'air et

$q = \frac{\rho}{2} Va^2$ pression aéro-dynamique: K représente un facteur numérique qui dépend essentiellement de la forme du tube Venturi et, qui dans le cas d'un ou de plusieurs tubes Venturi disposés l'un dans l'autre sur le même axe selon ce qui a été réalisé dans le modèle employé, dépend du nombre de tubes V employés. Ce modèle (fig. 3) correspond à un type de multiplicateur de la pression aéro-dynamique et par conséquent de la vitesse du courant d'air à l'extérieur, selon un brevet de l'A.

On savait déjà que ce facteur dépend fortement de la vitesse Va surtout en raison de la variation du numéro de Reynolds selon la vitesse par rapport à la viscosité dynamique et de l'influence de la comprimibilité de l'air. Selon ce qui est bien connu en aéro-dynamique, la loi de similitude mécanique seulement alors est valide c'est-à-dire le flux, ou mieux encore les formes de courant d'un fluide quelconque ou d'un gaz dans les corps géométriquement semblables, sont elles-mêmes géométriquement semblables (dans le cas où l'on considère seulement la viscosité et la portance et que l'on néglige la gravité, selon ce qui advient généralement pour le mouvement des fluides dans les tubes), lorsque la grandeur $\frac{\rho}{\mu}$ Vd, dans laquelle d est le diamètre du tube, reste constant. Cette condition de similitude a été énoncée pour la première fois par Osborne Reynolds et pour ce fait cette grandeur est appelée "nombre de Reynolds" et est indiquée par la lettre R. La necessité d'augmenter conformement la vitesse en proportion à la diminution des dimensions du modèle résulte alors évidente.

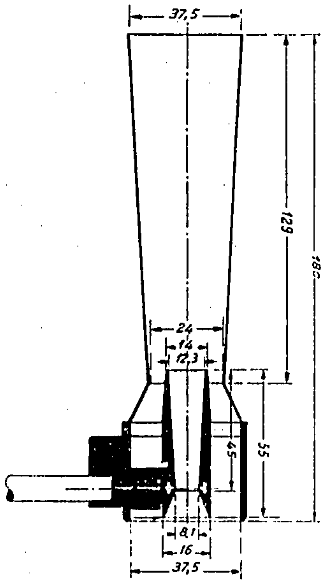

**Fig. 3** — Modèle du multiplicateur de pression aéro-dynamique employée dans les essais au tunnel aéro-dynamique.

En conséquence étant donné que les vitesses résultantes sur la section la plus étroite du modèle sont souvent de l'ordre de grandeur de la vitesse du son, il se produit de notables variations de la densité de l'air qui, peuvent avoir leur influence sur les indications du modèle. En variant seulement la vitesse il ne serait donc possible de séparer nettement ces deux influences. En outre pour des installations aéro-électriques situées à différentes hauteurs au dessus du niveau de la mer, correspondent des valeurs différentes du rapport $\mu/\rho$ (viscosité cynématique), à cause de la moindre densité et des plus basses températures: pour cette raison le nombre de Reynolds varie même indépendamment du rapport entre la vitesse du vent et la vitesse du son.

Dans les tunnels aéro-dynamiques les plus perfectionnés on a la possibilité de rendre l'air raréfié à l'intérieur; ainsi en variant la densité de l'air à étudier, on pourra déterminer l'influence du nombre de Reynolds indépendamment de celle de la comprimibilité de l'air.

D'après les expériences faites par les professeurs A. Betz et H. Peters en Allemagne en 1932 dans un tunnel aéro-dynamique de ce type, (1) ceci a été réalisé d'une façon assez satisfaisante en obtenant des résultats qui sont ci-dessous brièvement resumés.

Dans la fig. 4 on a rapporté le facteur K en fonction du nombre de Reynolds:

$$R = \frac{V_1 \, d_1 \, \rho_1}{\mu}$$

où $d_1$ représente le diamètre de la section la plus étroite mesurée, $V_1$ et $\rho_1$ la vitesse et la densité de l'air pendant le flux sur ce point. Dans cette formule il est préférable de prendre la viscosité dynamique de l'air

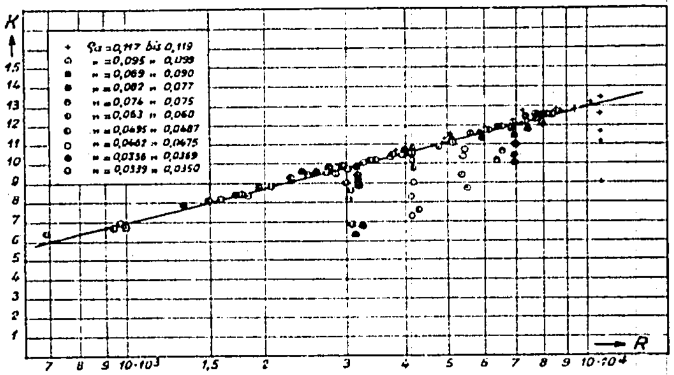

Fig. 4 — Le facteur de multiplication K en fonction du nombre de Reynolds pour différentes densités l'air.

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(1) Le: "Lufts laboratorium" der A. V. A. in Gottingen.

relative à la température de l'ambient extérieur. Les grandeurs $\rho_1$ et $V_1$ peuvent facilement être calculées en partant de la différence $p_a - p_1$ en se basant sur les formules de la dynamique des gaz. Etant donné que la comprimibilité de l'air a une influence sur les grandeurs V, $\rho$ et $\mu$ sur lesquelles est basé le nombre de Reynolds, il n'est pas possible de distinguer d'une façon incontestable l'influence de la comprimibilité de l'air de celle de la viscosité. Il y a cependant dans le choix du nombre de Reynolds une certaine liberté qui permet une différentiation de ces deux influences.

Sur la base des expériences qui ont été faites on relève de la fig. 4 en échelle logarithmique que toutes les valeurs trouvées pour K peuvent être disposées selon une fonction linéaire du nombre de Reynolds jusqu'au moment où la vitesse du son sera atteinte dans la section la plus étroite. Au delà de ce moment aucune augmentation de $V_1$ ne sera plus possible. Les résultats des expériences sur modèle donnent alors une valeur constante de la différence $p_a - p_1$, malgré l'augmentation de la vitesse du vent $V_a$. La valeur K en conséquence descend rapidement selon ce qui est indiqué par les points correspondants qui descendent presque verticalement. Sur le modèle employé pour les expériences, de dimensions assez réduites, la section la plus étroite était de 8,1 cm de diamètre; par conséquent le rapport de similitude avec une installation d'un moteur à vent d'un diamètre de 1 m 50 monté sur la section étroite du tube intérieur est de 1 à 18 environ. A la vitesse $V_1$, considerée égale à celle du son dans le modèle, devrait correspondre en conséquence une vitesse du courant d'air dans le tube intérieur de l'installation égale à 18,33 m/sec. et pour une valeur du facteur K égal à celui indiqué par les expériences, une vitesse du vent de 6m/sec environ. Pour des vitesses plus grandes ou des dimensions plus grandes de l'installation il faudrait entreprendre des expériences sur des modèles plus grands, mais toujours à condition que dans le modèle la valeur $V_1$ de la vitesse du son ne soit pas dépassée. D'ailleurs, selon ce qui a été dit, cet inconvénient pourra être évité en gardant un rapport entre la différence de la pression et la vitesse dans le tube au moyen d'une courbe d'étalonnage valable pour un tube Venturi géométriquement semblable.

Dans ce cas, pour une forme de l'appareil de grandeur naturelle géométriquement semblable au modèle réduit en adoptant la même courbe d'étalonnage, c'est-à-dire la ligne de la fig. 4, on aura, même pour des vitesses du vent supérieures à 6 m/sec, les valeurs du facteur K indiquées par le prolongement de la droite en question jusqu'à atteindre les ordonnées relatives au nombre de Reynolds correspondant.

Une première considération assez intéressante peut être déduite des résultats de ces expériences: c'est à dire la variation de K en fonction de la vitesse du vent et de la pression de l'air.

Cependant même la valeur K pourra varier selon que t varie; ceci pourra être facilement prouvé par les essais suivants.

Pour les buts pratiques ce qui intéresse c'est la dépendance du facteur K de la différence $p_a - p_i$ de pression. On devra alors transformer la relation $K = f(R)$ dans l'autre $K = f(p_a - p_i)$ en introduisant la pression $p_a$ et la température t comme paramètres. Si on pose:

$$K = \frac{p_a - p_i}{Va^2 \cdot \frac{\rho}{2}}$$

on aura en effet les valeurs K dans la fig. 5 pour plusieurs pressions $p_a$ (en kg/m²) et pour les températures t = — 40°, 0° et + 40° C.

Selon ce qu'on a vu, lorsqu'on atteint la vitesse du son dans la section la plus étroite, la différence de pression $p_a - p_i$, même si la vitesse augmente encore, reste presque constante. La pression aéro-dynamique maxima correspondante est représentée par

$$q_{max} = \frac{1 - \lambda}{K} \, p\,a$$

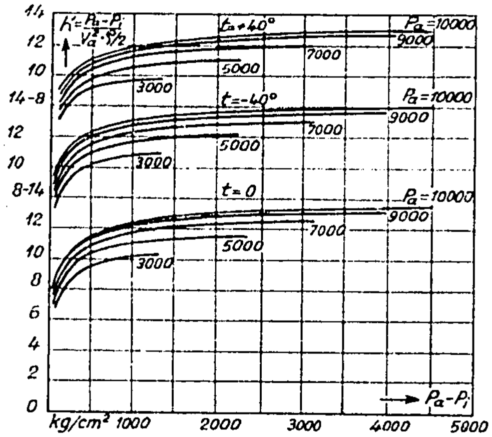

Fig. 5 — Le facteur de multiplication K en fonction de la différence de pression pour différentes pressions et températures.

où:

$$\lambda = \left(\frac{p_i}{p_a}\right)_{\text{critique}} = \left(\frac{2}{x+1}\right)^{\frac{x}{x-1}} \left(1 + \frac{Va^2 \rho a}{2} \frac{1}{p_a} \frac{x-1}{x}\right)^{\frac{x}{x-1}}$$

peut être calculé sur la base des lois fondamentales de l'aéro-dynamique.

Dans la fig. 6 on a reporté la courbe 1 — $\lambda$ qui représente la valeur théorique maxima de

$$\frac{p_a - p_i}{p_a}$$

Dans cette même fig. 6 on a reporté aussi les valeurs des rapports des différences de pression $p_a$ — $p_i$ avec la pression extérieure $p_a$ par rapport à la vitesse extérieure $V_a$. On aurait ainsi une bonne correspondance de ces deux valeurs lorsque la section où a lieu la mesure coïncide avec la section la plus étroite. Cependant étant donné que sur le modèle expérimenté la section où a lieu la mesure se trouve un peu en arrière de la section étroite, c'est à dire vers la partie où la section s'élargit, on a mesuré sur ce point une pression plus haute que sur cette dernière, lorsque la vitesse de l'air y est plus petite que celle du son (action du diffuseur). A peine cette vitesse aura été atteinte il est possible d'avoir sur le point où la section s'élargit une autre expansion; ainsi la pression sur la section choisie pour la mesure peut devenir plus petite.

Cette expansion successive cependant ne peut continuer à augmenter car la pression sur la section de sortie du diffuseur est toujours plus haute que sur la section la plus étroite. Dans le diffuseur on aura donc un saut de pression (coup de bélier) qui peut être soit axial soit oblique. Dans l'aéro-dynamique il est reconnu que ce phénomène varie d'un endroit à l'autre selon la pression de la section de sortie du diffuseur et selon les variations minimes de la forme du diffuseur et de ses caractéristiques superficielles. En conséquence la reproduction du saut de pression dans le même point aussi pour le même tube est assez problématique. La pression $p_i$ sur la section où l'on fait la mesure dépend du point où se forme le saut de pression. La fig. 6 montre le déplacement du saut de pression par rapport à la densité $p_a$ ou mieux encore du nombre de Reynolds par rapport à la section de mesure, comme si pour des nombres de Reynolds plus grands le saut de pression se produisait derrière la section où se fait la mesure: en conséquence

$$\left(\frac{p_a - p_i}{p_a}\right)_{max} > 1 - \lambda$$

tandis que pour des nombres de Reynolds plus petits elle passerait devant la section à mesurer immédiatement après la section plus étroite: ainsi

$$\left(\frac{p_a - p_i}{p_a}\right)_{max} < 1 - \lambda$$

D'après les expériences mentionnées on peut déduire les conclusions suivantes:

1) l'appareillage qui concerne le brevet précité, consiste en deux ou au maximum trois tubes Venturi montés sur le même axe disposés de façon à réaliser une forte augmentation de la dépression sur la section étroite du tube intérieur; cette disposition a un grand avantage sur le simple tube Venturi, car elle permet d'obtenir une plus grande valeur

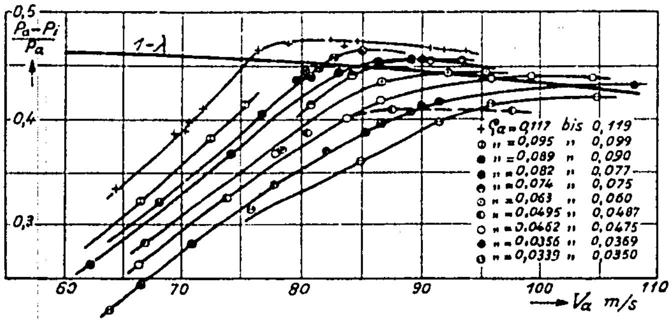

Fig. 6 — La différence de pression par rapport à la pression extérieure et en fonction de la vitesse du vent.

du facteur K de multiplication de la pression aéro-dynamique ou bien de la différence des pressions extérieure et intérieure avec un plus petit rapport entre les diamètres de la section antérieure et de la section étroite de chacun des tubes; en outre elle présente des limites de fonctionnement en dehors desquels ce facteur K reste constant avec l'augmentation de la vitesse du vent, ce qui arrive lorsque le courant d'air dans la section étroite du tube intérieur atteint la vitesse du son:

2) la loi de la similitude mécanique entre le modèle employé pour les expériences et l'appareillage pour les installations aéro-électriques en grandeur naturelle qu'on voudrait construire selon le modèle même mais de dimensions plus grandes, est valable et par conséquent les phénomènes remarqués dans les expériences sont extensibles aussi aux installations en grandeur naturelle lorsque le rapport entre les dimensions des tubes est égal au rapport inverse des vitesses des courants d'air qui se forment dans ces tubes. Pour des vitesses plus grandes il est indispensable d'avoir recours à une courbe d'étalonnage valable pour le champ des vitesses susdit pour le modèle et pour l'installation en grandeur naturelle, et de prolonger cette courbe, qui est une ligne droite, jusqu'à atteindre le champ du nombre de Reynolds correspondent aux vitesses et aux dimensions de l'installation réelle.

De la première conclusion on peut déduire d'abord tout au moins pour les installations de petite ou de moyenne puissance, la possibilité de rendre le système des tubes Venturi tournant sur un plan horizontal de façon à se placer dans la direction du vent. En outre, étant donné l'importante réduction des dimensions des tubes, qu'on obtient en employant le dispositif des plusieurs tubes Venturi concentriques même pour les installations fixes de grande puissance devant être installés dans une localité ayant un régime des vents dans une seule direction, la puissance installiée d'une seule unité de la centrale éolo-électrique est limitée seulement lorsque on atteint la vitesse du son dans la section étroite du tube le plus intérieur; ce fait peut se vérifier seulement avec trois tubes concentriques et peut être atteint seulement d'après les dimensions qu'auront les tubes mêmes et surtout la longueur du tube extérieur. Ces valeurs peuvent être comparées à celles des plus grandes unités des centrales hydro-électriques et thermiques et on a donc, même à cet égard, une parfaite égalité avec les systèmes de production d'énergie concurrents.

Ces considérations tout en étant évidentes par elles-mêmes sont confirmées par une série d'expériences faites sur des modèles hydrauliques pour l'expansion du flux divergent et de forme conique; au moyen de ces essais tout en ayant négligé les changements de densité et de température qui, sont pratiquement sans importance pour une vitesse de l'air inférieure à celle du son, on a mis en évidence les phénomènes mécaniques intérieurs sur les changements d'énergie qui se verifient avec ces expansions. Ces phénomènes ont une grande importance même pour le projet des pales du moteur à vent à placer dans un tuyau, dont le fonctionnement peut être comparé complètement à celui d'une turbine Kaplan ou à hélice, avec diffuseur, sauf la nature comprimable du fluide, ce qui, par ailleurs, pour les raisons énoncées, n'a aucune influence pour le résultat final.

En partant de la considération du problème à trois dimensions on peut alors évaluer les influences dépendant du nombre des pales, des valeurs des angles d'incidence des pales à l'entrée ou à la sortie, des trois dimensions du courant et de son aspect réel, ainsi que de sa conformation aéro-dynamique, dans la partie de la roue qui porte les pales.

De cette façon, compte tenu de toutes les circonstances qui ont une influence sur la puissance du moteur, on peut arriver à un système de calcul suffisamment exact et répondant aux exigences du projet normal de ce type de turbines qui permet d'atteindre un degré approximatif supérieur à celui des autres méthodes connues.

Tout en renvoyant l'étude approfondie de la question à la vaste bibliographie technique concernant ce sujet, et surtout au dernier mémoire du Prof. Medici (4), il est intéressant de remarquer que le fonctionnement du moteur à vent en tuyau est identique à celui d'une turbine à reaction installée à une certaine hauteur sur le niveau de déchargement, où la partie restante de la chute est utilisé en aspiration. Dans les turbines à grande vitesse, le tuyau d'aspiration doit fonctionner comme diffuseur pour récupérer l'énergie considerable de la vitesse de déchargement et il devient une partie essentielle de la turbine. D'une façon analogue, dans le fonctionnement du moteur à vent en tuyau la forme du diffuseur du tube Venturi, tronco-conique à génératrices rectilignes, a une grande importance.

Cependant, indépendamment du système décrit ci-dessus et en accord avec celui-ci une autre aspiration est obtenue, aux dépenses de l'énergie éolique disponible dans la localité, par la colonne d'air qui frappe les aspirateurs statiques ou les tours d'aspiration situées en proximité de la section de rétrécissement du premier ou du deuxième tube Venturi, ou bien de tous les deux. On indique dans les figs. 7 et 8 deux types d'aspirateurs et les diagrammes des débits relatifs en fonction

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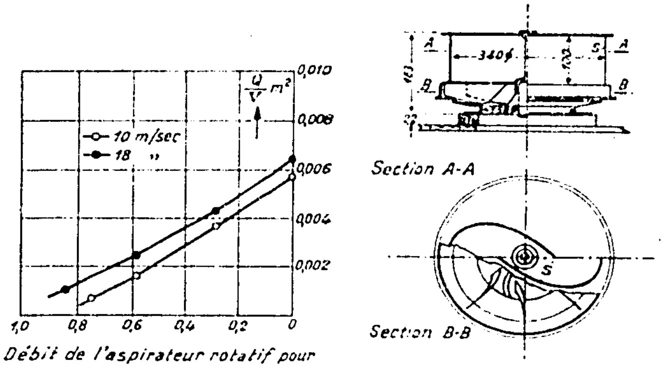
(4) — M. Medici — Nuovo assetto della teoria approssimata delle giranti radiali a palettatura convessa — "L'energia elettrica", septembre-octobre 1946.

de la vitesse du vent, des dépressions et de l'inclination du vent, selon ce qu'on a obtenu dans le tunnel aéro-dynamique. Etant donné que le débit $a$ de l'aspirateur croît proportionnellement à la vitesse du vent V, il a été suffisant de reporter sur ces diagrammes la valeur $\frac{Q}{V}$ [m²] qui est indépendante de V. Le même débit d'aspiration dépend de la dépression $p_a - p_i$ dans le tube Venturi; en conséquence pour un de ces aspirateurs on a reporté l'allure de la valeur $\frac{Q}{V}$ en fonction du rapport

$$\frac{p_i - p_a}{\frac{\rho}{2} - V^2}.$$

Pareillement se comportera l'autre pour lequel l'examen dans le tunnel aéro-dynamique a démontré que, du fait qu'il s'agit d'un long tuyau qui peut être frappé du vent obliquement, l'aspiration est plus grande par un vent oblique que par un vent horizontal.

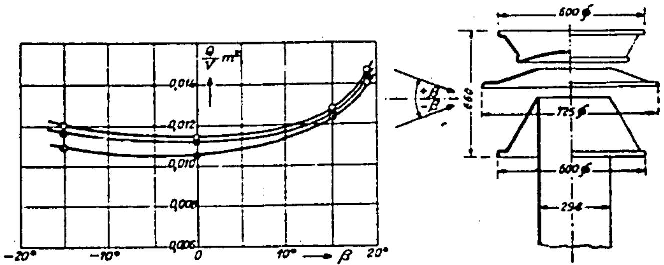


Débit de l'aspirateur rotatif pour différentes pressions intérieures.

Aspirateur rotatif

Fig. 7 — Type d'aspirateur rotatif et son diagramme relatif des débits.

D'autres et plus importantes aspirations sur les sections étroites des tubes Venturi pourront être obtenues en adoptant les moyens déjà en usage pour les aménagements hydro-électriques au fil de l'eau et à basse chute, ou bien en augmentant la depression sur les sections retrécies mêmes au moyeu de moteurs à vent à aspiration du type connu, c'est à dire ceux pour lesquels les pales caves en tournant produisent par effet de la force centrifuge sur le moyeu tubulaire une aspiration qui est transmise à ces sections au moyen de tuyaux. Les différentes combinaisons de ces divers systèmes d'aspiration avec des tubes Venturi offrent une grande variété d'aménagements aéro-électriques, dont la puissance ainsi augmentée par l'augmentation de la dépression dans les tubes Venturi à l'arrière des moteurs à vent, peut atteindre des valeurs très importantes, tout à fait comparables à celles des unités des usines hydro-électriques.



*Débit de l'aspirateur à tuyau par rapport de l'angle vertical d'inversion du vent.*

*Aspirateur à tuyau*

Fig. 8 — Type d'aspirateur fixe à tuyau et son diagramme relatif des débits.

## SUMMARY

In the first part it is shown the possibility of the institution of statistics of available aeolian resources, by means of the determination of curves of equal velocities of the wind of middle duration in the year and it is suggested a method of deduction of the velocities and directions of the wind from the isobars of the maps for the prediction of the weather extant by the Aeronautic Service in Italy.

In the second part it is reported the result of experiments made in the aerodinamic tunnel with models on a small scale of the assembly of two coaxial Venturi tubes proposed for the accumulation in the space of the energy of the wind, to the purpose of deriving important remarks on the from and disposition to assign to the said tubes for obtaining the maximal efficiency in the aero-electric plants.

## RÉSUMÉ

Dans la première partie on démontre la possibilité de l'institution d'une statistique de l'énergie éolienne disponible. moyennant le tracement de courbes d'égale vitesse du vent d'une durée moyenne dans l'année et on indique une méthode de déduction des vitesses et directions du vent à partir des isobares des cartes de prédiction du temps existantes en Italie près le Service Aéronautique.

Dans la deuxième partie on réfère les résultats obtenus avec les expériences effectuées dans le tunnel aéro-dynamique sur des modèles réduits du dispositif à deux tubes Venturi coaxials proposé pour l'accumulation dans l'espace de l'énergie éolienne. afin d'en dériver des observations importantes sur la forme et la disposition à donner à ces tubes pour obtenir le rendement maximum dans les centrales éolo-électriques.

## RESUMO

Na primeira parte da monografia. demonstra-se a possibilidade da instituição de uma estatistica das fontes de energia eólica disponiveis. por meio da determinação de curvas de igual velocidade do vento de duração média anual. indicando-se um método de dedução das velocidades e direção do vento baseado nas linhas isobáricas das cartas de previsão do tempo existentes na Itália. no Serviço Aeronáutico.

Na segunda parte da monografia. relatam-se os resultados obtidos com as experiências efetuadas no túnel aerodinâmico. com modelos em pequena escala do dispositivo de dois tubos Venturi coaxiais. proposto para a acumulação no espaço de energia eólica. a fim dai se tirarem observações importantes sôbre a forma e a disposição a dar a êsses tubos para obter o rendimento máximo nas centrais eolo-elétricas.

[redacted]

**CONFERÊNCIA MUNDIAL DA ENERGIA**
**WORLD POWER CONFERENCE**

Título 3
Assunto 3.2

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

MOURA (F. de)
Brasil

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# ARMAZENAMENTO, DISTRIBUIÇÃO E UTILIZAÇÃO DOS COMBUSTÍVEIS LIQUÍDOS NAS REGIÕES TROPICAIS E SUB-TROPICAIS

**Por FRANCISCO DE MOURA**
Químico Chefe da Shell Brazil Limited

**COMITÊ NACIONAL BRASILEIRO**

O título dêste trabalho permitiria uma amplitude impossível de alcançar dentro dos limites que o condicionam. Assim cingimo-nos a uma exposição sucinta da matéria com a intenção precípua de apresentar em um breve resumo certos aspectos mais característicos do armazenamento, distribuição e utilização dos produtos de petróleo usados como combustíveis em regiões tropicais e sub-tropicais.

Entre as características dessas regiões temos evidentemente em primeiro lugar as condições climáticas e essas de fato são as que mais irão ocupar a nossa atenção. Quanto ao sub-desenvolvimento dessas zonas, extremamente variáveis são o progresso industrial e agrícola, a densidade demográfica e conseqüentemente as demandas de produtos de petróleo e os conhecimentos técnicos dos consumidores que possibilitam um emprêgo mais ou menos amplo e eficiente dos mesmos. Dest'arte é difícil abranger num breve resumo tôdas essas variáveis, a exigir tratamentos específicos em qualquer dos três aspectos por nós ora focalizados, isto é, quer quanto ao armazenamento, como à distribuição e à utilização.

É indiscutível ser o petróleo de necessidade crescente no mundo moderno e os seguintes algarismos que dão o consumo per capita de produtos petrolíferos em 1950 e em diferentes regiões indicam o tremendo potencial de consumo das regiões menos desenvolvidas:

| | | |
|---|---|---|
| Estados Unidos e Canadá | 2.310 | litros |
| Austrália | 596 | " |
| Nova Zelândia | 553 | " |
| Escandinávia | 513 | " |
| Argentina, Paraguai e Chile | 118 | " |
| Inglaterra e Holanda | 346 | " |
| União Sul-Africana | 189 | " |
| Malaia | 162 | " |
| Europa Ocidental (Continente) | 118 | " |
| Outros países Sul-Americanos | 135 | " |
| Egito e Sudão | 130 | " |
| Brasil | 110 | " |
| Algéria e Marrocos Francês | 81 | " |
| Filipinas | 76 | " |
| Turquia e Levante | 50 | " |
| Ceilão | 50 | " |
| Japão | 27 | " |
| Outros territórios africanos | 18 | " |
| Indonésia | 13 | " |
| Indochina e Sião | 13 | " |
| India e Paquistão | 9 | " |

A demanda de produtos petrolíferos tem crescido de tal maneira nos últimos anos que se continuar nesse ritmo é de se esperar para 1967 uma produção anual superior a 1.200 milhões de toneladas de petróleo ou seja mais do dôbro da produção atual. O desenvolvimento industrial e agrícola requer energia sob tôdas as formas e a fig. 1 dá uma idéia de como as diferentes fontes de energia contribuiram para êsse progresso de 1920 a 1950, dando o índice 100 para o total relativo a 1920.

Aí vemos que enquanto em 1920 apenas 15% do suprimento de energia mundial se devia ao petróleo, essa percentagem no raiar de 1951 já era de 45%, quase igualando a derivada do carvão e lenhito, que no mesmo período desceu de 83% para menos de 50%.

O problema da alimentação, imperioso e premente, depende em larga escala da urgente mecanização da agricultura a demandar cada vez mais tratores e combustíveis de petróleo para os mesmos. Num total da ordem de 7 milhões de tratores existentes no mundo, a Ásia, a África e a América Latina têm apenas cêrca de 400.000 dessas máquinas, pouco mais de 5%, o que dá bem idéia da magnitude da demanda potencial das zonas sub-desenvolvidas situadas em grande parte em regiões tropicais e sub-tropicais.

## ARMAZENAMENTO

A natureza dos produtos em foco, desde a gasolina até o óleo combustível mais pesado, e principalmente seu estado liquido, condiciona o tipo de equipamento necessário a seu armazenamento e transporte. Essa aparelhagem e os métodos usados são de um modo geral os mesmos usados na indústria para outros liquidos, como p.ex., a água, com diferenças específicas a que limitaremos nossa atenção.

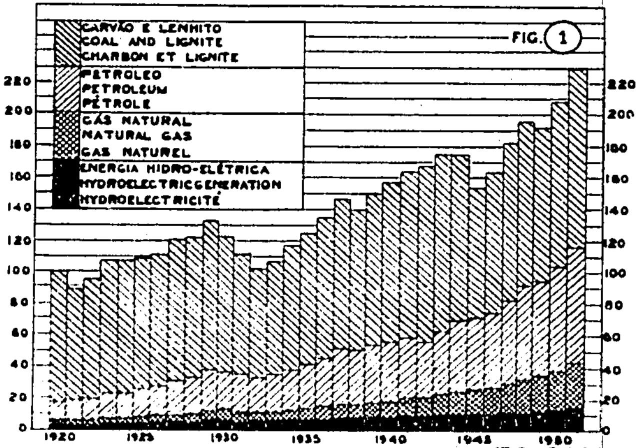


FIG. 1

T.S. 2051

### PRODUTOS VOLÁTEIS

Os tanques utilizados para o armazenamento dos produtos petrolíferos são geralmente munidos de suspiros dispostos de modo a, se necessário, permitir o escapamento de vapores para a atmosfera ou a entrada de ar para o interior do tanque. Assim, se exposto ao sol seu conteúdo se aquece e no caso de produtos voláteis, como a gasolina, há vapores que se expandem e descarregam para a atmosfera através dos suspiros; no caso inverso, isto é, quando há resfriamento, p.ex., à noite, há admissão de ar nos tanques. Se êsses suspiros não fôssem controlados, a repetição dêsses processos acarretaria a expulsão de grandes volumes de vapores, e quanto maior o gradiente de temperatura, maior seria a perda assim produzida. Nas regiões tropicais e sub-tropicais onde as temperaturas de insolação são elevadas, as perdas por evaporação durante o armazenamento dos produtos voláteis são consideráveis e consegue-se reduzi-las sensivelmente, quer protegendo os tanques contra a insolação, quer recorrendo a artifícios que contrarrestem o efeito da temperatura. Os principais meios para a consecução dêsses objetivos, considerados economicamente utilizáveis, são os seguintes:

a) Isolamento do teto do tanque,
b) emprêgo de pinturas refletoras do calor,
c) resfriamento com água,
d) tanques de teto flutuante, em que o espaço vasio (isto é, gasoso) é reduzido ao mínimo. O teto é uma estrutura móvel que flutua sôbre o produto contido no tanque,
e) tanques sob pressão,
f) sistema de conservação de vapores, em que os vapores formados vão ter a outros recipientes, não havendo entrada de ar no sistema.

Em todos os casos acima, exceto no do tipo de teto flutuante, os tanques são munidos de válvulas vácuo/pressão reguladas em limites compatíveis com a construção do tanque e sua resistência à pressão. Estas válvulas reduzem a "respiração" do tanque e conseqüentemente suas perdas por evaporação. A fig. 2 representa uma dessas válvulas de uso corrente nos tanques de armazenamento de gasolina.

Quanto às tintas especiais para a reflecção do calor, damos a seguir alguns valores relativos à sua eficiência. Deve-se considerar contudo que certas pinturas como as de alumínio, embora apresentem valores inferiores, são preferidas em virtude de sua durabilidade.

| | *Reflecção* | *Absorção* |
|---|---|---|
| Tinta branca | 80% | 20% |
| Cinza clara (naval) | 50% | 50% |
| Alumínio | 40% | 60% |
| Preto | 1% | 99% |

Em muitas regiões o álcool obtido de cereais ou da cana de açúcar é adicionado à gasolina e tais misturas apresentam uma tensão de vapor mais alta e conseqüentemente os tanques que as armazenam têm uma "respiração" acelerada e maiores perdas por evaporação. Nesses combustíveis ainda mais se complica o problema pela higroscopicidade do álcool; a humidade absorvida do ar é carreada para o tanque afetando a pureza do álcool e seu grau de miscibilidade com a gasolina. Nestes casos os dispositivos de suspiro dos tanques são equipados com cargas de substâncias higroscópicas tais como o cloreto de cálcio ou silica-gel, de modo que todo o ar "respirado" pelo tanque seja sêco.

No caso de produtos não voláteis as precauções anteriormente mencionadas são dispensáveis, bastando adaptar aos suspiros telas de proteção que evitem a entrada de corpos estranhos, insetos, ninhos de aves, casas de marimbondos, etc.

### Produtos Viscosos

Em contraste com os tanques de produtos voláteis, os de produtos viscosos são geralmente pintados de preto, utilizando, assim o calor do sol para reduzir a viscosidade do produto e aumentar portanto sua bombeabilidade. Mesmo em condições tropicais o calor solar pode não chegar para reduzir suficientemente a viscosidade de certos óleos combustíveis pesados, fazendo-se necessária a instalação de serpentinas de aquecimento no tanque, em tôda sua parte inferior ou sòmente em volta da saída do óleo, usando em ambos os casos vapor de baixa pressão. A temperatura do produto deve ser a mais baixa que permita o bombeamento, evitando perda de calor e dispêndio de vapor. A perda de calor do óleo para a atmosfera raramente passa de 10 kg/cals./$m^2$/°C/hora.

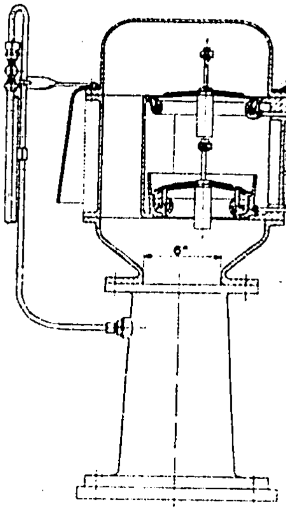


Fig. 2

VALVULA P.&V. 6"
6" P.&V. RELIEF VALVE
SOUPAPE P.&V. 6"

Podemos resumir as razões da necessidade de aquecimento dos óleos combustíveis pesados nas instalações dos consumidores industriais como segue:

1) a viscosidade elevada dos mesmos de modo que reduzindo esta, pelo aquecimento possam os óleos se escoar na velocidade requerida, do tanque de armazenamento para a bomba de transferência sob a influência conjunta da pressão atmosférica e da pressão estática representadas pela altura do óleo no tanque;
2) manter dentro de limites econômicos a potência absorvida no bombeamento do óleo à uma velocidade determinada;
3) evitar espessamento do óleo parado nos encanamentos;
4) fornecer o óleo ao queimador em viscosidade capaz de permitir uma pulverização completa.

Para não nos alongarmos neste particular, referimo-nos à Fig. 3 que dá as curvas de viscosidade de diferentes óleos combustíveis em função da temperatura e onde estão também indicados os limites de viscosidades tanto para um bombeamento econômico como para o suprimento à queimadores à jato-pressão.

Quanto à influência da temperatura sôbre os produtos viscosos armazenados em tanques providos de aquecimento, sabemos que a Shell Argentina Limited realizou observações detalhadas bastante interessantes e a curva da Fig. 4 demonstra bem a pouca importância das perdas de calor pelas paredes dos tanques nas zonas tropicais e semi-tropicais e portanto mostra ser dispensável seu isolamento nessas condições.

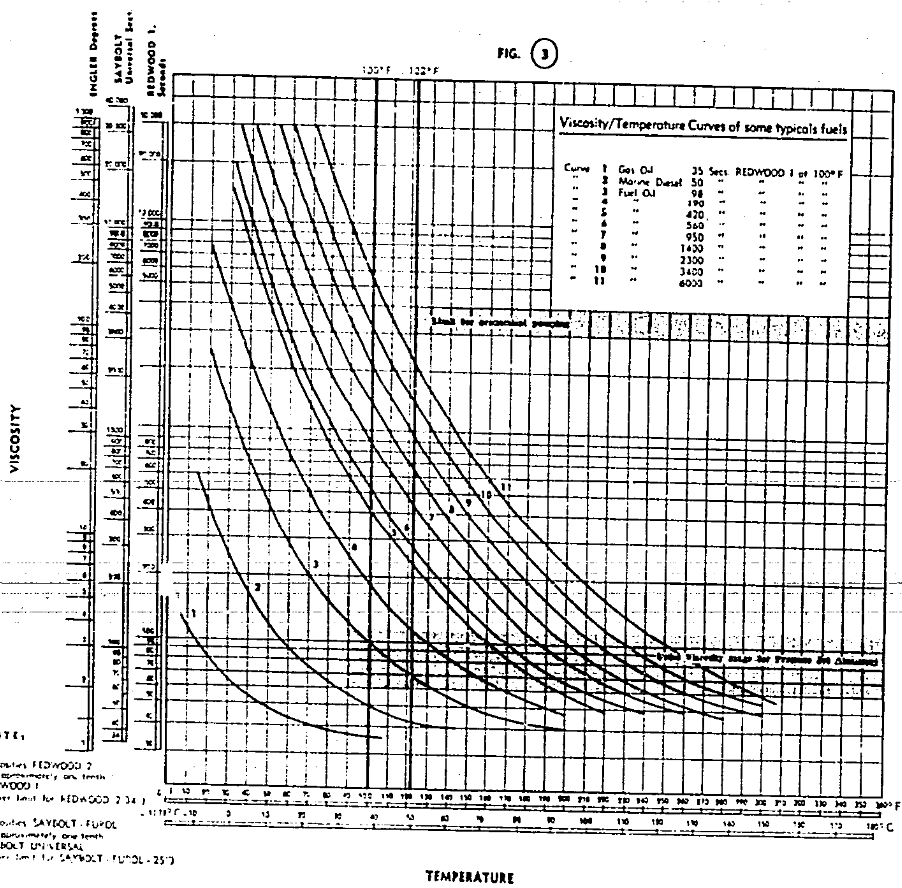
## DISTRIBUIÇÃO

Nos primórdios da indústria, os produtos petrolíferos eram transportados em barris de madeira, tanto por mar como em terra e com o tempo a necessidade de transportá-los à distâncias cada vez maiores em quantidade sempre crescente, incentivou seu transporte a granel — em terra por meio de oleodutos e carros tanques rodo e ferroviários e no mar por meio de navios-tanque.

A idéia de transportar líquidos por meio de tubulações é muito antiga. Acredita-se que já há mais de 7.000 anos os chineses usavam encanamentos de bambu. Em 525 A.C. Cambises, rei da Pérsia, utilizou-se de uma tubulação através do deserto, feita de couros de boi, a fim de suprir de água o exército com que invadiu o Egito.

O oleoduto é considerado como o meio mais econômico de transporte, embora em distâncias grandes o transporte por grandes petroleiros seja mais barato. Os custos comparativos dos diferentes meios de transporte foram recentemente calculados nos Estados Unidos (custos médios) como segue:

FIG. ③



NOTE:

Viscosities REDWOOD 2 are approximately one tenth REDWOOD 1
(Lower limit for REDWOOD 2 34 )

Viscosities SAYBOLT - FUROL are approximately one tenth SAYBOLT UNIVERSAL
(Lower limit for SAYBOLT - FUROL - 25)

| | | |
|---|---|---|
| Rodovia .................. | 0.0612 | US$/ton/milha |
| Ferrovia .................. | 0.01695 | " |
| Oleoduto (gasolina) ......... | 0.00445 | " |
| " (petróleo) ........ | 0.00344 | " |
| Transportes sôbre água ...... | 0.00082 | " |

Êstes algarismos variam de país para país e com a eficiência dos transportes rodo e ferroviário, mas sempre guardadas essas proporções, exceto em casos muito especiais apresentando condições peculiares.

Em quase tôda a parte, a área disponivel para a instalação de depósitos terminais de produtos petrolíferos se situa nos arredores dos portos marítimos, em terrenos baldios, freqüentemente alagadiços, necessitando aterros e obras que facilitem comunicações com os sistemas rodo e ferroviários locais. Tais terrenos apresentam ainda outros problemas, principalmente no que diz respeito à corrosão metálica. Os fundos de tanques, os oleodutos enterrados e expostos sofrem a ação corrosiva acelerada dos ácidos orgânicos provenientes da decomposição da matéria orgânica, requerendo pois precauções especiais para proteger o equipamento. Em outras zonas tropicais, êsses terrenos recuperados são infestados por variada fauna que se estabelece debaixo dos tanques, freqüentemente afetando suas fundações. Peculiares às regiões tropicais e semi-tropicais, são também inúmeros os insetos, que se aninham em caixas de fuzíveis, suspiros de tanques, cascos de motores e geradores e podem causar grandes danos a equipamentos de emergência ou de uso pouco freqüente.

A função de um depósito de produtos petrolíferos é recebê-los em grandes quantidades e redistribuí-los em parcelas menores. Assim é evidente que os depósitos terminais e os subseqüentes devem ser de tal modo projetados que a cadeia de distribuição até o consumidor seja a mais simples e econômica possivel, valendo-se dos meios de transporte disponíveis e naturalmente tendo em vista o desenvolvimento industrial ou agrícola do país e conseqüentes demandas de produtos de petróleo.

Como o transporte sôbre água é usualmente o meio mais econômico de transporte de grandes quantidades de combustíveis líquidos a granel, os principais terminais situam-se quer em rios navegáveis ou na costa marítima.

A escolha do lugar mais apropriado em vista da distribuição presente e futura é de suma importância. No Brasil, p.ex., temos um imenso território, um extenso litoral e os depósitos terminais estabelecidos nos principais portos, capazes de receber grandes petroleiros. Os parques de tanques existentes nessas instalações são as vêzes capazes de armazenar cargas completas dêsses petroleiros, reduzindo assim os fretes, embora na prática cada petroleiro comumente descarregue em dois ou três portos. Êsses terminais oceânicos eram a princípio os únicos depósitos a granel e dêles os produtos eram entregues ao consumo no interior através vagões-tanque ferroviários, em tambores devolvíveis ou em latas não devolvíveis. Com o aumento do consumo a quantidade de vasilhame em jôgo aumentou de tal modo que se tornou mais econômica a instalação de novos depósitos no interior. No caso de Santos, foram instalados tanques em São Paulo e no da região suprida do Rio de Janeiro foram montados tanques em Juiz de Fora e Belo Horizonte. Êsses depósitos recebiam por vagões tanques ferroviários a granel e transferiam por carros tanque rodoviários e (ou) em vasilhames. Evitou-se assim a longa viagem de vasilhame vasio para os portos, com grande economia de fretes. Continuando o desenvolvimento, êstes depósitos secundários se ampliaram e se tornaram mais flexíveis e importantes. Com a construção de boas estradas o transporte ferroviário a partir dos terminais foi suplementado pelo rodoviário, especialmente à vista das delongas daquele.

No caso de São Paulo as quantidades de produtos requeridas se tornaram tão grandes que afinal se fêz necessário um oleoduto e esta instalação, consistindo de duas linhas, hoje carréa produtos de petróleo importados a granel em Santos. Assim os depósitos de São Paulo são pràticamente uma extensão dos de Santos. Em futuro próximo, quando a refinaria de Cubatão estiver em produção, o mesmo oleoduto a ligará ao terminal de São Paulo. Parece-nos que estão sendo realizados estudos para a extensão do oleoduto até Campinas, a uma centena de quilômetros no interior. Dêstes terminais do oleoduto, o transporte rodo ou ferroviário levará os produtos de petróleo a outros depósitos a granel já existentes no interior. É óbvio que o caso do oleoduto Santos/São Paulo se reproduzirá em outras regiões dêste vasto país.

O que acima foi dito dá idéia de como o transporte a granel vem contìnuamente suplantando o de tambores e latas, contribuindo para um abastecimento mais regular e econômico do consumidor.

Nos últimos tempos a construção de novas estradas alterou considerávelmente o panorama e carros-tanque passaram a transportar produtos de depósitos regionais diretamente aos tanques dos postos de serviço ou às instalações dos consumidores.

Êste encadeiamento das linhas de distribuição dos terminais através da rêde de depósitos até o consumidor, recebe a atenção constante das emprêsas de petróleo, pois que se reflete imediatamente na economia e na capacidade de concorrência das mesmas. O consumidor se beneficia pela obtenção de produtos mais baratos e de modo mais regular, dispensando-o assim da necessidade de manter grandes estoques.

A distribuição costeira é feita por meios de petroleiros menores até depósitos oceânicos secundários.

O custo comparativo dos vários meios de transporte está sob constante observação e estudo pois que o desenvolvimento rodo ou ferroviário naturalmente afeta o problema; sua relação com o equipamento requerido sob a forma de carros-tanque, vagões-tanque, tanques de armazenamento, instalações de bombeamento, canalizações, etc., nos depósitos intermediários é capital.

O tipo de bombas usadas para a movimentação de produtos de petróleo varia com a volatilidade e a viscosidade dos mesmos. As bombas centrífugas preferidas para o bombeamento de produtos mais leves, quando operam com produtos voláteis, devem trabalhar afogadas a fim de evitar as obturações por vapor (vapour locks). Para líquidos muito viscosos são preferidas bombas de deslocamento variável, devendo ser tomado em consideração o líquido que permanece estático no cano depois de cessado o bombeamento, pois que pode ter aumentada de tal sorte sua viscosidade que o reinício do bombeamento seria sèriamente dificultado.

Como é sabido, a resistência dos líquidos ao movimento é dada pela conhecida fórmula de hidráulica:

$$H = 4.f.\frac{L}{d}.\frac{V^2}{2g}$$

em que

$H$ = perda de carga
$L$ = comprimento de canalização
$V$ = velocidade
$g$ = aceleração devida à gravidade
$d$ = diâmetro da canalização
$f$ = coeficiente de atrito, variando com o tipo de escoamento (com óleos pesados o escoamento é usualmente laminar) e com a viscosidade do fluído.

Há inúmeras curvas publicadas relacionando o importantíssimo coeficiente de atrito "f" às condições de escoamento e podem ser encontradas em livros de texto conhecidos.

Tomemos um óleo combustível típico de viscosidade igual a 800 cs. a 38° C e vamos bombeá-lo à razão de 500 ton/hora, por um cano de 12" de diâmetro primeiramente a 30° C e depois a 45° C (temperatura do óleo).

No primeiro caso há uma perda de carga de 10 kg/cm² ou 147 libras/polegada quadrada e por quilômetro de cano, enquanto que no segundo caso serão necessários sòmente 3.4 kg/cm² ou 50 libras/pol. quadrada para vencer o atrito.

A diferença de potência requerida de cêrca de 200 HP (com um rendimento de 75% na bomba) equivale a 130.000 kg/cals/hora na bomba. Para aquecer mais 15° C 500 tons de óleo, são requeridos 3.750.000 kg/cals. Mesmo admitindo um rendimento global de 25%, o calor requerido inicialmente é de sòmente 520.000 kg/cals. ou cêrca de $\frac{1}{7}$ do calor requerido para elevar a temperatura do óleo de 15° C. Neste exemplo não levamos em consideração outros pontos, tais como o maior custo das bombas de alta pressão e dos motores de alta potência, etc., que deverão ser levados em conta, bem como a resistência à pressão, e conseqüente custo mais elevado dos canos.

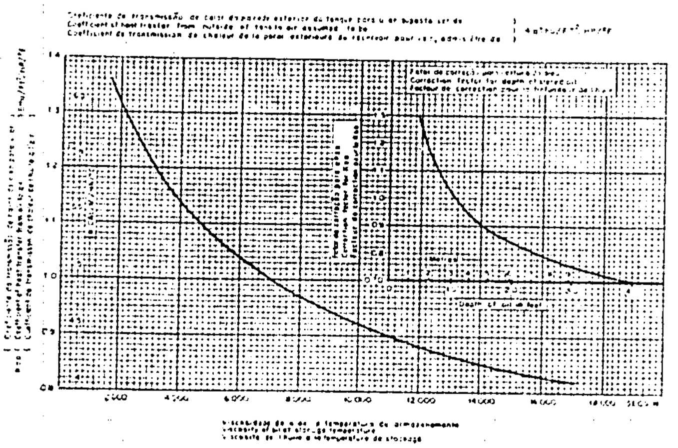


Fig. 4

## UTILIZAÇÃO

Dois fatôres principais podem condicionar as aplicações dos combustíveis líquidos de petróleo, quer quanto à variedade de aplicações, como quanto às massas utilizadas:

1.º — O grau de desenvolvimento tecnológico e industrial da região em causa, e
2.º — a disponibilidade de outros combustíveis em base econômica.

As gasolinas quer as comuns quer as destinadas à aviação, bem como os combustíveis para motores de combustão interna de um modo geral, têm função específica, de modo que resta o chamado óleo combustível como combustível por excelência para os processos industriais.

O primeiro ponto a considerar na escolha de um combustível na indústria é evidentemente o preço, mais exatamente o preço por caloria útil, por exemplo, no caso da geração a vapor, o custo do combustível capaz de produzir uma determinada quantidade de vapor é o que importa.

Outros fatôres a ponderar são os seguintes:

a) Despesa de armazenamento e manejo em geral,
b) disponibilidade e custo do espaço para armazenamento,

c) custo e praticabilidade comparada dos sistemas de distribuição interna do combustível (estradas de ferro, fitas transportadoras, guindastes, oleodutos ou tubulações de gás),
d) influência da natureza e composição do combustível sôbre a qualidade do produto industrial,
e) temperatura atingível na combustão,
f) tipo de chama produzida,
g) aplicabilidade de aparelhagem de contrôle automático,
h) custo e manutenção dos queimadores e fornos,
i) praticabilidade da recuperação de calor perdido,
j) necessidade de assistência técnica,
k) estabilidade de preços e qualidade,
l) garantia de continuidade de suprimentos,
m) higiene e segurança do trabalho.

Para completar o quadro no que tange ao tema de nosso trabalho temos de considerar que o óleo combustível apresenta as seguintes vantagens evidentes:

a) qualidade uniforme,
b) limpeza no armazenamento e manejo,
c) facilidade de armazenamento,
d) economia de trabalho,
e) facilidade de aplicação e contrôle,
f) facilidade de manejo,
g) ausência de cinza,
h) chama de alta temperatura,
i) eficiência térmica elevada dos fornos,
j) maiores rendimentos dos fornos.

Merece especial destaque entre as características acima alinhadas a propriedade do óleo combustível produzir chama de alta temperatura, justificando-se que nos detenhamos no capítulo referente à irradiação das chamas.

Nos fornos de alta temperatura o problema principal é obter uma transferência de calor adequada da chama para o objeto a aquecer, o que não é tão simples quando as temperaturas da chama e do objeto não diferem mais do que cêrca de 200 graus. Envidam-se, pois, todos os esforços no sentido de aumentar a temperatura da chama, pre-aquecendo o ar para a combustão a 1000º C e mais, mas há limites impostos pelas reações de dissociação particularmente acima de 1600º C, ficando as temperaturas reais aquém das teóricas pelo retardamento da combustão.

Num forno de aço em que o metal pode estar a 1600º C, ou num de vidro a 1250/1450º C, uma chama fortemente irradiante é de necessidade vital.

É conhecida a equação

$$H = \frac{4.93\ e}{10^8} \left( T_e^4 - T_r^4 \right) \text{ kg.cal/m}^2\text{/hora,}$$

baseada na lei de Stefan-Bolzmann e em que

$e$ = emissividade real entre chama e ambiente
$T_e$ = temperatura da chama em ° C abs.
$T_r$ = temperatura do corpo que recebe a irradiação.

Tomando dois fornos idênticos, um aquecido a óleo combustível e outro com gás de gasogênio, ambos com 20% de excesso de ar e ambos com ar pre-aquecido a 900° C, foi verificado que a chama de óleo terá uma temperatura de 2340° C, e a do gás de gasogênio 2120° C e o quadro abaixo dá as transferências de calor observadas em várias temperaturas admitindo $e = 1$:

| *Temperatura da superfície que recebe a irradiação* | *Kg/cals/m²/hora* | |
|---|---|---|
| | *Óleo* | *Gás* |
| 800° C | 2.210.000 | 1.540.000 |
| 1000° C | 2.170.000 | 1.480.000 |
| 1400° C | 1.890.000 | 1.239.000 |
| 1600° C | 1.680.000 | 1.000.000 |

Êste quadro mostra que nos processos industriais que requerem altas temperaturas o óleo combustível é superior ao gás de gasogênio em cêrca de 60% a 1600° C.

Não só nas altas temperaturas apresenta a chama de óleo combustível vantagens. Já em 1927 o Professor Lindmark e colaboradores, de Estocolmo, investigavam a emissividade de diferentes chamas e demonstravam o que era até então inesperado, isto é, que em suas fases iniciais a chama de óleo irradia mais intensamente do que a do carvão em pó, que entretanto, queimando mais lentamente conserva sua alta emissividade por um período mais extenso (fig. 7).

O Comitê Internacional de Investigações sôbre Irradiação das chamas, sediado em Ijmuiden na Holanda, continuou com a cooperação anglo-franco-holandesa, as pesquisas de Lindmark, verificando cuidadosamente a superioridade da chama de óleo sôbre a produzida por gás de coqueria. É de se notar que em seus trabalhos o Comitê Internacional estudou principalmente chamas de ângulos agudos, tais como as empregadas nos fornos Siemens-Martin e nos fornos de cimento, ràpidamente alongadas e encaminhando-se para câmaras de combustão extremamente quentes, nas quais o óleo (nessa passagem) é craqueado antes de encontrar o oxigênio para combustão. As minúsculas partículas de carbono resultantes em nuvem dão à chama nos estágios iniciais uma natureza irradiante próxima da de um "corpo negro".

Os trabalhos do Comitê Internacional apresentam duas outras conclusões valiosas:

a) as chamas fracamente irradiantes do gás de coqueria podem ter sua emissividade elevada por chamas de óleo de petróleo ou de alcatrão,

b) a emissibilidade da chama de óleo é grandemente influenciada pelo tipo de queimador. O atomizador longo de ângulo fechado dá chama mais radiante do que o de cone aberto bem ventilado do queimador comum a jato-pressão.

Segue-se do exposto acima que mesmo em países onde a maior parte do suprimento de combustiveis se baseia no combustível sólido local, é econômico usar-se óleo combustivel para o enriquecimento da chama.

Entre as indústrias que utilizam o óleo combustível vantajosamente, citemos as seguintes:

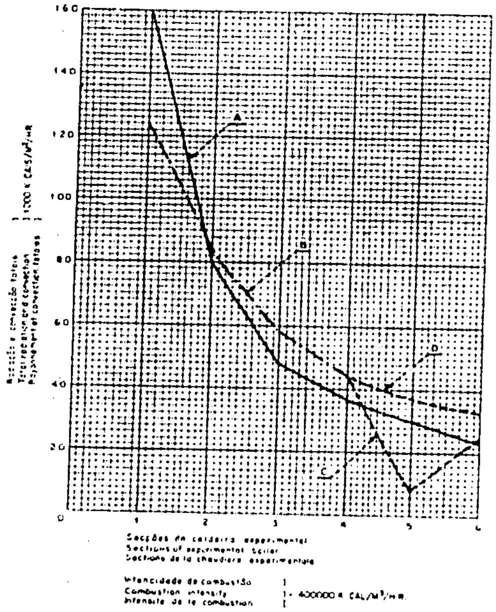
### ACIARIAS

Os fornos Siemens-Martin são operados a uma temperatura tão alta que uma grande proporção de combustível é utilizada não para fundir e refinar o metal, mas principalmente para manter a temperatura dos fornos. Assim sendo, o aumento de produção do forno não acarreta aumento sensivel de consumo de combustivel mas reduz-lhe o consumo médio por tonelada fundida. É pois de suma importância aumentar a produção e isto é possível com o emprêgo de chama altamente irradiante. A fim de conseguir tais chamas, os combustíveis gasosos são coadjuvados pelo emprêgo do alcatrão, mas êste é obtido da usina de coquefação em quantidades limitadas, sendo pois os melhores resultados conseguidos com o óleo combustível. Evidentemente o consumo de óleo também varia com a proporção de gusa, socata e metal quente direto do alto forno, e pode descer até cêrca de 101 litros por tonelada de aço ou, quando tôda carga é fria, subir até 180 litros/tonelada de aço. A instalação de controles automáticos pode melhorar ainda mais a eficiência, garantindo um equilíbrio estável entre o pêso do combustível queimado, o ar introduzido no forno e a temperatura de pressão da atmosfera interna dos fornos.

Nos fornos para aquecimento de chapas e lingotes o óleo combustível também tem sido usado com grande sucesso, usando-se em muitas usinas uma combinação de queimadores a gás e óleo; nos últimos anos têm sido igualmente obtidos ótimos resultados em fornos de recozimento a óleo.

## METALURGIA EM GERAL

De um modo geral nas oficinas metalúrgicas é muito empregado o gás de iluminação para o aquecimento de fornos de tratamento térmico, recozimento, etc., dada a possibilidade de ser êsse combustível especialmente purificado e dessulfurizado antes do uso, além da vantagem inerente aos combustíveis gasosos de permitir fácil mistura com o ar de modo a obter as atmosferas desejadas, oxidantes ou redutoras. É difícil obter os mesmos resultados com o óleo, mas os progressos recentemente reali-



A - Óleo (Series IV - ensaio 5)
Oil (Series IV - test 5)
Huile (Series IV - essai 5)

C - Observações feitas com as secções 5 e 6 revestidas de refratário
Actual observations due to firebrick lining in sections 5 and 6
Observations réalisées avec les sections 5 et 6 revêtues de refractaire

Fig. 5

B - Carvão pulverizado (ensaio 4)
Pulverized coal (test 4)
Charbon pulverisé (essai 4)

D - Secções 5 e 6 sem revestimento refratário (estimado)
Sections 5 and 6 without firebrick lining (extrapolated)
Sections 5 et 6 sans revêtement refractaire (extrapolé)

zados, principalmente na França e países adjacentes com um gaseificador capaz de permitir a transformação do óleo combustível, mesmo o mais pesado, em gás quente, contornou a situação. Êste aparelho foi projetado pelo "Office Central de Chauffe Rationelle" de Paris.

### Fábricas de Vidros

As considerações feitas à propósito dos fornos Siemens-Martin também se aplicam, de um modo geral aos de vidros quer os destinados à fabricação de frascos ou de vidros planos. A diferença está em que no caso de vidro o processo é contínuo.

### Fábricas de Cimento

Esta indústria merece ser mencionada não só pela sua influência no progresso das regiões sub-desenvolvidas, como pelo grande consumo de combustíveis, que é de molde a condicionar sua escolha em primeira linha pela disponibilidade local. Nos tradicionais fornos rotativos êsse consumo é da ordem de 1.7/kg/cal/kg de clinker no processo sêco e de 2.0 kg/cal/kg de clinker no processo húmido, dependendo evidentemente de fatôres inerentes a cada forno e operação. Os fornos Lepol, cuja introdução na Europa data dêstes últimos vinte anos, conseguiram melhorar notàvelmente essa eficiência, reduzindo o consumo a 1.0 kg/cal/kg de clinker, graças ao artifício de fazer passar os gases de saída por uma camada de matéria prima húmida, granulada, conduzida por um transportador de correntes ao forno.

A utilização simultânea de carvão em pó e de óleo como combustíveis é outro desenvolvimento digno de nota. Êstes fornos têm sido operados na Suécia, p.ex., e permitem a utilização de carvões inferiores, graças à ação supletiva do óleo combustível.

### Fornos de Cal

O emprêgo do óleo combustível nestes fornos oferece um exemplo do progresso que se pode esperar, notadamente nas regiões sub-desenvolvidas, onde ainda são maioria as velhas caieiras intermitentes. Já há vários tipos de fornos contínuos, a óleo, operando com grande vantagem em diferentes pontos.

### Estradas de Ferro

O grande surto verificado nos últimos anos, primeiramente nos países mais adiantados, não poderia deixar de se refletir também nas regiões tropicais ou sub-tropicais, no sentido da conversão da locomotiva para queima de óleo combustível, de um lado e principalmente no do desenvolvimento de locomotivas Diesel e Diesel elétricas de outro lado. Comparando com a lenha = 1 em qualquer dêsses sistemas, o pêso e o volume dos combustíveis em aprêço não vão a 0.2.

Nos países tropicais o emprêgo dos óleos de petróleo acaba com a ocorrência freqüente de incêndios causados por fagulhas ao longo das linhas quando servidas por locomotivas à lenha e a carvão. O desenvolvimento das locomotivas Diesel e Diesel elétricas é de grande alcance para zonas onde há escassez de água para as caldeiras, embora o custo inicial e a manutenção sejam elevados, notadamente se não aproveitada a capacidade de trabalho dessas locomotivas de muitas horas por dia superior e das locomotivas a combustível sólido. No caso das locomotivas de manobra, as movidas à motor Diesel são geralmente superiores às de qualquer outro tipo.

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## RESUMO

1) O trabalho mostra a demanda potencial de combustíveis líquidos em regiões tropicais e sub-tropicais, como decorrência de seu desenvolvimento agrícola e industrial.

2) O efeito do clima sôbre o armazenamento dos produtos de petróleo e os métodos empregados para reduzir as perdas por evaporação são discutidos e exemplificados. É também tratado do aquecimento dos produtos viscosos.

3) Uma breve comparação entre os vários métodos de transporte de produtos de petróleo a granel é feita, discutindo-se as alterações na distribuição verificadas com o desenvolvimento de uma zona, exemplificando-se com relação ao Brasil.

4) Embora a aplicação dos combustíveis liquidos na indústria não apresenta problemas especiais de monta nas regiões tropicais, enumera-se suas vantagens, ressaltando a natureza altamente radiante da chama de

óleo combustível. São apontadas algumas das indústrias mais beneficiadas pelo uso de combustíveis liquidos, pondo em relêvo os pontos mais interessantes.

### SUMMARY

1) The paper shows the potential demand for liquid petroleum fuels in tropical and sub tropical regions arising from the development of agriculture and industry in those territories.

2) The effect of climatic conditions on the storage of petroleum products and the methods employed for reducing evaporation losses are discussed and exemplified. The heating of viscous fuel is also dealt with.

3) A short comparison is made between the various methods of bulk transportation of petroleum fuels and the modifications in distribution arrangements which accompany the development of a territory are discussed and exemplified in respect of Brazil.

4) The application of fuels in industry presents no special problems in tropical territories; however, the advantages accruing from the use of liquid fuels in industry are enumerated and the high radiation characteristic of petroleum fuel flames is exemplified. The industries most benefited by the use of liquid fuels are given and the points of special interest are stressed.

### RESUMÉ

1) La demande potentielle des combustibles liquides est prèsentée par l'auteur pour les régions tropicales et sub-tropicales comme corollaire du développement agricole et industriel.

2) L'éffet du climat sur le stockage des produits pétrolifères et les procédés employés pour reduire les pertes par évaporation, sont discutés et exemplifiés. L'auteur traite aussi du chauffage des produits visqueux.

3) Une comparaison résumée entre les différentes méthodes de transport des produits pétrolifères est faite et les modifications apportées exemplifiées par rapport au Brésil.

4) L'usâge dans l'industrie, des combustibles liquides ne prèsente pas de problèmes spéciaux importants pour les pays tropicaux; néanmoins, ses avantages sont présentées, particullièrement le rayonnement elevé de la flamme du "fuel oil". Les industries les plus favorisées par l'emploi des huiles combustibles du pètrole sont ênumerées et les points plus importants sont focalisés.

[redacted]

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 2
Assunto 2.1.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro – 1954

FERRAZ (O.M.)
BALANÇA (A.)
(Brasil)

# LA COUPURE DU FLEUVE S. FRANCISCO À L'USINE DE PAULO AFONSO

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## INTRODUCTION

Dans le travail que nous avons présenté à cette section de la Conférence Mondiale de l'Energie, il a été mentionné les difficultés éprouvées par la Companhia Hidro-Elétrica do São Francisco lors de la construction des fondations du barrage mobile dans le lit du Bras Principal du São Francisco. Le fleuve a un débit de l'ordre de 1.300 $m^3$/sec pendant la plus grande partie de l'étiage (Juin Octobre), seule période durant laquelle il est possible de travailler.

La coupure, réalisée en deux temps, a été un problème ardu, mais ce sont toutefois les excavations à l'intérieur du batardeau qui se sont montrées les plus difficiles.

## PROBLÈME

Au point où le barrage coupe le Bras Principal, le fleuve est relativement étroit, le courant violent et la profondeur très appréciable. Le problème posé par la mise à sec du lit, était donc délicat à résoudre. C'est durant 4 à 5 mois par an seulement, quand le niveau du fleuve est suffisamment bas, que l'on peut songer à s'attaquer à des débits de 1.000 à 1.500 $m^3$/sec qui provoquent sur les ouvrages provisoires des impacts de plusieurs centaines de tonnes. De plus, il faut compter sur des crues variant entre 5.000 et 10.000 $m^3$/sec (exceptionellement encore plus) pendant la saison où les travaux sont interrompus. Il s'agissait donc de construire un batardeau dans des conditions particulièrement difficiles.

non seulement du fait de l'ampleur de l'opération, mais aussi à cause des sérieuses questions subsidiaires dont la résolution ne devait pas sortir d'un certain cadre physique et économique.

## DONNEES

A l'endroit où le barrage traverse le Bras Principal, celui-ci a, en période d'étiage, 120 mètres de large, une section mouillée de 800 m² et une profondeur moyenne de l'ordre de 7 m (on a même atteint jusqu'à 14 m lors du relevé batimétrique). La vitesse de l'eau est de l'ordre de 3,5 m/sec. En supposant la vitesse égale à 4,5 m/sec (pour avoir une certaine marge de sécurité) la formule de Dubuat donne sur une cellule de section 15 x 10 m, un impact de l'eau de l'ordre de 300 tonnes — ceci dans le cas où nous adopterions la solution du batardeau cellulaire.

Le fond du lit est extrêmement irrégulier la profondeur variant parfois brutalement de 8 mètres. Vu la vitesse du courant, le relevé batimétrique a été très difficile et assez approximatif, l'imprécision étant inévitable dans les sondages au poids: les spécialistes appelés ne sont pas parvenus à utiliser l'écho-batimètre.

## SOLUTIONS

Nous avons envisagé trois procédés pour réaliser la coupure soit en un, soit en deux temps.

a) — La première idée qui vient à l'esprit quand il s'agit de dévier un courant, est de construire un canal de dérivation. Le canal court-circuitant le site en question nécessiterait une excavation de 300.000 m3 de roche, en supposant qu'il n'ait que 350 m de long. Ce déblayge serait plus important que le total des excavations des fondations du barrage qui a plus de 4 km de long. Cette solution n'excluait d'ailleurs pas la construction d'un enrochement sur le fleuve obligeant l'eau à passer par la dérivation. Même en utilisant pour sa construction le matérial retiré de l'excavation du canal, la solution aurait été très coûteuse.

b) — Une autre solution était l'emploi du "crib cofferdam", mais elle exigeait un relevé précis et complet du fond du fleuve afin de permettre la construction exacte de la base du "crib" que doit l'épouser parfaitement. De plus, même ne supposant remplie la première condition, le prix du bois de qualité adéquate aurait été prohibitif.

c) — Restait la solution du batardeau cellulaire en palplanches métalliques. Les principales conditions que nous exigions d'un tel dispositif étaient les suivantes:

1) — adaptation au fond tourmenté du fleuve;
2) — capacité de résistir aux crues;
3) — prix de revient raisonnable;
4) — étanchéité acceptable;
5) — possibilité de montage en dépit des conditions locales;
6) — temps de montage réduit.

Certes le type cellulaire paraissait satisfaire aux exigences précitées mais les dérnières conditions conduisaient à de très sérieuses restrictions. En effect l'impact sur les palplanches rendait le montage très peu aisé sinon impossible, et ces difficultés risquaient de rendre le temps de montage trop long. Pour tâcher de résoudre ces problèmes (qui d'ailleurs seraient communs au "crib cofferdam"), on a pensé construire un enrochement en amont sur la rive gauche du fleuve, pour briser le courant et permettre le montage dans des conditions suffisamment sûres pour le personnel et le matériel. On aurait ensuite à rétirer l'enrochement, à en refaire un autre sur la rive droite pour répéter les mêmes opérations de montage. Malheureusement avec des vitesses de l'eau de l'ordre de 4 m/sec, les enrochements auraient dû être faits avec des blocs de béton pesant de 10 à 15 tonnes. Comment les enlever aprés l'opération? et à quel prix? La vitesse et la profondeur rendaient l'opération presque impossible.

## LE "NAVIO"

C'est alors que nous est venue l'idée de construire un écran mobile sous la forme d'un *caisson flottant* qui serait placé devant la cellule à monter.

Aprés avoir projeté ce dispositif nous avons fait un modèle réduit de la partie du fleuve qui nous intéressait et avons procédé à des essais ayant pour objet l'étude du comportement du caisson (dénommé "navio" (navire) au chantier), du comportement de la cellule (c'est-à-dire savoir si elle glissait sous l'action du courant) et finalement des variations de niveau pendant les opérations de coupure (fig. 1).

Les résultats des essais ont été satisfaisants et d'autre part le prix du "navio" était raisonnable, son poids étant de 125 tonnes environ (sans lest). Ces résultats acquis, nous avons projeté la coupure qui devait se faire en deux étapes. La première étape serait entreprise du côté rive gauche et serait constituée de 8 cellules dont 7 de 15,28 m de diamètre et 1 de 17,47 m. Un mur de maçonnerie de moellons fermerait l'enceinte du côté rive et formerait plateforme de manoeuvre des grues et camions, enfin servirait d'abri pour tout l'équipement de construction pendant la saison des crues (fig. 2).

La côte de l'eau, durant l'étiage variant de 219 a 221, nous avons fixé la côte du couronnemen tdu batardeau à 225 pour la première étape. Ainsi la hauteur des cellules – donc des palplanches – était en moyenne de 14 mètres. Les spécifications du "navio" ont été envoyeés à un constructeur spécialiste qui en a étudié les détails et exécuté la fabrication.

Le montage a été realisé sur une rampe au bord du fleuve, puis on a procédé au lancement non sans quelques incidents, d'ailleurs sans gravité. Le "navio" possédait des amarres principales d'une centaine de mètres de longueur et était déplacé à l'aide de treuils. A l'endroit approprié, il était coulé pour former écran. Il se vérifiait toutefois des courants assez

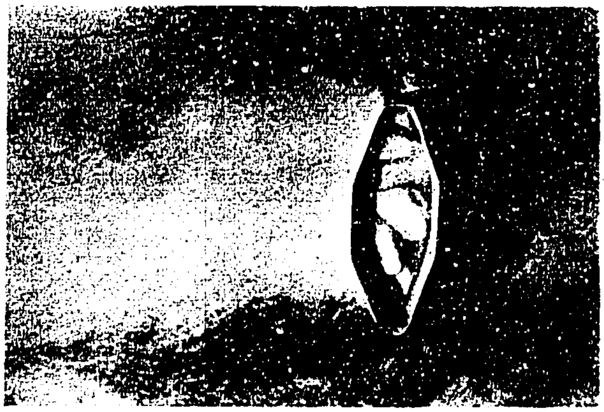


Fig. 1 — Étude sur modèle réduit du comportement du "navio"

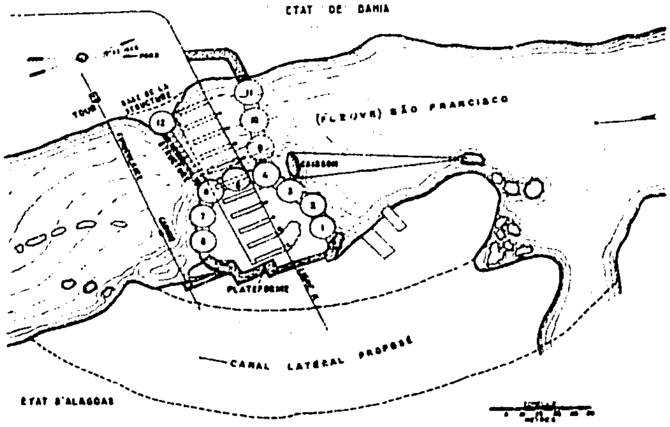


Fig. 2 — Plan général des travaux du bras principal

violents au-dessous de lui par suite de l'irrégularité du fond. L'obstruction était réalisé en appuyant des palplanches T sur le flanc amont du "navio" (voir fig. 3).

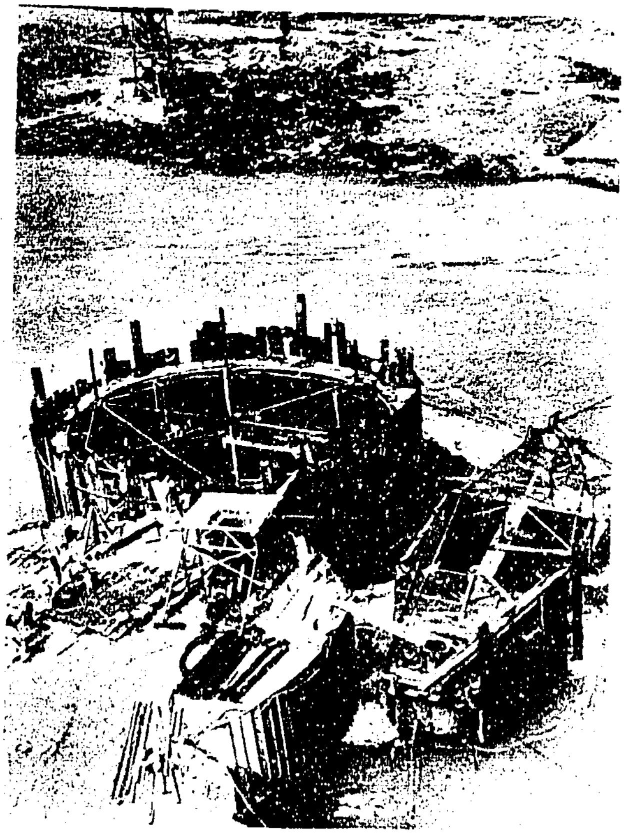


Fig. 3 — Construction de la cellule n.° 4 a l'abri du "navio"

## EXÉCUTION DE LA PREMIÈRE ÉTAPE

Les cellules n° 1, 2, 3 et 4 ont ainsi été construites. Les autres, n° 5, 6, 7 et 8 étaient en grande partie abritées du courant par les précédentes (fig. 4).

Fig. 4 — Mise en place du gabarit de la cellule 6

On recouvrait d'une couche de béton le fond des cellules pour parer aux inconvénients dûs à l'irrégularité du lit, puis celles-ci étaient remplies de sable.

Au début de l'épuisement on a vérifié que les infiltrations dépassaient la capacité des pompes disponibles (environ 2.000 l/sec). Comme nous avions de sérieuses raisons de penser que les cellules étaient pratiquement étanches, nous en avons conclu que des infiltrations se produisaient par des interstices entre les gros moellons couvrant le fond ou même par des communications directes entre l'extérieur et l'intérieur de l'enceinte (by-pass). Par la suite, on s'est aperçu que le lit du fleuve était constitué par d'énormes blocs de 2 à 20 m3 formant une base très perméable: ce que l'on avait relevé par des sondages n'était pas le vrai fond. Il convient de noter qu'un sondage plus rigoureux aurait était très long et très coûteux; la hauteur du barrage mobile ne le justifiait pas: on aurait pu, par exemple, creuser un puits vertical dans une des rives, puis un tunnel sous-fluvial qui aurait permis des sondages de bas en haut. Il est à noter aussi que ces inconvénients n'étaient pas inhérents au seul procédé cellulaire.

Aprés des injections de ciment et d'asphalte, on est parvenu à réduire les infiltrations à une valeur raisonnable et les pompes d'équipement ont pu les contrôler parfaitement (quelques unes étaient même laissées en réserve).

Le batardeau vidé, les excavations des piliers et des radiers du barrage ont pu être attaquées et l'on a pu constater que le fond était tel que l'on avait prévu. Ces travaux d'excavation ont été les plus durs que nous ayons rencontrés (y compris le montage des cellules dans le courant impétueux du São Francisco). Il s'agissait de retirer le couverture de moellons mélangés à du gravier et à du sable échappé des cellules. L'eau d'infiltration s'accumulait dans les creux (marmites) atteignant jusqu'à 80 $m^3$ dont l'asséchement était très difficile. On a dû faire des batardeaux auxiliaires internes fondés eux aussi sur une base perméable mais qui permettaient néanmoins de bétonner parcelle par parcelle. Malheureusement procédant ainsi on a perdu beaucoup de temps pour arriver à la côte du seuil des vannes: on avait prévu deux mois, on en a mis quatre.

En dépit des difficultés et d'un certain péril présentés par les travaux, nous n'avons eu à déplorer aucun accident durant le montage du batardeau et les excavations. La construction des piliers au-dessus du radier et le montage des vannes et du pont roulant, se sont déroulés normalement (fig. 5).

## DEUXIÈME ÉTAPE

### (Structure semi-flexioble)

Ainsi donc la première étape était terminée. Voyons maintenant ce qu'il a été prévu pour la deuxième étape.

Tout d'abord, il s'agit de compléter la coupure du fleuve pour faire fonctionner l'usine dont le montage est en voie d'achèvement. On a projeté de conserver les celules 4, 5 et 6 de la première étape et de faire une paroi facilement démontable entre le pilier 7 et la cellule 4. Celle-ci a d'ailleurs déjà été construite à sec, en même temps que les piliers de la première étape.

Les vannes étant en position fermées, on procédera au démontage des cellules nº 3, 2 et 1 puis 7 et 8. Cela fait on pourra penser à monter les celllules nº 9, 10 et 11, diminuant la vitesse de l'eau côté rive droite par ouverture des vannes. Même ainsi la vitesse est par trop considérable pour que l'on puisse songer à monter les celllules sans protection spéciale.

Nous inspirant de la coupure du Saguenay à la Chute à Caron et du projet de la Waneta Power Plant sur le Pend d'Oreille River en Colombie Britanique (Canada) nous avons en premier lieu pensé à jeter en travers du fleuve à hauteur de la cellule 6 un "obélisque", immense prisme de 40 m de long et 11 mètres de base d'une construction lente et délicate. Cet "obélisque" exigerait pour son lancement une base de grande résistance sur la rive droite et une *parfaite connaissance du lit* suivant son axe, ce qui n'est pas possible comme nous l'avons vu.

Devant ces difficultés nous avons cherché à remplacer l'"obélisque" par une ouvrage "maniable".

Comme avec un débit de 1.300 m³ sec la vitesse de l'eau est légèrement inférieure à 4 m/sec, nous pourrons placer sans trop de difficultés deux structures légères (20 tonnes) et semi-flexibles (fig. 6).

Fig. 5 — Vue aerienne de la premiere etape avant demontage des cellules

Ces structures, après avoir été placées de niveau, recevront côté aval des grilles en fer ronds de 1/2" formant des mailles de 25 cms. Convenablement amarrées, elles seront remplies de pierres de 30 cm environ qui, retenues par les grilles tomberont au fond et constitueront un enrochement qui obligera l'eau à passer entre les piliers de la première étape (fig. 7).

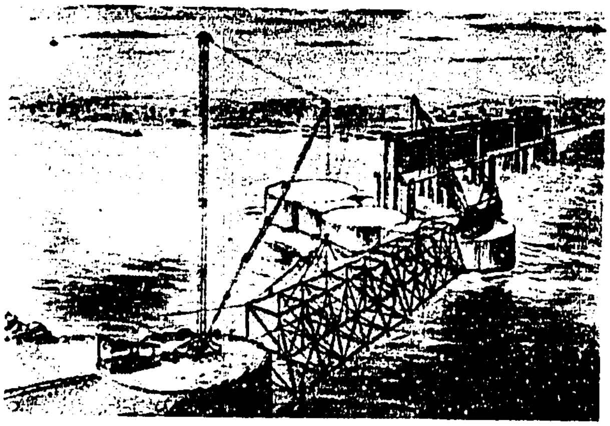
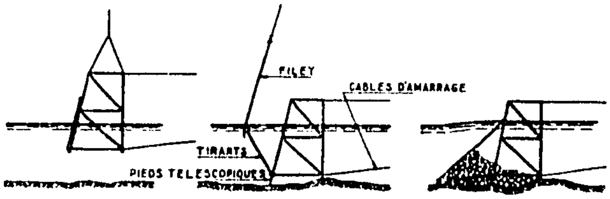


Fig. 6 — Mise en place des "structures semi-flexibles"



DESCENTE DE LA STRUCTURE — DESCENTE DU FILET — REMPLISSAGE

Fig. 7 — Methode de construction de l'enrochement (rock-fill)

Une fois l'eau tranquilisée les cellules 9, 10 et 11 seront montées sans difficulté.

On pourra alors attaquer l'excavation de la deuxième moitié du barrage mobile. Plus tard, aprés fermeture des vannes côté rive gauche, on pourra procéder -- pratiquement à sec -- au démontage des cellules 5 et 6, de l'enrochement (d'autant plus facilement qu'il est constitué d'éléments de petites dimensions) et des "structures semi-flexibles". Ceci permettra la construction des radiers et du pilier 6. L'eau serait alors deviée vers la prise d'eau et vers les autres barrages mobiles, ce qui n'était pas possible au début de la campagne vu l'état d'avancement du reste des travaux.

On se demandera pourquoi le "navio" ne sera pas utilisé? L'étude des variations des vitesses en fonction de l'étranglement de la section montre que si l'on n'utilisait pas l'enrochement en aval, et même si l'on parvenait à construire les cellules 9 et 11 la vitesse, entre ces deux cellules dépasserait 11 m/sec. Dans ces conditions la charge de rupture des câbles d'amarrage du "navio" serait plusieurs fois dépassée, et le déplacement exigerait des treuils extrêmement puissants.

Durant la première étape, usant des procédés tout de même assez peu communs, nous avons dû tâtonner à la recherche surtout, de la plus grande sécurité possible étant donné la "rusticité" du gros du personnel employé. Mais nous esperons que l'éxpérience acquise nous fera gagner du temps durant les travaux de ladeuxième étape.

## CONCLUSION

A notre avis, les procédés du "navio" et de la "structure semi-flexible" permettent de résoudre de façon relativement simple des coupures dans des fleuves profonds au courant violent. L'écran mobile constitué par le "navio" a une grande mobilité et un prix réduit et la "structure semi-flexible" autorise l'emploi de pierres de remplissage de petites dimensions, faciles à placer et à retirer.

## RÉSUMÉ

A l'endroit où la "Companhia Hidro Elétrica do São Francisco" doit construire une des parties mobiles du barrage destiné à retenir les eaux du São Francisco, le fleuve est relativement étroit, mais profond et impétueux; comme l'ont montré les sondages — d'ailleurs imparfaits — le fond est extrêmement tourmenté. D'où la grande difficulté d'assècher de lit.

Trois solutions ont été envisagées pour résoudre le problèma:

a) — enrochement et dérivation du fleuve (une seule étape)
b) — crib cofferdam (deux étapes)
c) — batardeau cellulaire (deux étapes)

C'est cette dernière qui a été adoptée. Comme il était impossible de monter les cellules sans protection contre le courant il a été utilisé un caisson flottant (appelé "navio") à l'abri duquel on pouvait travailler sans danger. Le montage de cette première étape du batardeau a été mené à bien et a permis après certaines difficultés, de construire la première moitié du barrage mobile.

Il s'agit maintenant, après démontage de la première étape du batardeau, de construire la deuxième moitié du barrage mobile. Comme il n'est pas possible d'utiliser à nouveau le caisson flottant vu l'accroissement de la vitesse du courant, on construira en aval des cellules à monter un enrochement dont les éléments rempliront deux "structures semi-flexibles" qui joueront de rôle d'armature. Dans le remous crée par cet enrochement il deviendra plus facile de travailler.

Les procédés du caisson flottant et de la structure semi-flexible se montrent assez "maniables" et relativement économiques. Ils peuvent être utilisés avec avantage dans les travaux en rivières profondes et tourentueuses.

### RESUMO

No lugar onde a Companhia Hidro Elétrica do São Francisco deve construir uma das partes móveis da barragem que represará as águas do rio São Francisco, êste é relativamente estreito, mas profundo e impetuoso; como mostraram as sondagens — aliás imperfeitas — o fundo é extremamente irregular. Portanto, grande será a dificuldade de secar o leito.

Três soluções foram consideradas para resolver o problema:

a) — enrocamento e desvio do rio (uma só etapa),
b) — crib cofferdam (duas etapas),
c) — ensecadeira do tipo celular (duas etapas).

Foi esta última a escolhida. Como não era possível montar as células sem proteção especial contra a correnteza, foi utilizado um caixão flutuante (chamado "navio") ao abrigo do qual se podia trabalhar sem perigo. A montagem dessa primeira etapa da ensecadeira foi levada a bom têrmo e permitiu — depois de certas dificuldades — a construção da primeira metade da barragem móvel.

É preciso agora, depois da desmontagem da primeira etapa da ensecadeira, construir a segunda etapa da barragem móvel. Como não é possível utilizar de novo o caixão flutuante, tendo em vista o aumento da velocidade da corrente, construir-se-á a jusante das células a montar, um enrocamento cujos elementos encherão duas "estruturas semi-flexíveis" que farão o papel de armação. No remanso assim criado por êste enrocamento, tornar-se-á fácil trabalhar.

Os processos do "navio" e da "estrutura semi-flexível" apresentam-se bastante "manejáveis" e relativamente econômicos. Podem ser utilizados com vantagem nos trabalhos em rios profundos e de águas tumultuosas.

### RESUME

As the place where the Companhia Hidro Elétrica do São Francisco has to build one of the movable parts of the dam which will hold the waters of the São Francisco river, the river is narrow but deep and rough; as shown by the soundings carried out — which could not be done accurately — the bottom of the river is extremely irregular. Therefore, there would be great difficulty in drying the river bed.

Three answers were taken into consideration to solve the problem:

a) — A rock-fill and lateral channel to divert the river. (To be done in one stage).
b) — Crib cofferdam (work divided into two stages).
c) — Cellular cofferdam (work to be done in two stages).

The last answer was adopted. As it was not possible to build the cells without a special protection against the current, there was utilized a floating "caisson" (called ship) which allowed the work to be carried out without danger. The first stage of this work in the cofferdam was performed satisfactorily and after overcoming certain difficulties it was possible to build the first half of the movable dam.

It is necessary now, after the dismantling of a part of the first stage of the cofferdam, to build the second stage of the movable dam. As it will not be possible to use the floating "caisson" due to the enormous increase of the current speed, two semi-flexible structures will be placed, downstream of the site where the last three cells will be buit, and rock-filled. In the still water resulted from the rock-fill the three cells will be easily erected.

The processes of the "floating caisson" and of the "semi-flexible structure" are easy to handle and economical. They can be used in working in deep and turbulent rivers, with advantage.

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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 2
Assunto 2.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

DIVISÃO DE ÁGUAS
Brasil

# SÍNTESE DOS ESTUDOS FLUVIOMÉTRICOS NO BRASIL

DIVISÃO DE ÁGUAS
do D. N. P. M. do Ministério da Agricultura
COMITÊ NACIONAL BRASILEIRO

## CAPÍTULO I

## RESENHA HISTÓRICA

As primeiras observações destinadas aos estudos de regime de nossos cursos d'água tiveram início em 1920, quando foi criada no antigo Serviço Geológico e Mineralógico do Brasil a Comissão de Estudos de Fôrças Hidráulicas.

Foram visadas de início as bacias dos rios São Francisco, Paraíba e Paraná, onde se procedeu a estudos de algumas de suas principais quedas d'água, os quais compreenderam levantamentos topográficos, bem como as primeiras medições de descarga, elementos indispensáveis à avaliação do potencial hidráulico do País.

Entretanto, sòmente em fins do ano de 1933, com a criação da atual DIVISÃO DE ÁGUAS, essas investigações começaram a ser intensiva e extensivamente feitas.

Em 1934, dada a amplitude da ação da Divisão de Águas, a qual se estende por todo o território nacional, foi o País dividido em circunscrições territoriais, denominadas distritos, a cujo cargo ficaram tôdas as operações de campo.

Atualmente há sete DISTRITOS cuja jurisdição abrange as seguintes zonas:

1.° distrito — com sede na capital de São Paulo, abrangendo as bacias hidrográficas dêsse estado, exceto as dos afluentes do rio Grande.

2.° distrito — sediado em Belo Horizonte, abrangendo as seguintes bacias hidrográficas: as do Estado de Minas Gerais, excetuando-se o rio São Francisco, a jusante da confluência do rio das Velhas; as dos afluentes do rio Paraíba, a do Jequitinhonha e as dos rios situados entre o Jequitinhonha e Doce; parte do Estado de São Paulo que contém a bacia do rio Grande; parte do Estado de Goiás, compreendendo as bacias dos afluentes do rio Parnaíba, e parte do Estado do Espírito Santo, onde se acha a bacia do rio Doce.

3.° distrito — com sede em Curitiba, abrangendo as bacias hidrográficas dos Estados do Paraná e Santa Catarina, excluídas as dos afluentes do rio Uruguai.

4.° distrito — sediado em Juàzeiro, abrangendo a bacia hidrográfica do rio São Francisco, a jusante do rio das Velhas, nos Estados de Minas Gerais, Bahia, Pernambuco, Sergipe e Alagoas.

5.° distrito — com sede em Salvador, abrangendo as bacias hidrográficas dos rios que desaguam no Oceano Atlântico, entre os rios São Francisco e Doce, nos Estados de Sergipe, Bahia, Minas Gerais e Espírito Santo.

6.° distrito — sediado em Niterói, abrangendo as bacias hidrográficas do Estado do Rio de Janeiro, parte das do Estado de Minas Gerais, que contém os afluentes do rio Paraíba, e parte do Estado do Espírito Santo, até o divisor de águas do rio Doce.

7.° distrito — com sede em Pôrto Alegre, abrangendo as bacias hidrográficas do Estado do Rio Grande do Sul e as dos afluentes do rio Uruguai, no Estado de Santa Catarina.

Os gráficos anexos permitem analisar, em linhas gerais, o desenvolvimento dos estudos de deflúvio que vêm sendo realizados em algumas de nossas principais bacias hidrográficas. (1)

Os estudos sistematizados de regime fluvial atingiram o limite máximo de nossas possibilidades de expansão, em face dos atuais recursos em verbas e da presente estruturação técnico-administrativa da Divisão de Águas.

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(1) O gráfico referente ao número de medições de descarga apresenta um decréscimo de produção em alguns anos, motivado pelas seguintes razões:

a) em 1937 — reorganização de alguns distritos;

b) em 1945 — racionamento de combustível impôsto pela guerra mundial;

c) em 1951 e 1952 — tardio recebimento das verbas destinadas aos serviços de campo.

## CAPITULO II

## SITUAÇAO ATUAL DOS ESTUDOS FLUVIOMÉTRICOS

O Brasil encerra em seu vasto território — de mais de oito milhões de quilômetros quadrados — uma das maiores senão a maior rêde potamográfica do mundo.

Não sendo possível, em vista da extensão territorial e dos parcos recursos de que dispomos, realizar simultâneamente, em tôdas as bacias hidrográficas de certa importância, observações e estudos hidrométricos detalhados, tais serviços se concentraram nas regiões de maior desenvolvimento econômico, as quais iriam exigir ou já estavam exigindo conhecimento seguro do regime dos seus rios, para projeto de obras hidráulicas de maior vulto.

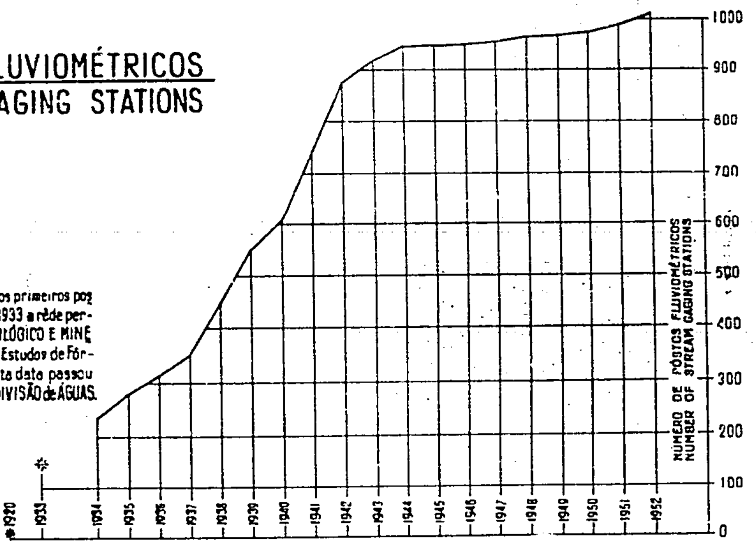
A DIVISÃO DE ÁGUAS efetua estudos sistemáticos de regime nas bacias dos seguintes rios, segundo localização de norte para sul:

1 — São Francisco
2 — Japaratuba
3 — Sergipe
4 — Vasa Barris
5 — Piauí
6 — Itapicuru
7 — Inhambupe
8 — Pojuca
9 — Joanes
10 — Subaé
11 — Cobre
12 — Paraguaçu
13 — Jaguaripe
14 — Jequiriçá
15 — Una
16 — Jequié
17 — Contas
18 — Almada
19 — Cachoeira (Est. da Bahia)
20 — Pardo
21 — Jequitinhonha
22 — Itanhém
23 — Mucuri
24 — São Mateus
25 — Doce
26 — Santa Maria
27 — Jucu
28 — Benevente
29 — Itapemirim
30 — Itabapoana
31 — Paraíba do Sul
32 — Macabu
33 — Macaé
34 — Macacu
35 — Mambucaba
36 — Ribeira do Iguape
37 — Cachoeira (Est. do Paraná)
38 — Nundiaquara
39 — Guaraguaçu
40 — Cubatão do Norte
41 — Itapocu
42 — Itajaí-Açu
43 — Tijucas
44 — Cubatão da Imperatriz
45 — Tubarão
46 — Araranguá
47 — Jacuí-Taquari
48 — Caí
49 — Sinos
50 — Gravataí
Bacia do Guaíba
51 — Camaquã
52 — Piratini
53 — Parnaíba
54 — Grande
55 — Tietê
56 — Peixe
57 — Paranapanema
58 — Ivaí
59 — Iguaçu
Bacia do Paraná
60 — Uruguai

MINISTÉRIO DA AGRICULTURA
D.N.P.M.
DIVISÃO DE ÁGUAS

# POSTOS FLUVIOMÉTRICOS
# STREAM GAGING STATIONS

Em 1920 fôram instalados os primeiros postos de observação; Até fins de 1933 a rêde pertencia ao antigo SERVIÇO GEOLÓGICO E MINERALÓGICO DO BRASIL (Com. de Estudos de Fôrças Hidráulicas). A partir desta data passou para a jurisdição da atual DIVISÃO de ÁGUAS.



MINISTÉRIO DA AGRICULTURA
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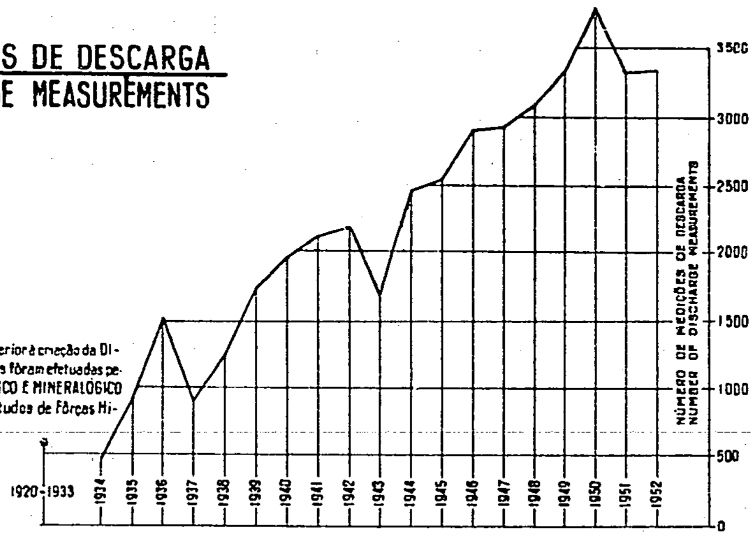
# MEDIÇÕES DE DESCARGA
# DISCHARGE MEASUREMENTS

No período 1920-1933, anterior à criação da DIVISÃO DE ÁGUAS, as medições fôram efetuadas pelo antigo SERVIÇO GEOLÓGICO E MINERALÓGICO DO BRASIL (Comissão de Estudos de Fôrças Hidráulicas).



Nas mencionadas bacias grande número de postos já possui a curva de descarga estabelecida e calculadas a vazão diária e as características fluviométricas mensais e anuais (máxima, mínima e média).

Relativamente às bacias dos rios Amazonas e Paraguai, só possuímos observações diárias do nível d'água; são dados de número reduzido de postos fluviométricos, quase todos pertencentes a entidades públicas e privadas, que colaboram com a Divisão de Águas.

Em 31 de dezembro de 1952 a nossa rêde fluviométrica compunha-se de 1021 postos em funcionamento, nos quais são efetuadas duas leituras diárias do nível d'água e até a referida data já haviam sido executadas 43.134 medições diretas de descarga com molinete, empregando-se aparelhagem moderna bem como processos técnicos padronizados.

## CAPÍTULO III

## DEFLÚVIO DE RIOS BRASILEIROS

Neste capítulo, apresentamos alguns dados fluviométricos das principais bacias hidrográficas em estudo, a fim de que dêem uma idéia das características hidrológicas dos rios brasileiros.

### Bacia do rio São Francisco

**Hidrografia:** o rio São Francisco nasce na serra da Canastra, no Estado de Minas Gerais, a uma altitude aproximada de 1400 metros; desagua no Oceano Atlântico, após um percurso, inteiramente em território nacional, de cêrca de 3100 quilômetros. É, em desenvolvimento, um dos maiores rios da América do Sul, figurando mesmo entre os vinte mais extensos do mundo.

A sua bacia hidrográfica é da ordem de 610.000 km², abrangendo grande parte dos Estados de Minas Gerais, Bahia, Pernambuco, Alagoas e Sergipe e pequeno trecho do sudeste goiano.

O São Francisco é um rio de planalto; desce, inicialmente, por serras alcantiladas e, em seguida, por chapadões e planaltos, passando depois a correr com pequeno declive, tendo normalmente extenso leito maior. Da cidade de Barra do Rio Grande, no Estado da Bahia, para jusante, atravessa região semi-árida, só recebendo daí até a foz dois afluentes perenes: o riacho do Salitre, situado a cêrca de 22 km a montante da cidade de Juàzeiro, no Estado da Bahia, e o rio Betume, já quase na sua desembocadura, no Estado de Sergipe.

No trecho situado entre as localidades de Jatobá e Pão de Açúcar, apresenta uma série de corredeiras e saltos, entre os quais sobressaem as grandes quedas de Paulo Afonso e Itaparica.

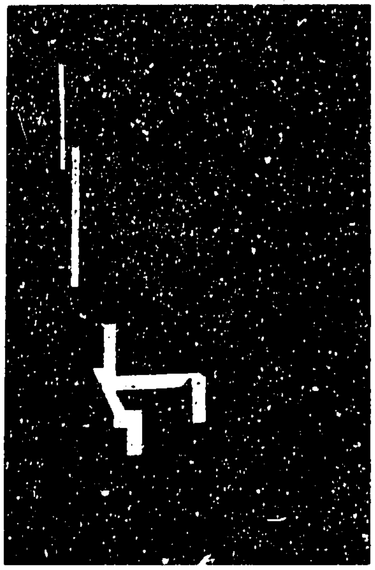
O rio São Francisco é navegável em mais de 1.700 quilômetros do seu curso, assim como em cêrca de 1.300 quilômetros de seus afluentes mineiros e bahianos (rios Paracatu, Urucuia, Corrente e Grande).

A sua bacia hidrográfica pode ser dividida em três secções: o alto São Francisco, das nascentes até Pirapora; o médio São Francisco, que se estende de Pirapora até a Cachoeira de Paulo Afonso ou até Pão de Açúcar, e o baixo São Francisco, daí até a foz.

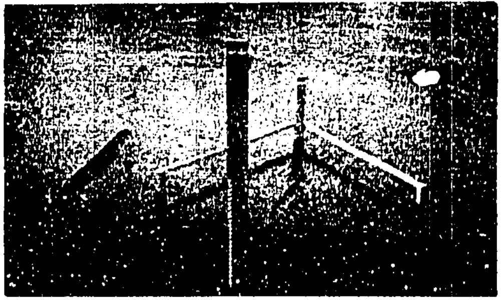
Recebe em seu percurso grande número de afluentes, entre os quais se destacam os rios Perdição (m.e.), Pará (m.d.), Paraopeba (m.d.), Indaiá (m.e.), Abaeté (m.e.), Velhas (m.d.), Jequitaí (m.d.), Pacuí (m.d.), Paracatu (m.e.), Urucuia (m.e.), Verde Grande (m.d.), Carinhanha (m.e.), Corrente (m.e.), Grande (m.e.), Salitre (m.d.), Pajeú (m.e.), Moxotó (m.e.) e Betume (m.d.).

Em 31 de dezembro de 1952, existiam 133 postos fluviométricos em funcionamento e haviam sido efetuadas 5.475 medições de descarga.

A seguir apresentamos algumas características hidrológicas do rio S. Francisco nas localidades de Pôrto da Barra, Barra do Paraopeba, Januária e Juàzeiro.



Escala fluviométrica no rio Piracicaba (bacia do Doce), na localidade de Antonio Diás, Estado de Minas Gerais.



Escala fluviométrica no rio Jacuí (bacia do Guaíba), na localidade de Dona Francisca, Estado do R. G. do Sul.

Medição de descarga, a váu, no rio Sapucaí (bacia de Grande), na localidade de Fazenda da Guarda, Estado de São Paulo.

Medição de descarga, em canôa, com cabo transversal duplo, no rio Lambari (bacia do Grande), na localidade de Fazenda Juca Casemiro, Estado de Minas Gerais.

Pôsto: **Pôrto da Barra**

Rio: **São Francisco**

Estado: **Minas Gerais**

Município: **Abaeté**

Localização: **cêrca de 12 km a montante da barra do rio Pará**

Área de drenagem: **12.300 km²**

Altitude do zero da escala: **549 m, aproximadamente**

Início das observações: **14-5-1939**

Número de medições de descarga: **15**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 90 % | 50 % | 10 % | MÁXIMA | | | MÉDIA | | | ALTURA DE [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1939 | 69 | 51.1 | 4.2 | 62.4 | 87.8 | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| 1940 | 73 | 57.2 | 4.7 | 61.4 | 87.8 | 152 | 402 | 394 | 930 | 75.6 | 182 | 218 | 17.7 | 660 |
| 1941 | 76 | 53.2 | 4.7 | 68.1 | 89.1 | 135 | 263 | 438 | 1135 | 92.3 | 159 | 210 | 17.1 | 538 |
| 1942 | 79 | 61.4 | 5.0 | 67.0 | 91.8 | 171 | 317 | 470 | 1297 | 105.0 | 169 | 230 | 18.7 | 590 |
| 1943 | 84 | 64.5 | 5.2 | 74.4 | 97.0 | 152 | 390 | 514 | 1536 | 124.9 | 169 | 330 | 26.8 | 846 |
| 1944 | 60 | 38.5 | 3.1 | 44.6 | 65.3 | 98 | 170 | 259 | 434 | 35.3 | 124 | 130 | 10.6 | 348 |
| 1945 | 78 | 57.5 | 4.7 | 68.2 | 93.5 | 168 | 362 | 440 | 1145 | 93.1 | 175 | 249 | 20.2 | 638 |
| 1946 | 90 | 71.8 | 5.8 | 81.0 | 107.0 | 180 | 343 | 606 | 2042 | 166.0 | 188 | 294 | 23.9 | 754 |
| 1947 | 95 | 78.4 | 6.4 | 86.4 | 119.0 | 182 | 320 | 467 | 1281 | 104.1 | 204 | 338 | 27.5 | 867 |
| 1948 | 61 | 39.3 | 3.2 | 47.6 | 74.4 | 133 | 267 | 404 | 977 | 79.4 | 151 | 194 | 15.8 | 498 |
| 1949 | 69 | 47.6 | 3.9 | 53.0 | 81.0 | 126 | 260 | 457 | 1230 | 100.0 | 166 | 248 | 20.2 | 656 |
| 1950 | 78 | 57.5 | 4.7 | 64.5 | 92.1 | 157 | 348 | 389 | 916 | 74.5 | 175 | 252 | 20.5 | 646 |
| 1951 | 73 | 54.1 | 4.4 | 62.1 | 87.8 | 145 | 401 | 389 | 916 | 74.5 | 180 | 273 | 22.2 | 699 |
| 1952 | 87 | 68.2 | 5.5 | 78.4 | 99.2 | 162 | 362 | 557 | 1772 | 144.1 | 192 | 325 | 26.4 | 836 |

Pôsto: **Barra do Paraopeba**

Rio: **São Francisco**

Estado: **Minas Gerais**

Município: **Abaeté**

Localização: **A jusante da confluência dos rios S. Francisco e Paraopeba**

Área de drenagem: **41.537 km²**

Altitude do zero da escala: **494 m, aproximadamente**

Início das observações: **11-5-1939**

Número de medições de descarga: **23**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | 20 | 152 | 3.2 | 145 | 225 | 410 | 908 | 670 | 2452 | 59.0 | 182 | 586 | 14.1 | 446 |
| 1941 | 40 | 184 | 4.4 | 219 | 283 | 386 | 724 | 619 | 2171 | 52.3 | 178 | 568 | 13.7 | 431 |
| 1942 | 37 | 176 | 4.2 | 194 | 276 | 467 | 853 | 700 | 2630 | 63.3 | 191 | 606 | 14.6 | 460 |
| 1943 | 70 | 250 | 6.0 | 267 | 337 | 475 | 1075 | -- | -- | -- | 254 | 828 | 19.9 | 629 |
| 1944 | 24 | 140 | 3.4 | 159 | 238 | 371 | 685 | 425 | 1310 | 31.5 | 153 | 476 | 11.5 | 362 |
| 1945 | OBSERVAÇÕES | | | | | | INTERROMPIDAS | | | | | | | |
| 1946 | 48 | 197 | 4.7 | 219 | 292 | 451 | 797 | 895 | -- | -- | 205 | 658 | 15.8 | 500 |
| 1947 | 48 | 197 | 4.7 | 240 | 335 | 507 | 1077 | 700 | 2630 | 63.3 | 233 | 769 | 18.5 | 584 |
| 1948 | OBSERVAÇÕES | | | | | | INTERROMPIDAS | | | | | | | |
| 1949 | 44 | 188 | 4.6 | 231 | 325 | 496 | 818 | 580 | -- | -- | 246 | 818 | 19.7 | 621 |
| 1950 | 58 | 175 | 4.2 | 188 | 260 | 491 | 1002 | 534 | 1756 | 42.3 | 201 | 618 | 14.9 | 470 |
| 1951 | 24 | 140 | 3.4 | 190 | 257 | 410 | 883 | 682 | 2525 | 60.8 | 196 | 616 | 14.8 | 468 |
| 1952 | 45 | 190 | 4.6 | 226 | 302 | 480 | 880 | 807 | -- | -- | 227 | 733 | 17.6 | 557 |

Pôsto: **Januária**

Rio: **São Francisco**

Estado: **Minas Gerais**

Município: **Januária**

Localização: **Na cidade de Januária, à margem esquerda**

Área de drenagem: **201.541 km²**

Altitude do zero da escala: **443 m, aproximadamente**

Início das observações: **23-8-1927**

Número de medições de descarga: **29**

## CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1940 | -11 | 491 | 2,4 | 538 | 773 | 1433 | 3420 | 647 | 6666 | 33.1 | 123 | 2157 | 10.7 | 338 |
| 1941 | 0 | 564 | 2,8 | 645 | 944 | 1464 | 3079 | 589 | 5973 | 29.6 | 189 | 2097 | 10.4 | 328 |
| 1942 | 4 | 591 | 2,9 | 624 | 960 | 1397 | 4007 | 692 | 7224 | 35.8 | 233 | 2524 | 12.5 | 395 |
| 1943 | 34 | 796 | 3,9 | 852 | 1236 | 1480 | 5197 | 929 | 10446 | 51.8 | 315 | 3382 | 16,8 | 529 |
| 1944 | -26 | 394 | 1,9 | 518 | 908 | 1342 | 3133 | 840 | 9180 | 45.5 | 197 | 2175 | 10.8 | 341 |
| 1945 | 68 | 1037 | 5.1 | 1176 | 1740 | 3239 | 6185 | 881 | 9755 | 48.4 | 386 | 3997 | 19.8 | 625 |
| 1946 | 50 | 908 | 4.5 | 1092 | 1334 | 2110 | 5020 | 971 | 11068 | 54.9 | 276 | 2916 | 14.5 | 456 |
| 1947 | [illegible] | 782 | 3.8 | 944 | 1311 | 2186 | 4419 | 743 | 7077 | 35.1 | 281 | 2938 | 14.6 | 460 |
| 1948 | -10 | 498 | 2.4 | 584 | 865 | 1480 | 3976 | 898 | 9431 | 46,8 | 220 | 2445 | 12,1 | 384 |
| 1949 | 36 | 809 | 4.0 | 908 | 1433 | 2152 | 3975 | 1015 | 11735 | 58.2 | 321 | 3420 | 17.0 | 535 |
| 1950 | - 4 | 538 | 2,6 | 624 | 800 | 1797 | 3069 | 651 | 6715 | 33.3 | 195 | 2125 | 10.5 | 332 |
| 1951 | -22 | 419 | 2.0 | 538 | 773 | 1284 | 2749 | 631 | 6472 | 32.1 | 176 | 1970 | 9.8 | 308 |
| 1952 | 6 | 604 | 3.0 | 734 | 1008 | 1902 | 3814 | 819 | 8891 | 44.1 | 252 | 2716 | 13.5 | 426 |

Pôsto: **Juàzeiro**

Rio: **São Francisco**

Estado: **Bahia**

Município: **Juàzeiro**

Localização: **Na extremidade leste da Praça da Bandeira**

Área de drenagem: **490.769 km² aproximadamente**

Altitude do zero da escala: **356,075 m. referida à altitude determinada por nivelamento geodésico do D.F.O.C.S.**

Início das observações: **6-9-1928**

Número de medições de descarga: **51**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE CHUVA |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1929 | 122 | 1166 | 2.5 | 1254 | 1839 | 2823 | 5445 | 592 | 8340 | 17.0 | 315 | 3738 | 7.6 | 240 |
| 1930 | 100 | 917 | 1.8 | 1007 | 1338 | 2139 | 3695 | 442 | 5480 | 11.2 | 232 | 2557 | 5.2 | 164 |
| 1931 | 138 | 1349 | 2.7 | 1483 | 1851 | 2321 | 5512 | 572 | 7910 | 16.1 | 297 | 3527 | 7.1 | 227 |
| 1932 | 100 | 917 | 1.8 | 935 | 1211 | 1616 | 3189 | 450 | 5610 | 11.4 | 209 | 2267 | 4.6 | 146 |
| 1933 | 104 | 962 | 1.9 | 985 | 1408 | 1970 | 3522 | 508 | 6650 | 13.5 | 250 | 2538 | 5.1 | 165 |
| 1934 | 86 | 759 | 1.5 | 849 | 926 | 1584 | 2223 | 538 | 7220 | 14.7 | 187 | 2025 | 4.1 | 150 |
| 1935 | 115 | 1064 | 2.1 | 1109 | 1211 | 2272 | 4675 | 506 | 6610 | 13.5 | 258 | 2953 | 6.0 | 190 |
| 1936 | 92 | 827 | 1.6 | 883 | 1109 | 1910 | 2746 | 412 | 4990 | 10.2 | 196 | 2068 | 4.2 | 435 |
| 1937 | 95 | 861 | 1.7 | 928 | 1211 | 2199 | 4506 | 500 | 6500 | 13.2 | 245 | 2762 | 5.6 | 178 |
| 1938 | 97 | 930 | 1.8 | 991 | 1220 | 1647 | 3797 | 532 | 7030 | 14.3 | 244 | 2461 | 5.0 | 158 |
| 1939 | 102 | 907 | 1.8 | 965 | 1138 | 1547 | 2534 | 546 | 7370 | 14.9 | 224 | 2401 | 4.8 | 154 |
| 1940 | 97 | 885 | 1.8 | 940 | 1277 | 2042 | 3976 | 492 | 6350 | 12.9 | 237 | 2658 | 5.4 | 171 |
| 1941 | 112 | 1053 | 2.1 | 1098 | 1476 | 1910 | 4257 | 458 | 5750 | 11.7 | 243 | 2715 | 5.5 | 174 |
| 1942 | 110 | 1030 | 2.1 | 1098 | 1407 | 2199 | 4553 | 478 | 6100 | 12.4 | 256 | 2987 | 6.0 | 192 |
| 1943 | 133 | 1232 | 2.6 | 1350 | 1770 | 2620 | 9800 | 768 | 12000 | 24.4 | 328 | 4070 | 8.2 | 262 |
| 1944 | 106 | 984 | 2.0 | 1050 | 1465 | 2100 | 6200 | 547 | 7300 | 14.9 | 258 | 2960 | 6.0 | 191 |
| 1945 | 166 | 1674 | 3.4 | 1730 | 2445 | 4070 | 7400 | 701 | 10400 | 21.1 | 393 | 4950 | 10.0 | 318 |
| 1946 | 148 | 1464 | 2.9 | 1530 | 1660 | 2430 | 5280 | 795 | 12600 | 25.6 | 325 | 4000 | 8.1 | 257 |
| 1947 | 141 | 1384 | 2.8 | 1522 | 1910 | 2952 | 5280 | 593 | 8360 | 17.0 | 310 | 3660 | 7.4 | 234 |
| 1948 | 122 | 1145 | 2.3 | 1246 | 1522 | 2078 | 5110 | 518 | 6800 | 13.9 | 272 | 3148 | 6.4 | 203 |
| 1949 | 146 | 1446 | 2.9 | 1490 | 2078 | 3080 | 7373 | 882 | 14409 | 29.4 | 372 | 4797 | 9.7 | 308 |
| 1950 | 117 | 1135 | 2.3 | 1209 | 1538 | 2420 | 3973 | 450 | 5619 | 11.4 | 249 | 2766 | 5.6 | 178 |
| 1951 | 98 | 940 | 1.9 | 1052 | 1262 | 1900 | 3917 | 462 | 5817 | 11.9 | 230 | 2542 | 5.1 | 163 |
| 1952 | 110 | 1063 | 2.1 | 1167 | 1480 | 2470 | 4663 | 585 | 8005 | 16.3 | 272 | 3151 | 6.3 | 202 |

## Bacia do rio Itapicuru

**Hidrografia:** nasce no município de Jaguarari, no Estado da Bahia, em altitude aproximada de 800 metros.

A sua bacia hidrográfica até a localidade denominada Itapicuru está situada no polígono das sêcas; o rio Itapicuru e os seus afluentes, nesse trecho, são, na sua maioria, intermitentes.

Lança-se no Oceano Atlântico, após um percurso de cêrca de 265 km inteiramente no Estado da Bahia; sua bacia hidrográfica é da ordem de 36 900 km² de área.

Os seus principais afluentes são: rios Itapicuru-Açu (m.d.), Itapicuru-Mirim (m.d.), Jacurici (m.e.) e Peixe de Baixo (m.d.).

Na bacia do rio Itapicuru havia em 31 de dezembro de 1952, 7 postos fluviométricos em funcionamento, e tinham sido realizadas até essa data 296 medições de descarga.

Abaixo se encontram características hidrológicas do mencionado rio no pôsto de Cipó.

Pôsto: **Cipó**

Rio: **Itapicuru**

Estado: **Bahia**

Município: **Cipó**

Localização: **30 metros a montante dos banheiros termais**

Área de drenagem: **28.785 km²**

Início das observações: **17-10-1934**

Número de medições de descarga: **35**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1935 | 50 | 2.10 | 0.07 | 3.05 | 7.26 | 14.70 | 28.00 | 348 | 207 | 7.2 | 112 | 25.8 | 0.90 | 28,0 |
| 1936 | 52 | 2.48 | 0.09 | 2.67 | 4.42 | 9.00 | 13.20 | 209 | 77 | 2.6 | 83 | 12.2 | 0.43 | 12.2 |
| 1937 | 54 | 2.86 | 0.10 | 3.05 | 3.43 | 7.55 | 15.40 | 336 | 193 | 6.7 | 86 | 14.4 | 0.50 | 14.8 |
| 1938 | 45 | 1.55 | 0.05 | 1.77 | 2.67 | 5.89 | 11.70* | 247 | 106 | 3.7 | 73 | 8.9 | 0.31 | 8.7 |
| 1939 | 53 | 2.67 | 0.09 | 2.67 | 3.24 | 5.81 | 6.97 | 315 | 170 | 5.9 | 68 | 7.9 | 0,27 | 7.7 |
| 1940 | 52 | 2.48 | 0.09 | 3.62 | 6.39 | 10.50 | 13.20 | 700 | 769 | 26.7 | 107 | 33.4 | 1.16 | 34.5 |
| 1941 | 48 | 1,88 | 0,06 | 2,10 | 4,00 | 11.10 | 17.40 | 391 | 265 | 9.2 | 96 | 19.5 | 0.68 | 20.5 |
| 1942 | 44 | 1.44 | 0.05 | 1.55 | 2.29 | 5.62 | 6.68 | 355 | 216 | 7.5 | 67 | 7.9 | 0.27 | 7.8 |
| 1943 | 40 | 1.00 | 0.04 | 1.33 | 3.62 | 5.68 | 12.00 | 178 | 55 | 1.9 | 76 | 10.0 | 0,35 | 10.2 |
| 1944 | 37 | 0.70 | 0.02 | 1.11 | 3.24 | 6.68 | 11.40 | 607 | 606 | 21.0 | 86 | 18.1 | 0.63 | 19.5 |
| 1945 | 37 | 0.70 | 0.02 | 1.77 | 9.00 | 17.00 | 27.50 | 244 | 104 | 3.6 | 105 | 19.6 | 0.68 | 21.5 |
| 1946 | 40 | 1.00 | 0.04 | 1,22 | 1,55 | 3.44 | 5.05 | 154 | 30 | 1.0 | 58 | 4.2 | 0.15 | 4.6 |
| 1947 | 39 | 0.90 | 0,03 | 1.33 | 2,10 | 7.84 | 17.80 | 517 | 460 | 15.9 | 96 | 22.6 | 0,78 | 24.9 |
| 1948 | 41 | 1.11 | 0.04 | 1.88 | 4.63 | 11.40 | 27.50 | 554 | 518 | 18.0 | 108 | 25.5 | 0.89 | 28.3 |
| 1949 | 48 | 1.88 | 0.06 | 2.10 | 4.21 | 6.97 | 12.60 | 902 | 1164 | 40.4 | 95 | 27.1 | 0.94 | 29.9 |
| 1950 | 42 | 1.22 | 0.04 | 1.44 | 3.05 | 3.26 | 8.42 | 187 | 61 | 2.1 | 70 | 7.3 | 0.25 | 8.1 |
| 1951 | 42 | 1.22 | 0.04 | 1.33 | 1.55 | 3.05 | 9.00 | 276 | 132 | 4.5 | 65 | 6.9 | 0.24 | 7.6 |
| 1952 | 37 | 0.70 | 0.02 | 0.70 | 1.44 | 2.48 | 5.05 | 563 | 534 | 18.5 | 60 | 7.8 | 0.27 | 8.6 |

## Bacia do rio Paraguaçu

**Hidrografia:** o rio Paraguaçu nasce na fralda ocidental da serra do Coral, município de Barra da Estiva, Estado da Bahia.

A sua bacia hidrográfica é da ordem de 70.400 km², sendo o maior rio que deságua na baía de Todos os Santos.

Os seus principais tributários são: rios Santo Antônio (m.e.), Una (m.d.), Tupim (m.e.), Piranhas (m.e.), Peixe (m.e.) e Jacuípe (m.e.); o rio Jacuípe, o maior afluente, tem quase a mesma extensão do Paraguaçu, todavia o seu curso não é perene.

Havia em 31 de dezembro de 1952, 13 postos fluviométricos e tinham sido executadas até essa data 291 medições de descarga.

A seguir figuram características hidrológicas do rio Paraguaçu no pôsto de Itaité.

Pôsto: **Itaité**
Rio: **Paraguaçu**
Estado: **Bahia**
Município: **Andaraí**
Localização: **No pôrto da Gameleira**
Área de drenagem: **20.000 km²**
Início das observações: **27-4-1931**
Número de medições de descarga: **58**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1932 | 388 | 6.0 | 0.30 | 7.1 | 9.2 | 14.0 | 29.2 | 726 | 156 | 7.9 | 450 | 22.4 | 1.1 | 33 |
| 1933 | 390 | 6.5 | 0.32 | 9.0 | 14.7 | 31.0 | 67.7 | 933 | 325 | 16.4 | 514 | 53.7 | 2.6 | 87 |
| 1934 | 396 | 7.4 | 0.37 | 8.0 | 12.0 | 17.0 | 27.9 | 842 | 271 | 13.5 | 465 | 24.4 | 1.2 | 65 |
| 1935 | 400 | 8.2 | 0.41 | 10.0 | 28.2 | 61.8 | 106 | 938 | 333 | 16.6 | 577 | 78.4 | 3.9 | 125 |
| 1936 | 418 | 12.0 | 0.60 | 14.3 | 29.5 | 58.7 | 112.5 | 913 | 312 | 15.6 | 585 | 76.4 | 3.8 | 131 |
| 1937 | 399 | 8.0 | 0.40 | 10.2 | 18.3 | 31.0 | 67.7 | 563 | 354 | 17.7 | 553 | 61.8 | 3.0 | 96 |
| 1938 | 392 | 7.3 | 0.36 | 9.0 | 14.0 | 20.8 | 34.4 | 764 | 204 | 10.2 | 476 | 31.4 | 1.5 | 43 |
| 1939 | 395 | 7.3 | 0.36 | 7.7 | 11.5 | 16.5 | 31.0 | 839 | 250 | 12.5 | 477 | 35.3 | 1.7 | 54 |
| 1940 | 425 | 13.5 | 0.68 | 16.1 | 26.5 | 54.5 | 206.2 | 1051 | 429 | 21.4 | 578 | 80.4 | 4.0 | 125 |
| 1941 | 406 | 9.4 | 0.47 | 10.4 | 22.1 | 34.4 | 74.5 | 894 | 296 | 14.8 | 542 | 64.2 | 3.2 | 98 |
| 1942 | 403 | 8.8 | 0.44 | 12.2 | 17.0 | 26.5 | 59.6 | 1054 | 431 | 21.5 | 541 | 69.4 | 3.4 | 109 |
| 1943 | 408 | 9.8 | 0.49 | 12.0 | 19.5 | 36.5 | 88.2 | 941 | 338 | 16.8 | 546 | 67.4 | 3.3 | 106 |
| 1944 | 404 | 9.0 | 0.45 | 11.6 | 15.7 | 25.6 | 40.8 | 986 | 374 | 18.7 | 504 | 47.2 | 2.3 | 75 |
| 1945 | 421 | 12.6 | 0.63 | 19.8 | 35.1 | 33.2 | 54.0 | 955 | 348 | 17.4 | 579 | 78.5 | 3.9 | 124 |
| 1946 | 402 | 8.6 | 0.43 | 9.6 | 19.5 | 30.1 | 52.2 | 919 | 317 | 15.8 | 508 | 43.5 | 2.1 | 68 |
| 1947 | 392 | 6.5 | 0.32 | 9.0 | 13.1 | 45.6 | 101.9 | 1142 | 505 | 25.2 | 560 | 78.4 | 3.9 | 126 |
| 1948 | 392 | 6.7 | 0.34 | 13.8 | 26.5 | 50.0 | 86.2 | 975 | 381 | 19.0 | 572 | 76.4 | 3.8 | 121 |
| 1949 | 418 | 12.0 | 0.60 | 14.5 | 20.0 | 32.3 | 60.9 | 964 | 372 | 18.6 | 529 | 54.4 | 2.7 | 94 |
| 1950 | 404 | 9.0 | 0.45 | 10.4 | 20.0 | 28.5 | 51.5 | 939 | 334 | 16.7 | 525 | 47.8 | 2.3 | 75 |
| 1951 | 383 | 5.2 | 0.26 | 5.4 | 9.2 | 20.3 | 51.3 | 893 | 296 | 14.8 | 483 | 37.9 | 1.8 | 60 |
| 1952 | 382 | 5.1 | 0.25 | 6.6 | 11.5 | 18.5 | 42.8 | 991 | 387 | 19.3 | 490 | 43.9 | 2.2 | 70 |

### Bacia do rio Jequiriçá

**Hidrografia:** nasce na serra Geral, município de Maracás, Estado da Bahia, em altitude aproximada de 700 metros e desagua no Oceano Atlântico, tendo todo o seu curso em terras bahianas; sua bacia hidrográfica é da ordem de 5.500 km².

Os seus principais afluentes são: rios Xenxem (m.e.), Jequiriçá-Mirim (m.e.) e Verde (m.e.).

A bacia do rio Jequiriçá tinha em 31 de dezembro de 1952, 4 postos fluviométricos em funcionamento e até essa época se havia procedido a 134 medições de descarga.

Apresentamos em seguida características hidrológicas do rio Jequiriçá em Laje.

Pôsto: **Laje**
Rio: **Jequiriçá**
Estado: **Bahia**
Município: **Laje**
Localização: **Na ponte de madeira**
Área de drenagem: **4.864 km²**
Altitude do zero da escala: **150 m aproximadamente**
Início das observações: **2-8-1927**
Número de medições de descargas: **41**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 90 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h<br>cm | Q<br>m³/s | q<br>l/s/km² | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | h<br>cm | Q<br>m³/s | q<br>l/s/km² | h<br>cm | Q<br>m³/s | q<br>l/s/km² | % |
| 1944 | 64 | 6.96 | 1.39 | 7.74 | 9.50 | 12.66 | 16.42 | 267 | 287 | 59.1 | 81 | 18.0 | 3.7 | 119 |
| 1945 | 58 | 4.82 | 0.96 | 6.18 | 9.50 | 13.22 | 19.45 | 146 | 96 | 19.5 | 81 | 18.9 | 3.7 | 119 |
| 1946 | 54 | 3.66 | 0.73 | 3.40 | 7.55 | 9.50 | 13.22 | 118 | 56 | 11.2 | 72 | 11.3 | 2.2 | 71 |
| 1947 | 51 | 2.79 | 0.56 | 3.66 | 6.96 | 10.42 | 14.90 | 267 | 287 | 59.1 | 73 | 17.1 | 3.4 | 108 |
| 1948 | 46 | 1.50 | 0.30 | 3.08 | 6.96 | 10.42 | 24.80 | 118 | 56 | 11.2 | 78 | 18.5 | 3.7 | 119 |
| 1949 | 56 | 4.24 | 0.83 | 3.11 | 6.97 | 8.62 | 12.10 | 109 | 44 | 8.8 | 72 | 10.7 | 2.1 | 67 |
| 1950 | 50 | 2.50 | 0.50 | 3.08 | 6.18 | 10.98 | 14.54 | 113 | 52 | 10.4 | 72 | 11.9 | 2.3 | 74 |
| 1951 | 44 | 1.00 | 0.20 | 1.73 | 3.27 | 4.82 | 7.55 | 139 | 87 | 17.4 | 62 | 7.2 | 1.4 | 45 |
| 1952 | 42 | 0.50 | 0.10 | 0.73 | 3.08 | 5.11 | 10.42 | 166 | 123 | 25.0 | 62 | 7.9 | 1.5 | 50 |

### Bacia do rio de Contas

**Hidrografia:** o rio de Contas nasce no município de Piatã, Estado da Bahia, e desemboca no Oceano Atlântico, na altura da cidade de Itacaré; sua bacia hidrográfica é da ordem de 63.000 km².

Acha-se inteiramente situado na zona sul da Bahia, figurando entre os cinco maiores componentes da rêde potamográfica dêsse Estado.

A sua bacia hidrográfica, até a cidade de Jequié, está na zona do polígono das sêcas; recebe vários afluentes de ambas as margens, todos de regime acentuadamente torrencial, entre os quais se destacam os rios Brumado (m.d.), Gavião (m.d.), Caqueira (m.d.), Sincorá (m.e.) e Jacaré (m.e.).

Êsses rios, apesar da grande área de drenagem, são na maioria intermitentes, em virtude das grandes perdas por infiltração e evaporação, que ocorrem naquele trecho da bacia; essa região constitui o alto rio de Contas.

A jusante da cidade de Jequié, após totalizar cêrca de 75% da sua bacia, apresenta o rio de Contas regime permanente, recebendo tributários de ambas as margens, como o Cachoeira (m.e.), Água Branca (m.e.), Peixe (m.d.), Gongogi (m.d.) e Cricó Grande (m.e). Por suas características, tão distintas da parte superior, recebe aí a denominação de baixo rio de Contas.

A sua rêde fluviométrica em 31 de dezembro de 1952 compunha-se de 6 postos em funcionamento e haviam sido executadas até essa data 268 medições de descarga.

Apresentamos em seguida características hidrológicas do rio de Contas nas localidades de Santo Antônio, Ipiaú (ex-Rio Novo) e Ubaitaba (ex-Itapira).

Pôsto: **Santo Antônio**

Rio: **Contas**

Estado: **Bahia**

Município: **Ituaçu**

Localização: **A jusante da ponte da V. F. F. L. B.**

Area de drenagem: **17.501 km²**

Altitude do zero da escala: **340 m aproximadamente**

Início das observações: **14-3-1935**

Número de medições de descarga: **51**

CARACTERISTICAS FLUVIOMETRICAS ANUAIS:

| ANO | mínimas | | | [illegible] | [illegible] | [illegible] | [illegible] | máximas | | | médias | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1936 | 180 | 0.63 | 0.03 | 0.91 | 2.00 | 6.05 | 15.00 | 371 | 123 | 7.0 | 223 | 11.3 | 0.65 | 20 |
| 1937 | 180 | 0.69 | 0.03 | 0.80 | 1.24 | 2.00 | 9.60 | 373 | 125 | 7.1 | 213 | 8.7 | 0.50 | 15 |
| 1938 | 165 | 0.00 | 0.00 | 0.00 | 0.00 | 0.64 | 1.70 | 298 | 53 | 3.0 | 189 | 2.4 | 0.14 | 4 |
| 1939 | 165 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.85 | 291 | 47 | 2.7 | 179 | 2.0 | 0.12 | 3 |
| 1940 | 192 | 1.39 | 0.07 | 1.77 | 3.56 | 6.54 | 19.00 | 560 | 372 | 2.1 | 229 | 21.2 | 1.21 | 38 |
| 1941 | 196 | 1.69 | 0.09 | 2.00 | 4.08 | 8.20 | 13.40 | 335 | 87 | 5.0 | 228 | 12.5 | 0.72 | 22 |
| 1942 | 192 | 1.39 | 0.07 | 1.85 | 2.52 | 4.00 | 16.00 | 755 | 708 | 40.4 | 236 | 26.6 | 1.52 | 48 |
| 1943 | 208 | 4.08 | 0.23 | 4.60 | 8.90 | 14.20 | 25.50 | 318 | 71 | 4.0 | 245 | 19.9 | 1.14 | 35 |
| 1944 | 206 | 3.56 | 0.20 | 4.34 | 7.21 | 8.20 | 14.60 | 378 | 130 | 7.4 | 233 | 14.8 | 0.85 | 26 |
| 1945 | 207 | 3.82 | 0.21 | 4.89 | 11.40 | 21.65 | 38.30 | 413 | 170 | 9.7 | 258 | 28.7 | 1.64 | 51 |
| 1946 | 198 | 1.85 | 0.10 | 3.56 | 5.18 | 8.20 | 19.00 | 365 | 116 | 6.6 | 229 | 12.8 | 0.73 | 23 |
| 1947 | 188 | 1.15 | 0.06 | 1.62 | 3.30 | 5.76 | 20.00 | 518 | 310 | 17.7 | 256 | 21.0 | 1.20 | 38 |
| 1948 | 209 | 4.34 | 0.24 | 6.54 | 8.90 | 13.80 | 23.30 | 512 | 302 | 17.2 | 249 | 22.1 | 1.27 | 40 |
| 1949 | 205 | 3.30 | 0.18 | 4.60 | 8.55 | 12.60 | 24.95 | 424 | 232 | 13.3 | 245 | 20.9 | 1.20 | 37 |
| 1950 | 192 | 1.39 | 0.07 | 1.62 | 3.30 | 5.18 | 9.95 | 391 | 144 | 8.2 | 218 | 9.6 | 0.55 | 17 |
| 1951 | - | - | - | 3.36 | 5.76 | 9.60 | 15.50 | 343 | 94 | 5.4 | 228 | 12.5 | 0.72 | 22 |
| 1952 | - | - | - | 1.24 | 2.00 | 5.18 | 11.40 | 377 | 129 | 7.3 | 221 | 11.7 | 0.67 | 21 |

Pôsto: **Ipiaú (ex-Rio Novo)**

Rio: **Contas**

Estado: **Bahia**

Município: **Ipiaú**

Localização: **Trecho do rio denominado Mira Rio, na cidade.**

Área de drenagem: **44.011 km²**

Altitude do zero da escala: **103 m aproximadamente.**

Início das observações: **20-4-1937**

CARACTERISTICAS FLUVIOMETRICAS ANUAIS:

| ANO | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | % |
| 1938 | 81 | 4.9 | 0.11 | 6.5 | 9.1 | 13.5 | 18.8 | 302 | 141 | 3.2 | 101 | 17.4 | 0.3 | 12 |
| 1939 | 70 | 1.5 | 0.03 | 2.4 | 3.9 | 6.1 | 9.7 | 215 | 164 | 3.7 | 89 | 10.9 | 0.2 | 7 |
| 1940 | 90 | 8.5 | 0.19 | 11.6 | 16.1 | 36.6 | 52.0 | 406 | 951 | 21.6 | 130 | 56.6 | 1.2 | 40 |
| 1941 | 86 | 6.9 | 0.15 | 9.1 | 18.8 | 25.7 | 39.2 | 580 | 836 | 18.9 | 125 | 45.6 | 1.0 | 32 |
| 1942 | 88 | 7.7 | 0.17 | 11.0 | 14.8 | 21.5 | 45.5 | 615 | 1880 | 42.7 | 156 | 69.2 | 2.0 | 64 |
| 1943 | 102 | 16.1 | 0.36 | 14.4 | 20.7 | 39.2 | 63.7 | 217 | 173 | 3.9 | 136 | 48.2 | 1.0 | 34 |
| 1944 | 95 | 10.5 | 0.23 | 15.5 | 16.8 | 20.8 | 30.9 | 505 | 502 | 11.4 | 121 | 37.6 | 0.9 | 28 |
| 1945 | 117 | 27.4 | 0.62 | 30.9 | 44.4 | 51.2 | 55.0 | 585 | 943 | 21.2 | 161 | 92.6 | 2.1 | 66 |
| 1946 | 85 | 6.5 | 0.14 | 9.1 | 16.1 | 22.5 | 29.1 | 213 | 175 | 3.9 | 115 | 28.5 | 0.6 | 20 |
| 1947 | 72 | 2.1 | 0.04 | 3.5 | 7.7 | 14.8 | 30.9 | 614 | 1875 | 42.6 | 125 | 67.7 | 1.5 | 45 |
| 1948 | 105 | 16.8 | 0.38 | 20.8 | 30.9 | 47.6 | 61.7 | 575 | 813 | 18.4 | 142 | 73.9 | 1.6 | 36 |
| 1949 | 96 | 12.2 | 0.27 | 16.1 | 24.0 | 30.9 | 45.5 | 472 | 354 | 8.0 | 128 | 45.0 | 0.9 | 30 |
| 1950 | 80 | 4.5 | 0.10 | 8.1 | 14.8 | 20.1 | 27.4 | 410 | 969 | 22.0 | 111 | 29.4 | 0.6 | 21 |
| 1951 | - | - | - | 3.9 | 9.7 | 16.8 | 26.6 | 277 | 345 | 7.8 | 105 | 21.6 | 0.4 | 16 |
| 1952 | - | - | - | 1.0 | 9.5 | 14.8 | 24.0 | 512 | 534 | 12.1 | 106 | 20.1 | 0.5 | 19 |

Pôsto: **Ubaitaba (ex-Itapira)**

Rio: **Contas**

Estado: **Bahia**

Município: **Ubaitaba**

Localização: **Próximo de um pequeno trecho de cais de alvenaria, na entrada da cidade.**

Área de drenagem: **52.227 km²**

Altitude do zero da escala: **47 m aproximadamente**

Início das observações: **10-9-1935**

Número de medições de descarga: **37**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1936 | 72 | 32.40 | 0.62 | 43.6 | 63.3 | 99.7 | 160.4 | 350 | 915 | 17.4 | 118 | 136.2 | 2.61 | 82 |
| 1937 | 30 | 13.75 | 0.26 | 17.2 | 34.8 | 54.4 | 92.3 | 278 | 645 | 12.3 | 95 | 82.5 | 1.58 | 49 |
| 1938 | 43 | 9.38 | 0.18 | 14.9 | 21.6 | 27.9 | 42.0 | 163 | 261 | 4.9 | 72 | 36.9 | 0.71 | 22 |
| 1939 | 25 | 4.06 | 0.08 | 5.5 | 8.8 | 13.8 | 19.5 | 142 | 197 | 3.7 | 54 | 20.0 | 0.38 | 11 |
| 1940 | 44 | 10.00 | 0.19 | 25.7 | 34.8 | 49.8 | 89.9 | 554 | 930 | 17.8 | 78 | 91.8 | 1.76 | 55 |
| 1941 | 60 | 19.45 | 0.37 | 22.6 | 37.2 | 57.5 | 108.2 | 369 | 976 | 18.7 | 101 | 97.4 | 1.86 | 58 |
| 1942 | 58 | 18.31 | 0.35 | 24.7 | 33.6 | 49.8 | 102.2 | 600 | 1958 | 37.4 | 109 | 128.1 | 2.45 | 77 |
| 1943 | 67 | 26.83 | 0.51 | 37.0 | 43.1 | 69.3 | 110.3 | 226 | 462 | 8.8 | 100 | 87.8 | 1.68 | 52 |
| 1944 | 58 | 18.31 | 0.35 | 24.7 | 30.0 | 59.6 | 61.5 | 359 | 951 | 18.2 | 89 | 73.3 | 1.40 | 44 |
| 1945 | 80 | 42.00 | 0.80 | 45.1 | 67.5 | 87.4 | 142.2 | 356 | 938 | 17.9 | 121 | 140.8 | 2.69 | 85 |
| 1946 | 52 | 14.89 | 0.28 | 13.3 | 33.6 | 45.7 | 61.5 | 253 | 230 | 4.4 | 84 | 52.6 | 1.01 | 31 |
| 1947 | 23 | 3.69 | 0.07 | 7.5 | 16.6 | 30.0 | 63.5 | 610 | 1956 | 38.2 | 90 | 99.0 | 1.89 | 60 |
| 1948 | 62 | 21.56 | 0.41 | 38.9 | 49.8 | 73.5 | 127.2 | 348 | 1112 | 21.3 | 110 | 120.9 | 2.31 | 73 |
| 1949 | 64 | 23.67 | 0.45 | 31.2 | 46.7 | 59.5 | 89.9 | 212 | 417 | 7.9 | 97 | 80.6 | 1.54 | 48 |
| 1950 | 51 | 14.34 | 0.27 | 18.3 | 28.9 | 56.7 | 69.5 | 405 | 996 | 19.0 | 86 | 61.9 | 1.19 | 37 |
| 1951 | - | - | - | 4.8 | 15.5 | 26.8 | 43.6 | 300 | 373 | 7.1 | 68 | 37.7 | 0.72 | 23 |
| 1952 | - | - | - | 2.9 | 14.9 | 21.6 | 39.6 | 207 | 674 | 12.9 | 65 | 41.8 | 0.80 | 25 |

## Bacia do rio Pardo

**Hidrografia:** nasce na encosta do monte denominado Pedra de Amolar, na serra das Almas, município de Rio Pardo, Estado de Minas Gerais, em altitude aproximada de 1.000 metros; desagua no Oceano Atlântico em frente da cidade de Canavieiras, no Estado da Bahia, após um percurso de cêrca de 790 km. Sua bacia hidrográfica é da ordem de 28.109 km² de área.

Os seus mais importantes tributários são: rios Ribeirão (m.e.), São João (m.e.) e o Mangeronas (m.d.).

Em 31 de dezembro de 1952, existiam 9 postos fluviométricos em funcionamento e até essa data tinham sido efetuadas 154 medições de descarga.

Abaixo figuram características hidrológicas do rio Pardo nos postos de Itambé e Mascote.

Pôsto: **Itambé**

Rio: **Pardo**

Estado: **Bahia**

Município: **Itambé**

Localização: **Ponto de abastecimento d'água**

Área de drenagem: **19.700 km²**

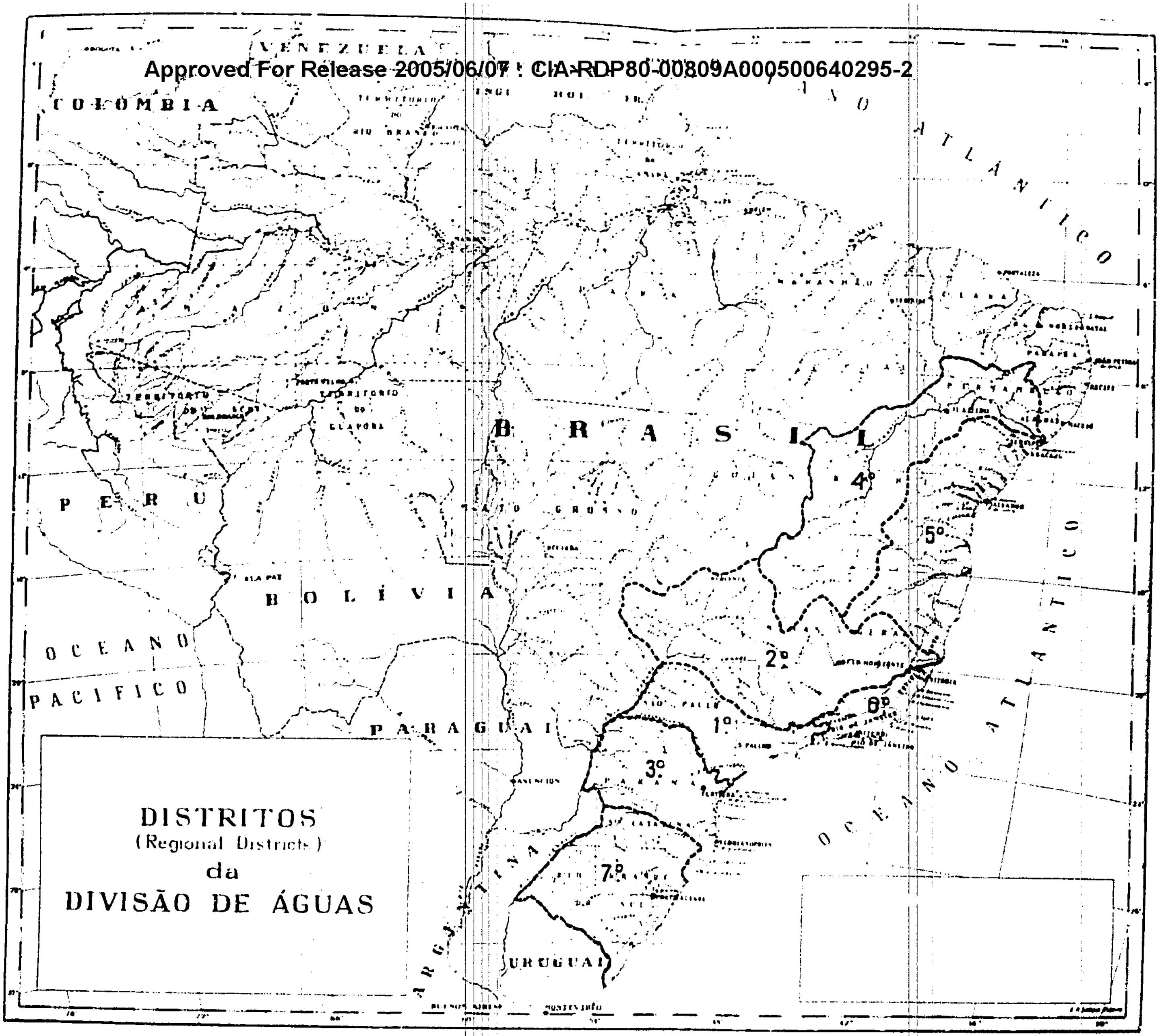
Altitude do zero da escala: **285 m aproximadamente**

Início das observações: **10-12-1935**

Número de medições de descarga: **36**

CARACTERISTICAS FLUVIOMETRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | % |
| 1944 | 45 | 5.07 | 0,16 | 4.40 | 9.56 | 15.26 | 31.70 | 274 | 164 | 8.3 | 91 | 23.9 | 1.21 | 38 |
| 1945 | 80 | 14.30 | 0.73 | 15.74 | 29.72 | 47.81 | 95.84 | 376 | 273 | 13.8 | 160 | 72.6 | 3.69 | 115 |
| 1946 | 62 | 7.78 | 0.35 | 9.77 | 12.65 | 17.66 | 32.39 | 250 | 140 | 7.1 | 96 | 25.3 | 1.28 | 40 |
| 1947 | 54 | 5.40 | 0.27 | 6.40 | 8.95 | 11.99 | 22.10 | 235 | 145 | 7.3 | 91 | 24.5 | 1.23 | 39 |
| 1948 | 45 | 5.45 | 0.17 | 4.21 | 7.31 | 12.65 | 24.50 | 405 | 310 | 15.7 | 91 | 26.6 | 1.35 | 45 |
| 1949 | 63 | 8.13 | 0.41 | 10.18 | 14.30 | 25.30 | 40.67 | 567 | 262 | 13.3 | 111 | 35.7 | 1.81 | 56 |
| 1950 | 44 | 3.26 | 0.16 | 3.83 | 8.95 | 15.31 | 30.38 | 218 | 115 | 5.7 | 88 | 22.8 | 1.12 | 35 |
| 1951 | 20 | 0.40 | 0.02 | 0.96 | 3.45 | 8.95 | 15.97 | 176 | 80 | 4.0 | 65 | 11.7 | 0.59 | 18 |
| 1952 | 31 | 1.24 | 0.06 | 2.22 | 6.15 | 10.59 | 20.90 | 268 | 139 | 7.0 | 82 | 20.7 | 1.05 | 33 |



DISTRITOS
(Regional Districts)
da
DIVISÃO DE ÁGUAS

Pôsto: **Mascote**

Rio: **Pardo**

Estado: **Bahia**

Município: **Canavieiras**

Localização: **Na foz do córrego Peixoto**

Área de drenagem: **30.400 km²**

Início das observações: **29-4-1936**

Número de medições de descarga: **41**

CARACTERISTICAS FLUVIOMETRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h<br>cm | Q<br>m³/s | q<br>l/s/km² | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | h<br>cm | Q<br>m³/s | q<br>l/s/km² | h<br>cm | Q<br>m³/s | q<br>l/s/km² | % |
| 1944 | 70 | 17.5 | 0.58 | 22.5 | 28.5 | 40.2 | 56.8 | 554 | 542 | 18.0 | 129 | 56.5 | 1.8 | 58 |
| 1945 | 118 | 43.8 | 1.44 | 50.4 | 70.5 | 91.9 | 156.7 | 655 | 719 | 23.6 | 226 | 141.8 | 4.6 | 146 |
| 1946 | 68 | 16.6 | 0.54 | 20.0 | 31.5 | 48.6 | 66.1 | 352 | 242 | 7.9 | 130 | 53.6 | 1.7 | 55 |
| 1947 | 40 | 7.0 | 0.23 | 8.8 | 13.9 | 20.0 | 59.6 | 1005 | 1421 | 46.7 | 129 | 76.7 | 2.5 | 79 |
| 1948 | 70 | 17.5 | 0.58 | 22.5 | 40.2 | 49.2 | 80.4 | 629 | 674 | 22.1 | 156 | 79.6 | 2.6 | 83 |
| 1949 | 70 | 17.5 | 0.58 | 26.1 | 42.0 | 62.7 | 86.0 | 540 | 527 | 17.3 | 162 | 80.7 | 2.6 | 83 |
| 1950 | 50 | 10.0 | 0.33 | 13.0 | 27.4 | 37.3 | 49.2 | 610 | 642 | 21.1 | 115 | 46.9 | 1.5 | 48 |
| 1951 | 10 | 8.0 | 0.26 | 8.8 | 18.7 | 23.8 | 32.2 | 270 | 172 | 5.6 | 70 | 26.4 | 0.8 | 27 |
| 1952 | 18 | 9.8 | 0.32 | 11.6 | 16.5 | 22.9 | 30.1 | 457 | 404 | 13.3 | 82 | 39.4 | 1.2 | 37 |

## Bacia do rio Jequitinhonha

**Hidrografia:** o rio Jequitinhonha tem sua nascente na serra do Espinhaço, município de Serro, Estado de Minas Gerais; após percorrer cêrca de 1.200 km lança-se no Oceano Atlântico, em Belmonte, Estado da Bahia. Sua bacia hidrográfica é de 62.100 km² aproximadamente.

Ao atravessar as montanhas e chapadas do norte de Minas Gerais, em direção à costa, apresenta o seu leito encachoeirado, sendo a mais importante a cachoeira do Salto Grande, na divisa mineiro-bahiana.

Próximo à sua foz, forma um canal natural que o vai ligar ao rio Pardo, um pouco acima da cidade de Canavieiras.

Recebe em seu percurso vários afluentes dentre os quais os rios Itacambira (m.e.), Vacaria (m.e.), Arassuaí (m.d.), São Miguel (m.d.) e São Francisco (m.e.).

A sua rêde fluviométrica, em 31 de dezembro de 1952, compunha-se de 29 postos e haviam sido efetuadas até essa data 1.173 medições de descarga.

A seguir apresentamos algumas características hidrológicas do rio Jequitinhonha em Jequitinhonha.

Pôsto: **Jequitinhonha**
Rio: **Jequitinhonha**
Estado: **Minas Gerais**
Município: **Jequitinhonha**
Localização: **No local de travessia de balsas**
Área de drenagem: **49.700 km²**
Altitude do zero da escala: **220 m aproximadamente**
Início das observações: **10-6-1939**
Número de medições de descarga: **74**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| 1944 | 103 | 116.8 | 2.3 | 146.0 | 182.0 | 255 | 432 | 649 | 3599 | 72.4 | 195 | 353.5 | 7.1 | 232 |
| 1945 | 130 | 200.0 | 4.0 | 212.6 | 299.4 | 501 | 1089 | 709 | 5202 | 104.7 | 297 | 852.4 | 17.1 | 540 |
| 1946 | 119 | 144.2 | 2.9 | 166.7 | 221.0 | 329 | 525 | 562 | 2712 | 54.6 | 215 | 413.6 | 8.3 | 262 |
| 1947 | 86 | 92.0 | 1.8 | 106.4 | 142.4 | 212 | 391 | 557 | 2488 | 50.1 | 185 | 353.4 | 7.1 | 224 |
| 1948 | 68 | 67.4 | 1.3 | 81.7 | 115.6 | 161 | 380 | 628 | 3380 | 68.0 | 177 | 491.5 | 9.8 | 239 |
| 1949 | 115 | 137.0 | 2.7 | 133.3 | 200.0 | 347 | 630 | 650 | 3400 | 68.4 | 240 | 583.0 | 11.7 | 360 |
| 1950 | 87 | 92.9 | 1.8 | 99.4 | 129.0 | 184 | 337 | 493 | 2068 | 41.6 | 167 | 288.4 | 5.8 | 171 |
| 1951 | 55 | 48.6 | 0.9 | 66.1 | 96.5 | 146 | 242 | 445 | 1680 | 33.8 | 151 | 205.0 | 4.1 | 150 |
| 1952 | 73 | 73.9 | 1.4 | 98.0 | 140.6 | 237 | 449 | 558 | 2672 | 53.8 | 194 | 400.3 | 8.0 | 209 |

### Bacia do rio Mucuri

**Hidrografia:** o rio Mucuri nasce na serra da Noruega, município de Malacacheta, Estado de Minas Gerais, em altitude aproximada de 660 metros.

Após um percurso de cêrca de 530 km, servindo de limite entre os Estados de Minas Gerais e Bahia e entre Bahia e Espírito Santo, desagua no Oceano Atlântico; sua bacia hidrográfica é da ordem de 15.000 km².

Os seus principais afluentes são: rios Prêto (m.e.), Todos os Santos (m.d.) e Pampam (m.d.).

Em 31 de dezembro de 1952 havia, na bacia do rio Mucuri, 4 postos fluviométricos em funcionamento e tinham sido realizadas até essa data 220 medições de descarga.

Abaixo se encontram características hidrológicas do citado rio na localidade de Carlos Chagas.

Pôsto: **Carlos Chagas**

Rio: **Mucuri**

Estado: **Minas Gerais**

Município: **Carlos Chagas**

Localização: **Na ponte sôbre o rio Mucuri, próximo da cadeia.**

Área de drenagem: **9.800 km²**

Altitude do zero da escala: **146 m aproximadamente**

Início das observações: **13-12-1939**

Número de medições de descarga: **65**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE DEFLÚVIO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1944 | 185 | 29.63 | 3.0 | 34.27 | 44.60 | 56.48 | 86.2 | 421 | 314 | 32.0 | 225 | 70.0 | 7.2 | 228 |
| 1945 | 199 | 42.68 | 4.3 | 48.53 | 67.82 | 98.61 | 168.4 | 611 | 628 | 64.1 | 279 | 136.3 | 13.9 | 439 |
| 1946 | 184 | 20.72 | 2.9 | 32.35 | 43.62 | 55.46 | 85.0 | 528 | 487 | 49.7 | 225 | 72.2 | 7.3 | 232 |
| 1947 | 171 | 17.23 | 1.7 | 21.60 | 29.63 | 38.90 | 57.3 | 354 | 227 | 23.2 | 203 | 50.9 | 5.1 | 163 |
| 1948 | 166 | 13.02 | 1.3 | 18.98 | 29.63 | 36.06 | 57.3 | 417 | 308 | 31.4 | 206 | 52.2 | 5.3 | 169 |
| 1949 | 170 | 16.56 | 1.6 | 30.54 | 48.53 | 76.32 | 126.1 | 540 | 508 | 51.8 | 252 | 103.0 | 10.5 | 329 |
| 1950 | 170 | 16.56 | 1.6 | 22.47 | 35.12 | 49.58 | 60.5 | 311 | 172 | 17.5 | 206 | 50.6 | 5.1 | 162 |
| 1951 | 148 | 0.00 | 0.0 | 1.60 | 14.69 | 25.34 | 32.3 | 260 | 107 | 11.0 | 180 | 26.1 | 2.6 | 83 |
| 1952 | 166 | 13.02 | 1.3 | 22.47 | 37.01 | 53.43 | 100.9 | 516 | 467 | 47.6 | 233 | 83.2 | 8.4 | 268 |

## Bacia do rio Doce

**Hidrografia:** o rio Doce nasce com o nome de rio Piranga, num dos contrafortes da Serra da Trapizonga, município de Barbacena, Estado de Minas Gerais, em altitude aproximada de 1.200 metros; depois de sua confluência com o rio do Carmo, passa a chamar-se rio Doce, desaguando no Oceano Atlântico, no litoral do Estado do Espírito Santo, após um desenvolvimento de cêrca de 700 km. Sua bacia hidrográfica é da ordem de 84.700 km² de área.

São seus principais tributários: rios Carmo (m.e.), Piracicaba (m.e.), Santo Antônio (m.e.), Suassuí Grande (m.e.) e Manhuaçu (m.d.).

Em 31 de dezembro de 1952 existiam em funcionamento, na bacia do rio Doce, 88 postos fluviométricos, e até êsse dia haviam sido efetuadas 4.810 medições de descarga.

Apresentamos em seguida características hidrológicas da bacia do Doce em Ponte Nova e Colatina.

Pôsto: **Ponte Nova**
Rio: **Piranga**
Estado: **Minas Gerais**
Município: **Ponte Nova**
Localização: **Na ponte da E. F. Leopoldina**
Área de drenagem: **6.195 km²**
Altitude do zero da escala: **393 m. aproximadamente**
Início das observações: **19-3-1939**
Número de medições de descarga: **146**

### CARACTERISTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA |  |  | 95 % | 75 % | 50 % | 25 % | MÁXIMA |  |  | MÉDIA |  |  | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
|  | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1939 | 97 | 45.6 | 7.0 | 51.4 | 61.5 | 78.8 | - | 300 |  |  | - | - | - | - |
| 1940 | 94 | 41.8 | 6.8 | 45.6 | 54.6 | 80.9 | 114 | 360 |  |  | 145 | 99 | 16.0 | 505 |
| 1941 | 115 | 57.2 | 9.2 | 61.5 | 73.4 | 86.8 | 120 | 280 |  |  | 153 | 95 | 15.3 | 483 |
| 1942 | 110 | 52.9 | 8.5 | 57.2 | 70.2 | 95.5 | 139 | 360 |  |  | 158 | 113 | 18.2 | 574 |
| 1943 | 125 | 66.3 | 10.7 | 72.3 | 85.6 | 108.0 | 179 | 360 |  |  | - | - | - | - |
| 1944 | 115 | 55.5 | 9.0 | 59.8 | 71.2 | 95.3 | 142 | 380 |  |  | 160 | 113 | 18.2 | 579 |
| 1945 | 118 | 59.2 | 9.6 | 67.5 | 80.7 | 105.0 | 155 | 320 |  |  | 167 | 124 | 20.0 | 631 |
| 1946 | 107 | 48.5 | 7.8 | 51.3 | 62.2 | 80.7 | 108 | 258 | 211 | 34.1 | 144 | 93 | 15.0 | 474 |
| 1947 | 110 | 51.3 | 8.3 | 57.2 | 69.6 | 90.2 | 126 | 310 |  |  | 154 | 106 | 17.1 | 540 |
| 1948 | 98 | 40.2 | 6.5 | 47.6 | 65.4 | 90.2 | 129 | 380 |  |  | 155 | 111 | 17.9 | 567 |
| 1949 | 122 | 63.5 | 10.2 | 68.5 | 81.8 | 114.0 | 166 | 425 |  |  | 176 | 142 | 22.9 | 723 |
| 1950 | 106 | 47.6 | 7.7 | 50.4 | 64.5 | 88.9 | 152 | 301 |  |  | 154 | 108 | 17.4 | 550 |
| 1951 | 114 | 55.3 | 8.9 | 58.2 | 65.3 | 101.0 | 171 | 495 |  |  | 168 | 134 | 21.6 | 682 |
| 1952 | 132 | 73.9 | 11.9 | 80.7 | 92.6 | 122.0 | 244 | 514 |  |  | 188 | 165 | 26.6 | 843 |

Pôsto: **Colatina**

Rio: **Doce**

Estado: **Espirito Santo**

Município: **Colatina**

Localização: **Na ponte municipal**

Área de drenagem: **77.407 km²**

Altitude do zero da escala: **32 m. aproximadamente**

Início das observações: **30-12-1937**

Número de medições de descarga: **37**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA H cm | MÍNIMA Q m³/s | MÍNIMA q l/s/km² | [illegible] % Q m³/s | [illegible] % Q m³/s | [illegible] % Q m³/s | [illegible] % Q m³/s | MÁXIMA H cm | MÁXIMA Q m³/s | MÁXIMA q l/s/km² | MÉDIA H cm | MÉDIA Q m³/s | MÉDIA q l/s/km² | [illegible] mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1938 | 70 | 407 | 5.3 | 420 | 533 | 726 | 953 | 381 | 3294 | 42.6 | 123 | 802 | 10.4 | 327 |
| 1939 | 56 | 285 | 3.7 | 336 | 400 | 464 | 695 | 510 | 5023 | 64.9 | 94 | 663 | 8.6 | 272 |
| 1940 | 54 | 277 | 3.6 | 299 | 390 | 624 | 1027 | 331 | 2739 | 35.4 | 117 | 800 | 10.3 | 327 |
| 1941 | 84 | 462 | 6.0 | 499 | 612 | 776 | 1237 | 427 | 3869 | 50.0 | 146 | 972 | 12.6 | 396 |
| 1942 | - | - | - | - | - | - | - | 562 | 5767 | 74.5 | - | - | - | - |
| 1943 | 86 | 513 | 6.6 | 547 | 778 | 1033 | 1907 | 622 | 6716 | 86.8 | 211 | 1524 | 19.7 | 622 |
| 1944 | 76 | 447 | 5.8 | 486 | 660 | 891 | 1308 | 388 | 3379 | 43.7 | 155 | 1055 | 13.6 | 431 |
| 1948 | 68 | 316 | 4.1 | 357 | 473 | 656 | 1052 | 597 | 6487 | 84.7 | 157 | 1015 | 13.1 | 413 |
| 1949 | 110 | 592 | 7.7 | 637 | 801 | 1079 | 1993 | 598 | 6373 | 82.3 | 223 | 1625 | 21.0 | 663 |
| 1950 | 85 | 394 | 5.1 | 399 | 502 | 697 | 1091 | 462 | 4400 | 56.8 | 150 | 881 | 11.4 | 358 |

NOTA: No período 1945 - 1947 houve modificação na curva de descarga

## Bacia do rio Itapemirim

**Hidrografia:** nasce êste rio no morro do Valentim, município de Iuna, Estado do Espírito Santo, em altitude aproximada de 700 metros; lança-se no Oceano Atlântico, tendo todo o seu curso nesse Estado. Sua bacia hidrográfica é da ordem de 6.820 km² de área.

Os seus principais afluentes são: rios Santa Cruz (m.d.), Castelo (m.e.) e Muqui do Norte (m.d.).

A bacia do rio Itapemirim tinha em 31 de dezembro de 1952, 6 postos fluviométricos em funcionamento e até essa época se havia procedido a 245 medições de descarga.

A seguir figuram características hidrológicas do mencionado rio no pôsto de Cachoeiro do Itapemirim.

Pôsto: **Cachoeiro do Itapemirim**
Rio: **Itapemirim**
Estado: **Espírito Santo**
Município: **Cachoeiro do Itapemirim**
Localização: **4 km a jusante da Estação da E. F. L.**
Área de drenagem: **5.220 km²**
Início das observações: **18-8-1935**
Número de medições de descarga: **86**

### CARACTERISTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1936 | 70 | 19.0 | 3.6 | 20.9 | 29.4 | 38.4 | 61.2 | 309 | 321 | 61.5 | 120 | 52.9 | 10.1 | 320 |
| 1937 | 97 | 28.8 | 5.5 | - | - | - | - | - | - | - | - | - | - | - |
| 1938 | 105 | 33.5 | 6.4 | 37.1 | 45.7 | 65.6 | 88.9 | 371 | 296 | 56.8 | 159 | 75.7 | 14.5 | 457 |
| 1939 | 83 | 21.4 | 4.1 | 24.0 | 28.5 | 35.5 | 49.9 | 644 | 691 | 132.4 | 126 | 53.6 | 10.2 | 324 |
| 1940 | 85 | 21.4 | 4.1 | 25.5 | 34.1 | 57.5 | 97.7 | 404 | 342 | 65.5 | 155 | 75.5 | 14.4 | 456 |
| 1941 | 93 | 30.0 | 5.7 | 32.9 | 45.7 | 65.6 | 105.7 | 416 | 358 | 68.7 | 169 | 85.9 | 16.4 | 518 |
| 1942 | 98 | 29.4 | 5.6 | 32.5 | 45.0 | 69.3 | 132.7 | 664 | 720 | 138.0 | 197 | 119.1 | 22.8 | 719 |
| 1943 | 111 | 37.1 | 7.1 | 41.7 | 57.5 | 85.4 | 155.1 | 725 | 807 | 154.6 | 209 | 127.5 | 24.5 | 768 |
| 1944 | 100 | 30.5 | 5.8 | 32.9 | 47.1 | 78.6 | 122.3 | 557 | 535 | 102.5 | 179 | 96.2 | 18.4 | 581 |
| 1945 | 99 | 30.0 | 5.7 | 36.5 | 51.4 | 85.4 | 138.4 | 620 | 655 | 125.6 | 190 | 105.4 | 20.2 | 636 |
| 1946 | 86 | 23.0 | 4.4 | 26.6 | 36.5 | 55.8 | 88.9 | 411 | 351 | 67.3 | 151 | 70.2 | 13.4 | 424 |
| 1947 | 85 | 22.5 | 4.3 | 27.2 | 37.8 | 55.8 | 92.4 | 429 | 377 | 72.2 | 157 | 76.4 | 14.6 | 461 |
| 1948 | 79 | 19.5 | 3.7 | 21.5 | 31.7 | 55.8 | 87.1 | 611 | 686 | 131.5 | 162 | 86.5 | 16.6 | 524 |
| 1949 | 110 | 36.5 | 7.0 | 43.0 | 63.6 | 97.7 | 174.5 | 565 | 572 | 109.6 | 216 | 131.8 | 25.2 | 796 |
| 1950 | 86 | 23.0 | 4.4 | 25.0 | 34.1 | 54.3 | 88.0 | 621 | 657 | 125.9 | 152 | 72.9 | 14.0 | 440 |
| 1951 | 76 | 18.1 | 3.4 | 21.0 | 30.5 | 47.1 | 80.5 | 442 | 395 | 75.7 | 141 | 63.2 | 12.1 | 381 |
| 1952 | 92 | 26.1 | 5.0 | 31.7 | 44.5 | 69.3 | 139.4 | 564 | 573 | 109.9 | 187 | 105.5 | 20.2 | 639 |

### Bacia do rio Itabapoana

**Hidrografia:** nasce no sudoeste mineiro, na serra do Caparaó, município de Espera Feliz; serve de limite entre os Estados do Espírito Santo e Rio de Janeiro até desembocar no Oceano Atlântico, na Barra do Itabapoana, após um percurso de 264 km aproximadamente. Sua bacia hidrográfica é de cêrca de 3.180 km² de área.

Os seus principais tributários são: rios Prêto (m.e.), Veado (m.e.), Varre Sae (m.d.) e Muqui do Sul (m.e.).

Na bacia do rio Itabapoana, em 31 de dezembro de 1952, havia 5 postos fluviométricos e tinham sido realizadas 205 medições de descarga até essa data.

Abaixo se encontram características hidrológicas do mencionado rio em Itabapoana (Ponte).

Pôsto: **Itabapoana (Ponte)**
Rio: **Itabapoana**
Estado: **Espírito Santo**
Localização: **No encontro da m.e. da ponte inter-estadual.**
Area de drenagem: **2.940 km²**
Início das observações: **5-9-1930**
Número de medições de descarga: **55**

CARACTERISTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | [illegible] % | [illegible] % | [illegible] % | [illegible] % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | [illegible] |
| 1931 | 86 | 18.3 | 6.2 | 21.1 | 29.9 | 53.0 | 73.7 | 268 | 300 | 102.0 | 130 | 63.6 | 21.6 | 682 |
| 1932 | 86 | 18.3 | 6.2 | 21.8 | 35.1 | 46.0 | 70.0 | 255 | 272 | 92.5 | 129 | 59.3 | 20.2 | 638 |
| 1933 | 88 | 19.8 | 6.7 | 24.0 | 35.1 | 66.2 | 179.3 | 388 | 604 | 205.4 | 159 | 111.1 | 37.7 | 1191 |
| 1934 | 91 | 21.8 | 7.4 | 26.1 | 3[illegible] | 43.2 | 70.0 | 377 | 574 | 195.2 | 129 | 62.2 | 21.1 | 667 |
| 1935 | 83 | 16.6 | 5.6 | 18.5 | 24.7 | 56.3 | 64.0 | 268 | 300 | 102.0 | 121 | 51.5 | 17.5 | 552 |
| 1936 | 76 | 12.4 | 4.2 | 13.5 | 19.8 | 28.5 | 39.8 | 185 | 129 | 43.9 | 105 | 34.5 | 11.7 | 370 |
| 1937 | 81 | 15.3 | 5.2 | 10.5 | 26.1 | 43.2 | 71.2 | 369 | 552 | 187.7 | 130 | 66.7 | 22.6 | 715 |
| 1938 | 77 | 13.0 | 4.4 | 14.1 | 21.1 | 29.1 | 39.8 | 207 | 173 | 59.0 | 106 | 35.7 | 12.1 | 382 |
| 1939 | 64 | 6.1 | 2.0 | 9.0 | 12.4 | 18.5 | 29.1 | 257 | 233 | 79.3 | 93 | 25.8 | 8.7 | 277 |
| 1940 | 70 | 9.0 | 3.0 | 11.3 | 18.5 | 32.3 | 54.0 | 255 | 225 | 76.5 | 111 | 41.8 | 14.2 | 448 |
| 1941 | 84 | 17.2 | 5.8 | 26.9 | 29.9 | 37.1 | 55.0 | 240 | 239 | 81.3 | 117 | 46.5 | 15.8 | 498 |
| 1942 | 84 | 17.2 | 5.8 | 19.8 | 28.3 | 39.8 | 77.5 | 305 | 387 | 131.6 | 131 | 67.8 | 23.0 | 727 |
| 1943 | 89 | 20.3 | 6.9 | 24.0 | 35.5 | 46.0 | 84.2 | 366 | 544 | 185.0 | 138 | 76.4 | 25.9 | 819 |
| 1944 | 82 | 16.0 | 5.4 | 17.2 | 28.3 | 38.9 | 61.7 | 305 | 387 | 131.6 | 120 | 51.1 | 17.4 | 549 |
| 1945 | 80 | 14.7 | 5.0 | 18.5 | 26.9 | 41.5 | 67.5 | 225 | 209 | 71.0 | 121 | 50.5 | 17.2 | 541 |
| 1946 | 82 | 16.0 | 5.4 | 17.9 | 24.0 | 35.5 | 54.0 | 245 | 246 | 83.6 | 115 | 45.6 | 15.5 | 488 |
| 1947 | 82 | 16.0 | 5.4 | 17.9 | 25.4 | 34.7 | 55.0 | 284 | 328 | 111.6 | 114 | 43.1 | 14.7 | 462 |
| 1948 | 74 | 11.3 | 3.8 | 16.0 | 22.5 | 33.9 | 54.0 | 302 | 380 | 129.2 | 115 | 47.2 | 16.1 | 507 |
| 1949 | 86 | 18.3 | 6.2 | 21.8 | 35.1 | 49.0 | 88.5 | 289 | 349 | 118.7 | 135 | 69.8 | 23.7 | 748 |
| 1950 | 82 | 16.0 | 5.4 | 17.9 | 25.4 | 37.1 | 58.4 | 236 | 231 | 78.6 | 117 | 47.0 | 16.0 | 504 |
| 1951 | 72 | 10.1 | 3.4 | 14.7 | 21.1 | 34.7 | 55.0 | 266 | 296 | 100.7 | 115 | 44.1 | 15.0 | 472 |
| 1952 | 86 | 18.3 | 6.2 | 22.5 | 31.5 | 34.7 | 77.5 | 269 | 303 | 103.1 | 130 | 62.7 | 21.3 | 674 |

### Bacia do rio Paraíba do Sul

**Hidrografia:** o rio Paraíba do Sul é formado pelos rios Paraitinga e Paraíbuna.

O rio Paraitinga tem suas nascentes na serra da Bocaina, maciço pertencente ao sistema da cordilheira do Mar, quase no limite dos Estados de São Paulo e Rio de Janeiro, em altitude de 1.800 metros.

Após um percurso de 200 km aproximadamente, abrangendo uma bacia hidrográfica de cêrca de 2.500 km², junta-se ao rio Paraibuna, em altitude de 620 metros, e toma o nome de Paraíba do Sul.

O rio Paraibuna nasce na serra do Parati, contraforte da cordilheira do Mar, na linha divisória dos Estados do Rio de Janeiro e São Paulo, em altitude de 1.600 metros; conflue com o rio Paraitinga depois de percorrer cêrca de 140 km, e sua bacia hidrográfica é estimada em 1.900 km².

A bacia do rio Paraíba, drena uma região que estende por três unidades da Federação, São Paulo, Minas Gerais e Rio de Janeiro; pela sua situação geográfica, é das mais importantes de nosso país.

Em sua periferia se acham localizadas as duas maiores cidades brasileiras: São Paulo e Rio de Janeiro, ambas com mais de dois milhões de habitantes, e em seu eixo se encontra Volta Redonda, marco de nossa indústria pesada.

A bacia hidrográfica do rio Paraíba tem aproximadamente 57.000 km² de área e pode ser dividida em três secções: superior, média e inferior.

O curso superior estende-se das nascentes até a cidade de Guararema, no Estado de São Paulo; o médio, de Guararema até a localidade de Itaocara, no Estado do Rio de Janeiro, e o inferior daí até a foz, no Oceano Atlântico.

Recebe em seu percurso grande número de afluentes, cujos principais são: rios Jaguari (m.e.), Buquira (m.e.), Bocaina (m.d.), Piabanha (m.d.), Prêto-Paraibuna (m.e.), Paquequer (m.d.), Pomba (m.e), Dois Rios (m.d.) e Muriaé (m.e.).

A sua rêde fluviométrica, em 31 de dezembro de 1952, compunha-se de 95 postos em funcionamento, e até essa data haviam sido efetuadas 5.862 medições de descarga.

A seguri apresentamos características hidrológicas do rio Paraíba, nos postos de Guararema, Resende e Campos.

Pôsto: **Guararema**
Rio: **Paraíba do Sul**
Estado: **São Paulo**
Município: **Guararema**
Localização: **Próximo da ponte da E. F. C. B.**
Area de drenagem: **5.300 km²**
Início das observações: **19-10-1922**
Número de medições de descarga: **65**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/seg | l/seg/km² | m³/seg | m³/seg | m³/seg | m³/seg | cm | m³/seg | l/seg/km² | cm | m³/seg | l/seg/km² | mm |
| 1923 | 131 | 51.6 | 9.7 | 55.4 | 70.5 | 91.2 | 125.1 | 622 | 517 | 97.7 | 204 | 105.2 | 19.8 | 625 |
| 1924 | 110 | 38.2 | 7.2 | 43.8 | 54.8 | 76.0 | 119.5 | 604 | 496 | 93.7 | 193 | 98.5 | 18.6 | 587 |
| 1925 | 104 | 34.7 | 6.5 | 40.1 | 52.2 | 73.9 | 101.9 | 461 | 345 | 65.2 | 177 | 84.8 | 16.0 | 504 |
| 1926 | 114 | 40.7 | 7.6 | 50.9 | 62.0 | 79.5 | 116.3 | 442 | 315 | 59.4 | 194 | 97.9 | 18.5 | 582 |
| 1927 | 130 | 50.9 | 9.6 | 56.0 | 69.2 | 86.0 | 117.9 | 446 | 320 | 60.4 | 194 | 97.2 | 18.3 | 578 |
| 1928 | 103 | 34.1 | 6.4 | 38.9 | 50.5 | 65.2 | 97.3 | 421 | 295 | 55.8 | 171 | 81.3 | 15.3 | 485 |
| 1929 | 127 | 49.0 | 9.2 | 54.8 | 67.9 | 90.4 | 139.3 | 521 | 397 | 75.1 | 215 | 114.9 | 21.7 | 683 |
| 1930 | 116 | 42.0 | 7.9 | 47.7 | 62.6 | 77.6 | 109.8 | 377 | 272 | 51.3 | 185 | 90.3 | 17.0 | 537 |
| 1931 | 118 | 43.2 | 8.1 | 48.5 | 62.6 | 85.1 | 126.8 | 457 | 330 | 62.4 | 200 | 102.7 | 19.4 | 611 |
| 1932 | 119 | 43.9 | 8.2 | 49.6 | 59.3 | 77.4 | 109.0 | 449 | 323 | 61.0 | 187 | 92.5 | 17.5 | 551 |
| 1933 | 95 | 29.6 | 5.5 | 34.7 | 41.4 | 50.9 | 73.2 | 320 | 201 | 38.0 | 144 | 60.6 | 11.4 | 360 |
| 1934 | 95 | 29.6 | 5.5 | 31.9 | 42.0 | 59.3 | 85.3 | 414 | 288 | 54.4 | 160 | 73.9 | 13.9 | 439 |
| 1935 | 95 | 29.6 | 5.5 | 37.6 | 49.0 | 62.6 | 93.4 | 437 | 311 | 58.7 | 173 | 81.0 | 15.3 | 481 |
| 1936 | 109 | 37.6 | 7.0 | 40.7 | 48.5 | 58.6 | 91.2 | 518 | 394 | 74.4 | 167 | 78.5 | 14.8 | 468 |
| 1937 | 98 | 31.3 | 5.9 | 34.7 | 45.8 | 69.2 | 94.8 | 370 | 246 | 46.5 | 167 | 77.6 | 14.6 | 461 |
| 1938 | 117 | 42.6 | 8.0 | 52.2 | 66.5 | 82.4 | 111.5 | 430 | 304 | 57.4 | 169 | 92.5 | 17.5 | 550 |
| 1939 | 99 | 31.9 | 6.0 | 38.2 | 49.6 | 69.9 | 98.8 | 551 | 409 | 77.2 | 169 | 80.2 | 15.1 | 477 |
| 1940 | 100 | 32.4 | 6.1 | 34.7 | 45.9 | 65.3 | 100.3 | 595 | 482 | 91.1 | 173 | 83.2 | 15.7 | 496 |
| 1941 | 92 | 28.0 | 5.2 | 31.3 | 43.9 | 63.9 | 90.4 | 299 | 183 | 34.5 | 156 | 69.7 | 13.2 | 414 |
| 1942 | 91 | 27.5 | 5.1 | 34.7 | 45.8 | 61.3 | 81.6 | 372 | 248 | 46.8 | 157 | 68.3 | 12.9 | 406 |
| 1943 | 78 | 21.1 | 3.9 | 28.6 | 37.0 | 48.3 | 72.6 | 283 | 169 | 31.9 | 139 | 58.4 | 11.0 | 347 |
| 1944 | 82 | 23.0 | 4.3 | 30.8 | 41.4 | 57.3 | 90.4 | 656 | 536 | 101.3 | 166 | 79.7 | 15.0 | 473 |
| 1945 | 100 | 32.4 | 6.1 | 37.0 | 49.0 | 62.6 | 88.2 | 582 | 469 | 88.6 | 166 | 77.8 | 14.7 | 462 |
| 1946 | 77 | 20.6 | 3.8 | 29.6 | 43.9 | 57.3 | 93.4 | 326 | 206 | 39.0 | 155 | 67.0 | 12.6 | 398 |
| 1947 | 136 | 55.1 | 10.4 | 65.2 | 77.4 | 98.0 | 154.2 | 551 | 414 | 78.1 | 219 | 119.6 | 22.6 | 711 |
| 1948 | 115 | 41.3 | 7.7 | 50.9 | 62.0 | 79.3 | 125.5 | 375 | 248 | 46.9 | 190 | 97.0 | 18.3 | 578 |
| 1949 | 107 | 36.5 | 6.8 | 41.4 | 51.6 | 62.6 | 94.2 | 455 | 322 | 60.9 | 168 | 79.4 | 15.0 | 472 |
| 1950 | 96 | 30.2 | 5.7 | 42.6 | 56.7 | 76.0 | 136.7 | 483 | 348 | 65.8 | 206 | 110.5 | 20.8 | 657 |
| 1951 | 124 | 47.1 | 8.8 | 50.9 | 63.3 | 88.9 | 136.7 | 447 | 315 | 59.5 | 202 | 106.9 | 20.2 | 636 |
| 1952 | 116 | 41.9 | 7.9 | 47.7 | 58.0 | 72.6 | 116.3 | 579 | 442 | 83.3 | 187 | 98.9 | 18.7 | 590 |

Pôsto: **Resendo**
Rio: **Paraíba do Sul**
Estado: **Rio de Janeiro**
Município: **Resende**
Localização: **Na ponte da cidade**
Área de drenagem: **13.930 km²**
Altitude do zero da escala: **387,796 m (referido à E. F. C. B.)**
Início das observações: **6-9-1922**
Número de medições de descarga: **61**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | [illegible] % | [illegible] % | [illegible] % | [illegible] % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | % |
| 1923 | 35 | 122.0 | 8.8 | 134.4 | 180 | 263 | 384 | 265 | 968 | 69.5 | 86 | 302 | 21.8 | 687 |
| 1924 | 22 | 86.2 | 6.2 | 100.0 | 129 | 197 | 397 | 355 | 1436 | 103.1 | 84 | 295 | 21.3 | 678 |
| 1925 | 19 | 82.8 | 5.9 | 95.3 | 137 | 220 | 334 | 206 | 732 | 52.5 | 70 | 245 | 24.8 | 555 |
| 1926 | 20 | 103.8 | 7.5 | 125.7 | 172 | 251 | 424 | 500 | 2163 | 155.2 | 89 | 303 | 23.2 | 712 |
| 1927 | 37 | 120.4 | 9.2 | 146.7 | 187 | 240 | 375 | 240 | 870 | 62.4 | 84 | 297 | 21.4 | 675 |
| 1928 | 24 | 92.8 | 6.7 | 99.0 | 131 | 192 | 314 | 199 | 706 | 50.7 | 67 | 237 | 17.1 | 538 |
| 1929 | 36 | 125.2 | 9.0 | 142.7 | 180 | 264 | 480 | 286 | 1090 | 78.2 | 102 | 360 | 26.0 | 819 |
| 1930 | 30 | 106.0 | 7.6 | 111.0 | 147 | 258 | 318 | 237 | 857 | 61.5 | 72 | 254 | 18.3 | 578 |
| 1931 | 30 | 106.0 | 7.6 | 118.8 | 167 | 242 | 456 | 292 | 1120 | 80.4 | 94 | 332 | 24.1 | 759 |
| 1932 | 30 | 106.0 | 7.6 | 118.8 | 149 | 228 | 392 | 255 | 938 | 67.3 | 78 | 274 | 19.8 | 616 |
| 1933 | 20 | 84.0 | 6.0 | 86.2 | 116 | 153 | 235 | 166 | 588 | 42.2 | 52 | 184 | 13.2 | 417 |
| 1934 | 16 | 79.2 | 5.7 | 84.0 | 106 | 155 | 274 | 188 | 667 | 47.9 | 60 | 211 | 15.2 | 480 |
| 1935 | 22 | 88.4 | 6.3 | 103.8 | 132 | 185 | 160 | 302 | 1170 | 84.0 | 70 | 246 | 17.9 | 564 |
| 1936 | 27 | 99.4 | 7.1 | 106.0 | 132 | 167 | 345 | 274 | 1030 | 73.9 | 68 | 238 | 17.1 | 53 |
| 1937 | 20 | 84.0 | 6.0 | 92.8 | 138 | 238 | 345 | 254 | 934 | 67.0 | 77 | 270 | 19.8 | 615 |
| 1938 | 33 | 115.6 | 8.3 | 138.0 | 181 | 249 | 356 | 235 | 849 | 61.0 | 80 | 280 | 20.2 | 636 |
| 1939 | 18 | 81.6 | 5.9 | 95.0 | 132 | 195 | 342 | 230 | 827 | 59.4 | 67 | 235 | 17.0 | 536 |
| 1940 | 18 | 81.6 | 5.9 | 88.4 | 116 | 178 | 306 | 237 | 857 | 61.6 | 68 | 240 | 17.2 | 539 |
| 1941 | 14 | 76.8 | 5.5 | 81.6 | 119 | 206 | 278 | 138 | 488 | 35.0 | 57 | 199 | 14.3 | 452 |
| 1942 | 23 | 88.4 | 6.3 | 101.6 | 138 | 205 | 295 | 178 | 631 | 45.3 | 63 | 221 | 15.9 | 502 |
| 1943 | 18 | 81.6 | 5.9 | 92.8 | 119 | 163 | 292 | 212 | 755 | 54.2 | 59 | 204 | 14.6 | 462 |
| 1944 | 14 | 76.8 | 5.5 | 82.8 | 106 | 156 | 295 | 291 | 1115 | 80.0 | 66 | 277 | 19.9 | 629 |
| 1945 | 20 | 84.0 | 6.0 | 106.0 | 138 | 195 | 324 | 357 | 1446 | 103.8 | 71 | 252 | 18.1 | 571 |
| 1946 | 16 | 79.2 | 5.7 | 86.2 | 132 | 178 | 335 | 344 | 1381 | 99.1 | 66 | 235 | 16.8 | 528 |
| 1947 | 45 | 156.0 | 11.2 | 181.0 | 224 | 281 | 460 | 366 | 1491 | 107.0 | 110 | 388 | 27.8 | 879 |
| 1948 | 30 | 106.0 | 7.6 | 122.0 | 170 | 231 | 438 | 255 | 938 | 67.3 | 85 | 301 | 21.6 | 685 |
| 1949 | 17 | 80.4 | 5.8 | 86.2 | 119 | 163 | 306 | 252 | 924 | 66.3 | 64 | 225 | 16.2 | 511 |
| 1950 | 27 | 99.4 | 7.1 | 106.0 | 160 | 256 | 488 | 356 | 1441 | 103.4 | 94 | 336 | 24.2 | 762 |
| 1951 | 27 | 99.4 | 7.1 | 103.8 | 160 | 206 | 442 | 220 | 786 | 56.4 | 81 | 285 | 20.5 | 646 |
| 1952 | 25 | 95.0 | 6.8 | 102.2 | 145 | 199 | 333 | 251 | 920 | 66.0 | 77 | 272 | 19.5 | 617 |

Pôsto: **Campos**
Rio: **Paraíba do Sul**
Esatdo: **Rio de Janeiro**
Município: **Campos**
Localização: **Na ponte municipal**
Área de drenagem: **55.770 km²**
Altitude do zero da escala: **1,56 m**
Início das observações: **1-1-1923**
Número de medições de descarga: **39**

CARACTERISTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA |  |  | [illegible] % | 75 % | [illegible] % | [illegible] % | MÁXIMA |  |  | MÉDIA |  |  | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | h<br>cm | Q<br>m³/s | q<br>l/s/km² | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | h<br>cm | Q<br>m³/s | q<br>l/s/km² | h<br>cm | Q<br>m³/s | q<br>l/s/km² | mm |
| 1931 | 650 | 444 | 7.9 | 515 | 640 | 941 | 1599 | 1028 | 3836 | 68.8 | 772 | 1104 | 19.8 | 624 |
| 1932 | 636 | 386 | 6.9 | 456 | 533 | 718 | 1432 | 1016 | 3680 | 66.0 | 745 | 933 | 16.7 | 529 |
| 1933 | 633 | 374 | 6.7 | 419 | 542 | 729 | 1094 | 1026 | 3810 | 68.3 | 735 | 1810 | 32.5 | 1025 |
| 1934 | 609 | 286 | 5.1 | 343 | 444 | 650 | 991 | 1038 | 3966 | 71.1 | 779 | 1153 | 20.7 | 652 |
| 1935 | 634 | 378 | 6.7 | 448 | 556 | 707 | 1197 | 1048 | 4096 | 73.4 | 742 | 742 | 13.3 | 399 |
| 1936 | 618 | 317 | 5.6 | 340 | 456 | 528 | 772 | 959 | 2718 | 48.7 | 656 | 656 | 11.8 | 372 |
| 1937 | 616 | 310 | 5.5 | 340 | 505 | 846 | 1279 | 1085 | 4577 | 82.7 | 820 | 1471 | 26.4 | 832 |
| 1938 | 630 | 363 | 6.5 | 491 | 610 | 840 | 1219 | 996 | 3421 | 61.3 | 745 | 934 | 16.7 | 528 |
| 1939 | 596 | 238 | 4.2 | 321 | 427 | 590 | 974 | 952 | 2874 | 51.5 | 704 | 704 | 12.6 | 398 |
| 1940 | 610 | 289 | 5.1 | 310 | 453 | 660 | 1219 | 996 | 3421 | 61.3 | 799 | 1301 | 23.3 | 737 |
| 1941 | 610 | 289 | 5.1 | 374 | 538 | 675 | 1035 | 905 | 2328 | 41.7 | 715 | 762 | 13.7 | 431 |
| 1942 | 628 | 355 | 6.3 | 410 | 561 | 806 | 1264 | 990 | 3345 | 60.0 | 739 | 897 | 16.1 | 507 |
| 1943 | 642 | 410 | 7.3 | 542 | 665 | 840 | 1644 | 1118 | 5006 | 89.8 | 777 | 1348 | 24.2 | 762 |
| 1944 | 614 | 303 | 5.4 | 367 | 524 | 718 | 1271 | 988 | 3319 | 59.5 | 741 | 1027 | 18.4 | 582 |
| 1945 | 614 | 303 | 5.4 | 406 | 524 | 740 | 1242 | 985 | 3281 | 58.8 | 752 | 939 | 16.8 | 531 |
| 1946 | 610 | 289 | 5.1 | 324 | 478 | 625 | 1022 | 1070 | 4382 | 78.6 | 713 | 829 | 14.9 | 468 |
| 1947 | 671 | 538 | 9.6 | 615 | 745 | 960 | 1475 | 1082 | 4538 | 81.4 | 776 | 1254 | 22.5 | 709 |
| 1948 | 616 | 310 | 5.5 | 423 | 547 | 754 | 1271 | 1019 | 3719 | 66.7 | 743 | 1022 | 18.3 | 569 |
| 1949 | 624 | 340 | 6.1 | 419 | 556 | 745 | 1264 | 1012 | 3633 | 65.1 | 744 | 1044 | 18.7 | 590 |
| 1950 | 629 | 359 | 6.4 | 456 | 570 | 904 | 1475 | 1028 | 3836 | 68.8 | 759 | 1139 | 20.4 | 644 |
| 1951 | 618 | 317 | 5.6 | 436 | 575 | 794 | 1509 | 992 | 3370 | 60.4 | 652 | 1083 | 19.4 | 612 |
| 1952 | 640 | 402 | 7.2 | 505 | 660 | 881 | 1599 | 1002 | 3498 | 62.7 | 771 | 1239 | 22.2 | 702 |

### Bacia do rio Ribeira do Iguape

**Hidrografia:** nasce na serra das Almas, município de Ponta Grossa, Estado do Paraná, em altitude aproximada de 1.200 metros e desagua no Oceano Atlântico no litoral paulista; sua bacia hidrográfica é da ordem de 24.500 km² de área.

Os seus principais afluentes são: rios Assungui (m.d.), Turvo (m.e.), Botari (m.e.), Pilões (m.e.), Juquiá (m.e.), Jacupiranga (m.d.) e Una d'Aldeia (m.e.).

Na bacia do rio Ribeira do Iguape, em 31 de dezembro de 1952, havia 17 postos fluviométricos em funcionamento e tinham sido executadas até essa data 1.148 medições de descarga.

Apresentamos a seguir características hidrológicas do rio Ribeira do Iguape em Balsa do Cerro Azul, Capela da Ribeira e Iporanga.

Pôsto: **Balsa do Cerro Azul**
Rio: **Ribeira do Iguape**
Estado: **Paraná**
Município: **Cerro Azul**
Localização: **No pôrto da balsa, a cêrca de 8 km da cidade**
Área de drenagem: **4.731 km²**
Início das observações: **7-5-1930**
Número de medições de descarga: 102

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | [illegible] | [illegible] | [illegible] | [illegible] | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1931 | 32 | 43.5 | 9.2 | 49.8 | 56.2 | 65.5 | 84.7 | 250 | 374 | 79.2 | | 78.1 | 16.5 | 582 |
| 1932 | 44 | 55.1 | 11.7 | 59.6 | 71.1 | 82.2 | 101.9 | 290 | 450 | 95.3 | | 95.5 | 20.2 | 659 |
| 1933 | 8 | 27.0 | 5.7 | 30.7 | 37.5 | 44.4 | 59.6 | 162 | 222 | 47.0 | | 52.7 | 11.1 | 551 |
| 1934 | 2 | 23.7 | 5.0 | 25.9 | 30.0 | 34.5 | 45.5 | 170 | 235 | 49.7 | | 45.0 | 9.5 | 300 |
| 1935 | 8 | 27.0 | 5.7 | 29.4 | 35.9 | 44.4 | 85.9 | 355 | 578 | 122.3 | | 75.1 | 15.9 | 501 |
| 1936 | 20 | 34.5 | 7.3 | 35.9 | 45.5 | 50.7 | 70.0 | 350 | 568 | 120.2 | | 66.8 | 14.1 | 447 |
| 1937 | 20 | 34.5 | 7.3 | 38.8 | 47.1 | 57.5 | 74.7 | 477 | 481 | 101.7 | | 72.6 | 15.3 | 404 |
| 1938 | 20 | 40.2 | 8.5 | 44.4 | 52.9 | 61.8 | 78.5 | 195 | 276 | 58.4 | | 70.2 | 14.8 | 460 |
| 1939 | 24 | 37.5 | 7.9 | 41.6 | 49.8 | 62.9 | 83.4 | 255 | 346 | 73.3 | | 73.2 | 15.5 | 401 |
| 1940 | 10 | 28.1 | 5.9 | 30.7 | 35.9 | 40.9 | 51.8 | 141 | 189 | 40.1 | | 46.7 | 9.9 | 318 |
| 1941 | 16 | 32.0 | 6.7 | 35.9 | 40.2 | 50.7 | 73.5 | 435 | 736 | 155.6 | | 66.0 | 14.0 | 460 |
| 1942 | 22 | 35.9 | 7.6 | 38.8 | 47.1 | 55.1 | 71.1 | 285 | 441 | 93.2 | | 69.1 | 14.6 | 461 |
| 1943 | 12 | 29.4 | 6.2 | 30.0 | 32.6 | 37.5 | 42.6 | 117 | 152 | 32.2 | | 41.3 | 8.7 | 275 |
| 1944 | -8 | 18.9 | 4.0 | 22.6 | 27.6 | 32.6 | 40.2 | 138 | 184 | 39.1 | | 39.2 | 8.2 | 262 |
| 1945 | -4 | 20.8 | 4.4 | 22.2 | 25.9 | 28.8 | 33.9 | 217 | 314 | 66.4 | | 35.8 | 7.5 | 259 |
| 1946 | -1 | 22.2 | 4.7 | 25.9 | 41.6 | 48.0 | 73.5 | 355 | 578 | 122.3 | | 76.0 | 16.1 | 507 |
| 1947 | 23 | 36.6 | 7.7 | 38.8 | 45.5 | 56.2 | 81.0 | 345 | 558 | 118.1 | | 74.2 | 15.7 | 495 |
| 1948 | 22 | 35.9 | 7.6 | 40.9 | 47.1 | 55.1 | 72.3 | 312 | 493 | 104.4 | | 67.6 | 14.3 | 452 |
| 1949 | -1 | 22.2 | 4.7 | 25.4 | 29.4 | 32.0 | 35.2 | 92 | 115 | 24.3 | | 33.8 | 7.1 | 226 |
| 1950 | 6 | 25.9 | 5.4 | 27.0 | 31.3 | 37.5 | 52.9 | 256 | 462 | 97.8 | | 49.7 | 10.5 | 352 |
| 1951 | 6 | 25.9 | 5.4 | 29.4 | 34.3 | 40.9 | 41.6 | 217 | 314 | 66.5 | | 56.7 | 12.0 | 378 |
| 1952 | 2 | 23.7 | 5.0 | 24.8 | 27.4 | 33.2 | 41.6 | 278 | 427 | 90.4 | | 41.8 | 8.8 | 280 |

Pôsto: **Capela da Ribeira**

Rio: **Ribeira do Iguape**

Estado: **São Paulo**

Município: **Ribeira**

Localização: **Cêrca de 300 metros da Igreja**

Área de drenagem: **7.192 km²**

Início das observações: **20-10-1936**

Número de medições de descarga: **95**

## CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 90 % | 70 % | 50 % | 10 % | MÁXIMA | | | MÉDIA | | | ALTURA DE DEFLÚVIO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h<br>cm | Q<br>m³/s | q<br>l/s/km² | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | h<br>cm | Q<br>m³/s | q<br>l/s/km² | h<br>cm | Q<br>m³/s | q<br>l/s/km² | %. |
| 1938 | 57 | 65.7 | 9.1 | 72.1 | 81.5 | 94.4 | 115.8 | 250 | 388 | 54.1 | — | 106.2 | 14.8 | 466 |
| 1939 | 39 | 68.1 | 9.4 | 62.0 | 77.4 | 94.4 | 121.9 | 341 | 528 | 73.5 | — | 108.4 | 15.1 | 475 |
| 1940 | 23 | 49.6 | 6.9 | 45.7 | 49.6 | 59.6 | 74.2 | 162 | 253 | 35.3 | — | 66.8 | 9.3 | 294 |
| 1941 | 19 | 45.3 | 6.3 | 48.5 | 57.1 | 72.1 | 108.1 | 425 | 654 | 90.9 | | 95.5 | 13.3 | 419 |
| 1942 | 87 | 53.9 | 7.5 | 60.8 | 72.1 | 84.3 | 105.2 | 328 | 508 | 70.7 | | 101.1 | 14.1 | 443 |
| 1943 | 13 | 41.8 | 5.8 | 45.3 | 51.7 | 60.8 | 76.1 | 155 | 243 | 33.8 | | 69.3 | 9.6 | 304 |
| 1944 | 3 | 32.0 | 4.4 | 34.3 | 40.9 | 50.7 | 64.5 | 203 | 316 | 44.0 | | 61.9 | 8.6 | 272 |
| 1945 | 1 | 30.3 | 4.2 | 32.7 | 39.1 | 42.7 | 55.0 | 365 | 565 | 78.6 | | 59.2 | 8.2 | 260 |
| 1946 | 7 | 35.0 | 4.8 | 50.7 | 58.3 | 69.4 | 102.0 | 560 | 864 | 120.2 | | 104.3 | 14.5 | 457 |
| 1947 | 28 | 55.0 | 7.6 | 58.3 | 69.4 | 84.3 | 118.6 | 448 | 692 | 96.3 | | 112.6 | 15.7 | 495 |
| 1948 | 25 | 51.7 | 7.2 | 59.6 | 72.1 | 85.7 | 111.3 | 346 | 536 | 74.5 | | 102.7 | 14.3 | 452 |
| 1949 | 4 | 32.7 | 4.5 | 36.5 | 41.8 | 46.4 | 55.0 | 79 | 126 | 17.6 | | 50.3 | 6.9 | 220 |
| 1950 | 12 | 36.1 | 5.0 | 33.5 | 50.7 | 64.5 | 94.5 | 432 | 667 | 92.9 | | 83.3 | 11.6 | 366 |
| 1951 | 13 | 40.0 | 5.5 | 45.5 | 52.8 | 64.5 | 97.4 | 269 | 417 | 58.1 | | 87.8 | 12.2 | 385 |
| 1952 | 8 | 35.0 | 4.9 | 37.5 | 42.7 | 51.7 | 68.1 | 434 | 671 | 93.3 | | 64.3 | 8.9 | 283 |

## Bacia do rio Tietê

**Hidrografia:** nasce no Pico do Corcovado, município de Salesópolis, Estado de São Paulo, em altitude aproximada de 900 metros; lança-se no rio Paraná pela margem esquerda. Sua bacia hidrográfica é da ordem de 71.900 km² de área.

São seus principais tributários os rios Capivari (m.d.), Sorocaba (m.e.), Piracicaba (m.d.), Jacaré-Pepira (m.d.), Jacaré-Guaçu (m.d.), Porcos (m.d.), Batalha (m.e.) e Dourados (m.e.).

Em 31 de dezembro de 1952 existiam 28 postos fluviométricos em funcionamento e tinham sido realizados até essa época 1.350 medições de descarga.

A seguir se encontram características hidrológicas do rio Tietê em Tietê, Barra Bonita e Lussanvira.

Pôsto: **Tietê**

Rio: **Tietê**

Estado: **São Paulo**

Município: **Tietê**

Localização: **Na ponte da cidade de Tietê**

Área de drenagem: **9.070 km²**

Início das observações: **20-5-1939**

Número de medições de descarga: **67**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1940 | 97 | 26.8 | 2.9 | 28.9 | 41.5 | 58.2 | 94.9 | 539 | 494 | 54.5 | 186 | 98.2 | 10.8 | 342 |
| 1941 | 92 | 24.1 | 2.6 | 28.4 | 39.7 | 64.7 | 95.0 | 312 | 206 | 22.7 | 164 | 71.8 | 7.2 | 249 |
| 1942 | 100 | 28.4 | 3.1 | 35.7 | 49.4 | 73.4 | 115.0 | 589 | 300 | 33.1 | 182 | 86.5 | 9.5 | 300 |
| 1943 | 84 | 19.9 | 2.1 | 28.4 | 40.5 | 55.8 | 100.5 | 527 | 225 | 24.6 | 165 | 72.6 | 8.0 | 252 |
| 1944 | 66 | 11.1 | 1.2 | 18.5 | 28.4 | 45.1 | 69.0 | 574 | 281 | 31.0 | 147 | 63.2 | 6.9 | 220 |
| 1945 | 97 | 28.2 | 3.1 | 31.2 | 41.5 | 55.0 | 79.5 | 560 | 264 | 29.1 | 165 | 75.4 | 8.3 | 262 |
| 1946 | 78 | 18.6 | 2.0 | 25.5 | 39.7 | 56.9 | 108.4 | 568 | 274 | 30.2 | 170 | 81.9 | 9.0 | 284 |
| 1947 | 114 | 38.2 | 4.2 | 51.9 | 66.1 | 85.3 | 140.9 | 560 | 525 | 57.7 | 210 | 115.5 | 12.7 | 401 |
| 1948 | 110 | 35.7 | 3.9 | 44.5 | 60.1 | 78.0 | 135.3 | 592 | 598 | 65.9 | 209 | 113.8 | 12.5 | 396 |
| 1949 | 80 | 19.5 | 2.1 | 26.8 | 42.1 | 62.8 | 87.0 | 460 | 390 | 43.0 | 165 | 75.4 | 8.3 | 262 |
| 1950 | 84 | 21.4 | 2.3 | 21.4 | 32.9 | 47.5 | 115.9 | 476 | 410 | 45.2 | 171 | 86.1 | 9.4 | 299 |
| 1951 | 72 | 15.9 | 1.7 | 19.9 | 29.5 | 45.7 | 74.1 | 448 | 374 | 41.2 | 155 | 70.0 | 7.7 | 243 |
| 1952 | 69 | 14.6 | 1.6 | 16.8 | 22.0 | 29.5 | 56.5 | 550 | 227 | 25.0 | 176 | 49.7 | 5.4 | 172 |

Pôsto: **Iporanga**

Rio: **Ribeira do Iguape**

Estado: **São Paulo**

Município: **Iporanga**

Localização: **Na cidade de Iporanga**

Área de drenagem: **13.160 km²**

Início das observações: **1-11-1941**

Número de medições de descarga: **93**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h<br>cm | Q<br>m³/s | q<br>l/s/km² | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | h<br>cm | Q<br>m³/s | q<br>l/s/km² | h<br>cm | Q<br>m³/s | q<br>l/s/km² | mm |
| 1942 | 60 | 94.8 | 7.2 | 104.5 | 124.5 | 150.4 | 194 | 325 | 891 | 67.7 | 99 | 186 | 14.2 | 446 |
| 1943 | 46 | 72.9 | 5.5 | 80.1 | 96.7 | 111.8 | 148 | 188 | 427 | 32.4 | 77 | 136 | 10.4 | 327 |
| 1944 | 34 | 57.6 | 4.3 | 64.5 | 77.8 | 104.3 | 154 | 268 | 605 | 32.1 | 74 | 131 | 10.0 | 315 |
| 1945 | 37 | 61.0 | 4.6 | 67.5 | 80.1 | 93.2 | 130 | 359 | 1032 | 78.4 | 72 | 128 | 9.7 | 307 |
| 1946 | 59 | 93.8 | 7.0 | 100.5 | 122.2 | 148.2 | 213 | 498 | 1700 | 129.2 | 108 | 216 | 16.5 | 519 |
| 1947 | 66 | 106.2 | 8.0 | 113.7 | 146.0 | 179.9 | 235 | 467 | 1520 | 115.5 | 117 | 231 | 17.6 | 555 |
| 1948 | 62 | 98.6 | 7.4 | 113.8 | 141.6 | 173.1 | 260 | 298 | 789 | 60.0 | 109 | 208 | 15.8 | 501 |
| 1949 | 44 | 70.1 | 5.3 | 72.9 | 85.0 | 100.5 | 122 | 185 | 418 | 31.8 | 67 | 112 | 8.5 | 269 |
| 1950 | 44 | 70.1 | 5.3 | 75.7 | 100.5 | 135.0 | 201 | 340 | 951 | 72.3 | 92 | 171 | 13.0 | 411 |
| 1951 | 40 | 64.5 | 4.9 | 72.9 | 94.8 | 122.2 | 187 | 247 | 615 | 46.8 | 87 | 158 | 12.0 | 379 |
| 1952 | 41 | 65.9 | 5.0 | 68.7 | 80.1 | 102.4 | 152 | 400 | 1215 | 92.3 | 75 | 133 | 10.1 | 320 |

## Bacia do rio Itajaí-Açu

**Hidrografia:** o rio Itajaí-Açu nasce com o nome de Itajaí do Oeste, na serra do Espigão, município de Rio do Sul, Estado de Santa Catarina, em altitude aproximada de 1.200 metros.

Após receber o rio Itajaí do Sul, toma a denominação de Itajaí-Açu; drena grande área ao longo da serra Geral e vai lançar-se no Oceano Atlântico, na cidade de Itajaí. Sua bacia hidrográfica é da ordem de 14.800 km², inteiramente situada em território catarinense.

Recebe diversos tributários, dentre os quais os rios Trombudo (m.d.), Itajaí do Sul (m.d.), Itajaí do Norte (m.e.), Benedito (m.e.), Luiz Alves (m.e.) e Itajaí-Mirim (m.d.).

Em 31 de dezembro de 1952 existiam 26 postos fluviométricos em funcionamento e haviam sido efetuadas 1.635 medições de descarga até essa data.

Abaixo se encontram características hidrológicas do rio Itajaí-Açu nas localidades de Rio do Sul, Apiúna e Itoupava Norte (Sêca).

Pôsto: **Rio do Sul**
Rio: **Itajaí-Açu**
Estado: **Santa Catarina**
Município: **Rio do Sul**
Localização: **A jusante da confluência dos rios Itajaí do Sul e Itajaí do Oeste**
Área de drenagem: **5.117 km²**
Início das observações: **1-11-1927**
Número de medições de descarga: **113**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA |  |  | [illegible] % | [illegible] % | [illegible] % | [illegible] % | MÁXIMA |  |  | MÉDIA |  |  | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1942 | 74 | 14.10 | 2.7 | 20.40 | 36.20 | 59.11 | 74.6 | 477 | 387 | 75.8 |  | 63.4 | 12.5 | 391 |
| 1943 | 65 | 8.00 | 1.5 | 10.50 | 22.00 | 52.18 | 102.7 | 874 | 739 | 144.3 |  | 68.4 | 13.3 | 422 |
| 1944 | 64 | 8.50 | 1.6 | 10.00 | 14.10 | 21.20 | 39.1 | 378 | 295 | 57.7 |  | 36.9 | 7.2 | 229 |
| 1945 | 56 | 5.10 | 1.0 | 7.50 | 12.80 | 18.80 | 37.2 | 309 | 230 | 45.1 |  | 29.5 | 5.7 | 181 |
| 1946 | 77 | 16.05 | 3.1 | 22.00 | 40.96 | 60.07 | 134.5 | 699 | 595 | 116.4 |  | 100.2 | 19.5 | 617 |
| 1947 | 74 | 14.10 | 2.7 | 19.60 | 38.15 | 59.66 | 116.7 | 583 | 486 | 95.0 |  | 90.4 | 17.6 | 557 |
| 1948 | 69 | 11.00 | 2.1 | 21.20 | 40.08 | 65.40 | 109.2 | 890 | 774 | 151.3 |  | 96.9 | 18.9 | 599 |
| 1949 | 66 | 9.50 | 1.8 | 11.50 | 18.80 | 33.48 | 57.8 | 556 | 274 | 53.7 |  | 47.9 | 9.3 | 295 |
| 1950 | 73 | 14.75 | 2.8 | 18.00 | 28.80 | 46.57 | 78.4 | 773 | 664 | 129.9 |  | 67.0 | 13.0 | 431 |
| 1951 | 64 | 8.50 | 1.6 | 10.00 | 18.00 | 40.02 | 95.2 | 610 | 512 | 100.1 |  | 73.9 | 14.4 | 436 |
| 1952 | ... | INTERROMPIDO |  |  |  |  |  |  |  |  |  |  |  |  |

Pôsto: **Apiúna**
Rio: **Itajaí-Açu**
Estado: **Santa Catarina**
Município: **Indaial**
Localização: **Cêrca de 150 metros da Estação da Estrada de Ferro**
Área de drenagem: **9.460 km²**
Altitude do zero da escala: **327 m aproximadamente**
Início das observações: **16-10-1927**
Número de medições de descarga: **93**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h cm | Q m³/s | q l/s/km² | Q m³/s | Q m³/s | Q m³/s | Q m³/s | h cm | Q m³/s | q l/s/km² | h cm | Q m³/s | q l/s/km² | % |
| 1928 | 42 | 34.64 | 3.6 | 47.66 | 106.20 | 173.9 | 302.2 | 582 | 2165 | 228.9 | | 277.5 | 29.3 | 928 |
| 1929 | 43 | 36.27 | 3.8 | 47.66 | 65.35 | 106.2 | 219.1 | 407 | 1410 | 149.0 | | 181.8 | 19.2 | 606 |
| 1930 | 32 | 21.08 | 2.2 | 24.94 | 37.09 | 61.4 | 128.9 | 274 | 841 | 88.9 | | 118.9 | 12.6 | 396 |
| 1931 | 37 | 27.52 | 2.9 | 34.64 | 73.93 | 126.1 | 222.4 | 527 | 1927 | 203.7 | | 207.7 | 21.9 | 692 |
| 1932 | 39 | 33.56 | 3.6 | 69.52 | 98.19 | 149.3 | 239.1 | 450 | 1595 | 168.6 | | 216.4 | 22.9 | 723 |
| 1933 | 34 | 23.65 | 2.5 | 33.01 | 33.56 | 71.7 | 111.8 | 512 | 1863 | 196.9 | | 117.3 | 12.4 | 391 |
| 1934 | 41 | 33.01 | 3.4 | 47.66 | 67.58 | 90.4 | 167.0 | 328 | 1070 | 113.2 | | 144.3 | 15.3 | 481 |
| 1935 | 28 | 16.60 | 1.7 | 31.58 | 57.49 | 90.4 | 209.1 | 407 | 1410 | 149.0 | | 135.8 | 14.3 | 451 |
| 1936 | 36 | 26.25 | 2.7 | 21.08 | 34.64 | 65.4 | 180.3 | 402 | 1733 | 183.2 | | 170.2 | 18.0 | 569 |
| 1937 | 41 | 33.01 | 3.4 | 37.89 | 55.32 | 73.9 | 117.4 | 295 | 929 | 98.2 | | 111.2 | 11.8 | 372 |
| 1938 | 41 | 33.01 | 3.4 | 42.78 | 63.39 | 80.7 | 131.8 | 328 | 1070 | 113.1 | | 136.1 | 14.4 | 454 |
| 1939 | 36 | 26.25 | 2.7 | 34.64 | 59.46 | 95.6 | 170.8 | 451 | 1600 | 169.1 | | 159.5 | 16.9 | 532 |
| 1940 | 43 | 36.27 | 3.8 | 42.78 | 59.46 | 80.7 | 131.8 | 318 | 1001 | 105.8 | | 117.5 | 12.4 | 392 |
| 1941 | 46 | 41.15 | 4.3 | 61.42 | 85.35 | 123.2 | 183.4 | 255 | 762 | 80.5 | | 151.8 | 16.0 | 506 |
| 1942 | 44 | 37.89 | 4.0 | 42.78 | 69.38 | 100.8 | 140.6 | 279 | 862 | 91.1 | | 125.6 | 13.3 | 418 |
| 1943 | 28 | 16.60 | 1.7 | 35.08 | 46.03 | 93.0 | 170.8 | 461 | 1643 | 173.7 | | 141.0 | 14.9 | 470 |
| 1944 | 31 | 19.79 | 2.0 | 21.08 | 26.25 | 39.3 | 65.4 | 104 | 477 | 50.3 | | 62.0 | 6. 6 | 207 |
| 1945 | 21 | 9.93 | 1.0 | 16.60 | 24.94 | 56.3 | 57.3 | 200 | 540 | 57.1 | | 52.3 | 5.5 | 174 |
| 1946 | 40 | 31.58 | 3.3 | 47.66 | 70.13 | 117.4 | 235.8 | 348 | 1156 | 122.2 | | 182.7 | 19.3 | 609 |
| 1947 | 38 | 28.81 | 3.0 | 37.89 | 63.39 | 109.0 | 196.2 | 313 | 1014 | 107.2 | | 157.3 | 16.6 | 524 |
| 1948 | 38 | 28.81 | 3.0 | 41.15 | 73.93 | 180.3 | 196.2 | 387 | 1927 | 203.7 | | 180.5 | 19.1 | 603 |
| 1949 | 31 | 19.79 | 2.0 | 24.94 | 41.13 | 39.3 | 93.0 | 202 | 548 | 57.9 | | 82.1 | 8.7 | 274 |
| 1950 | 40 | 31.58 | 3.3 | 37.89 | 57.49 | 80.7 | 128.9 | 426 | 1492 | 157.7 | | 122.9 | 13.0 | 410 |
| 1951 | 29 | 17.33 | 1.8 | 21.08 | 36.27 | 72.7 | 150.6 | 349 | 1160 | 122.6 | | 126.1 | 13.3 | 420 |
| 1952 | 24 | 12.80 | 1.3 | 16.60 | 32.38 | 65.4 | 117.4 | 201 | 870 | 92.1 | | 111.4 | 11.8 | 372 |

Pôsto: **Itoupava Norte (Sêca)**

Rio: **Itajaí-Açu**

Estado: **Santa Catarina**

Município: **Blumenau**

Localização: **No fundo da Estação de Itoupava Sêca, arrabalde de Blumenau**

Área de drenagem: **11.856 km²**

Altitude do zero da escala: **0,86 m aproximadamente**

Início das observações: **1-4-1928**

Número de medições de descarga: **47**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMAS | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1941 | 92 | 73.20 | 6.3 | 85.80 | 109.4 | 164.1 | 258 | 610 | 811 | 68.4 | | 187 | 15.8 | 499 |
| 1942 | 67 | 55.85 | 4.6 | 69.25 | 97.2 | 154.2 | 189 | 770 | 1077 | 90.8 | | 174 | 14.7 | 465 |
| 1943 | 27 | 29.85 | 2.5 | 41.55 | 72.7 | 122.0 | 218 | 1099 | 1600 | 135.0 | | 181 | 15.3 | 483 |
| 1944 | 24 | 28.20 | 8.3 | 36.45 | 50.0 | 59.8 | 106 | 461 | 578 | 48.8 | | 100 | 8.5 | 269 |
| 1945 | 26 | 29.30 | 2.4 | 37.65 | 50.8 | 68.9 | 91 | 575 | 755 | 63.5 | | 96 | 8.1 | 258 |
| 1946 | 66 | 54.50 | 4.6 | 76.05 | 102.0 | 161.7 | 350 | 964 | 1376 | 116.1 | | 257 | 21.7 | 685 |
| 1947 | 69 | 56.75 | 4.7 | 67.55 | 102.0 | 167.6 | 291 | 765 | 1055 | 88.8 | | 234 | 19.8 | 625 |
| 1948 | 40 | 37.00 | 3.1 | 65.90 | 108.3 | 162.9 | 271 | 1161 | 1704 | 143.7 | | 239 | 20.2 | 637 |
| 1949 | 45 | 38.95 | 3.2 | 47.40 | 65.9 | 89.6 | 128 | 603 | 800 | 67.5 | | 119 | 10.1 | 319 |
| 1950 | 57 | 48.05 | 4.0 | 55.75 | 78.6 | 101.0 | 165 | 975 | 1391 | 117.2 | | 160 | 13.6 | 428 |
| 1951 | 25 | 28.75 | 2.4 | 32.60 | 48.1 | 87.7 | 187 | 804 | 1119 | 94.4 | | 157 | 13.3 | 419 |
| 1952 | 9 | 21.70 | 1.8 | 31.50 | 55.8 | 77.7 | 127 | 696 | 947 | 79.8 | | 131 | 11.1 | 351 |

## Bacia do rio Tubarão

**Hidrografia:** nasce o rio Tubarão no município de Orleans, Estado de Santa Catarina e lança-se no Oceano Atlântico, tendo todo o seu curso nesse Estado; sua bacia hidrográfica é de 4.000 km² aproximadamente.

Os seus principais afluentes são: rios Laranjeiras (m.e.), Palmeiras (m.d.), Braço do Norte (m.e.) e Capivari (m.e.).

Existiam em 31 de dezembro de 1952, na bacia do rio Tubarão, 8 postos fluviométricos e tinham sido executadas até essa época 516 medições de descarga.

A seguir figuram características fluviométricas do rio Tubarão em rio do Pouso.

Pôsto: **Rio do Pouso**

Rio: **Tubarão**

Estado: **Santa Catarina**

Município: **Tubarão**

Localização: **Na travessia do rio Tubarão pela estrada de rodagem Tubarão a Florianópolis**

Área de drenagem: **2.735 km²**

Início das observações: **25-3-1939**

Número de medições de descarga: **68**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 90 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1940 | 32 | 16.44 | 6.0 | 19.66 | 28.39 | 45.32 | 72.79 | 381 | 362 | 132.6 | | 53.33 | 19.5 | 619 |
| 1941 | 39 | 22.08 | 8.0 | 27.77 | 30.90 | 47.70 | 69.14 | 322 | 298 | 109.2 | | 56.85 | 20.7 | 655 |
| 1942 | 29 | 11.16 | 4.0 | 15.63 | 21.27 | 27.77 | 42.68 | 310 | 285 | 104.3 | | 37.90 | 13.8 | 437 |
| 1943 | 20 | 7.86 | 2.8 | 11.16 | 18.05 | 26.96 | 38.48 | 379 | 360 | 131.8 | | 32.22 | 11.7 | 371 |
| 1944 | 16 | 5.49 | 2.0 | 9.18 | 16.44 | 24.52 | 46.08 | 280 | 262 | 95.9 | | 39.44 | 14.4 | 456 |
| 1945 | 13 | 3.86 | 1.4 | 7.86 | 11.90 | 18.05 | 28.39 | 200 | 171 | 62.6 | | 25.44 | 9.3 | 293 |
| 1946 | 21 | 8.32 | 3.1 | 14.83 | 21.27 | 32.68 | 60.96 | 316 | 292 | 106.8 | | 49.48 | 18.0 | 570 |
| 1947 | 25 | 9.64 | 3.6 | 22.89 | 30.22 | 45.25 | 67.32 | 322 | 298 | 109.2 | | 57.05 | 20.8 | 658 |
| 1948 | 27 | 12.63 | 4.6 | 19.66 | 35.98 | 54.73 | 87.54 | 649 | 676 | 247.3 | | 77.81 | 28.4 | 899 |
| 1949 | 24 | 10.50 | 3.8 | 17.24 | 27.41 | 38.48 | 59.17 | 289 | 263 | 96.3 | | 49.25 | 18.0 | 568 |
| 1950 | 30 | 13.13 | 4.8 | 13.19 | 21.54 | 31.54 | 46.26 | 440 | 501 | 183.3 | | 44.79 | 16.3 | 516 |
| 1951 | 17 | 6.16 | 2.2 | 8.64 | 15.19 | 27.90 | 54.74 | 311 | 317 | 116.2 | | 47.47 | 17.3 | 547 |
| 1952 | 21 | 8.06 | 2.9 | 10.09 | 20.74 | 34.27 | 53.80 | 272 | 267 | 97.8 | | 42.77 | 15.6 | 495 |

## Bacia do Rio Jacuí-Taquari

**Hidrografia:** os rios Jacuí e Taquari são os principais formadores do rio Guaíba.

O rio Jacuí tem suas nascentes no município de Passo Fundo, Estado do Rio Grande do Sul, em altitude aproximada de 680 metros; o seu curso tem cêrca de 520 km de extensão até a confluência com o Taquari.

O rio Taquari nasce nesse mesmo Estado, no município de Aparados da Serra, a uma altitude aproximada de 1.200 metros, com o nome de rio das Anats; após a confluência com o rio Guaporé passa a denominar-se Taquari.

A bacia hidrográfica do Jacuí-Taquari tem aproximadamente 72.960 km$^2$, isto é, cêrca de um têrço da superfície do Estado do Rio Grande do Sul.

Os principais afluentes do Jacuí são: rios Ingaí m.d.), Jacuizinho (m.e.), Vacacaí (m.d.) e Pardinho (m.e.).

Os principais tributários do Taquari são: rios Camisas (m.e.), Tainhas (m.e.), Lajeado Grande (m.e.), Quebra Pente (m.d.), Prata (m.d.,) Guaporé (m.d.), Forqueta (m.d.) e Taquari-Mirim (m.d.).

A bacia do Jacuí-Taquari, em 31 de dezembro de 1952, tinha 83 postos fluviométricos em funcionamento e até êsse dia haviam sido realizadas 2.417 medições de descarga.

Apresentamos em seguida características hidrológicas da mencionada bacia nos postos de Cachoeira, Mussum e Bom Retiro.

Pôsto: **Cachoeira**

Município: **Iandaial**

Rio: **Jacuí**

Estado: **R. G. do Sul**

Município: **Cachoeira**

Localização: **Na cidade de Cachoeira**

Área de drenagem: **30.466 km²**

Início das observações: **13-12-1939**

Número de medições de descarga: **19**

CARACTERISTICAS FLUVIOMETRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | % |
| 1934 | 7 | 7.8 | 0.26 | 22.0 | 230 | 400 | 704 | 845 | 1895 | 62.2 | 299 | 501 | 16.4 | 517 |
| 1935 | 20 | 13.0 | 0.43 | 67.6 | 117 | 390 | 854 | 1148 | 4277 | 140.0 | 335 | 618 | 20.3 | 645 |
| 1936 | 99 | 90.4 | 2.97 | 108.0 | 212 | 502 | 856 | 1600 | — | — | 361 | 834 | 27.4 | 860 |
| 1937 | | OBSERVAÇÕES INTERROMPIDAS | | | | | | | | | | | | |
| 1938 | 126 | 139.0 | 4.56 | 173.0 | 258 | 424 | 770 | 906 | 2541 | 83.4 | 332 | 576 | 18.9 | 594 |
| 1939 | 103 | 97.4 | 3.20 | 126.0 | 234 | 414 | 858 | 1020 | 2946 | 96.7 | 335 | 647 | 21.2 | 675 |
| 1940 | 158 | 196.0 | 6.43 | 244.0 | 632 | 1067 | 1612 | 1151 | 4413 | 145.0 | 387 | 1277 | 41.9 | 1328 |
| 1941 | 154 | 153.0 | 5.02 | 189.0 | 410 | 815 | 1758 | 1510 | — | — | 548 | 1423 | 46.7 | 1479 |
| 1942 | 64 | 44.0 | 1.44 | 57.2 | 124 | 364 | 779 | 1271 | 6271 | 206.0 | 321 | 642 | 21.1 | 670 |
| 1943 | 44 | 25.2 | 0.83 | 23.4 | 42 | 89 | 262 | 810 | 1748 | 57.4 | 145 | 199 | 6.5 | 207 |
| 1944 | 31 | 17.5 | 0.57 | 24.4 | 49 | 90 | 270 | 278 | 2624 | 86.1 | 136 | 301 | 9.9 | 313 |
| 1945 | 13 | 10.2 | 0.33 | 11.0 | 17 | 37 | 175 | 759 | 2475 | 81.2 | 123 | 182 | 6.0 | 189 |
| 1946 | 62 | 42.0 | 1.38 | 54.8 | 105 | 191 | 410 | 990 | 2707 | 88.9 | 222 | 356 | 11.7 | 371 |
| 1947 | 70 | 50.0 | 1.64 | 69.0 | 186 | 240 | 517 | 950 | 2431 | 79.8 | 236 | 422 | 13.8 | 438 |
| 1948 | 43 | 22.0 | 0.72 | 69.0 | 177 | 348 | 647 | 850 | 1916 | 62.9 | 279 | 459 | 15.1 | 476 |
| 1949 | 40 | 22.0 | 0.72 | 37.0 | 76 | 168 | 344 | 795 | 1691 | 55.5 | 193 | 286 | 9.4 | 298 |
| 1950 | 50 | 30.0 | 0.98 | 54.8 | 105 | 200 | 535 | 872 | 2019 | 66.3 | 250 | 404 | 13.3 | 420 |
| 1951 | 50 | 30.0 | 0.98 | 34.0 | 50 | 79 | 214 | 745 | 1550 | 50.9 | 148 | 199 | 6.5 | 207 |
| 1952 | 23 | 14.2 | 0.47 | 17.0 | 38 | 146 | 348 | 980 | 2638 | 86.6 | 249 | 451 | 14.8 | 472 |

Pôsto: **Mussum**

Rio: **Taquari**

Estado: **R. G. do Sul**

Município: **Guaporé**

Localização: **Na vila do Mussum**

Área de drenagem: **16.078 km²**

Início das observações: **15-2-1940**

Número de medições de descarga: **120**

## CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] % | [illegible] % | [illegible] % | [illegible] % | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | — |
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | % |
| 1940 | 96 | 92.0 | 5.72 | 119.0 | 198.0 | 292 | 462 | 1512 | 5682 | 353 | 220 | 415 | 25.8 | 819 |
| 1941 | 69 | 42.6 | 2.65 | 67.4 | 155.0 | 328 | 575 | 1925 | 8385 | 522 | 258 | 564 | 35.1 | 1111 |
| 1942 | 47 | 15.7 | 0.98 | 37.0 | 114.0 | 196 | 261 | 1200 | 4150 | 258 | 155 | 265 | 16.5 | 523 |
| 1943 | 56 | 5.6 | 0.35 | 12.4 | 31.4 | 90 | 249 | 650 | 1730 | 108 | 121 | 170 | 10.6 | 334 |
| 1944 | 40 | 8.0 | 0.50 | 20.1 | 42.6 | 124 | 196 | 1000 | 3260 | 203 | 124 | 171 | 10.6 | 337 |
| 1945 | 28 | 2.4 | 0.15 | 3.8 | 15.7 | 51 | 146 | 890 | 2779 | 173 | 98 | 121 | 7.5 | 238 |
| 1946 | 62 | 32.8 | 2.04 | 41.2 | 92.0 | 155 | 356 | 1956 | 8462 | 526 | 166 | 282 | 17.5 | 553 |
| 1947 | 59 | 28.9 | 1.80 | 39.8 | 112.0 | 174 | 265 | 752 | 2218 | 138 | 152 | 238 | 14.8 | 468 |
| 1948 | 56 | 5.6 | 0.35 | 44.0 | 138.0 | 206 | 302 | 1072 | 3577 | 222 | 173 | 301 | 18.7 | 592 |
| 1949 | 54 | 4.6 | 0.29 | 13.5 | 69.2 | 150 | 278 | 930 | 2952 | 184 | 149 | 238 | 14.9 | 471 |
| 1950 | 54 | 4.6 | 0.29 | 15.7 | 47.6 | 119 | 215 | 1610 | 6270 | 390 | 131 | 199 | 12.4 | 395 |
| 1951 | 48 | 16.8 | 1.04 | 25.6 | 90.0 | 148 | 280 | 872 | 2705 | 168 | 149 | 234 | 14.6 | 459 |
| 1952 | 39 | 7.4 | 0.46 | 15.5 | 55.0 | 143 | 261 | 665 | 1862 | 116 | 135 | 179 | 11.1 | 352 |

Pôsto: **Bom Retiro**

Rio: **Taquari**

Estado: **R. G. do Sul**

Município: **Taquari**

Localização: **Na cidade do Bom Retiro**

Área de drenagem: **24.225 km²**

Início das observações: **8-6-1939**

Número de medições de descarga: **79**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 10 % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1940 | 100 | 110.0 | 4.54 | 158.0 | 290.0 | 515 | 842 | 1690 | 10955 | 452 | 346 | 724 | 29.9 | 950 |
| 1941 | 68 | 71.6 | 2.96 | 98.0 | 222.0 | 526 | 957 | 1850 | — | --- | 376 | 989 | 40.8 | 1279 |
| 1942 | 26 | 24.0 | 0.99 | 46.4 | 104.0 | 244 | 455 | 1510 | 8375 | 346 | 219 | 426 | 17.6 | 556 |
| 1943 | 15 | 14.0 | 0.58 | 22.0 | 57.0 | 74 | 292 | 790 | 2371 | 98 | 142 | 231 | 9.5 | 302 |
| 1944 | 22 | 20.0 | 0.82 | 28.0 | 58.4 | 118 | 224 | 1440 | 7485 | 309 | 148 | 256 | 10.6 | 333 |
| 1945 | 0 | 2.0 | 0.08 | 6.8 | 25.0 | 60 | 160 | 1135 | 4617 | 191 | 102 | 173 | 7.2 | 228 |
| 1946 | 45 | 44.0 | 1.82 | 56.0 | 92.0 | 176 | 497 | 1720 | — | — | 212 | 408 | 16.8 | 530 |
| 1947 | 44 | 42.8 | 1.77 | 56.0 | 116.0 | 192 | 375 | 962 | 3434 | 142 | 198 | 337 | 13.9 | 435 |
| 1948 | 30 | 28.0 | 1.16 | 68.0 | 169.0 | 254 | 455 | 1211 | 5220 | 215 | 232 | 420 | 17.3 | 548 |
| 1949 | 30 | 28.0 | 1.16 | 37.0 | 90.8 | 198 | 396 | 1140 | 4655 | 192 | 199 | 352 | 14.5 | 460 |
| 1950 | I N T E R R O M P I D O. | | | | | | | | | | | | | |

## Bacia do rio Grande

**Hidrografia:** o rio Grande tem suas nascentes no Alto do Mirantão, na serra da Mantiqueira, município de Itamonte, Estado de Minas Gerais, em altitude aproximada de 1.900 metros.

Suas águas correm para o interior do País, e nos últimos 600 km de seu curso inferior serve de limite entre os Estados de Minas Gerais e São Paulo.

Após um percurso de 1.300 km, com uma bacia hidrográfica da ordem de 143.000 km², junta-se ao rio Parnaíba, formando o caudaloso Paraná; êste, sucessivamente engrossado pelos rios Tietê, Sucuriú, Aguapeí, Verde, Peixe, Pardo, Paranapanema, Ivaí, Pequiri, Iguaçu, Paraguai, Salado e Carcaraná, vai, com o nome de rio da Prata, lançar-se no Oceano Atlântico, com uma das maiores bacias hidrográficas do mundo.

O rio Grande recebe vários afluentes, entre os quais se destacam os rios Aiuruoca (m.e.), Mortes (m.d.), Jacaré (m.d.), Sapucaí (m.e.), S. João (m.e.), Sapucaí-Mirim (m.e.), Uberaba (m.d.), Pardo (m.e.), Verde (m.d.) e o Turvo (m.e.).

A sua rêde fluviométrica, em 31 de dezembro de 1952, compunha-se de 131 postos; até essa data haviam sido efetuadas 7.868 medições de descarga.

Abaixo figuram características hidrológicas do rio Grande nas localidades de Pôrto Capetinga, São José da Barra e Pôrto José Américo.

Pôsto: **Pôrto Capetinga**

Rio: **Grande**

Estado: **Minas Gerais**

Município: **Capetinga**

Localização: **80 metros a jusante da barra do ribeirão Capetinga**

Área de drenagem: **25.520 km²**

Altitude do zero da escala: **713 m, aproximadamente**

Início das observações: **1-10-1930**

Número de medições de descarga: **17**

## CARACTERÍSTICAS FLUVIOMETRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] % | [illegible] % | [illegible] % | [illegible] % | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | % |
| 1931 | 108 | 215 | 8.4 | 225 | 277 | 384 | 632 | 388 | 1698 | 66.5 | 174 | 515 | 20.1 | 634 |
| 1932 | 92 | 167 | 6.5 | 191 | 242 | 323 | 674 | 368 | 1581 | 61.9 | 165 | 466 | 18.3 | 579 |
| 1933 | 90 | 162 | 6.4 | 176 | 200 | 258 | 407 | 326 | 1350 | 53.1 | 150 | 348 | 13.6 | 429 |
| 1934 | 70 | 113 | 4.4 | 120 | 146 | 203 | 523 | 306 | 1209 | 47.4 | 119 | 282 | 11.1 | 347 |
| 1935 | 100 | 191 | 7.5 | 209 | 255 | 343 | 611 | 366 | 1569 | 61.5 | 166 | 480 | 18.8 | 593 |
| 1936 | 86 | 151 | 5.9 | 156 | 188 | 242 | 571 | 314 | 1257 | 49.3 | 132 | 322 | 12.6 | 398 |
| 1937 | 84 | 146 | 5.7 | 162 | 231 | 384 | 711 | 416 | 1855 | 72.7 | 177 | 541 | 21.2 | 669 |
| 1938 | 105 | 206 | 8.1 | 218 | 292 | 433 | 728 | 432 | 1941 | 76.1 | 181 | 539 | 21.1 | 665 |
| 1939 | 86 | 151 | 5.9 | 191 | 248 | 355 | 591 | 437 | 1967 | 77.1 | 169 | 492 | 19.3 | 609 |
| 1940 | 92 | 167 | 6.5 | 182 | 252 | 371 | 706 | 320 | 2336 | 91.5 | 176 | 540 | 21.2 | 670 |
| 1941 | 94 | 174 | 6.8 | 197 | 255 | 326 | 501 | 364 | 1558 | 61.0 | 160 | 442 | 17.5 | 546 |
| 1942 | 98 | 185 | 7.3 | 194 | 270 | 373 | 581 | 348 | 1462 | 57.3 | 164 | 457 | 17.9 | 565 |
| 1943 | 110 | 221 | 8.7 | 231 | 298 | 388 | 805 | 442 | 1993 | 78.1 | 195 | 587 | 23.0 | 725 |
| 1944 | 84 | 146 | 5.7 | 168 | 235 | 307 | 512 | 340 | 1414 | 55.4 | 157 | 413 | 16.2 | 511 |
| 1945 | 90 | 160 | 6.4 | 179 | 220 | 346 | 556 | 402 | 1777 | 69.6 | 160 | 441 | [illegible] | 545 |

Pôsto: **São José da Barra**

Rio: **Grande**

Estado: **Minas Gerais**

Município: **Guapé**

Localização: **400 metros a jusante da confluência dos rios Grande e Sapucaí**

Área de drenagem: **52.110 km²**

Altitude do zero da escala: **696 m, aproximadamente**

Início das observações: **7-6-1930**

Número de medições de descarga: **17**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1931 | 103 | 433 | 8.4 | 456 | 589 | 966 | 2018 | - | - | - | 236 | 1278 | 24.5 | 773 |
| 1932 | 84 | 362 | 7.0 | 388 | 482 | 676 | 1461 | 403 | 2482 | 47.6 | 188 | 942 | 18.1 | 572 |
| 1933 | 62 | 288 | 5.5 | 313 | 354 | 423 | 687 | 308 | 1705 | 32.7 | 123 | 555 | 10.6 | 537 |
| 1934 | 44 | 237 | 4.6 | 250 | 294 | 363 | 645 | 358 | 2448 | 47.0 | 113 | 548 | 10.5 | 531 |
| 1935 | 88 | 376 | 7.2 | 423 | 532 | 697 | 1344 | 460 | 3166 | 60.8 | 197 | 998 | 19.2 | 605 |
| 1936 | 72 | 320 | 6.1 | 347 | 403 | 527 | 809 | 396 | 2431 | 46.7 | 151 | 716 | 13.7 | 433 |
| 1937 | 70 | 313 | 6.0 | 340 | 504 | 827 | 1381 | 494 | 3390 | 65.1 | 206 | 1070 | 20.5 | 646 |
| 1938 | 94 | 399 | 7.7 | 427 | 565 | 850 | 1525 | 512 | 3449 | 66.2 | 202 | 1015 | 19.5 | 615 |
| 1939 | 60 | 282 | 5.4 | 351 | 465 | 692 | 1089 | 528 | 3590 | 68.9 | 179 | 911 | 17.5 | 552 |
| 1940 | 81 | 351 | 6.7 | 373 | 513 | 786 | 1674 | 518 | 3502 | 67.2 | 212 | 1115 | 21.4 | 677 |
| 1941 | 74 | 318 | 6.1 | 350 | 495 | 667 | 1024 | 411 | 2560 | 49.1 | 167 | 798 | 15.3 | 483 |
| 1942 | 87 | 371 | 7.1 | 392 | 547 | 775 | 1120 | 390 | 2408 | 46.2 | 183 | 903 | 17.3 | 546 |
| 1943 | 97 | 413 | 7.9 | 440 | 566 | 748 | 1350 | 555 | 3825 | 73.4 | - | - | - | - |
| 1944 | 58 | 257 | 4.9 | 283 | 422 | 547 | 968 | 378 | 2298 | 44.1 | 154 | 735 | 14.1 | 446 |
| 1945 | 70 | 302 | 5.8 | 334 | 426 | 646 | 1139 | 440 | 2815 | 54.0 | 172 | 845 | 16.2 | 511 |
| 1946 | 74 | 318 | 6.1 | 342 | 528 | 792 | 1247 | 656 | 4680 | 89.8 | 190 | 970 | 18.6 | 507 |
| 1947 | 116 | 499 | 9.6 | 552 | 683 | 950 | 1618 | 685 | 4930 | 94.6 | 238 | 1303 | 25.0 | 788 |
| 1948 | 70 | 302 | 5.8 | 338 | 405 | 786 | 1193 | 424 | 2675 | 51.3 | 183 | 921 | 17.7 | 559 |
| 1949 | 56 | 250 | 4.8 | 203 | 366 | 731 | 1068 | 460 | 2990 | 57.3 | 184 | 939 | 18.0 | 568 |
| 1950 | 100 | 426 | 8.2 | 453 | 600 | 861 | 1403 | 471 | 3090 | 59.3 | 215 | 1114 | 21.4 | 674 |
| 1951 | 116 | 499 | 9.6 | 523 | 620 | 748 | 1303 | 425 | 2680 | 51.4 | 198 | 992 | 19.0 | 600 |

Pôsto: **Barra Bonita**

Rio: **Tietê**

Estado: **São Paulo**

Município: **Barra Bonita**

Localização: **Na ponte da cidade de Barra Bonita**

Área de drenagem: **33.800 km²**

Início das observações: **8-7-1930**

Número de medições de descarga: **71**

## CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA h cm | MÍNIMA Q m³/s | MÍNIMA q l/s/km² | 95 % Q m³/s | 75 % Q m³/s | 50 % Q m³/s | 25 % Q m³/s | MÁXIMA h cm | MÁXIMA Q m³/s | MÁXIMA q l/s/km² | MÉDIA h cm | MÉDIA Q m³/s | MÉDIA q l/s/km² | ALTURA DE ESCOAMENTO mm |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1931 | 154 | 247 | 7.3 | 268 | 325 | 478 | 894 | 739 | 2325 | 68,7 | 285 | 669 | 19,7 | 624 |
| 1932 | 124 | 173 | 5.1 | 197 | 258 | 381 | 690 | 451 | 1297 | 56,6 | 224 | 462 | 13,6 | 432 |
| 1933 | 100 | 117 | 3.4 | 144 | 165 | 222 | 383 | 356 | 883 | 26,1 | 163 | 280 | 8,2 | 261 |
| 1934 | 90 | 95 | 2.8 | 121 | 140 | 152 | 290 | 606 | 1822 | 53,9 | 156 | 266 | 7,8 | 248 |
| 1935 | 114 | 149 | 4.4 | 177 | 229 | 424 | 673 | 422 | 1128 | 33,4 | 205 | 404 | 13.0 | 376 |
| 1936 | 103 | 124 | 3.6 | 144 | 199 | 274 | 465 | 384 | 985 | 29,1 | 189 | 358 | 10,5 | 334 |
| 1937 | 118 | 158 | 4.6 | 182 | 250 | 459 | 628 | 489 | 1380 | 40,8 | 230 | 481 | 14,2 | 448 |
| 1938 | 110 | 140 | 4.1 | 170 | 222 | 315 | 427 | 341 | 830 | 24,5 | 186 | 344 | 10.1 | 321 |
| 1939 | 89 | 92 | 2.7 | 118 | 175 | 282 | 447 | 407 | 1071 | 31,7 | 184 | 344 | 10.1 | 321 |
| 1940 | 100 | 117 | 3.4 | 135 | 175 | 256 | 444 | 377 | 1712 | 50,7 | 205 | 438 | 12.9 | 409 |
| 1941 | 87 | 88 | 2.6 | 106 | 135 | 222 | 335 | 334 | 806 | 23,8 | 158 | 253 | 7.4 | 236 |
| 1942 | 99 | 115 | 3.4 | 135 | 175 | 260 | 405 | 337 | 887 | 26,2 | 175 | 312 | 9.2 | 291 |
| 1943 | 97 | 114 | 3.3 | 140 | 156 | 207 | 387 | 359 | 823 | 24,3 | 162 | 281 | 8.3 | 262 |
| 1944 | 76 | 85 | 2,5 | 95 | 120 | 163 | 247 | 342 | 834 | 24,7 | 139 | 225 | 6,6 | 210 |
| 1945 | 93 | 108 | 3.2 | 123 | 154 | 202 | 306 | 361 | 901 | 26,7 | 135 | 261 | 7.7 | 243 |
| 1946 | 97 | 114 | 3.3 | 131 | 170 | 237 | 500 | 424 | 1135 | 33,6 | 186 | 353 | 10,4 | 329 |
| 1947 | 120 | 163 | 4.8 | 212 | 263 | 325 | 599 | 561 | 1652 | 48,9 | 255 | 504 | 14,9 | 470 |
| 1948 | 115 | 151 | 4.4 | 175 | 224 | 284 | 539 | 484 | 1362 | 40,3 | 211 | 428 | 12,6 | 400 |
| 1949 | 98 | 116 | 3.4 | 140 | 154 | 229 | 369 | 396 | 1030 | 30,5 | 167 | 295 | 8,7 | 275 |
| 1950 | 100 | 120 | 3.5 | 135 | 207 | 295 | 573 | 551 | 1614 | 48,8 | 210 | 432 | 12,7 | 405 |
| 1951 | 98 | 116 | 3.4 | 140 | 189 | 271 | 516 | 510 | 1460 | 43,2 | 204 | 412 | 12,1 | 384 |
| 1952 | 99 | 118 | 3.4 | 129 | 175 | 212 | 320 | 377 | 959 | 28,4 | 160 | 286 | 8,4 | 267 |

## Bacia do rio Paranapanema

**Hidrografia:** tributário pela margem esquerda do alto Paraná. nasce na serra dos Agudos Grandes, divisa dos municípios de Capão Bonito e Xixirica, no Estado de São Paulo; serve de limite entre êste Estado e o do Paraná.

O rio Paranapanema, com aproximadamente 107.400 km² de área, é o afluente do Paraná de maior bacia hidrográfica.

Recebe em seu percurso grande número de afluentes, entre os quais se destacam os rios Itapetininga (m.d.), Apiaí (m.e.), Taquari (m.e.), Itararé (m.e.), Turvo (m.d.), Cinzas (m.e.), Tibagi (m.e.) e Pirapó (m.e.).

Na bacia do Paranapanema, em 31 de dezembro de 1952, havia 35 postos fluviométricos em funcionamento e tinham sido realizadas até essa data 2.449 medições de descarga.

A seguir figuram características hidrológicas do rio Paranapanema nas localidades de pôrto Paranapanema e Baguaçu (Salto nema e Baguaçu (Salto Grande).

Pôsto: **Pôrto Paranapanema**
Rio: **Paranapanema**
Estado: **São Paulo**
Município: **Avaré**
Localização: **A montante da ponte da estrada de rodagem Itaí-Avaré.**
Área de drenagem: **12.900 km²**
Início das observações: **4-11-1938**
Número de medições de descarga: **90**

CARACTERISTICAS FLUVIOMÉTRICAS ANUAIS:

| [illegible] | [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | | [illegible] | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1939 | 37 | 40.5 | 3.1 | 52.5 | 85.5 | 128.0 | 181 | 350 | 382 | 29.6 | 128 | 140 | 10.9 | 342 |
| 1940 | 36 | 39.5 | 3.0 | 44.5 | 57.5 | 77.5 | 130 | 408 | 452 | 35.0 | 98 | 108 | 8.4 | 264 |
| 1941 | 41 | 45.5 | 3.5 | 48.6 | 64.5 | 98.0 | 162 | 363 | 398 | 30.9 | 107 | 118 | 9.1 | 288 |
| 1942 | 54 | 61.0 | 4.7 | 68.0 | 92.5 | 120.5 | 175 | 333 | 368 | 28.5 | 135 | 147 | 11.4 | 359 |
| 1943 | 46 | 51.5 | 3.9 | 70.5 | 78.5 | 102.5 | 185 | 347 | 379 | 29.4 | 124 | 135 | 10.5 | 329 |
| 1944 | 32 | 34.5 | 2.6 | 38.5 | 50.5 | 68.0 | 100 | 308 | 332 | 25.7 | 78 | 86 | 6.7 | 210 |
| 1945 | 40 | 44.5 | 3.4 | 57.5 | 75.0 | 96.0 | 147 | 374 | 411 | 31.9 | 115 | 126 | 9.8 | 307 |
| 1946 | 50 | 56.0 | 4.3 | 70.5 | 89.0 | 117.5 | 187 | 550 | 600 | 46.5 | 150 | 163 | 12.6 | 398 |
| 1947 | 70 | 80.0 | 6.2 | 91.5 | 115.5 | 149.0 | 272 | 526 | 595 | 46.0 | 190 | 209 | 16.2 | 510 |
| 1948 | 56 | 63.5 | 4.9 | 75.0 | 96.0 | 150.0 | 198 | 469 | 525 | 40.7 | 157 | 171 | 13.3 | 418 |
| 1949 | 42 | 46.5 | 3.6 | 52.5 | 65.5 | [illegible] | 124 | 290 | 310 | 24.0 | 93 | 104 | 8.1 | 254 |
| 1950 | 48 | 54.0 | 4.1 | 56.0 | 81.0 | 119.5 | 189 | 454 | 508 | 39.4 | 142 | 156 | 12.1 | 381 |
| 1951 | 48 | 54.0 | 4.1 | 61.0 | 98.0 | 114.5 | 175 | 462 | 518 | 40.2 | 139 | 128 | 9.9 | 312 |
| 1952 | 42 | 46.5 | 3.6 | 50.5 | 64.5 | 85.5 | 132 | 313 | 338 | 26.2 | 97 | 107 | 8.3 | 262 |

Pôsto: **Pôrto José Américo**

Rio: **Grande**

Estado: **São Paulo**

Município: **Guaraci**

Localização: **3 km a jusante da cachoeira dos Maribondos**

Área de drenagem: **118.534 km²**

Altitude do zero da escala: **380 m, aproximadamente**

Início das observações: **10-6-1928**

Número de medições de descarga: **60**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | [illegible] % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1948 | 804 | 601 | 5.1 | 668 | 894 | 1508 | 2572 | 900 | 4366 | 36.8 | 526 | 1725 | 14.6 | 460 |
| 1949 | 863 | 522 | 4.4 | 575 | 791 | 1106 | 2165 | 1040 | 4797 | 40.5 | 502 | 1636 | 13.8 | 435 |
| 1950 | 508 | 668 | 5.6 | 723 | 997 | 1645 | 2927 | 1157 | 5710 | 48.2 | 596 | 2117 | 17.9 | 470 |
| 1951 | 808 | 593 | 5.0 | 687 | 926 | 1575 | 2950 | 1104 | 5291 | 44.6 | 564 | 1940 | 16.4 | 518 |

Pôsto: **Lussanvira**

Rio: **Tietê**

Estado: **São Paulo**

Município: **Araçatuba**

Localização: **Próximo da Estação da E. F. Noroeste do Brasil**

Área de drenagem: **69.500 km²**

Início das observações: **16-10-1936**

Número de medições de descarga: **34**

CARACTERISTICAS FLUVIOMÉTRICAS ANUAIS :

| ANO | MÍNIMA | | | [illegible] % | [illegible] % | [illegible] % | [illegible] % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1938 | 132 | 265 | 3.7 | 314 | 406 | 596 | 809 | 330 | 1258 | 18.1 | 204 | 618 | 8.8 | 280 |
| 1939 | 115 | 186 | 2.6 | 240 | 343 | 581 | 644 | 370 | 1465 | 21.0 | 208 | 632 | 9.1 | 288 |
| 1940 | 132 | 263 | 3.7 | 268 | 358 | 546 | 915 | 530 | 2289 | 32.9 | 240 | 800 | 11.5 | 364 |
| 1941 | 109 | 160 | 2.3 | 186 | 249 | 406 | 637 | 318 | 1197 | 17.2 | 171 | 430 | 6.1 | 195 |
| 1942 | 116 | 190 | 2.7 | 240 | 343 | 491 | 778 | 378 | 1506 | 21.6 | 198 | 588 | 8.4 | 266 |
| 1943 | 116 | 190 | 2.7 | 226 | 343 | 456 | 768 | 361 | 1418 | 20.4 | 194 | 568 | 8.1 | 257 |
| 1944 | 95 | 99 | 1.4 | 129 | 204 | 310 | 546 | 329 | 1253 | 18.0 | 161 | 410 | 5.9 | 186 |
| 1945 | 102 | 129 | 1.8 | 168 | 259 | 353 | 581 | 344 | 1331 | 19.1 | 169 | 447 | 6.4 | 202 |
| 1946 | 121 | 213 | 3.0 | 249 | 334 | 476 | 890 | 405 | 1645 | 23.6 | 206 | 632 | 9.0 | 266 |
| 1947 | 131 | 259 | 3.7 | 416 | 526 | 677 | 1038 | 522 | 2248 | 32.3 | 239 | 798 | 11.4 | 362 |
| 1948 | 119 | 204 | 2.9 | 319 | 441 | 581 | 1033 | 418 | 1712 | 24.6 | 214 | 670 | 9.6 | 304 |
| 1949 | 86 | 61 | 0.8 | 182 | 268 | 416 | 707 | 340 | 1310 | 18.8 | 168 | 448 | 6.4 | 205 |
| 1950 | 128 | 245 | 3.5 | 348 | 511 | 682 | 1089 | 509 | 2181 | 31.4 | 239 | 799 | 11.5 | 362 |
| 1951 | 184 | 226 | 3.2 | 348 | 396 | 546 | 1000 | 446 | 1856 | 26.7 | 229 | 747 | 10.7 | 338 |
| 1952 | 125 | 222 | 3.1 | 254 | 310 | 466 | 717 | 389 | 1565 | 22.4 | 196 | 581 | 8.3 | 264 |

Pôsto: **Baguaçu (Salto Grande)**
Rio: **Paranapanema**
Estado: **São Paulo**
Município: **Salto Grande**
Localização: **A 2 km da cidade de Salto Grande**
Área de drenagem: **37.840 km²**
Início das observações: **15-9-1930**
Número de medições de descarga: **114**

## CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 90 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H | Q | q | Q | Q | Q | Q | H | Q | q | H | Q | q | — |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | % |
| 1931 | 94 | 229 | 6,0 | 254 | 308 | 425 | 594 | 280 | 1245 | 32,9 | 149 | 481 | 12.7 | 400 |
| 1932 | — | — | — | — | — | — | — | 231 | 950 | 25,1 | — | — | — | — |
| 1933 | 68 | 128 | 3.3 | 135 | 201 | 258 | 368 | 265 | 1152 | 30.4 | 110 | 312 | 8,2 | 260 |
| 1934 | 46 | 55 | 1.4 | 74 | 121 | 166 | 297 | 217 | 869 | 23,0 | 93 | 243 | 6.4 | 202 |
| 1935 | 67 | 125 | 3.3 | 166 | 229 | 330 | 501 | 296 | 1346 | 35.6 | 126 | 388 | 10.3 | 325 |
| 1936 | 69 | 132 | 3.4 | 173 | 221 | 280 | 496 | 321 | 1507 | 39.8 | 122 | 372 | 9,8 | 310 |
| 1937 | 88 | 205 | 5.4 | 258 | 358 | 474 | 616 | 393 | 2002 | 52.9 | 154 | 532 | 14.1 | 443 |
| 1938 | 86 | 196 | 5.1 | 217 | 254 | 317 | 393 | 200 | 772 | 20.4 | 117 | 332 | 8.8 | 276 |
| 1939 | 67 | 125 | 3.3 | 147 | 225 | 321 | 438 | 215 | 858 | 22.7 | 118 | 345 | 9.1 | 287 |
| 1940 | 60 | 128 | 3.3 | 143 | 177 | 234 | 353 | 240 | 1003 | 26,5 | 107 | 299 | 7.9 | 249 |
| 1941 | 68 | 128 | 3.3 | 151 | 188 | 280 | 398 | 216 | 863 | 22,8 | 110 | 315 | 8.3 | 260 |
| 1942 | 81 | 177 | 4.6 | 205 | 230 | 363 | 512 | 261 | 1128 | 29.8 | 134 | 425 | 11,2 | 352 |
| 1943 | 73 | 147 | 3.8 | 162 | 213 | 271 | 453 | 217 | 869 | 23.0 | 116 | 335 | 8.9 | 279 |
| 1944 | 55 | 84 | 2.2 | 100 | 125 | 173 | 238 | 184 | 682 | 18.0 | 86 | 203 | 5.4 | 169 |
| 1945 | 59 | 97 | 2.5 | 135 | 169 | 209 | 321 | 225 | 915 | 24,2 | 102 | 275 | 7.3 | 229 |
| 1946 | 75 | 154 | 4.0 | 184 | 254 | 330 | 485 | 326 | 1540 | 40.7 | 132 | 421 | 11.1 | 350 |
| 1947 | 88 | 205 | 5.4 | 263 | 330 | 428 | 660 | 310 | 1435 | 37.9 | 151 | 515 | 13.6 | 429 |
| 1948 | 82 | 175 | 4.6 | 217 | 263 | 340 | 479 | 250 | 1210 | 32.0 | 130 | 394 | 10.4 | 329 |
| 1949 | 58 | 105 | 2.7 | 135 | 162 | 205 | 297 | 164 | 547 | 14.5 | 95 | 227 | 6,0 | 189 |
| 1950 | 74 | 151 | 3.9 | 162 | 225 | 297 | 468 | 264 | 1355 | 35,8 | 128 | 394 | 10.4 | 328 |
| 1951 | 77 | 163 | 4.3 | 180 | 242 | 326 | 501 | 254 | 1280 | 33.8 | 128 | 406 | 10.7 | 338 |
| 1952 | 70 | 138 | 3,6 | 143 | 188 | 242 | 353 | 150 | 768 | 20,3 | 107 | 295 | 7,8 | 246 |

## Bacia do rio Iguaçu

**Hidrografia:** o rio Iguaçu é formado pelos rios Atuba e Iraí, que nascem respectivamente nos municípios de Colombo e Piraquara, no primeiro planalto do Estado do Paraná.

Toma a direção geral leste oeste, e após um percurso de aproximadamente 700 km, vai lançar-se no rio Paraná, pela margem esquerda, totalizando uma bacia hidrográfica de cêrca de 70.800 km² de área.

Os seus principais tributários são: rios Negro (m.e.), Potinga (m.d.), Jordão (m.d.) e Chopim (m.e.).

A bacia do Iguaçu, em 31 de dezembro de 1952, possuía 23 postos fluviométricos em funcionamento e haviam sido efetuadas 1.424 medições de descarga até essa data.

Apresentamos abaixo características hidrológicas do citado rio em Pôrto Amazonas, União da Vitória e Salto Osório.

Pôsto: **Pôrto Amazonas**
Rio: **Iguaçu**
Estado: **Paraná**
Município: **Palmeira**
Área de drenagem: **3.774 km²**
Altitude do zero da escala: **777 metros aproximadamente**
Início das observações: **6-8-1935**
Número de medições de descarga: **161**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 95 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h<br>cm | Q<br>m³/s | q<br>l/s/km² | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | Q<br>m³/s | h<br>cm | Q<br>m³/s | q<br>l/s/km² | h<br>cm | Q<br>m³/s | q<br>l/s/km² | mm |
| 1936 | 92 | 10.35 | 2.7 | 12.81 | 21.43 | 42.73 | 92.6 | 422 | 277 | 73.5 | | 59.1 | 15.7 | 496 |
| 1937 | 96 | 12.81 | 3.3 | 17.58 | 30.35 | 47.71 | 74.8 | 474 | 344 | 91.2 | | 61.6 | 16.3 | 515 |
| 1938 | 106 | 19.89 | 5.2 | 23.89 | 39.22 | 57.78 | 95.5 | 494 | 370 | 98.2 | | 71.5 | 19.0 | 598 |
| 1939 | 100 | 15.28 | 4.0 | 19.12 | 31.78 | 52.79 | 81.1 | 366 | 211 | 55.9 | | 60.1 | 15.9 | 503 |
| 1940 | 95 | 12.20 | 3.2 | 13.45 | 17.58 | 22.97 | 36.8 | 308 | 164 | 43.6 | | 30.8 | 8.2 | 259 |
| 1941 | 98 | 14.05 | 3.7 | 17.58 | 22.20 | 46.44 | 80.1 | 356 | 245 | 65.0 | | 58.0 | 15.4 | 485 |
| 1942 | 98 | 14.05 | 3.7 | 19.12 | 26.66 | 41.56 | 61.5 | 494 | 370 | 92.2 | | 55.6 | 14.6 | 465 |
| 1943 | 94 | 11.58 | 3.0 | 14.05 | 20.66 | 28.51 | 46.4 | 195 | 108 | 28.6 | | 34.2 | 9.1 | 286 |
| 1944 | 89 | 8.19 | 2.1 | 9.12 | 13.43 | 19.89 | 38.0 | 412 | 264 | 70.2 | | 32.4 | 8.6 | 272 |
| 1945 | 88 | 8.19 | 2.1 | 10.97 | 16.05 | 22.97 | 40.5 | 425 | 281 | 74.5 | | 37.7 | 10.0 | 316 |
| 1946 | 105 | 19.12 | 5.0 | 24.81 | 38.05 | 57.78 | 102.8 | 587 | 499 | 132.2 | | 81.6 | 21.6 | 683 |
| 1947 | 106 | 19.89 | 5.2 | 22.97 | 38.05 | 60.13 | 97.1 | 467 | 334 | 88.7 | | 75.4 | 20.0 | 631 |
| 1948 | 100 | 15.28 | 4.0 | 17.58 | 26.66 | 41.56 | 68.1 | 443 | 303 | 80.5 | | 52.7 | 14.0 | 442 |
| 1949 | 94 | 11.58 | 3.0 | 14.66 | 19.12 | 24.81 | 36.8 | 258 | 135 | 35.9 | | 32.0 | 8.5 | 267 |
| 1950 | 94 | 11.58 | 3.0 | 14.05 | 22.97 | 40.39 | 73.9 | 511 | 393 | 104.3 | | 54.1 | 14.4 | 452 |
| 1951 | 90 | 9.12 | 2.4 | 10.97 | 18.35 | 32.20 | 72.6 | 406 | 257 | 68.2 | | 52.6 | 14.0 | 440 |
| 1952 | 90 | 9.12 | 2.4 | 10.35 | 18.35 | 32.20 | 60.1 | 330 | 171 | 45.5 | | 41.6 | 11.0 | 349 |

Pôsto: **União da Vitória**

Rio: **Iguaçu**

Estado: **Paraná**
Município: **União da Vitória**

Localização: **Na ponte da Estrada de Ferro (Rêde Viação Paraná-Sta. Catarina)**

Área de drenagem: **24.846 km²**

Altitude do zero da escala: **723 metros aproximadamente**

Início das observações: **22-5-1930**

Número de medições de descarga: **129**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | [illegible] % | [illegible] % | [illegible] % | [illegible] % | MÁXIMA | | | MÉDIA | | | ALTURA DE ESCOAMENTO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | H cm | Q m³/s | q l/s/km² | Q m³/s | Q m³/s | Q m³/s | Q m³/s | H cm | Q m³/s | q l/s/km² | H cm | Q m³/s | q l/s/km² | mm |
| 1936 | 156 | 110.8 | 4.4 | 123.1 | 226 | 314 | 709 | [illegible] | 1234 | 49.7 | | 456 | 18.4 | 562 |
| 1937 | 153 | 103.9 | 4.1 | 127.6 | 206 | 301 | 524 | 499 | 1371 | 55.2 | | 409 | 16.5 | 519 |
| 1938 | 170 | 145.3 | 5.8 | 181.6 | 234 | 346 | 595 | 682 | 2207 | 68.8 | | 538 | 21.7 | 684 |
| 1939 | 160 | 120.0 | 4.8 | 155.4 | 225 | 317 | 551 | 563 | 1661 | 66.8 | | 435 | 17.5 | 553 |
| 1940 | 154 | 106.2 | 4.2 | 125.1 | 145 | 158 | 292 | 502 | 564 | 22.7 | | 233 | 9.4 | 297 |
| 1941 | 168 | 140.2 | 5.6 | 178.9 | 249 | 366 | 517 | 574 | 1261 | 50.7 | | 424 | 16.7 | 527 |
| 1942 | 161 | 122.5 | 4.9 | 142.8 | 218 | 360 | 542 | 457 | 1186 | 47.7 | | 418 | 16.8 | 531 |
| 1943 | 141 | 76.3 | 3.0 | 92.4 | 163 | 282 | 437 | 389 | 896 | 36.0 | | 320 | 12.9 | 407 |
| 1944 | 133 | 55.8 | 2.2 | 65.6 | 94 | 147 | 304 | 402 | 953 | 38.4 | | 238 | 9.6 | 304 |
| 1945 | 142 | 78.6 | 3.1 | 90.1 | 130 | 176 | 314 | 462 | 1208 | 48.6 | | 232 | 9.4 | 295 |
| 1946 | 160 | 120.0 | 4.8 | 184.4 | 273 | 465 | 807 | 673 | 2166 | 87.2 | | 656 | 26.4 | 833 |
| 1947 | 156 | 110.8 | 4.4 | 193.4 | 352 | 403 | 717 | 574 | 1711 | 68.9 | | 529 | 21.3 | 672 |
| 1948 | 153 | 103.9 | 4.1 | 130.1 | 209 | 396 | 567 | 508 | 1411 | 56.8 | | 342 | 13.8 | 420 |
| 1949 | 145 | 85.3 | 3.4 | 101.6 | 140 | 181 | 273 | 365 | 805 | 32.2 | | 233 | 9.4 | 296 |
| 1950 | 149 | 94.7 | 3.8 | 110.8 | 165 | 276 | 403 | 542 | 1565 | 63.0 | | 351 | 14.2 | 446 |
| 1951 | 133 | 55.8 | 2.2 | 74.0 | 106 | 234 | 589 | 456 | 1182 | 47.6 | | 370 | 14.9 | 470 |
| 1952 | 135 | 61.0 | 2.4 | 68.8 | 127 | 184 | 425 | 434 | 1088 | 43.8 | | 296 | 11.9 | 375 |

Pôsto: **Salto Osório**

Rio: **Iguaçu**

Estado: **Paraná**

Município: **Laranjeiras do Sul**

Área de drenagem: **46.415 km²**

Início das observações: **16-10-1940**

Número de medições de descarga: **7**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 90 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DO DEFLÚVIO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | — |
| | cm | m³/seg | l/seg/km² | m³/seg | m³/seg | m³/seg | m³/seg | cm | m³/seg | l/seg/km² | cm | m³/seg | l/seg/km² | mm |
| 1941 | 284 | 452 | 9.3 | 573 | 815 | 1069 | 1549 | 750 | 3003 | 64.7 | | 1126 | 24.2 | 765 |
| 1942 | 201 | 255 | 5.4 | 272 | 509 | 695 | 950 | 605 | 2041 | 44.0 | | 781 | 16.8 | 531 |
| 1943 | 74 | 127 | 2.7 | 175 | 324 | 396 | 907 | 575 | 1885 | 40.6 | | 659 | 14.2 | 448 |
| 1944 | 33 | 102 | 2.2 | 111 | 173 | 287 | 628 | 547 | 1739 | 37.5 | | 446 | 9.6 | 304 |
| 1945 | 101 | 148 | 3.2 | 170 | 255 | 358 | 521 | 692 | 2495 | 53.7 | | 457 | 9.8 | 311 |
| 1946 | 205 | 259 | 5.5 | 443 | 750 | 1229 | 1828 | 885 | 3497 | 75.3 | | 1333 | 28.7 | 906 |
| 1947 | 208 | 262 | 5.6 | 572 | 609 | 1032 | 1531 | 894 | 3544 | 76.4 | | 1143 | 24.6 | 776 |
| 1948 | 178 | 226 | 4.8 | 303 | 473 | 770 | 1204 | 742 | 2755 | 59.3 | | 884 | 19.0 | 602 |
| 1949 | 123 | 167 | 3.6 | 198 | 271 | 379 | 569 | 969 | 1854 | 39.9 | | 491 | 10.5 | 333 |
| 1950 | 155 | 200 | 4.3 | 242 | 384 | 690 | 1022 | 913 | 3643 | 78.5 | | 814 | 17.5 | 553 |
| 1951 | 63 | 119 | 2.5 | 150 | 210 | 534 | 1329 | 822 | 3169 | 68.3 | | 794 | 17.1 | 539 |
| 1952 | 75 | 127 | 2.7 | 147 | 279 | 456 | 929 | 980 | 3991 | 86.0 | | 718 | 15.4 | 489 |

**Hidrografia:** nasce com o nome de rio Pelotas, no morro da Igreja, município de São Joaquim, Estado de Santa Catarina, em altitude aproximada de 1.800 metros.

Em grande parte de seu percurso — após receber o rio Piperi Guaçu — serve de limite entre o Brasil e a Argentina; desagua no Oceano Atlântico, formando com o Paraná o rio da Prata.

A sua bacia hidrográfica, em território brasileiro, abrange uma extensão de cêrca de 174.300 km² de área.

Os seus mais importantes afluentes, no Brasil, são os rios: Canoas (m.d.), Peixe (m.d.), Xapecó (m.d.), Piperi-Guaçu (m.d.) Camandaí (m.e.), Ijuí (m.e.), Piratini (m.e.), Icamaquam (m.e.) Ibicuí (m.e.) e Quaraí (m.e.).

A sua rêde fluviométrica, em 31 de dezembro de 1952, compunha-se de 91 postos e até essa época haviam sido executadas 1.261 medições de descarga.

Apresentamos em seguida características hidrológicas do rio Uruguai nos postos de Canoas e Marcelino Ramos.

Pôsto: **Canoas**
Rio: **Canoas**
Estado: **Santa Catarina**
Município: **Lajes**
Localização: **Na ponte da estrada Lajes-Curitibanos**
Área de drenagem: **4.365 km²**
Início das observações: **23-4-1940**
Número de medições de descarga: **25**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA | | | 90 % | 75 % | 50 % | 25 % | MÁXIMA | | | MÉDIA | | | ALTURA DE PRECIPITAÇÃO |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | Q | q | Q | Q | Q | Q | h | Q | q | h | Q | q | |
| | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1941 | 150 | 38.0 | 8.7 | 43.7 | 60.8 | 89.5 | 170.0 | 556 | 521 | 119.4 | 253 | 133 | 30.5 | 961 |
| 1942 | 135 | 25.0 | 5.7 | 30.0 | 41.4 | 55.1 | 60.0 | 517 | 360 | 82.5 | 172 | 63 | 14.4 | 456 |
| 1943 | 153 | 16.8 | 3.8 | 19.2 | 34.4 | 63.1 | 133.0 | 698 | 766 | 175.5 | 214 | 111 | 25.4 | 803 |
| 1944 | 126 | 18.6 | 4.2 | 20.4 | 25.0 | 34.4 | 52.8 | 336 | 253 | 58.0 | 154 | 45 | 10.3 | 394 |
| 1945 | 111 | 10.0 | 2.3 | 14.0 | 21.0 | 29.9 | 47.1 | 250 | 158 | 36.0 | 146 | 37 | 8.5 | 267 |
| 1946 | 139 | 28.2 | 6.4 | 31.7 | 46.0 | 69.4 | 134.0 | 443 | 396 | 90.7 | 211 | 109 | 25.0 | 795 |
| 1947 | 140 | 29.0 | 6.6 | 32.6 | 47.1 | 65.4 | 118.0 | 402 | 452 | 103.5 | 202 | 98 | 22.5 | 709 |
| 1948 | 125 | 18.0 | 4.1 | 20.4 | 30.8 | 57.4 | 132.0 | 778 | 913 | 209.2 | 232 | 143 | 32.7 | 1022 |
| 1949 | 128 | 17.4 | 3.9 | 19.8 | 38.6 | 59.1 | 110.0 | 372 | 320 | 60.7 | 185 | 80 | 18.3 | 578 |
| 1950 | 140 | 29.0 | 6.6 | 30.8 | 44.8 | 58.3 | 84.7 | 290 | 625 | 143.2 | 192 | 86 | 19.7 | 625 |
| 1951 | 65 | 18.0 | 4.1 | 20.4 | 33.2 | 57.4 | 106.0 | 485 | 456 | 104.5 | 152 | 89 | 20.4 | 636 |
| 1952 | 60 | 18.9 | 4.3 | 22.6 | 63.1 | 64.2 | 106.0 | 418 | 442 | 101.3 | 148 | 100 | 22.9 | 724 |

Pôsto: **Marcelino Ramos**

Rio: **Uruguai**

Estado: **R. G. do Sul**

Município: **Marcelino Ramos**

Localização: **Na cidade do Marcelino Ramos**

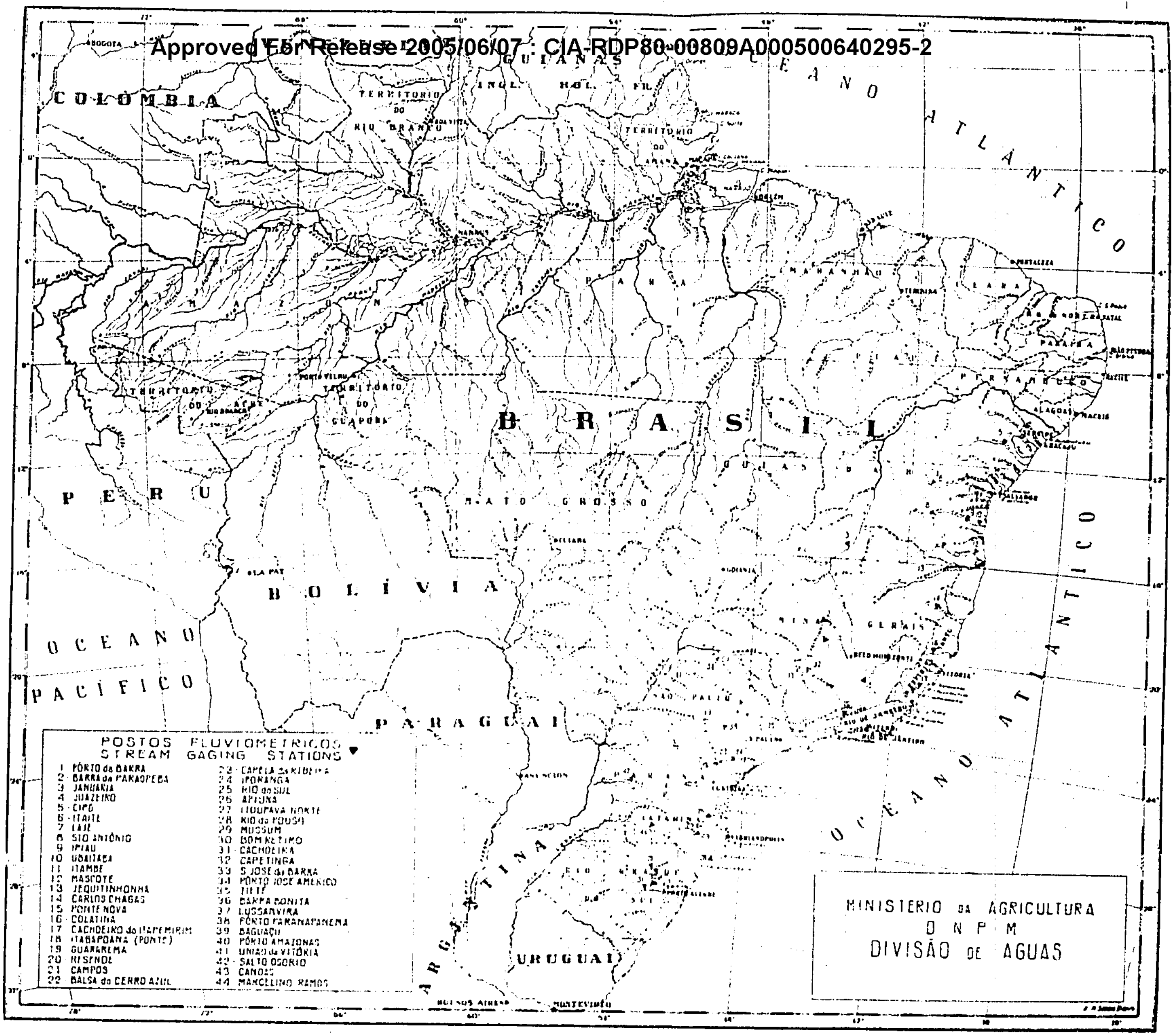
Área de drenagem: **40.785 km²**

Início das observações: **24-10-1939**

Número de medições de descarga: **32**

CARACTERÍSTICAS FLUVIOMÉTRICAS ANUAIS:

| ANO | MÍNIMA |  |  | 95 % | 75 % | 50 % | 25 % | MÁXIMA |  |  | MÉDIA |  |  | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
|  | cm | m³/s | l/s/km² | m³/s | m³/s | m³/s | m³/s | cm | m³/s | l/s/km² | cm | m³/s | l/s/km² | mm |
| 1940 | 141 | 197 | 4.8 | 240 | 397 | 601 | 905 | 450 | 4406 | 110 | 197 | 770 | 18.9 | 598 |
| 1941 | 150 | 236 | 5.8 | 318 | 552 | 810 | 1417 | 776 | — | — | 235 | 1256 | 30.8 | 972 |
| 1942 | 100 | 120 | 2.9 | 150 | 289 | 515 | 765 | 551 | 6807 | 167 | 181 | 668 | 16.4 | 516 |
| 1943 | 74 | 58 | 1.4 | 69 | 157 | 318 | 1079 | 709 | — | — | 177 | 733 | 18.0 | 569 |
| 1944 | 76 | 62 | 1.5 | 74 | 150 | 193 | 541 | 587 | 1667 | 41 | 128 | 271 | 6.6 | 210 |
| 1945 | 66 | 45 | 1.0 | 60 | 85 | 140 | 211 | 260 | 2441 | 60 | 111 | 190 | 4.7 | 146 |
| 1946 | 104 | 133 | 3.2 | 169 | 255 | 515 | 1110 | 515 | 5883 | 144 | 152 | 833 | 20.4 | 642 |
| 1947 | 109 | 120 | 2.9 | 143 | 259 | 416 | 702 | 450 | 4074 | 100 | 171 | 564 | 13.8 | 435 |
| 1948 | 110 | 124 | 3.7 | 220 | 306 | 464 | 848 | 785 | — | — | 192 | 818 | 20.1 | 637 |
| 1949 | 96 | 109 | 2.6 | 150 | 229 | 341 | 685 | 560 | 2739 | 68 | 166 | 534 | 13.1 | 414 |
| 1950 | 116 | 177 | 4.3 | 216 | 284 | 352 | 560 | 950 | — | — | 172 | 640 | 15.7 | 562 |
| 1951 | 86 | 83 | 2.0 | 101 | 165 | 289 | 676 | 720 | — | — | 160 | 618 | 15.2 | 472 |
| 1952 | 80 | 69 | 1.7 | 92 | 165 | 318 | 858 | 528 | 6241 | 153 | 177 | 740 | 18.1 | 573 |


COLOMBIA
GUIANAS
INGL.
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FR.
OCEANO ATLÂNTICO
TERRITÓRIO DO RIO BRANCO
TERRITÓRIO DO AMAPÁ
MANAUS
BELÉM
FORTALEZA
MARANHÃO
CEARÁ
PIAUÍ
PARÁ
RIO GRANDE DO NORTE
NATAL
PARAÍBA
PERNAMBUCO
RECIFE
ALAGOAS
MACEIÓ
SERGIPE
ARACAJU
PÔRTO VELHO
TERRITÓRIO DO ACRE
TERRITÓRIO DO GUAPORÉ
BRASIL
GOIÁS
BAHIA
SALVADOR
MATO GROSSO
PERU
BOLÍVIA
OCEANO PACÍFICO
MINAS GERAIS
BELO HORIZONTE
SÃO PAULO
RIO DE JANEIRO
PARAGUAI
ASSUNCION
SANTA CATARINA
FLORIANÓPOLIS
RIO GRANDE DO SUL
PÔRTO ALEGRE
ARGENTINA
URUGUAI
BUENOS AIRES
MONTEVIDÉU
POSTOS FLUVIOMETRICOS
STREAM GAGING STATIONS ▼
1 PÔRTO da BARRA
2 BARRA da PARAOPEBA
3 JANUARIA
4 JUAZEIRO
5 CIPÓ
6 ITAITE
7 LAJE
8 STO ANTÔNIO
9 IPIAU
10 UBAITABA
11 ITAMBE
12 MASCOTE
13 JEQUITINHONHA
14 CARLOS CHAGAS
15 PONTE NOVA
16 COLATINA
17 CACHOEIRO do ITAPEMIRIM
18 ITABAPOANA (PONTE)
19 GUARAREMA
20 RESENDE
21 CAMPOS
22 BALSA do CERRO AZUL
23 CAPELA da RIBEIRA
24 IPORANGA
25 RIO do SUL
26 APIUNA
27 ITOUPAVA NORTE
28 RIO do POUSO
29 MUSSUM
30 BOM RETIRO
31 CACHOEIRA
32 CAPETINGA
33 S. JOSE da BARRA
34 PÔRTO JOSE AMERICO
35 TIETE
36 BARRA BONITA
37 LUSSANVIRA
38 PÔRTO PARANAPANEMA
39 BAGUAÇU
40 PÔRTO AMAZONAS
41 UNIÃO da VITÓRIA
42 SALTO OSORIO
43 CANOAS
44 MARCELLINO RAMOS
MINISTERIO DA AGRICULTURA
D N P M
DIVISÃO DE AGUAS

## Resumo

Os estudos de regime de cursos d'água brasileiros tiveram início em 1920, quando foi criada no antigo Serviço Geológico e Mineralógico do Brasil a Comissão de Estudos de Fôrças Hidráulicas.

Entretanto, sòmente em fins do ano de 1933, com a instituição da atual DIVISÃO DE ÁGUAS, essas investigações começaram a ser intensiva e extensivamente feitas.

Os gráficos que figuram às páginas 4 e 5 permitem analisar, em linhas gerais, o desenvolvimento dos estudos de deflúvio que vêm sendo realizados em algumas de nossas principais bacias hidrográficas.

O Brasil encerra em seu vasto território, de mais de oito milhões de quilômetros quadrados, uma das maiores senão a maior rêde potamográfica do mundo.

Não sendo possível, em vista da extensão territorial e dos parcos recursos de que dispomos realizar simultâneamente, em tôdas as bacias hidrográficas de certa importância, observações e estudos hidrométricos detalhados, tais serviços se concentraram nas regiões de maior desenvolvimento econômico, as quais iriam exigir ou já estavam exigindo conhecimento seguro do regime dos seus rios, para projeto de obras hidráulicas de maior vulto.

A DIVISÃO DE ÁGUAS efetua estudos sistemáticos de regime em bacias de rios situados nas regiões abrangidas pelos seus DISTRITOS, denominação dada às circunscrições territoriais em que foi dividido o país (vide mapa anexo).

Naquelas bacias, grande número de postos já possui a curva de descarga estabelecida e calculadas a vazão diária e as características fluviométricas mensais e anuais (máxima, mínima e média).

Em 31 de dezembro de 1952 a rêde fluviométrica compunha-se de 1.021 postos em funcionamento, nos quais são efetuadas duas leituras diárias do nível d'água e até a referida data haviam sido executadas 43.134 medições diretas de descarga com molinete, empregando-se aparelhagem moderna, bem como processos técnicos padronizados.

A seguir apresentamos alguns dados fluviométricos das principais bacias hidrográficas em estudo, a fim de que dêem uma idéia das características volumétricas dos rios brasileiros.

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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 2
Assunto 2.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

BROWN (M.J.)
Brasil

# ADVANCED SWITCHGEAR PRACTICES EMPLOYED BY PAULO AFONSO PROJECT

By M. J. BROWN

BRAZILIAN NATIONAL COMMITTEE

The Paulo Afonso Project has the unique problem of developing a vast source of hydro-electric power at a location hundreds of miles from the consuming public. Two long lines connect the inland power generating area with its principal loads at the coastal towns of Recife and Salvador. The North Line to Recife is 405 kilometers (250 miles) long and the South Line to Salvador is 456 kilometers (285 miles) long. Both of these are to be operated at 220 kV and each has a tap station at about the midway point.

Operating problems are encountered due to the high charging currents taken by these lines at 220 kV. The unusual length is a problem too, for the transmission of carrier current, because it introduces high losses. Another major consideration is the interrupting requirements that must be met by the circuit breakers at the transmitting end of these lines when the project is expanded to its ultimate capacity of 900,000 kW.

The application of control, relaying, power line carrier equipment and circuit breakers resulted in some interesting features on the initial phase of the project. Outstanding examples are as follows:

1. The high voltage breakers are suitable for conversion to a design that will provide single pole tripping and reclosing. The ultimate size of the project will demand breaker interrupting capacities of 5,000,000 kVa; the breakers can be modified to provide this capacity. When the ultimate size of the project is reached, the operation of the system will benefit measurably by selective phase relaying and single pole breaker tripping and reclosing.
2. Single sideband power line carrier apparatus is used to provide reliable operation through the high attenuation of these long lines.
3. The carrier-pilot relaying system uses an audio frequency channel over the single sideband carrier channel. This is a unique version

of the pilot channel required for relaying and it is used because it is a means of obtaining a high ratio of signal to noise. The relaying system can be altered in the future to provide selective pole tripping and reclosing.

4. Semi-automatic control of the switching for the synchronous machines permits fast and simple operating procedures at the receiving stations.

5. The substation switchboards are of the duplex tunnel type. At the Paulo Afonso station a control desk type duplex benchboard is used.

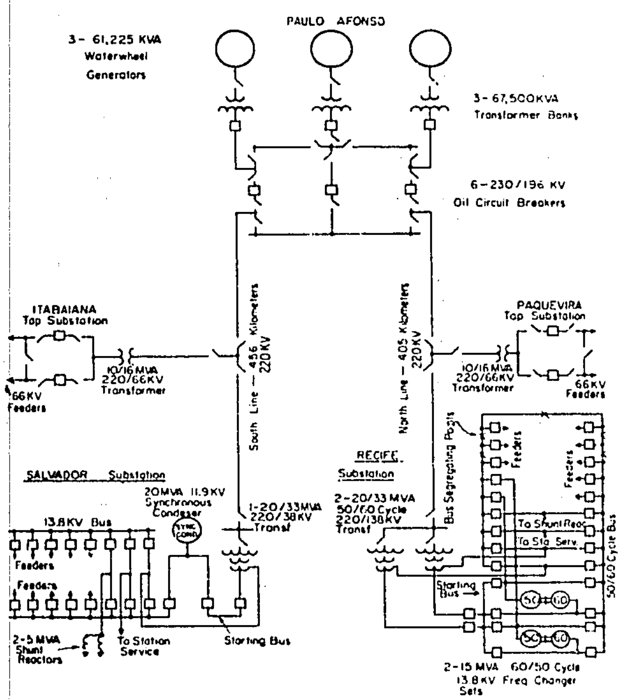


Fig. 1 — Single line diagram of system.

6. All 15 kV class switching uses modern metal clad switchgear with drawout air breakers.
7. All station service and battery switchgear uses modern low voltage metal enclosed switchgear.

## THE 220 kV AND 60 kV LINE CIRCUIT BREAKERS

The system arrangement, Figure 1, shows how the North Line connects the Paulo Afonso Plant to Recife and how the South Line connects it to Salvador. The double bus system at Paulo Afonso provides a tie breaker that may be used on either line when the normal line breaker is out of service for maintenance. Thus there are three breakers at Paulo Afonso that may be used as terminal breakers on the two lines. At the substations, however, no breakers are used in the 220 kV circuits. Consequently, line switching must be done with low voltage breakers at these locations.

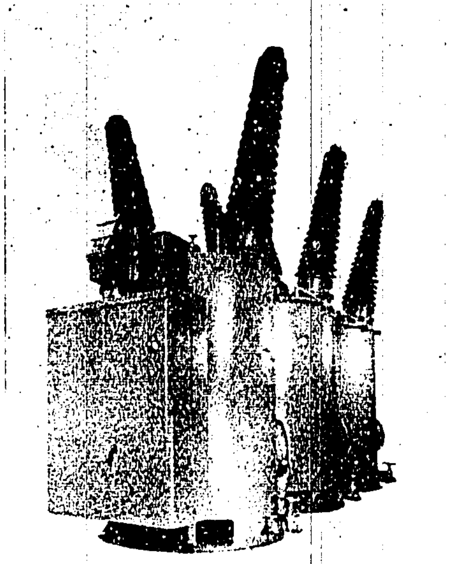


Fig. 2 — Photograph of the 230 kV line breaker.

Coordination between the initial and ultimate operations at Paulo Afonso powerhouse is reflected in the high voltage breaker ratings. The five initial units are identical, being rated at 800 amperes, 230/196 kV. The line breakers will in the future be converted to operate as single pole tripping and closing units. Although they have separate pole units, they are initially operated by one mechanism as a three pole breaker.

Modifications of the breakers can be made which will raise the interrupting capacity from 3,500,000 kVa to 5,000,000 kVa. This is planned at a later date when the project is expanded towards its ultimate capacity. The initial design with 3,500,000 kVa interrupting capacity will clear 8800 amperes in three cycles. The ultimate of 5,000,000 kVa will raise the current value to 12,500 amperes. The reclosing time will be 20 cycles, on a 60 cycle base.

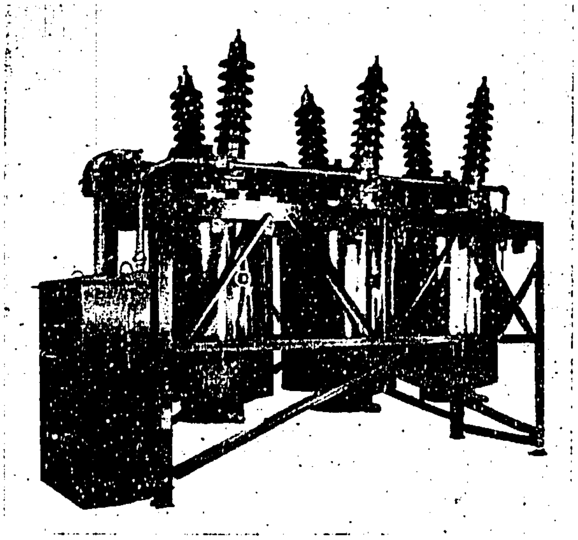


Fig. 3 — Photograph of the 69 kV line breaker.

The breakers use multi-flow "De-ion Grid" interrupters insuring short arcing time, reduced arc energy, low maintenance and high interrupting capacity. Bushings are of the condenser type, providing maximum mechanical and electrical strength with minimum size and weight.

Metal and porcelain enclosure gives complete protection under all weather conditions. The closing mechanisms are pneumatically operated using a design that is mechanically and electrically trip free allowing unrestrained opening under all conditions.

At Paquevira and Itabaiana, the tap stations, 69 kV breakers are used which are electro-pneumatically operated, and mechanically and electrically trip free. They are in a frame mounting for outdoor service.

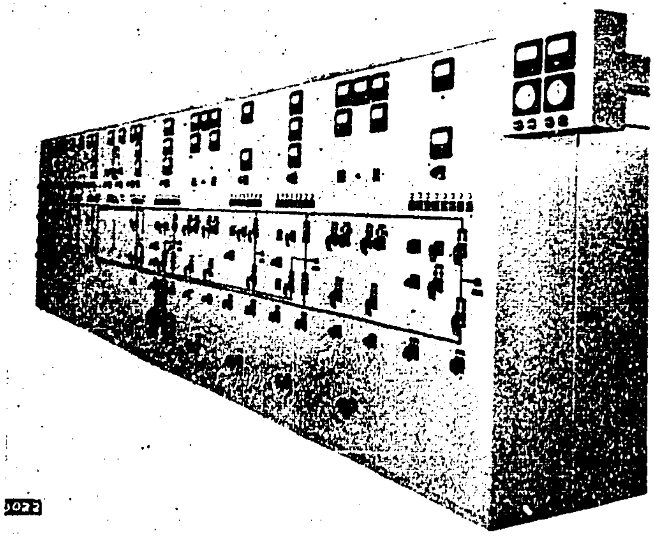


Fig. 4 — Front view of the Recife control board showing mimic bus.

A photograph of the 230 kV line breaker is shown in Figure 2. The 69 kV breaker is shown in Figure 3.

## LINE PROTECTIVE RELAYS

The line protective relaying employs carrier distance pilot relays, zero sequence product ground relays and instantaneous overvoltage relays.

An unusual condition, contributing to overvoltage, exists on the system. The two lines leaving the Paulo Afonso Generating Station terminate at two receiving stations, Recife and Salvador. At Recife, two frequency changer sets connect the 60 cycle generating system to the 50 cycle consumer load. At Salvador, a 60 cycle synchronous condenser is used on the receiving bus. The line capacitance is of such magnitude, in each case, that it is capable of over-exciting the receiving machines. Overvoltage will result if these machines are loaded with only the charging current of the line. Consequently, relaying and line switching provides for the opening of the receiving station machine breaker before the generating station line breaker is opened. This is accomplished by transmitting a signal over the carrier channel.

A similar tripping system is used to open the line breaker at Paulo Afonso for a transformer fault at a receiving station, there being no line breakers at the latter locations. Likewise, carrier tripping clears power feed from the two ends of each line in the event of a transformer fault at a tap station. These stations have no line breakers of their own.

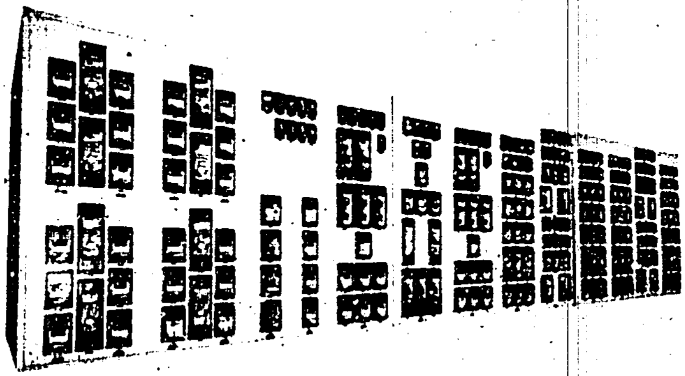


Fig. 5 — Rear view of the Recife control board.

The long distances between Paulo Afonso and the receiving stations imposes unusual conditions of attenuation upon the carrier channels. For this reason, single side band transmission is used. To obtain the necessary selectivity and receiver gain, carrier relaying uses a 2900 cycle audio signal, modulating the single side band equipment.

## SEMI AUTOMATIC CONTROL

At the receiving stations partial automatic control allows the operator to start the synchronous machines with a minimum of manual supervision. A novel system of pole finding uses a pole position generator on the shaft of each synchronous machine. It provides a quick and direct means of matching the frequency changer pole positions into the 50 and 60 cycle system phase relationships. Another important function, is the ability of this control to find the proper field excitation polarity when the receiving station machines are started from the sending end bus, using the line as a series reactor. Any attempt to apply d-c magnetizing in a direction opposite to the a-c magnetization would cause undesirable over-voltage conditions. Since the synchronous condenser at the Salvador Station is line started, it too has pole finding equipment.

Fig. 6 — Interior of the Recife control board, taken at the factory, with shipping braces in place.

## STATION CONTROL SWITCHBOARDS

At the Paulo Afonso Plant, the main control board is in the form of an operator's desk. Mimic bus provides means for quick and accurate visualization of the system.

At the substations, duplex tunnel type switchboards are used. These too employ mimic bus. The convenience of the duplex switchboard comes from the readily employed facility of putting the control switches and instrumentation on the front panels and the relays on the rear panels. The operator thus faces the most frequently used components and at the same time has access to the relays on the rear of the switchboard.

The switchboard for Recife Substation is shown in Figures 4, 5 and 6.

## METAL CLAD SWITCHGEAR

Metal clad switchgear is used for all of the 15 KV class of switching on the project. The breakers are air, drawout type. Ratings extend to the 2000 amperes, 500,000 KVa level. The breaker housings, which are jig assembled at the factory, provide facilities for complete interchangeability of the breakers, as shown in Figure 7. Continuity of service is benefitted by the ease with which breakers may be interchanged during inspection procedures. Components, such as current transformers and bus, Figure 8, are readily reached for inspection, maintenance or extension. Removable coverplates and barriers provide access to these components. Potential transformers may be withdrawn to a de-energized and grounded position for inspection and replacement of fuses.

Fig. 7 — 15 kV circuit breaker withdrawn from metal clad switchgear and covers removed.

The breakers themselves, Figure 9, are held to close dimensional tolerances to allow easy interchangeability in the stationary structure. The primary disconnects are a full floating design with high pressure finger segments individually sprung in a single retaining ring. These segments are located on the main studs of the drawout unit which permits convenient inspection and maintenance. Arc chutes of true ceramic material provide unusually high resistance to heat shock.

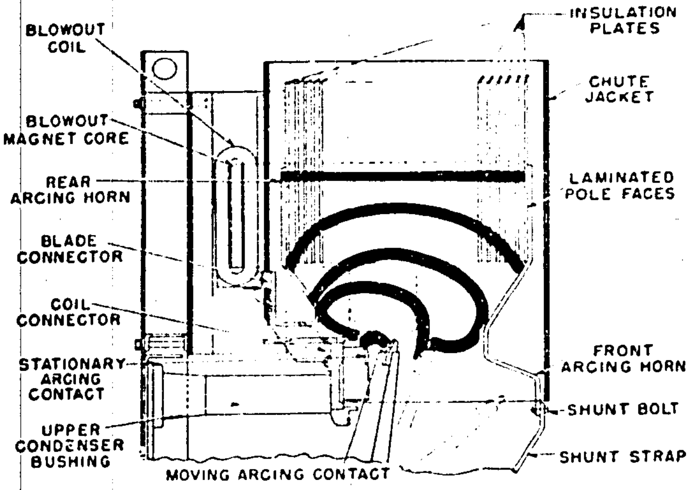
Fig. 8 — Coverplates removed from metal clad switchgear for inspection.

The "De-ion" principle of interrupting an arc in air is illustrated in Figure 10. When the arcing contacts separate, an arc is drawn between them without the blowout coil carrying current. The arc rises rapidly under the influence of the magnetic field created by the iron of the blowout magnet. This causes the arc to impinge on the arcing horns, thus inserting the blowout coil in series with the arc.

cranked in or out and cannot be closed while being cranked in or out of place. The movement of the breakers is horizontal and the crank can be easily turned.

A ground bus connects to all breakers and cells. To promote safety, the grounding connection is made before the primary contacts are made. When a breaker is either removed to the test position or fully withdrawn, a heavy metal shutter closes by gravity over the main stud entry ports, completely isolating the live parts in the interior of the cells. Upon repositioning the breaker, the shutter automatically opens.

The test position of the breakers allows breaker operation while the primary contacts are disconnected. The secondary contacts, connecting to the auxiliary switches and the breaker closing and tripping coils may or may not be connected in the test position at the users discretion. An extendable secondary contact assembly provides this feature.



Arc chute and blowout coil.

Fig. 10 — Arc chute and blowout coil interrupting an arc.

## LOW VOLTAGE SWITCHGEAR

The battery circuits and station service are distributed through a switchboard employing manually operated plastic case air circuit breakers. These breakers, using the "De-ion" principle of arc interruption are equipped with thermal and magnetic trip elements, the former providing coordinated inverse time tripping and the latter instantaneous tripping on overload. Metal enclosures provide dead front construction.

Distribution to motor loads is made through a control center assembly that contains the linestarters. Separate buses for each machine are used to supply the linestarters associated with it so that a diversity of supply will be available to the separate loads.

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 2
Assunto 2.1.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

MARCHETTI (D.)
Brasil

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# NOTÍCIAS SÔBRE AS ESCAVAÇÕES SUBTERRÂNEAS DA USINA HIDRO-ELÉTRICA DE PAULO AFONSO

**Por DOMINGOS MARCHETTI**
Engenheiro — Consultor Técnico da Companhia Hidro Elétrica do São Francisco

COMITÊ NACIONAL BRASILEIRO

No Brasil temos hoje, pràticamente prontas ou em construção, quatro grandes ou médias usinas hidro-elétricas subterrâneas. A primeira a ser projetada dêsse tipo e a primeira a ser iniciada foi a de Paulo Afonso, da Companhia Hidro-Elétrica do S. Francisco.

Dos vários fatôres que determinaram para Paulo Afonso a escolha do tipo subterrâneo, o decisivo foi o fator econômico, isto é, o mesmo fator que, a meu ver, justificou a difusão do tipo, nesses últimos anos, em tôda parte e em modo particular na Europa. Tratando-se do primeiro exemplo no Brasil e também de um dos primeiros exemplos em tôdas as Américas, é natural que, quando o projeto foi divulgado, tenham surgido discussões sôbre a oportunidade do tipo escolhido. A maior preocupação era motivada pelo receio de dificuldades construtivas. As escavações subterrâneas, mormente quando de grande vão, podem sempre apresentar surprêsas, mas um cuidadoso estudo prévio do terreno reduz grandemente as incertezas; no nosso caso particular, a pequena área e a pequena profundidade atingidas pelas escavações permitiu se concentrar num espaço relativamente pequeno um estudo altamente eficiente. Hoje, concluídas as obras, é possível afirmar que as previsões a favor do tipo subterrâneo foram confirmadas, no sentido de que as dificuldades encontradas não foram além das previstas, que elas foram vencidas de acôrdo com o planejamento prévio e que os custos foram mantidos dentro dos limites orçados, pôsto que as pequenas majorações verificadas acham-se largamente justificadas pelos aumentos, durante o desenvolvimento das obras, dos salários e dos materiais.

Julgamos então que não seja desinteressante uma exposição sôbre os métodos de escavação previstos e realizados em Paulo Afonso.

Do projeto geral do aproveitamento das quedas de Paulo Afonso ideado pelo diretor técnico da CHESF, engenheiro Octavio Marcondes Ferraz, destacamos a figura 1, que representa o sistema da adução, casa das máquinas e descarga. A própria figura é, por si, explicativa na disposição e nas dimensões dos singulos elementos, e dispensa uma descrição minuciosa: descrição, aliás, que se encontra na monografia apresentada pelo próprio Dr. Marcondes Ferraz. Todos os elementos: poços adutores (1 A, 1 B, 1 C), casa das máquinas, túneis de sucção, chaminé de equilíbrio (poço 3), túnel de descarga, poços de acesso (poço 2 e poço 4) representam, em conjunto, 70 000 metros cúbicos de escavação. Não é muito, se considerarmos a importância e a multiplicidade dos elementos da obra a que êsse volume se refere. Aliás, um simples exame da figura 1 mostra a extraordinária compacidade do conjunto, compacidade que se traduz fatalmente em baixo custo de obras por KW instalado.

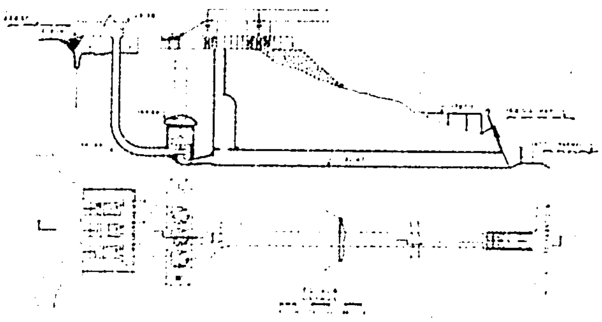

Fig. 1

Na zona de Paulo Afonso aflora uma possante formação granítica; o maciço principal do granito é cortado por uma rêde de veios de sienito róseo, e o todo é entrecortado por uma segunda rêde de veios mais delgados de pegmatito e aplito. A superfície aflorante, submetida à rigorosa ação atmosférica do sertão nordestino, apresenta-se fortemente fraturada; nela são reconhecíveis três direções de fendilhamento grosseiramente normais entre si, sendo a mais importante aquela em plano quase vertical, paralelo ao eixo do canion. A primeira impressão a respeito da compacidade da rocha foi pouco animadora, mas um estudo cuidadoso das condições locais nos levou a conclusões mais otimistas. Pouco distante do local da casa das máquinas existe uma parede vertical de uns 70 metros de altura que cai sôbre um dos braços secundários da cachoeira; trata-se da parede leste do Cêrro Pelado, cuja formação é devida a um desmoronamento relativamente recente provocado pela ação erosiva da cachoeira agindo na sua base. Esta parede é um grande corte vertical do maciço rochoso e dá uma idéia bastante favorável da sua estrutura interna. Notamos também a falta total de vestígios de água ao longo do barranco do canion, mesmo durante as enchentes, quando são invadidos pelas águas todos os braços do rio que se encontram a montante em cota bem mais alta e a pequena distância horizontal; fomos assim induzidos a pensar na quase impermeabilidade do terreno e na pouca probabilidade de encontrar fendas mais ou menos abertas. Enfim, a interpretação das numerosas sondagens efetuadas confirmou as nossas observações e nos convenceu da possibilidade de realizar em profundidade escavações de grande vão sem ou quase sem necessidade de escoramento. Consideramos então eliminados os principais fatôres que podiam desaconselhar a solução subterrânea. As mesmas considerações sôbre a natureza da rocha animaram o projetista a orientar os vários elementos obedecendo ùnicamente a motivos de ordem hidráulica, desprezando tôda preocupação que podia ser sugerida pela orientação dos principais planos de fendilhamento da rocha.

Sempre levando em conta as características físicas da rocha, foi previsto o seguinte tipo de estrutura em concreto armado para a estabilidade definitiva do teto e das paredes da casa das máquinas. Para o teto, uma série de arcos parabólicos com afastamento máximo de 3 metros entre os eixos, com 0,40 m de largura e altura variável de 1,20 m no fêcho até 1,70 m nas impostas, apoiados sôbre duas vigas longitudinais com dimensão de 1,70 m por 0,60 m; essas vigas distribuem a reação dos arcos sôbre a rocha e a esta são ancoradas com barras de aço de uma polegada chumbadas com cimento em furos de um metro de profundidade. Para as paredes, uma série de pilares nos mesmos planos verticais dos arcos, com 0,40 m no sentido paralelo ao eixo longitudinal da usina e com dimensão mínima, no outro sentido, de 0,50 m, acompanhando as irregularidades da rocha; os pilares, de metro em metro, são ancorados na rocha com barras de aço de uma polegada chumbadas em furos de 2,50 m de profundidade, e sobem até encostar nos arcos. As vigas para as pontes rolantes, com dimensão de 0,50 m por 1,00 m, apoiam sôbre consolos engastados nos pilares e, através dos mesmos pilares, são ancoradas na rocha com 8 barras de aço de uma polegada chumbadas em furos de 4,80 m de comprimento. Os cálculos estáticos da estrutura foram elaborados pelo Prof. Telémaco Van Langendonck.

Além da consolidação das paredes realizada pelos pilares, nos painéis entre os pilares a rocha foi injetada com cimento em furos de 2,40 m de profundidade, sob a pressão de cem libras.

Um dos fatôres básicos que influenciaram o plano geral das escavações depende do fato de estar, durante boa parte do ano, parcial ou totalmente submersa a bôca de saída do túnel de descarga, não podendo essa ser utilizada para a retirada do material escavado. A máxima flutuação do nível d'água entre estiagem e enchente é aí prevista em 32 metros, e o limite máximo para uma enchente excepcional (cota 168) indica que a quase totalidade do material escavado deve ser elevada, mesmo ideando caminhos auxiliares de saída. Assim excluído o ataque principal pela cota inferior do sistema, foi previsto o ataque pelos poços 2 e 3.

Êstes dois poços foram atacados simultâneamente, de cima para baixo, em seção plena (6,50 m de diâmetro), com avanços de 2,40 m em cada fogo. O material escavado foi retirado com um único "derrick" servindo os dois poços. O poço 2 foi escavado até à cota 137,50 e o poço 3 até à cota 131,50. Em cada poço foi instalado um elevador capaz de elevar dois vagonetes de um metro cúbico em cada viagem, realizando uma viagem, inclusive carga e descarga, em três minutos. O material elevado era despejado em silos e daí levado à central de britagem.

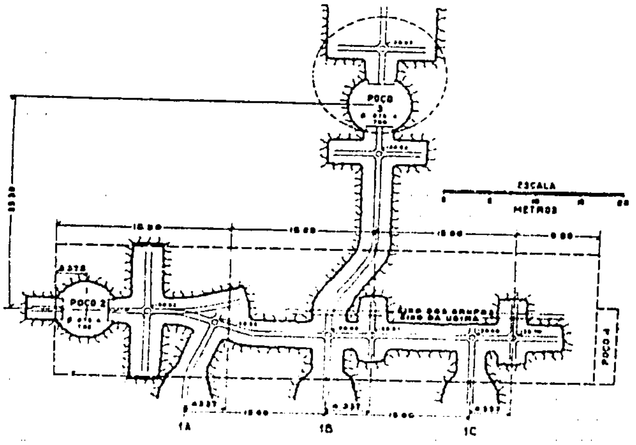

Fig. 2

Partindo do poço 2, foram abertas duas galerias horizontais ao longo do eixo longitudinal da casa das máquinas; uma, a superior, na cota 159,50, a segunda na cota 138,62; estas duas galerias foram ligadas entre si furando três poços verticais locados nos eixos dos grupos geradores. Partindo do poço 3, foi atacado, do lado de jusante o túnel de descarga abrindo uma galeria inferior na cota 132,57; do lado de montante foram abertas duas galerias ligando o poço 3 à casa das máquinas, sendo uma, a superior, na cota 138,62, a segunda na cota 132,57. Tôdas as cotas referem-se ao trilho das linhas Decauville.

Conseguimos assim, na cota 138,62, uma rêde de linhas como mostra a fig. 2; os vagonetes procedentes do túnel de descarga eram encaminhados diretamente ao elevador 3; os vagonetes procedentes dos ramos horizontais da adução 1 A, 1 B, 1 C, e das bôcas inferiores dos três poços abertos nos eixos dos grupos, destinados êsses a receber a quase totalidade do desmonte da casa das máquinas, podiam ser encaminhados indiferentemente ao elevador 2 ou ao 3, utilizando ao máximo a instalação de elevação.

Enquadrado assim o plano geral, vamos agora considerar o sistema adotado para escavar as diversas partes.

A escavação da casa das máquinas em cota superior a 159,50 foi feita alargando a galeria anteriormente aberta na mesma cota ao longo do eixo longitudinal. Em primeiro lugar foi elevado o teto até à cota do extradorso dos arcos de sustentação; foram feitos depois os alargamentos laterais. De acôrdo com a previsão, apesar da existência de algumas fendas, foi possível, sem usar escoramento, alargar tôda a zona da abóbada no vão de 20 metros necessário à concretagem das vigas de apoio e dos arcos. Vigas e arcos foram concretados logo depois de concluído o alargamento, lançando o concreto em parte com ar comprimido e em parte com bomba.

O desmonte da casa das máquinas entre a cota 159,50 e a cota 138,62 foi feito abrindo e alargando uma cratera ao redor de cada um dos três poços verticais abertos anteriormente ao longo dos eixos dos grupos geradores; êsses poços funcionavam como silos, despejando o material, através de bicas móveis aplicadas às bôcas inferiores, nos vagonetes estacionados na galeria inferior. Alcançando as crateras o limite perimetral da casa das máquinas, a escavação era levada verticalmente de cima para baixo, até aprumar uma faixa de 5 metros de altura abaixo da viga de apoio dos arcos; a êsse ponto procedia-se à concretagem do segmento superior dos pilares, inclusive os consolos para as vigas das pontes rolantes e as próprias vigas. A fase descrita está representada na figura 3. Levando adiante o desmonte, continuamos a adotar êsse sistema de concretar os pilares em segmentos à medida que, de cima para baixo, era aprumada uma nova faixa de parede. Conseguimos assim dois resultados: quando avançávamos para baixo aprumando as paredes, a parte superior já estava consolidada pelos pilares; apressamos a montagem das pontes rolantes, sendo essas postas sôbre as vigas antes que a escavação e os pilares fôssem concluídos até às suas bases.

A escavação dos ramos horizontais da adução 1 A, 1 B, 1 C, e dos ramos curvos foi feita partindo da galeria longitudinal ao longo da casa das máquinas na cota 138,62. A primeira fase consistiu em avançar na parte inferior da seção alternando os fogos com a retirada do material desmontado; a segunda fase em desmontar a parte superior da seção, partindo da curva e dirigindo-se à galeria longitudinal, com sucessão contínua de fogos, deixando o material no local, sendo que os operários trabalhavam na furação pisando sôbre o material desmontado; a terceira fase consistiu na retirada, em sucessão contínua, do material desmontado.

Adotando um sistema igual ao precedente, foi escavado o túnel de descarga em quase tôda a sua extensão, deixando só um delgado diaframa na extremidade de jusante para evitar a invasão pela água do rio. O túnel de descarga foi revestido com concreto simples, concretando em primeiro lugar a parte inferior e em seguida as partes laterais e o fêcho; nesta segunda operação foram usadas fôrmas metálicas em elementos deslocáveis com 5 metros de comprimento. O concreto foi confeccionado no próprio túnel e lançado com bomba nas partes laterais e com ar comprimido no fêcho.

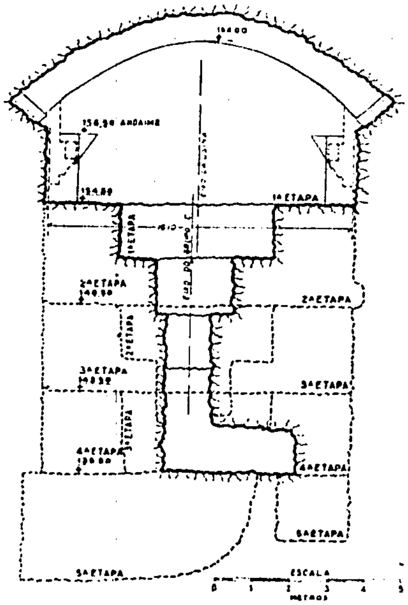

Fig. 3

A escavação na casa das máquinas nas cotas inferiores a 138,62 foi feita retirando o material desmontado pelo elevador do poço 3. Durante essa operação o elevador do poço 2 já tinha sido removido e já tínhamos em funcionamento a ponte rolante externa destinada a descer as máquinas pelo poço 2, e as pontes rolantes internas. Isto nos auxiliou bastante em tôdas as operações de concretagem e de acabamento do complicado sistema de valas, poços e nichos existente na parte inferior da casa das máquinas, inclusive o delicado preparo das fôrmas e a concretagem dos blocos de sucção das turbinas.

Tôdas as operações descritas foram levadas a cabo em trabalho contínuo, com 3 turmas de 8 horas por dia, a elas reservando a precedência na disponibilidade de mão-de-obra e de equipamento. Os outros elementos da obra, isto é, ramos verticais 1 A, 1 B, 1 C, da adução, poço 4, túneis de sucção das turbinas no trecho entre a casa das máquinas e chaminé de equilíbrio, obras na bôca de saída do túnel de descarga, foram executadas mais ou menos espaçadamente durante todo o prazo de construção do grôsso das obras, em ritmo mais ou menos acelerado de acôrdo com a oportunidade e a conveniência do momento. Os poços 1 A, 1 B, 1 C, servidos por um único "derrick", foram executados de cima para baixo em passos de 2,40 m em cada fogo, em seção plena de 6 metros de diâmetro, deixando assim uma espessura mínima de 0,60 m para o revestimento. O poço 4 foi escavado, também em seção plena, parte de cima para baixo e parte, partindo da casa das máquinas, de baixo para cima; as paredes dêste poço foram injetadas e revestidas. Os túneis de sucção entre a casa das máquinas e a chaminé de equilíbrio foram iniciados depois de concluída a consolidação da parede da casa das máquinas do lado da descarga e a concretagem dos blocos de sucção das turbinas; foram concluídos em três etapas de escavação e imediata concretagem. Nas obras na bôca de saída do túnel de descarga foi possível trabalhar sòmente durante as estiagens; mesmo assim, foi necessário deixar um dique de rocha ao longo do rio e os trabalhos desenvolveram-se a céu aberto entre êste dique e o diafragma deixado na extremidade de jusante do túnel de descarga; êste diafragma foi desmontado na última estiagem, na iminência da montagem das comportas de saída: montadas as comportas, não restou que desmontar o delgado dique ao longo do rio.

Última operação de escavação subterrânea foi o alargamento do poço 3 até alcançar as dimensões previstas para a chaminé de equilíbrio; retirado o elevador do poço 3, o material desmontado no alargamento é retirado com um "derrick" pela bôca do mesmo poço.

As escavações suplementares destinadas a auxiliar a realização do plano geral foram de pequena entidade; foram elas a porção do poço 2 abaixo da cota 150 que foi entulhada com blocos de pedra e massa de cimento, e um pequeno volume da galeria na cota 138,62 entre a casa das máquinas e o poço 3, que foi concretado juntamente com a abóbada do túnel de sucção da turbina central.

Em tôdas as operações de escavação foram usadas brocas de aço com ponta de carbureto de tungstênio solidária com a haste, na escala 800 milímetros de comprimento por 34 de largura, 1600 por 33, 2400 por 32, 3200 por 31, 4800 por 30. As brocas eram acionadas por martelos pneumáticos leves com injeção de água, manobrados, nos furos horizontais e nos verticais de baixo para cima, com o auxílio do avanço pneumático. No granito de Paulo Afonso tivemos uma velocidade média de penetração, incluindo o tempo gasto nas substituições das brocas e nas paradas inevitáveis, da ordem de 8 metros por hora em furo vertical de cima para baixo e de 6 metros em furo horizontal e vertical de baixo para cima; a máxima velocidade instantânea alcançou 32 centímetros por minuto; cada broca furou em média, antes de ser refugada ou destinada a serviços de menor responsabilidade, 100 metros de furo.

Usamos explosivo de fabricação nacional, de várias qualidades; na maior parte nitrato de amônea 62%, com um gasto médio de 0,75 kg por metro cúbico de rocha. As explosões foram provocadas com espoletas de tempo detonadas elètricamente.

Para o transporte do material desmontado usamos vagonetes do tipo Decauville, reforçados, com a capacidade de um metro cúbico. O carregamento foi feito usando carregadeiras mecânicas.

Na central de ar comprimido foram instalados 5 compressores de 405 pés cúbicos por minuto.

A ventilação foi garantida instalando 2 ventiladores, um na bôca do poço 2 e um na bôca do poço 3, a corrente de ar reversível, com a capacidade cada um de 10 metros cúbicos por segundo.

As infiltrações de água foram mínimas; a maior parte da vasão, recalcada por uma pequena bomba instalada no fundo do poço 3 e outra no fundo do poço 2, era proveniente da água injetada nos martelos pneumáticos em operação nas numerosas frentes de desmonte.

A pedido da Diretoria Técnica da CHESF, foram realizadas várias provas de medida de deformações da rocha. Estas experiências foram planejadas, preparadas e realizadas pelos técnicos do Instituto de Pesquisas Tecnológicas de São Paulo, com instrumentos ideados e realizados pelo mesmo Instituto. A primeira série de provas determinou as deformações em câmaras cilíndricas escavadas em profundidade na rocha e submetidas a pressões hidráulicas de várias intensidades; a máxima deformação registrada foi de 0,37 milímetros, no sentido de um diâmetro vertical, sob a pressão de 16 kg por centímetro quadrado numa câmara cilíndrica horizontal com o diâmetro médio de 2,30 m. Uma segunda série de provas foi feita com o fim de medir as deformações da rocha libertando-a das pressões intrínsecas; estas provas foram feitas nas paredes da galeria escavada na cota 138,62, isto é, sob uma capa de recobrimento de cêrca de 75 metros de rocha. A máxima extensão verificou-se no sentido vertical entre dois pontos afastados de 254 milimetros e foi de 0,15 milímetros. Os resultados de tôdas essas experiências foram valiosos para o projetista no cálculo do revestimento dos poços adutores.

As obras descritas constituem a primeira etapa de Paulo Afonso; nas duas extremidades da casa das máquinas deixamos embocados os túneis de ligação com as casas das máquinas previstas para as etapas futuras. Estas cabem, tôdas no mesmo alinhamento da existente, no grande massiço entre o chamado Poço Verde e o Cêrro Pelado. Podíamos ter imaginado de instalar tôdas as máquinas numa única usina de grande comprimento; por motivos de segurança, em virtude da locação paralela ao canion e a não grande afastamento do mesmo, paralela também ao principal plano de fendilhamento da rocha, preferimos imaginá-las em vários grupos instalados em várias usinas, deixando entre elas blocos de terreno virgem atravessados por um túnel de ligação de pequena seção.

Esperamos que esta relação possa ser de alguma utilidade para os que realizarão as etapas futuras de Paulo Afonso no progressivo aproveitamento daquele grande cabedal de energia; e, como contribuição ao estudo de novos aproveitamentos, insistimos em notar que a experiência de Paulo Afonso veio confirmar que, desde que um cuidadoso estudo prévio dê suficientes garantias sôbre a natureza do terreno, a preocupação de dificuldades construtivas e de conseqüentes desagradáveis surprêsas nos custos e nos prazos, não deve constituir fator dominante contrário à solução subterrânea.

## RESUMO

A escolha do tipo subterrâneo para a usina de Paulo Afonso foi devida principalmente a motivos econômicos, pois o principal fator contrário, isto é, a preocupação de dificuldades construtivas, foi considerado inexistente depois de um cuidadoso estudo do terreno. A realidade confirmou as previsões. A monografia descreve os métodos de escavação e concretagem adotados e relata dados sôbre equipamento, materiais e provas de carga sôbre a rocha.

## SUMMARY

The choice of the subsoil for the Paulo Afonso Power House has been dictated principally for economical reasons, because the most serious opposition, represented by the preoccupation of the constructive difficulties, was considered inexistent after a very careful study of the ground. These forecasts were confirmed by the reality. The monography describes the adopted excavation methods and relates notices on the equipment, materials and charge essays on the rock.

## RÉSUMÉ

Le choix du type souterrain pour la céntral de Paulo Afonso fut adopté principalement pour des motifs économiques, parce que ce qui pouvait être consideré le plus important point contre-indiqué, c'est-à-dire la préoccupation des difficultés de construction, fut considéré nul après des études bien sérieuses du terrain. La réalité a confirmé ces previsions. La monographie décrit les méthodes d'excavation adoptées, et relate quelques données sur l'équipement, les matériaux et les essais de charge sur la roche.

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# PLANO DE ELETRIFICAÇÃO DO ESTADO DE MINAS GERAIS COMO PARTE DE UM PLANO DE DESENVOLVIMENTO ECONÔMICO REGIONAL

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O Estado de Minas Gerais, um dos mais importantes do Brasil, econômica e politicamente, com uma área equivalente à da França, está empenhado num plano de eletrificação estatal, concebido como base de um programa econômico geral para melhor aproveitamento das suas abundantes riquezas minerais. Os problemas e as soluções investigadas refletem situações bastante freqüentes em regiões sub-desenvolvidas.

## I

O Estado de Minas Gerais (593.810 km$^2$) ocupa uma região de planaltos e de montanhas, ao Norte da área mais desenvolvida do Brasil, que se estende do Rio de Janeiro para o Sul. Foi povoado no período colonial por ondas de imigrantes, que se localizaram nos distritos de mineração de ouro e diamantes, cedo descobertos e explorados pelos portuguêses. Ao se esgotarem as mais ricas reservas de minerais preciosos, de caráter aluvionar, iniciou-se o ciclo lento da ocupação agrícola. Nesse período, enquanto por um lado a criação de grandes rebanhos bovinos contribuia para a dispersão dos habitantes por quase tôda a região, a cultura do café criava, por outro lado, condições para uma maior concentração de população no Sul e Sudoeste.

O Estado tem clima favorável, pois a elevação do território (média 600 metros) corrige em grande parte as temperaturas elevadas das baixas latitudes e o regime de chuvas é satisfatório. Como, entretanto, não possui grandes áreas contínuas de boas terras agrícolas, mas uma multidão de pequenas áreas de bons solos, o panorama da ocupação humana se definiu no aparecimento de grande número de pequenas cidades e vilas e em larga dispersão de populações agrícolas.

Novo fator veio alterar-lhe o quadro econômico, quando com o desenvolvimento do País se valorizaram as suas enormes reservas minerais, especialmente de ferro, manganês, calcáreo, cristal, mica, bauxita, pirita, etc., que se localizam nas áreas centrais em tôrno de sua Capital, Belo Horizonte.

A exportação dêsses minerais e a criação de indústrias locais de processamento tornaram-se o objetivo lógico para um desenvolvimento econômico equilibrado do Estado.

Contra o rápido surto de industrialização da riqueza mineral, atuavam entretanto os seguintes fatôres, principais: falta de combustíveis fósseis; deficiência e más condições técnicas das vias de transporte existentes, que atravessam regiões montanhosas; dispersão de população prêsa às atividades agrícolas; baixo índice de formação do capital e acentuada migração de capitais locais para áreas mais próximas do litoral, tais como as cidades do Rio de Janeiro e São Paulo.

Visando a criar condições favoráveis ao desenvolvimento industrial, vem o Govêrno do Estado dispendendo últimamente grandes esforços em dois setores básicos — energia elétrica e transportes — que constituem fatôres de estrangulamento econômico quando deficientes, e fatôres de germinação econômica quando adequados.

## II

A indústria da eletricidade no Estado de Minas ainda se caracteriza por grande número de pequenas usinas, predominantemente hidráulicas, servindo a cidades isoladas, indústrias ou pequenas vilas. Quando se elaborou em 1949 o Plano de Eletrificação atualmente em curso, existiam 439 usinas, abastecendo 688 localidades e operadas por 359 entidades distintas. A capacidade instalada era de 205 000 kW, conduzindo a uma capacidade média por usina de 462 kW e a uma capacidade média por localidade servida de, aproximadamente, 300 kW. Sendo a população do Estado, então, de cêrca de 8 milhões de habitantes, a capacidade instalada, per capita era da ordem de 25 watts apenas.

Além destas, existia um total de 3 400 pequenas usinas rurais, abastecendo fazendas e distritos, com uma capacidade global de 11 500 kW, constituídas na sua maioria de pequenos grupos hidroelétricos, que aproveitavam as abundantes quedas d'água dos riachos que descem das encostas montanhosas.

A esta dispersão física das usinas correspondia uma dispersão operativa da indústria, revelada pelo fato de que as 439 usinas existentes eram operadas por 359 entidades diversas — privadas ou municipais — com a média de 1,2 usina e 570 kW por entidade.

As maiores indústrias do Estado haviam construído usinas elétricas próprias, para suprirem a deficiência das emprêsas concessionárias locais.

Como é natural, tão grande dispersão da indústria conduziu à diversidade de características técnicas da energia distribuída. Cêrca de 57% das usinas de mais de 1 000 kW operam em 60 ciclos, enquanto que os restantes 43% operam em 50 ciclos, notando-se também enorme diversidade nas tensões de transmissão e distribuição.

## III

Desde 1940 o Govêrno do Estado começou a participar da industria da eletricidade, construindo algumas usinas pequenas (1 000 a 3 000 kW), com a finalidade de fomentar o desenvolvimento de regiões de interêsse, em que uma obra hidroelétrica se conjugou a um programa de fomento, à produção agrícola e ao turismo. Em 1940 inaugurou-se projeto de maior vulto: uma obra hidroelétrica se conjugou ao plano da criação de uma cidade industrial. Visando a incentivar a criação de indústrias e localizá-las segundo um projeto urbanístico preconcebido, construiu o Estado a Usina do Gafanhoto (13 000 kW), a 80 km. Oeste da cidade de Belo Horizonte, e junto a essa Capital criou um núcleo industrial satélite, provido de água, comunicações, urbanização, etc., cuja extensa área é cedida em lotes aos industriais, na base de arrendamento perpétuo.

Êsse projeto obteve notável êxito. Na Cidade Industrial de Belo Horizonte se instalaram dezenas de indústrias diversas, tais como as de cimento, refratários, tecidos, vagões ferroviários, etc., esgotando-se ràpidamente a capacidade da Usina do Gafanhoto.

O feliz resultado dêste empreendimento, aliado aos reflexos em Minas Gerais do surto econômico (principalmente industrial) ocorrido em todo o Brasil após a segunda guerra mundial, sugeriu a elaboração de um amplo estudo da economia do Estado como base de um plano de eletrificação de maior amplitude.

Sôbre os fundamentos de detalhada investigação da geografia econômica e humana, e das tendências demográficas e econômicas regionais, foi tentado um zoneamento industrial, em que se destacaram as áreas de maior vocação para a criação de indústrias e desenvolvimento urbano. Para essas áreas foram feitas estimativas de consumos energéticos e esboços preliminares dos sistemas elétricos indispensáveis ao seu desenvolvimento econômico.

A fig. 1 mostra, em relação ao sistema ferroviário existente, as principais áreas de tendência industrial do Estado de Minas e regiões vizinhas, classificadas pela natureza das indústrias predominantes. Essa figura sintetiza os resultados dos estudos procedidos na definição geográfica das áreas a serem atendidas com prioridade no Plano de Eletrificação do Estado. Neste plano se destaca a região central de Minas (em tôrno de Belo Horizonte), onde se executam no momento as principais obras de suprimento de energia elétrica, conforme se verá adiante.

## IV

A investigação econômica mencionada levou a duas conclusões básicas no que diz respeito à indústria da eletricidade. A primeira foi a de ação mais positiva e direta do ovêrno no campo da eletrificação, que que havia grandes áreas de marcada tendência industrial estranguladas por deficiência de suprimento de energia; a segunda, a de que a indústria existente não tinha recursos financeiros para se expandir na escala desejada e criar fontes pioneiras de energia. Tornava-se pois necessária uma ação mais positiva e direta do Govêrno no campo da eletrificação, que não se limitasse apenas a planejamentos e recomendações técnicas.

Ao justificar o projeto da lei que iria autorizar o Estado a criar companhias de economia mista de eletricidade e instituir um fundo especial de capitalização, o Governador Juscelino Kubitschek definiu as linhas gerais da politica a ser seguida, em um trecho da Mensagem ao Legislativo do Estado em 1952 que é reproduzido a seguir:

"1 — O Govêrno de Minas reconhece que, na fase atual de desenvolvimento do Estado, é indispensável o crescimento rápido e racional da indústria de energia elétrica, devendo o Govêrno incentivar a iniciativa privada e suplementá-la ou substitui-la quando deficiente ou inexistente. Reconhece, por conseguinte, como de interêsse público, sua intervenção no campo da eletrificação e julga que esta se deve enquadrar na estrutura do Plano Nacional de Eletrificação.

2 — Reconhece, também, não ser suficiente que um plano de eletrificação para regiões pouco desenvolvidas se baseie na extrapolação das tendências anteriores de consumo de energia. As dimensões e os parâmetros de um sistema elétrico que se projete, devem ser determinados pela função que êsse sistema possa vir a ter no desenvolvimento global do potencial econômico da região.

3 — Reconhece que esta politica de intervenção exigirá a aplicação de métodos diversos em regiões diferentes do Estado, para se atingir ao objetivo do suprimento adequado de energia elétrica; e que é dever o Govêrno definir com objetividade as obras que pretende executar em prazos determinados, para que a iniciativa privada possa também fixar seus objetivos, sem o risco de perturbações por parte da iniciativa governamental. Uma politica de intervenção do Estado, sem a fixação de objetivos definidos, é um elemento de inibição para a iniciativa privada, de conseqüências funestas.

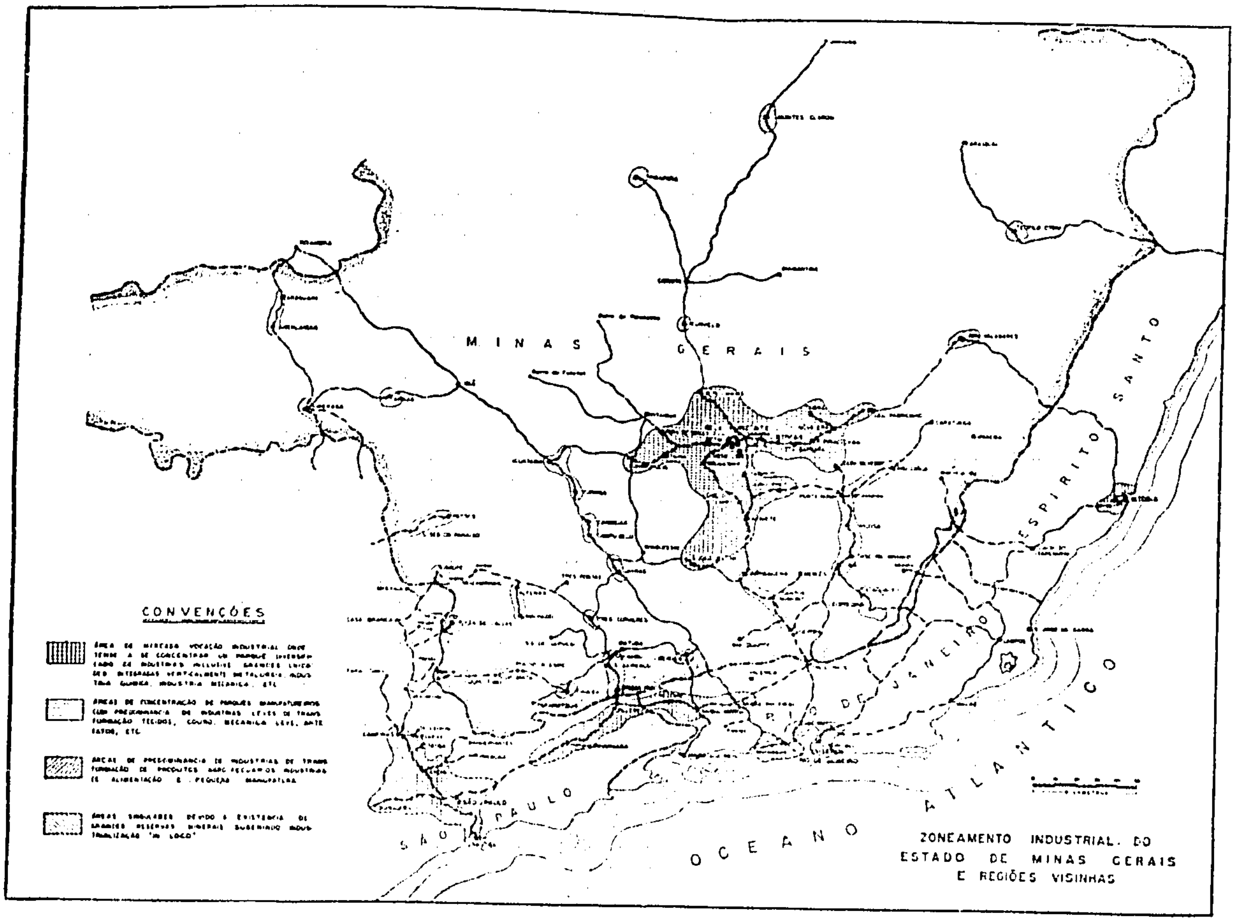

Fig. 1 — Áreas de marcada tendência industrial no Estado de Minas Gerais — regiões vizinhas.

4 — Reconhece mais que a técnica moderna de eletrificação aconselha a criação de grandes sistemas de usinas interligadas, com a concentração da produção de energia em grandes unidades, operadas sob normas de coordenação que ofereçam o máximo rendimento econômico; e não sendo possivel no momento criar e operar um único sistema em todo o território do Estado, deve o Govêrno procurar estruturar sistemas regionais, capazes de interligação futura. Para isto, deve agir no sentido de que sejam uniformizadas as caracteristicas técnicas de energia gerada e distribuida, através da padronização de ciclagem e de tensões de transmissão e distribuição, bem como especificados os equipamentos para um trabalho paralelo.

5 — Nas áreas de maior desenvolvimento, onde já existem sistemas elétricos de iniciativa privada, deve o Estado atuar no sentido de que se integrem nos sistemas regionais os serviços isolados de propriedade privada ou municipal, agindo como fiador, no sentido de que essa integração se faça em beneficio coletivo. Nessas áreas a atuação direta do Estado se deve restringir à construção e operação de grandes usinas e linhas de transmissão, vendendo energia aos sistemas de distribuição de propriedade privada ou municipal, para revenda aos consumidores. Essas usinas, cuja construção só se justificará quando a região necessitar de grandes reservas de energia de caráter pioneiro, isto é, de incentivo, deverão ser projetadas para operar como elemento básico de ligação de sistemas vizinhos de distribuição.

6 — Nas regiões menos desenvolvidas, onde por algum tempo só poderão existir usinas e pequenos grupos isolados, a atuação do Estado deve restringir-se a auxilios técnicos e facilidades para a obtenção de recursos financeiros por parte das emprêsas privadas ou municipais, providenciando, entretanto, no sentido de que estas unidades isoladas se possam, no futuro, integrar em sistemas regionais.

7 — Reconhecendo o Estado que um dos maiores entraves à execução dos sistemas elétricos é a falta de novos capitais; reconhecendo que os capitais estrangeiros tendem a condicionar o seu afluxo à existência de capitais nacionais que a êles se associem em identidade de riscos; reconhecendo também que não dispõe o Govêrno de rendas normais suficientes para o financiamento da expansão necessária de seus sistemas elétricos, julga indispensável atuar no sentido de criar um clima favorável ao investimento, na indústria de energia elétrica, de economias particulares ou coletivas, através de uma politica tarifária de estimulo a novas inversões, bem como no sentido da criação de fundos de eletrificação, para os quais seja solicitada a contribuição dos consumidores, indiretamente, através de taxas especiais, e, diretamente, sob a forma de tomada de ações ou aquisição de titulos de divida das emprêsas de eletricidade.

8 — Reconhece o Estado que, nas oportunidades em que fôr necessária sua intervenção direta na indústria da eletricidade, deverá organizar

entidades nos moldes das sociedades anônimas, para a operação dos sistemas que construir, e que é seu dever manter órgãos especializados para o estudo dos problemas de energia elétrica, capazes de auxiliar as emprêsas estatais e privadas e defender os interêsses dos consumidores."

## V

Assim definida uma politica clara de atuação do Govêrno do Estado na indústria da energia elétrica, foram criadas e organizadas várias companhias regionais, do tipo das sociedades anônimas, controladas por uma "holding" denominada Centrais Elétricas de Minas Gerais, S.A. — CEMIG.

A idéia de criar várias companhias regionais independentes, em vez de uma apenas, prende-se ao fato de ser mais fácil atrair capitais privados nas zonas a serem diretamente servidas por elas.

A formação do capital dessas companhias se fêz mediante a subscrição, por parte do Estado, da maioria de suas ações, contribuindo os particulares (indústrias, bancos e companhias de eletricidade locais) com o restante, em proporções variáveis, conforme os recursos de cada região.

A parte do Estado na formação dêsses capitais provém de uma taxa estadual especial, vinculada à CEMIG, que incide sôbre vendas e consignações na proporção de 0.4%. Essa taxa foi aprovada pelo Legislativo Estadual para um periodo de 5 anos, prevendo-se porém a sua prorrogação até que as companhias estejam em posição financeira de se expandirem dentro dos mercados normais de capital.

Está previsto que, à medida que as emprêsas forem atingindo um nivel satisfatório de rentabilidade, as ações do Estado serão progressivamente transferidas ao público, a fim de que a importância obtida seja reinvertida na expansão dos serviços.

Está previsto também que o Estado não reterá dividendos de suas ações, os quais serão reinvertidos nos serviços, com uma quota razoável reservada para um fundo de eletrificação rural e para inversões pioneiras não remuneráveis na sua fase incipiente.

## VI

A CEMIG estenderá eventualmente suas atividades por todo o Estado de Minas. Na etapa inicial, entretanto, começou pela região central, num raio de cêrca de 200 km em tôrno da cidade de Belo Horizonte (ver Fig. 2), que é a região de maior progresso industrial e onde, devido à exuberância das riquezas minerais, principalmente ferro, manganês, e calcáreo, ràpidamente se desenvolve uma concentração de indústrias básicas de alto consumo de eletricidade.

Desde os fins da última grande guerra, manifestou-se nessa região um surto industrial, caracterizado pelo aparecimento de várias indústrias metalúrgicas e derivadas, fábricas de cimento, etc., ao mesmo tempo que tomou impulso a eletrificação ferroviária. Prevê-se que êste surto seja acelerado por melhoramentos nas ferrovias existentes e pela construção de novas rodovias ligando Belo Horizonte aos três importantes portos de Santos, Rio de Janeiro e Vitória. Resultará disso o desenvolvimento industrial da região, que demandará um programa de eletrificação intenso, empreendido com bastante antecipação das necessidades.

A região a ser atendida pelo sistema inicial da CEMIG dispõe hoje de uma potência total instalada de cêrca de 150 000 kW, inteiramente esgotada. Até poucos anos atrás, a carga vinha crescendo de forma moderada, com um fator de carga anual da ordem de 50%, podendo tal crescimento ser atendido por um programa de novas instalações relativamente modesto.

Entretanto, com a afluência de indústrias eletro-metalúrgicas e a adoção da eletricidade para a calefação doméstica, alterou-se completamente êsse ritmo e não só a carga passou a crescer aos saltos, como o fator de carga aumentou consideràvelmente. Pelas indústrias já em construção e já programadas, estima-se que nos próximos 10 anos o consumo nessa região atinja 3 500 000 000 kWh por ano, com uma demanda de ordem de 600 000 kW.

Para atender a essa previsão, o programa inicial consiste na construção de 4 usinas com uma capacidade instalada total de 170 500 kW, e de um reservatório de acumulação estacional, para firmar a capacidade da Usina do Gafanhoto, além de uma rêde básica de linhas de transmissão e sub-estações abaixadoras.

As usinas e barragens em construção são especificamente as seguintes, conforme está indicado na Fig. n.° 2:

1) — Usina hidroelétrica de Salto Grande, a 150 Km Ne de Belo Horizonte, no rio Santo Antônio, afluente da margem esquerda do rio Doce. Com uma bacia hidrográfica de 9 200 km$^2$ e uma queda bruta de 100 m, a Usina terá uma capacidade de 100 000 kW. É a principal obra do programa, não só pela sua potência como pela complexidade da obra em si que consiste na construção de duas barragens, de cêrca de 8 300 m de túnel, de uma chaminé de equilíbrio de uma casa de fôrça do tipo convencional, para 4 unidades de 25 000 kW cada uma. Essa obra exigiu a construção de duas estradas de acesso, num total de 140 Km, para ligação com as estradas de ferro e de rodagem mais próximas. Prevê-se a inauguração dessa Usina no segundo semestre de 1955.

2) — Usina hidroelétrica de Itutinga, a 170 Km. Sw de Belo Horizonte, no Alto Rio Grande, formador do rio Paraná e do rio da Prata. Com uma bacia hidrográfica de 6 200 Km$^2$ e uma queda bruta de 30 m, terá uma capacidade instalada de 36 000 kW. Trata-se de obra relativamente compacta, consistindo em uma barragem mista de alvenaria e terra, um canal de acesso à tomada d'água e uma casa de fôrça ao tempo, com 3 unidades de 12 000 kW e previsão para uma eventual quarta, cada qual alimentada por um tubo forçado independente. Deverá estar concluida em 1954.

3) — Usina hidroelétrica do Piáu, a 170 Km ao Sul de Belo Horizonte, no rio Pomba, da bacia do rio Paraiba. Essa usina, com uma bacia hidrográfica de 370 km$^2$ terá uma queda de 210 m, com instalação de 27 000 kW em 3 unidades de 9 000 kW. Ao contrário das demais, ela operará na freqüência de 50 ciclos, visto ter de se enquadrar em sistema local dessa freqüência. Sua eventual interligação com as demais usinas, por meio de estações conversoras de freqüência, está porém prevista. Deverá concluir-se no 2.° semestre de 1954.

4) — Usina hidroelétrica de Tronqueiras, no rio Tronqueiras, afluente do rio Suassui Pequeno, que por sua vez é afluente da margem esquerda do rio Doce. Trata-se de um aproveitamento pequeno, de interêsse local, para atender ao abastecimento da cidade de Governador Valadares, que há poucos anos era simples aldeia e hoje é uma das mais prósperas cidades do Estado, com população avaliada em 40 000 habitantes. Com bacia hidrográfica de 500 km$^2$ e queda bruta de 120 m, essa Usina terá uma capacidade de 7 500 kW. Sua eventual interligação com o sistema geral também está prevista. Será concluida em 1954.

5) — Barragem do Cajuru-Reservatório de acumulação estacional, de 184 000 000 m$^3$ úteis, a montante da Usina do Gafanhoto, que tem uma capacidade instalada de 13 000 kW, numa queda de 30 m. Trata-se de barragem de concreto, de 23 m de altura e 438 m de comprimento, com pequena ombreira de terra na margem esquerda. Está prevista a instalação futura de uma unidade de 10 000 kW ao seu pé. Essa obra foi concluida em 1953.

Êsse programa de obras será executado em duas fases, consistindo a primeira na construção de quase tôdas as obras hidráulicas e na instalação de 96 000 kW, dos quais 50 000 kW em Salto Grande, 24 000 kW em Itutinga, 18 000 kW em Piáu e 4 000 kW em Tronqueiras, devendo seguir-se ràpidamente a instalação da capacidade restante prevista.

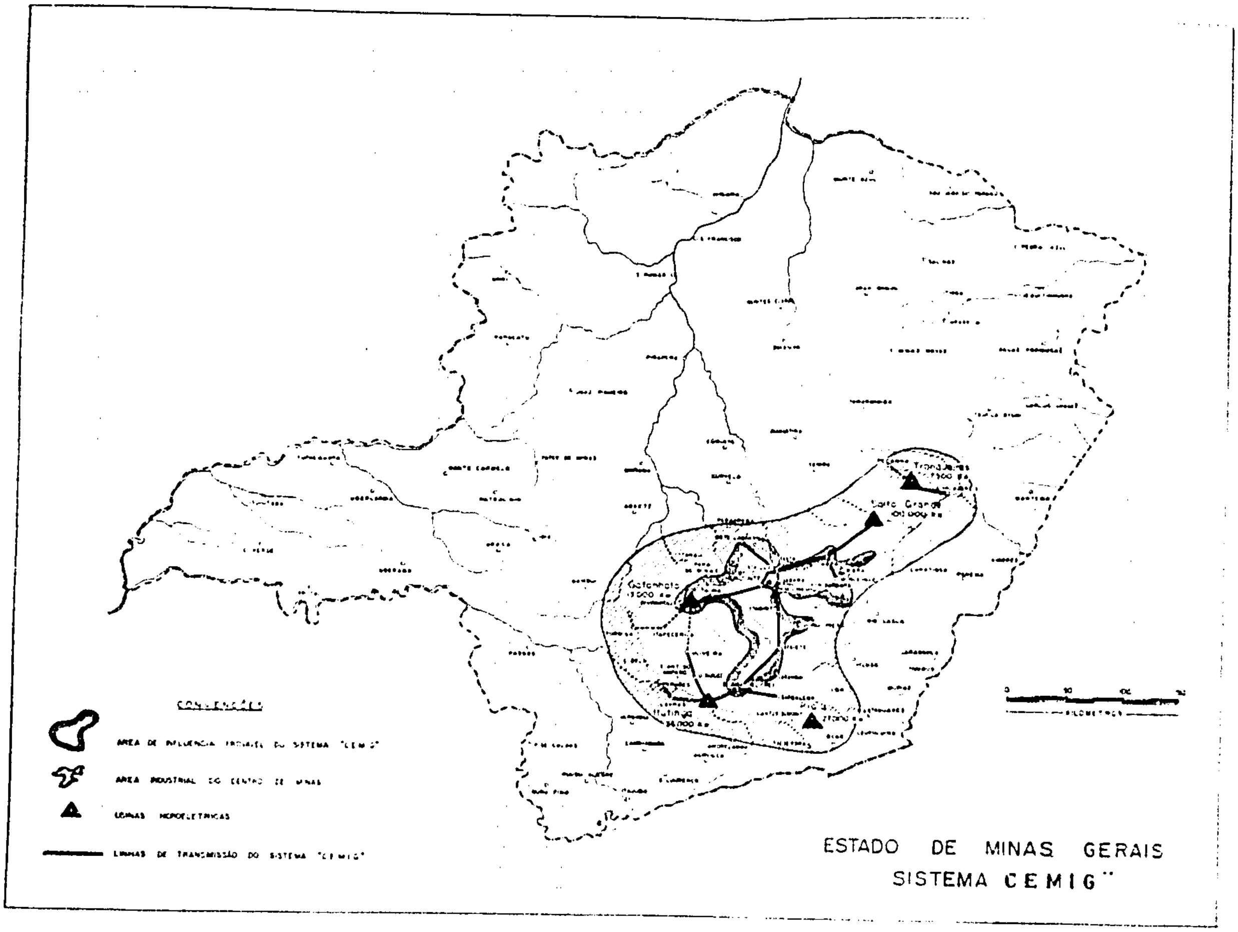

Fig. 2 — O Sistema Elétrico da Cemig e sua zona de influência.

Inicialmente as Usinas do Piáu e Tronqueiras funcionarão isoladas das restantes pelos motivos expostos. As demais, isto é, as Usinas de Salto Grande e Itutinga e a existente do Gafanhoto, operarão em sistema interligado, através de um anel de alta tensão construido em tôrno da cidade de Belo Horizonte, para onde convergirão as linhas de transmissão principais.

Apesar da tendência para a padronização da freqüência em 60 ciclos, ainda estamos longe, no Brasil, de uma uniformidade, havendo regiões importantes, como a da própria Capital do País, a cidade do Rio de Janeiro, onde a freqüência é de 50 ciclos. Há casos em que as duas freqüências co-existem em áreas relativamente restritas, como acontece na região a ser atravessada pelas linhas da CEMIG. Esta falta de padronização ocorre também com as tensões de transmissão, ainda enormemente diversificadas no território nacional, inclusive nas zonas de operação da CEMIG.

Seguindo porém a tendência já esboçada no País durante os últimos anos, o sistema da CEMIG está sendo construido para 60 ciclos e com tensões de 220 kV, 138 kV e 69 kV para transmissão e sub-transmissão, e 13.8 kV para distribuição, de maneira a acelerar a padronização e simplificar a interligação com sistemas vizinhos. Paralelamente, estão sendo feitas, sempre que possível, alterações nas voltagens das linhas já existentes, a fim de reduzir ao mínimo a diversidade de tensões.

Conforme se vê na Fig. 1, a região de Belo Horizonte está relativamente próxima dos dois maiores centros industriais do Brasil, compreendendo respectivamente as zonas das cidades do Rio de Janeiro e São Paulo; deve-se prever, portanto, num futuro não muito remoto, a integração geral dessas áreas num super-sistema elétrico de grande magnitude. Todo o planejamento da CEMIG está sendo feito, por isso, tendo em vista esta eventualidade.

## SUMMARY

The State of Minas Gerais, in area equivalent to France and one of the most important in Brazil is carrying out a Plan of Electrification conceived as basis of a general economic program for development of its abundant resources. The problems and solutions investigated are recurrent in under-developed regions.

I — The State (593 810 sq. km) extending north of São Paulo and west of Rio is located in a mountainous regions that was peopled initially by pioneers searching for gold and diamond resources. After the exhaustion of these then followed a cycle of agricultural occupation and cattle raising, which, because of the dispersal of the good agricultural land caused a spreading of population over a large area. Recently, following the general development of the country as a whole, this picture has changed towards industrialization due to the progressive increase in value of the State's abundant increase resources including iron, manganese, calcites, mica, etc.

This trend towards industrialization has however been hindered by lack of fossil fuels, defficient transport facilities, dispersion of the population and scarcity of capital. For the correction of these factors, the State is actively working in two basic plans: electric power and transport. This paper refers to the former.

II — At the present time the electrical industry in the State is made up of several small widely scattered hydroelectric stations. When the Electrification Plan, now on progress, was organized in 1943 there were 439 stations supplying 688 localities; total installed capacity was 205 mW and average of 462 kW per station or only 25 watts per capita. There is also lack of standartization of voltages and frequencies, 57% of the stations being of 60 c.p.s. and the remainder at 50 c.p.s.

III — The State begun to enter the power industry in 1940 when it built the 13 mW Gafanhoto hydroelectric plant as part of a program of fomentation of new industries which included the construction of a planned industrial development near Belo Horizonte. Various new industries grew in the area and rappidly absorbed the capacity of the station, which encouraged the government in undertaking a similar plan in a state wide scale. This plan was preceeded by a detailed investigation of the economic tendencies and related power requirements of the various different areas, particularly of these of industrial capabilities as shown in fig. 1.

IV — This investigation emphasized two points: First that the development of various large areas was jeopardized for lack of electrical supply. Secondly, the existing utilities did not have the necessary financial backing for the required expansion. As a consequence the Government decided to take direct action rather than limit itself to general planning and recommendations. The policy to be followed in the new program was expressed by the State Governor in his 1952 message to the State Legislation, the main directives of which were:

1) Expand the power resources for beyond the requirements indicated by past load trends in order to create, by the very abundance of power available, attractive conditions for a rappid industrialization, encouraging private enterprize and supplementing or replacing it when necessary.

2) Limit itself to the construction and operating of large plants and transmission network and to the wholesaling of power to local utilities and large industries. To include initially in the program isolated, regional systems, planned for future interconnection.

3) Since the governments normal resources could not support the financing of a large electrification program, create a special electrification fund and follow a rate policy that would encourage participation of private capital.

V — Having established the policy above, the State Government organized several joint stock corporations controlled by a holding company, Centrais Elétricas de Minas Gerais S/A — CEMIG. The creation of several regional companies was chosen in view of the greater facility of obtaining regional private capital. The subscription capital of the companies is made largerly by the State and in lesser proportion by private organizations (industries, banks, local utilities). State funds are obtained through a special State sales tax of 0.4% in bond to CEMIG. The State shares in the companies will be progressively transferred to the public and the corresponding funds used for expansion. The State will apply its dividends in expansion, rural electrification and non-rentable services.

VI — CEMIG will eventually extends its activity over all the State, but initially will operate in the central region only in a radius of 200 km around Belo Horizonte, which is the most progressive region, rich in iron, manganese, calcites and other minerals. This area has been developing very rappidly since the last world war and has now a total installed generating capacity of 150 mW entirely loaded up.
With the new electrometallurgical loads and other new industries in the next 10 years a load of 3 500 000 000 kW/yearly with a peak load of 600 mW is antecipated.
The initial program consists of the construction of 4 hydroelectric stations totalizing 170 500 kW and a seasonal storage reservoir, namely (see fig 2).

1) *Salto Grande Station* — 150 km NE of Belo Horizonte on the Santo Antônio river of the Doce river basin. Drainage area, 9 200 sq. km. gross head 100 m, capacity 100 mW. It includes two dams, 8 300 m of tunnel, surge tank and a power house with 4-25 mW units. Will operate in the second half of 1955.

2) *Itutinga Station* — 170 km SW of Belo Horizonte on the Rio Grande river of the River Plate basin. Drainage 6 200 sq. km, gross head 30 m, capacity 36 mW. A compact pro-

[illegible] with a concrete gravity dam, a short canal and an outdoor power house with three (provisionally) for an eventual [illegible] mW units. Will operate at the end of 1954.

(g) *Piau Station.* — 170 km South of Belo Horizonte on the [illegible] of the Paraiba river basin. Drainage area 370 sq km, gross head [illegible] m, capacity 27 mW in three 9 mW units. Will operate at the end of 1954.

(h) *Tronqueiras Station.* — On the Tronqueiras river of the Rio Doce basin, it is a small plant with capacity of 7 500 kW designed for local supply of the town of Governador Valadares. Will operate at the end of 1954.

(i) *Cajuru Dam.* — A seasonal storage reservoir completed in 1954 has a capacity of 184 000 cu m and firms the capacity of the Gafanhoto plant (13 000 kW).

These projects will be built in two steps with initial installation of [illegible] mW to be followed shortly by the remainder. Salto Grande, Itutinga and Gafanhoto will be interconnected through a transmission ring around Belo Horizonte.

Following the general trend in the country CEMIG's system is being built for 60 cycle frequency and transmission voltages of 220, 138 and 69 kV and primary distribution at 13.8 kV.

It is expected that in a not too remote future the CEMIG's system will be interconnected with the larger Rio de Janeiro and São Paulo systems.

## Resumo

O Estado de Minas Gerais, com uma área equivalente à da França e um dos mais importantes do Brasil, está executando um Plano de Eletrificação concebido como a base de um programa econômico geral para o desenvolvimento de seus abundantes recursos naturais. Os problemas e soluções para êsse fim estudadas são periódicos em regiões sub-desenvolvidas.

I — O Estado (593 810 km²), extendendo-se do norte de São Paulo a oeste do Rio de Janeiro, localiza-se em uma região montanhosa originalmente habitada por povos pioneiros à procura de ouro e diamantes. Após o esgotamento dessas riquezas naturais, seguiu-se um período de atividade agrícola e criação de gado, ocupações essas que, em conseqüência da dispersão das terras aproveitáveis, resultaram na distribuição da população sôbre grandes áreas. Recentemente, seguindo tendência observada em todo o país, êsse quadro tem evoluído no sentido da industrialização, para o que tem concorrido o aumento progressivo observado no valor dos abundantes depósitos de ferro, manganês, calcáreos, mica, etc., existentes no Estado.

Entretanto, essa tendência para a industrialização tem sido perturbada pela falta de combustíveis fósseis, deficiência de meios de transporte, dispersão da população e escassez de capital. Para correção dêsses fatôres, o Estado está ativamente trabalhando em dois planos básicos: energia elétrica e transportes. A presente monografia refere-se ao primeiro dêsses planos.

II — No momento presente a indústria da energia elétrica é constituida por grande número de pequenas usinas hidroelétricas espalhadas por todo o Estado. Em 1943, ano em que foi organizado o Plano de Eletrificação atualmente em execução, havia 439 usinas fornecendo energia a 688 localidades; sua capacidade total instalada importava em 205 mW, ou seja, uma média de 462 kW por usina e 25 watts per capita. Observa-se também a falta de padronização de voltagem e freqüência, 57% das usinas operando em 60 c.p.s. e as restantes na de 50 c.p.s.

III — O Estado começou a participar da indústria da energia elétrica em 1940, quando construiu a usina hidroelétrica de Gafanhoto, com a potência de 13 mW, como parte de um programa de fomento de novas indústrias, no geral foi incluido o estabelecimento de um parque industrial planificado nas proximidades de Belo Horizonte, a capital do Estado. Várias indústrias novas instalaram-se nessa área e absorveram ràpidamente a capacidade da referida usina hidroelétrica, o que estimulou o Govêrno a levar a efeito plano semelhante de maior envergadura, em escala estadual. Para êsse fim foram realizados estudos detalhados das tendências econômicas das várias regiões e avaliadas as respectivas necessidades energéticas, particularmente em relação à potencialidade industrial, como ilustra a fig. 1.

IV — Dois fatos foram evidenciados pelos estudos realizados: 1) o desenvolvimento de várias regiões extensas estava sendo prejudicado pela falta de energia; 2) as emprêsas fornecedoras existentes não dispunham do apoio financeiro necessário para a indispensável expansão de seus sistemas. À vista disso o Govêrno decidiu agir diretamente, ao invés de se restringir ao planejamento geral e a fazer recomendações. A política a ser adotada nesse novo programa foi exposta pelo Governador do Estado na mensagem que dirigiu em 1952 à Câmara Estadual, cujas diretivas principais foram as seguintes:

1) Expandir as disponibilidades de energia bastante acima das necessidades previstas pelo crescimento de carga no passado, a fim de prover, mediante a abundância de energia, condições favoráveis à rápida industrialização, estimulando a iniciativa privada e suplementando-a ou a substituindo quando necessário.

2) Limitar a atividade à construção de grandes usinas geradoras e rêdes de transmissão, e à venda de energia em grosso aos con-

cessionários locais e às grandes indústrias. Incluir inicialmente no programa sistemas regionais isolados mas planejados tendo em vista sua futura interligação.

3) Em virtude de serem os recursos normais do Govêrno insuficientes para suportar o financiamento de um grande plano de eletrificação, criar um fundo especial para êsse fim e adotar uma política tarifária que estimule a participação do capital privado.

V — Estabelecidas as diretivas acima, o Govêrno do Estado organizou várias sociedades anônimas controladas por uma "holding". Centrais Elétricas de Minas Gerais S.A. (CEMIG). A criação de várias sociedades regionais foi decidida a fim de facilitar a obtenção de capitais privados locais. A subscrição do capital foi feita em sua maior parte pelo Estado e em proporção menor por organizações privadas (indústrias, bancos, concessionários e serviços públicos). Os fundos para a participação do Estado resultaram de um impôsto estadual especial de 0.4% sôbre vendas penhorado à CEMIG. As ações adquiridas pelo Estado serão progressivamente transferidas ao público, sendo os fundos correspondentes utilizados na expansão dos sistemas. O Estado aplicará os dividendos que lhe couberem à expansão, eletrificação rural e serviços sem rendimento.

VI — A CEMIG estenderá suas atividades, eventualmente, a todo o Estado, mas inicialmente operará na região central apenas num raio de 200 km em volta de Belo Horizonte, que é a região de maior progresso, rica em ferro, manganês, calcites e outros minerais. Essa área tem se desenvolvido muito ràpidamente desde a última guerra mundial e possui, agora, uma capacidade geradora total instalada de 150 mW inteiramente tomada.

Com as novas cargas eletrometalúrgicas e as de outras novas indústrias, previu-se para os próximos 10 anos uma necessidade de ...... 3.500.000.000 kWh anuais com uma carga máxima de 600 mW.

O programa inicial consiste na construção de 4 usinas hidroelétricas totalizando 170 500 kW e um reservatório de acumulação sasonal, a saber (veja fig. 2).

1) *Usina de Salto Grande* — a 150 km NE de Belo Horizonte no rio Santo Antônio da bacia do rio Doce. Área de drenagem 9 200 km², queda bruta 100 m, capacidade 100 mW. Incluindo duas barragens, 8 300 m de túnel, um castelo d'água e uma casa de máquinas de fôrça motriz com 4-25 mW unidades. Funcionará na segunda metade de 1955.

2) *Usina de Itutinga* — a 170 km SO de Belo Horizonte no rio Rio Grande da bacia do Rio da Prata. Drenagem 6 200 km², queda bruta 30 m, capacidade 36 mW. Um projeto compacto

com uma barragem de concreto, um curto canal e uma casa externa de máquinas de fôrça motriz com três (possivelmente uma eventual quarta) 12 mW unidades. Funcionará no fim de 1954.

3) *Usina de Piãu* — a 170 km ao Sul de Belo Horizonte no rio Pomba da bacia do rio Paraiba. Área de drenagem 370 $km^2$, queda bruta 210 m, capacidade 27 mW com três 9 mW unidades. Funcionará no fim de 1954.

4) *Usina de Tronqueiras* — No rio Tronqueiras da bacia do rio Doce, sendo uma pequena usina com capacidade de 7 500 kW designada para suprimento local da cidade de Governador Valadares. Funcionará no fim de 1954.

5) *Barragem de Cajuru* — Um reservatório de acumulação sasonal concluída em 1953, tem a capacidade de 184 000 $m^3$ e firma a capacidade da usina de Gafanhoto (13 000 kW).

Êsses projetos serão realizados em duas partes, com a instalação inicial de 96 mW a ser seguida, em breve, pela parte restante. As usinas de Salto Grande, Itutinga e Gafanhoto serão interconectadas através de um circulo de transmissão em volta de Belo Horizonte.

De acôrdo com a orientação geral no pais, o sistema da CEMIG está sendo construido para a freqüência de 60 ciclos, voltagens de transmissão de 220, 138 e 69 kV, e distribuição primária a 13,8 kV.

Espera-se que em futuro não muito remoto, o sistema da CEMIG será interconectado com os sistemas maiores do Rio de Janeiro e S. Paulo.

## Résumé

L'État de Minas Gerais, dont la superficie est égale à celle de la France, et que est l'un des États les plus importants du Brésil, est en train d'exécuter un Plan d'Électrification devant servir de base à un programme économique général pour le développement de ses abondantes ressources. Les problèmes et les solutions proposées sont caractéristiques des régions sous-développées.

I — L'État (593.810 km. carrés) s'étend au Nord de São Paulo et à l'Ouest de Rio de Janeiro et est situé dans une région montagneuse peuplée d'abord par des pionniers à la recherche d'or et de diamants. Après l'épuisement de ces richesses, il s'ensuivit un cycle d'activité agricole et d'élevage de bétail qui, en vue de la grande distance que sépare les régions aptes à l'agriculture, causa le dispersement de la population sur une vaste étendue. Récemment, comme conséquence du développement général du pays, et grâce à l'accroissement progressif de la valeur des grandes ressources de l'État en fer, manganèse, calcite, mica etc., l'industrialisation a pris le dessus. Cette tendance à l'industrialisation a cependant rencontré des obstacles: le manque de combustibles fossiles, l'insuffisance des moyens de transport, la dispersion de la population et la rareté des capitaux. Afin de remédier à cet état de choses, Minas Gerais travaille aujourd'hui activement à l'exécution de deux plans basiques: l'énergie électrique et les transports. Le présente monographie s'occupe du premier de ces plans.

II — A présent, l'énergie électrique dans l'État de Minas est fournie par plusieurs petites centrales hidroélectriques très disseminées. Lorsque son Plan d'Électrification, en voie d'éxécution, fut elaboré en 1943, il y avait 439 centrales dont dependaient 688 localités; la capacité totale installée était de 205 mW, avec une moyenne de 462 kW par centrale ou à peine 25 watts par habitant. On observe également un manque de standardisation des voltages et des fréquences: 57% des centrales à 60 c.p.s. et le reste à 50 c.p.s.

III — Ce n'est qu'en 1940 que l'État de Minas commença à développer l'industrie électrique, par la construction de la centrale hydroélectrique de "Gafanhoto", de 13 mW, comprise dans un programme de développement de nouvelles industries selon un plan industriel aux environs de Belo Horizonte. Plusieurs industries nouvelles s'installèrent dans cette région et absorbèrent rapidement la capacité de la centrale, ce qui encouragea le Gouvernement à entreprendre l'éxecution d'un plan semblable pour tout l'État. Ce plan fut précédé par une enquête minutieuse sur les tendances économiques et les besoins correspondants, en énergie, des différentes régions, en particulier celles d'une certaine possibilité industrielle (fig. 1).

IV — Lenquête fit ressortir deux points: (a) le développement de plusieurs vastes régions était entravé par le manque d'électricité; (b) les moyens existants n'avaient pas le support financier capable d'assurer l'expansion désirée. Le Gouvernement décida, comme conséquence, d'entreprendre une action directe au lieu de se borner aux projets et recommendations d'ordre général. La politique à suivre selon le nouveau programme fut indiquée par le Gouverneur de l'État à l'Assemblée Législative de Minas Gerais dans son Exposé de 1952, dont voici les principales directives:

1) Augmenter les ressources en énergie bien au-delà des besoins résultant des tendances de charge du passé, afin de créer, par une grande abondance d'énergie disponible, des conditions attrayantes pour une rapide industrialisation, encourageant l'entreprise privée, quitte à la compléter ou à la remplaçant en cas de nécessité.

2) Se limiter à la construction et à l'opération de grandes centrales et de vastes réseaux de transmission, pour vendre en gros l'énergie aux services publics et aux grandes industries. Considerer d'abord, dans le programme, des systèmes régionaux isolés, mais projetés en vue d'une ultérieure interconnection.

3) Étant donné que les ressources ordinaires du Gouvernement ne pourraient pas supporter le financement d'un vaste programme d'électrification, crées un fond spécial d'électrification et adopter pour la fixation des tarifs une politique capable d'encourager la participation du capital privé.

V — D'accord avec cette politique, le Gouvernement de Minas organisa plusieurs sociétés d'économie mixte contrôlées par une compagnie "holding", la "Centrais Elétricas de Minas Gerais S.A. — CEMIG". La création de plusieurs compagnies régionales a été adoptée en vue d'une plus grande facilité pour obtenir le capital régional privé. Le capital de ces compagnies sera souscrit en plus de 50% par l'État, le reste devant provenir d'organisations privées (industries, banques, services locaux). Les fonds de l'État seront obtenus au moyen d'un impôt spécial, sur les ventes, de 0,4%, en Bons pour la CEMIG. Les actions de l'État dans ces compagnies seront progressivement transférées au public et les fonds correspondants seront destinés au projet d'expansion. Les profits de l'État seront appliqués à l'expansion, à l'électrification rurale et à des services non lucratifs.

VI — La CEMIG étendra éventuellement ses activités au-delà des frontières de l'État, mais elle agira d'abord dans la région centrale, sur un rayon de 200 km. autour de Belo Horizonte, la plus developpée, riche en fer, en manganèse, en calcites et autres mineraux. Cette partie de l'État a été développée très rapidement depuis la dernière guerre; elle a maintenant une capacité totale d'énergie installée de 150 mW entièrement utilisée.

Avec les exigences récentes électrométallurgiques et celles d'autres industries nouvelles on prévoit pour les dix années à venir un besoin de 3.500.000.000 kWh annuels avec une pointe de charge de 600 mW.

Le programme initial consiste dans la construction de quatre centrales hydroélectriques avec un puissance globale de 170.500 kW et un réservoir d'accumulation saisonnier (fig. 2).

1.° — La Centrale de "Salto Grande", située à 150 km. au N.E. de Belo Horizonte sur le fleuve Santo Antônio, du bassin du fleuve Doce. Superficie de drainage, 9.200 km. carrés; chute totale, 100 m.; puissance 100 mW. Elle comprend deux barrages, 8.300 m. de tunnel, un château d'eau et une centrale avec 4 groupes générateurs de 24 mW chaque. L'inauguration de cette centrale est prévue pour la seconde moitié de 1955.

2.° — La centrale de "Itutinga", située à 170 km. au S.W. de Belo Horizonte, sur le rio Grande, du bassin du rio Prata. Drainage, 6.200 km. carrés; chute totale, 30 m.; puissance, 36 mW. Le projet comprend un déversoir en béton, un court canal et une centrale extérieure avec 3 (et éventuellement 4) groupes de 12 mW chaque. Elle doit entrer en fonctionnement vers la fin de 1954.

3.° — La centrale de "Piáu", située à 170 km. au Sud de Belo Horizonte, sur le fleuve Pomba, du bassin du fleuve Paraiba. Superficie da drainage, 370 km. carrés; chute 210 m.; puissance, 27 mW, avec 3 groupes de 9 mW chaque. Elle entrera en fonctionnement vers la fin de 1954.

4.° — La centrale de "Tronqueiras", sur le fleuve Tronqueiras, du bassin du rio Doce. Petite centrale de 7.500 kW, destinée aux besoins locaux de la mairie de Governador Valadares. Elle entrera en fonctionnement à la fin de 1954.

5.° — Le barrage de "Cajurú", réservoir d'accumulation saisonnier de 184.000 mètres cubes, terminé en 1953, ayant pour but d'assurer la puissance de la centrale de "Gafanhoto" (13.000 kW).

Ces projets seront construits en deux étapes: l'installation initiale de 96 mW, suivie de près par le reste. "Salto Grande", "Itutinga" et "Gafanhoto" seront reliées par un anneau de transmission tout autour de Belo Horizonte.

Pour suivre la tendance générale du pays, le système de la CEMIG adoptera la fréquence de 60 cycles, et des voltages de transmission de 220, 138 et 69 kV; la distribution primaire se fera à 13.8 kV.

On espère que, dans un futur peu éloigné, le système de la CEMIG sera relié aux grands systèmes de Rio de Janeiro et de São Paulo.

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# TÉLÉPHONIE, TÉLÉMESURE ET TÉLÉCOMMANDE DANS LES RÉSEAUX HAUTE TENSION

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## A) OBJET DE LA TRANSMISSION

Il ne fait aucun doute que la qualité des liaisons de télécommunication entre les stations qui produisent, répartissent et utilisent l'énergie électrique est déterminante. D'une part, la sécurité de service du réseau et la rapidité avec laquelle les dérangements sont supprimés, et d'autre part la rentabilité de l'ensemble de l'installation haute tension dépendent de la coopération facile et rapide du personnel chargé du service et de l'entretien de l'installation réparti sur de vastes territoires. Cette étroite coordination ne peut être assurée que par un réseau de communication constamment prêt au service.

Dans les pays où la télécommunication est développée, la question de savoir à quel point on peut utiliser le réseau public de communication des PTT pour le service des réseaux haute tension joue un grand rôle. Une telle utilisation n'est pas recommandée. Le plus souvent, les usines électriques construisent et entretiennent elles-mêmes la plus grande partie de leur réseau de communication, afin que les lignes nécessaires à l'exploitation soient disponibles sans délais d'attent. En même temps, les frais d'acquisition et les frais courants peuvent être maintenus dans des limites aussi réduites que possible, et le personnel propre des usines peut remédier immédiatement aux dérangements survenant sur les lignes de communication. Sur les parcours secondaires, les lignes des PTT sont louées pour de courtes distances si l'on se trouve dans ce cas en face de conditions favorables au point de vue technique et économique.

Dans les pays où la télécommunication en est à son stade primitif, le réseau de répartition d'énergie est établi souvent longtemps avant le réseau de télécommunication public, si bien que la question d'utiliser des lignes étrangères aux usines électriques n'est pas à débattre.

Alors que le réseau public de communication comporte entre deux points terminaux des forts faisceaux, par exemple des voies téléphoniques entre les bureaux interurbains de deux grandes villes, on ne nécessite en comparaison que de faibles faisceaux de voies pour les lignes de communication entre les stations d'un réseau haute tension et en présence des mêmes distances géographiques. Quelques liaisons téléphoniques suffisent, ainsi que quelques voies pour la télémesure, le télécomptage ou la protection du réseau.

### 1. *Téléphonie et télégraphie*

Le moyen le plus répondu pour la transmission des messages de tous genres est de loin le téléphone, qui est utilisé egalement de préférence pour le service des usines électriques. Les voies de transmission doivent être appropriées à une exploitation dans les deux directions de trafic et transmettre une bande de fréquences comprise entre 300 et 2400 c/s au moins. Pour la transmission sur des lignes haute tension, on se limite à cette bande de fréquences, car sinon la pénurie d'ondes existant dans la gamme de fréquences étroite disponible serait accrue. Des expériences acquises au cours de longues années dans un grand nombre de pays ont montré que, de cette façon, une exploitation parfaite pouvait être assurée. En cas de lignes aménagées spécialement pour la téléphonie, on utilise également une bande de fréquences comprise entre 300 et 3400 c/s.

En plus de la transmission de la voix, il est nécessaire de transmettre d'autres signaux pour l'établissement des communications. Sur les lignes secondaires, un appel de 25 c/s suffit. Sur les parcours principaux, les tronçons désirés sont interconnectés en une liaison à grande distance à l'aide d'équipements de sélecteurs commandés par des impulsions de sélection. L'appel vers l'abonné éloigné est déclenché dans le dernier équipement de cette chaine. Pour la transmission de signaux de sélection, on ne nécessite qu'une voie pour une bande de fréquences sensiblement étroite, du fait que les signaux émis par le disque d'appel ont une fréquence de 10 impulsions par seconde. Ces impulsions sont transmises à des voies téléphoniques car la sélection précède toujours la conversation.

La transmission téléphonique était limitée en premier lieu à des lignes séparées. Peu à peu, s'est constitué un ensemble de réseaux de télécommunication sans préparation préalable d'un plan bien déterminé. Pour cette raison, on a rencontré dans la pratique de grandes difficultés lors de l'utilisation d'équipements d'ancienne construction. De tels équipements peuvent faire naître également certains inconvénients quant à l'établissement rapide des liaisons téléphoniques. Il importe donc de remplacer avec une certaine largeur de vue les équipements téléphoniques d'ancien modèle par des équipements modernes sur les parcours principaux, et de continuer à exploiter les anciens équipements sur les lignes secondaires. Seule cette mesure permet d'obtenir les conditions requises pour un trafic téléphonique à grande distance parfait, à travers de nombreux tronçons, en ce qui concerne la transmission des impulsions de sélection et la qualité de la transmission de la voix.

La télégraphie sous forme de téléimprimeurs est un moyen de communication beaucoup plus récent que la téléphonie et permet également la transmission de messages de tous genres. Cette technique n'a cependant pas été encore jusqu'à présent mise à profit dans la même mesure. Un personnel instruit spécialement et familiarisé avec la manipulation d'un clavier de machine à écrire est nécessaire pour la transmission des messages par téléimprimeurs. Pour certains types de messages, les téléimprimeurs offrent malgré tout pour l'exploitation des usines électriques de grands avantages en comparaison de la téléphonie, si bien que l'introduction des téléimprimeurs s'accroît de plus en plus.

Les voies de transmission pour la télégraphie doivent également être appropriées à un service dans les deux directions de trafic, mais elles sont prévues pour une bande de fréquences relativement étroite par rapport à la téléphonie. Les téléimprimeurs fonctionnent d'après l'alphabet international No. 2 avec une vitesse de 7 signes par seconde environ. Une voie de transmission de 80 c/s de large suffit.

Pour des raisons économiques, un réseau de téléimprimeurs propre au service d'une usine d'énergie électrique ne peut pas être aménagé sur tous les parcours avec des voies de transmission exclusivement réservées à la télégraphie. C'est pourquoi l'on exploite très souvent les liaisons téléphoniques et de téléimprimeurs sur les mêmes voies de transmission. On distingue les abonnés téléphoniques et de téléimprimeurs à l'aide de numéros d'appel différents, et l'on utilise rarement les téléimprimeurs pendant les heures de trafic intense du réseau téléphonique, seulement pour la transmission de messages brefs mais importants, et pour ce motif écrits. Par contre, les téléimprimeurs sont utilisés dans les heures de faible trafic pour de longs messages ne présentant pas une grande urgence, et transmis autant que possible à l'aide de transmetteurs automatiques.

L'établissement d'une liaison entre téléimprimeurs à laide d'impulsions de sélection s'effectue de la même façon que pour une liaison téléphonique.

## 2. *Télémesure et télécomptage*

La télémesure et le télécomptage de valeurs électriques représentent une transmission de messages spéciaux n'offrant d'intérêt que pour les réseaux de distribution d'énergie. Aussi bien pour la télémesure, c'est-à-dire pour la télétransmission de valeurs momentanées, telles que puissance, courant, tension, etc. que pour le télécomptage (télétransmission de valeurs d'énergie transportée), les voies de transmission ne sont exploitées que dans une direction de trafic, à savoir de l'émetteur vers le récepteur. La largeur de la bande de fréquences à transmettre dépend pour la télémesure du principe utilisé, c'est-à-dire des valeurs auxiliaires dans lesquelles les valeurs de mesure sont transformées au lieu d'émission pour la télétransmission. Les procédés par impulsions à fréquence réduite sont réalisables avec des voies à bande étroite que sont prévues en général pour des raisons d'uniformité, avec une largeur de bande de 80 c/s comme pour les voies de téléimprimeurs. D'autres méthodes de télémesure qui utilisent comme valeur auxiliaire une fréquence variable dans de grandes limites ou des impulsions à fréquence plus élevée exigent des bandes de fréquences plus larges. En règle générale, on n'envisage cependant aucun système de télémesure dont le besoin en fréquences surpasse la largeur de bande d'une voie téléphonique, afin de pouvoir utiliser un schéma de fréquences uniforme pour les voies téléphoniques et les voies de télémesure.

Pour le télécomptage, on n'utilise en général que des impulsions comme valeur auxiliaire pour la transmission, chaque impulsion correspondant à une quantité déterminée des unités de mesure à compter.

Des erreurs de transmission dans les systèmes de télémesure parviennent au récepteur aussi longtemps qu'un dérangement existe. Dans les systèmes de télécomptage par contre, les erreurs provenant de dérangements de transmission s'additionnent dans les stations de réception pendant toute une période d'enregistrement. C'est pourquoi les voies de télécomptage requièrent une protection beaucoup plus sévère contre les erreurs de transmission que les voies de télémesure.

La télétransmission de valeurs de mesure et de comptage crée la possibilité d'additionner dans un poste de contrôle les valeurs provenant de points très éloignés les uns des autres. Les sommes obtenues permettent de se rendre compte constamment de la répartition de l'énergie dans le réseau. Afin d'éviter des informations erronées résultant du manque d'un terme de la somme au lieu de réception, les termes des sommes télétransmis sont surveillés en permanence par des équipements automatiques dans de telles installations enregistreuses.

### 3. *Télécommande et téléréglage*

Alors que la téléphonie et la télégraphie n'assurent dans l'exploitation du réseau que les liaisons entre le personnel, le télémesure et le télécomptage communiquent au poste de contrôle du répartiteur de charge à travers de grandes distances les valeurs mesurées et comptées en permanence sans exiger la présence d'un opérateur au lieu d'émission. Pour un répartiteur de charge, un équipement téléphonique et un équipement de télémesure suffisent, si les postes de contrôle éloignés disposent de personnel chargé d'exécuter les ordres donnés. La télécommande permet en plus d'exécuter sans personnel toutes les opérations de connexion dans les postes éloignés et de transmettre les informations nécessaires vers le répartiteur de charge. Le téléréglage consiste par exemple en un actionnement direct du régulateur des machines sans intervention de personnel.

La télécommande ainsi que le téléréglage représentent ainsi des processus, pour lesquels des erreurs de transmission pourraient occasionner directement un actionnement erroné des équipements à courant fort. Afin d'éviter absolument de telles erreurs, les équipements de télécommande et de téléréglage sont toujours prévus de telle façon que, en cas d'un dérangement dans la transmission, les équipements à courant fort ne soient pas actionnés et que les processus de commande et de réglage ne puissent agir qu'après la suppression du dérangement.

Le répartiteur de charge disposé d'un grand nombre de moyens auxiliaires qui ont été créés pour donner un aperçu rapide de l'état d'un réseau étendu, tels que schémas symboliques du réseau, installations enregistreuses de valeurs de mesure, etc.

Toutefois, l'activité de l'opérateur du répartiteur de charge doit être limitée, car celui-ci serait surchargé de travail et perdrait toute impression d'ensemble sur un réseau étendu. La télécommande doit par conséquent être toujours réservée dans son utilisation à des secteurs facilement contrôlables d'un réseau haute tension. Les opérations de connexion sont exécutées à partir de plusieurs répartiteurs de charge de district. Pour le téléréglage par contre, aucun personnel n'intervient, si bien que de telles restrictions ne sont pas à considérer.

Les voies de télécommande sont toujours prévues pour une exploitation dans les deux directions de trafic. Dans une direction, on transmet la commande, dans l'autre direction des informations concernant l'exécution de la commande. Des informations peuvent être également transmises sans opération de commande préalable. Le téléréglage consiste parfois à transmettre certaines valeurs de mesure, les récepteurs de mesure agissant sur un régulateur aménagé au lieu de réglage. Dans ce cas, on ne nécessite qu'une direction de transmission. Si la machine d'une station éloignée est commandée, il faut prévoir deux directions de transmission, l'une pour le réglage, l'autre pour la transmission du résultat du réglage.

## 4. *Protection du réseau*

La télécommande consiste en général à exécuter à une grande distance dans l'espace de quelques secondes, le processus de connexion désiré. La protection du réseau doit garantir la déconnexion des commutateurs de puissance haute tension en quelques fractions de seconde, aux extrémités d'une ligne à courant triphasé défectueuse, sans l'intervention de personnel.

La protection du réseau est assurée en grande partie par des jeux de relais de protection modernes qui sont raccordés aux jeux de transformateurs de mesure aux extrémités des lignes, sans que des signaux doivent être transmis entre les extrémités des lignes. S'il s'agit cependant d'aménager une protection de fonctionnement particulièrement rapide devant déconnecter avec la même rapidité des défectuosités un point quelconque de la ligne, l'installation normale doit être complétée par un dispositif de protection rapide. On nécessite alors des voies de transmission entre les points extrêmes de la ligne à protéger. En cas normal, ce sont des voies à fréquences porteuses sur les lignes haute tension.

Ces voies de transmission sont exploitées dans les deux directions de trafic. Il est souvent rationnel de les combiner avec les voies de transmission téléphoniques. Pendant la brève période de transmission des signaux de protection, on peut déconnecter les liaisons téléphoniques, ce qui ne dérange pas les interlocuteurs. En cas de transmission à fréquences porteuses, on obtient ainsi une grande sécurité contre les dérangements de transmission qui peuvent survenir par suite du dérangement de la ligne haute tension.

## B) LES VOIES DE TRANSMISSION

Différents moyens se présentent pour la transmission des messages que nous avons exposée ci-dessus. Le moyen le plus simple et utilisé souvent est représenté par des lignes en fils prévues seulement pour la transmission des messages. Ces lignes peuvent être des câbles ou des lignes aériennes qui sont exploités à l'aide des moyens connus de télécommunication, tout en soulignant le fait que ces lignes sont influencées par les lignes à courant fort situées dans leur voisinage, et que des mesures de protection appropriées sont à prendre dans ce cas. Les lignes peuvent être envisagées pour la transmission de messages à l'aide d'équipements à fréquences porteuses, car elles présentent de très bonnes propriétés de transmission pour ces fréquences. Cette solution est adoptée très souvent, de sorte que la plus grande partie de toutes les voies de communication utilisent les lignes à courant fort.

Il existe en plus des cas pour lesquels une transmission radio-électrique paraît plus favorable. A l'encontre des autres moyens de transmission, il existe alors la possibilité d'un trafic omnidirectionnel. Des faisceaux de voies de communication entre deux ou plusieurs points peuvent être aménagés également à l'aide de liaisons hertziennes en insérant éventuellement des stations relais.

### 1. *Lignes de communication spéciales*

Si la transmission des messages doit être indépendante de l'état des lignes haute tension, il est recommandé d'utiliser des lignes spéciales. On envisage alors dans ce but des câbles ou des lignes aériennes. En raison des frais élevés à couvrir pour les mâts, on prévoit de préférence la suspension des câbles aériens et des lignes aériennes aux mâts de la ligne haute tension. Des câbles souterrains peuvent être posés aussi bien le long des lignes haute tension qu'à distance de celles-ci. Toutes ces lignes sont plus ou moins influencées par les lignes haute tension. Il en résulte des perturbations dans les lignes et un risque de danger pour les lignes, et les équipements de télécommunication qui y sont raccordés ainsi que pour le personnel de service. Des mesures de protection doivent par conséquent être prises.

Ce sont les lignes aériennes qui subissent le plus l'influence des lignes haute tension, à savoir l'influence du champ électrique et du champ magnétique de ces dernières. Le champ électrique provoque une tension transversale en cas d'asymétrie des capacitances partielles des deux conducteurs dans la ligne de télécommunication. Le champ magnétique induit une tension longitudinale. On parle d'une perturbation de la ligne de télécommunication si la tension psophométrique est supérieure à 10 mV à l'extrémité de la ligne, et d'un danger si la ligne reçoit une tension de crête supérieure à 300 V contre terre. Afin de maintenir la tension psophométrique dans des limites réduites, des mesures spéciales doivent être prises, avant tout lorsque les lignes sont posées sur les mâts haute tension.

La ligne à courant triphasé doit être transférée, c'est-à-dire que la place des conducteurs des 3 phases doit être échangée à des intervalles réguliers, afin d'améliorer la symétrie de la ligne à courant triphasé. De plus, les conducteurs de la ligne de télécommunication doivent être croisés à des intervalles réguliers, le plan de croisement et le plan de transposition de la ligne à courant triphasé devant être adaptés. Un service téléphonique satisfaisant avec des tensions de service allant jusqu'à 60 kV doit être réalisable, en respectant les conditions suivantes: un intervalle minimum de 2 mètres par exemple, entre la ligne à courant fort et la ligne de télécommunication, en tenant compte de la flèche maximum, une limite de 50 cm pour la distance entre les deux fils de la ligne de télécommunication, une grande exactitude de construction pour les deux lignes.

Du fait qu'il existe toujours pour les lignes posées sur les mâts haute tension, le danger d'un contact direct entre la ligne de télécommunication et la ligne haute tension par suite d'une rupture de ligne, des mesures spéciales sont à prendre. On connecte en premier lieu aux extrémités de la ligne de télécommunication une bobine d'écoulement symétrique, puis des parafoudres, des fusibles et finalement un transformateur de protection isolé fortement entre l'enroulement primaire et l'enroulement secondaire, Fig. 1.

Afin de pouvoir effectuer une sélection sur de telles lignes verrouillées par des transformateurs de protection, une sélection inductive est à envisager.

La plupart du temps une seule conversation BF peut avoir lieu sur de telles lignes. Si l'on nécessite cependant plusieurs voies téléphoniques, on peut également exploiter les équipements téléphoniques à fréquences porteuses à 3 voies développés pour les lignes aériennes des PTT. Après de nombreuses mesures effectuées sur de telles lignes, on n'a constaté que des tensions psophométriques relativement réduites dans la bande de fréquences comprise entre 4 et 32 kc/s occupée par de tels équipements à fréquences porteuses.

Les systèmes à fréquences porteuses transmettent 3 voies téléphoniques avec une largeur de bande BF de 0,3 à 3,4 kc/s et un écart réciproque de 4 kc/s entre les porteurs. La bande comprise entre 4 et 16 kc/s est occupée dans une des directions, la bande comprise entre 20 et 32 kc/s est occupée dans la direction opposée. Le niveau d'émission par voie au début de la ligne aérienne est de + 2 N, l'atténuation maximum admissible de 4 N en règle générale.

Du fait que les transformateurs de protection ont une trop grande atténuation pour les fréquences porteuses, il faut connecter sur le côté ligne du transformateur, un aiguillage comprenant un filtre passe-bas pour la transmission BF et un filtre passe-haut pour les voies de porteurs. L'aiguillage est protégé par les fusibles et les parafoudres déjà mentionnés ci-dessus. Ses éléments de construction, en particulier les condensateurs du filtre passe-haut doivent être dimensionnés pour une tension de 5 et 10 kV, car ceux-ci ont pour fonction de bloquer la haute tension.

Il est recommandé de se limiter à un système à 3 voies, car la bande de fréquences supérieure 50 kc/s doit être réservée pour le système à courants porteurs sur lignes haute tension.

Pour les tensions de service supérieures à 60 kV, il faut envisager des lignes de communication en câble. Le champ électrique des lignes haute tension est alors écranté par la gaine des câbles, et des perturbations ne sont induites que par le champ magnétique. Si la ligne de télécommunication doit suivre le même tracé que la ligne haute tension, le câble peut être posé comme câble souterrain on suspendu comme câble aérien sur les mâts de la ligne haute tension. On utilise dans la plupart de cas des câbles aériens à auto-suspension qui ont été exploités avantageusement comme câble parafoudre. La gaine du câble sert alors à la dérivation des coups de foudre éventuels. Si le tracé de la ligne de télécommunication est établi à distance de la ligne haute tension, les câbles sont posés en règle générale comme câbles souterrains.

La protection assurée par la gaine du câble et la torsion des conducteurs de câbles, maintient le plus souvent les perturbations dans des limites admissibles. Toutefois une tension présentant des risques peut exister sur les lignes de communication, par suite de mise à la terre accidentelle de la ligne haute tension. On répartit alors souvent les circuits de télécommunication par des transformateurs insérés le long du parcours. La tension longitudinale dangereuse peut être également réduite par l'armature appropriée de la gaine du câble. Si de grandes distances doivent être franchies, il est recommandé de pupiniser les lignes. Seules des conversations BF peuvent être établies sur des lignes pupinisées, mais on économise des amplificateurs intermédiaires dont les tubes peuvent être une source de dérangements. D'un autre côté, la pupinisation fait augmenter le temps de propagation dans la voie de transmission, si bien qu'une exploitation de lignes pupinisées sur des grandes distances en vue de la protection du réseau ne peut pas être envisagée.

Si de forts faisceaux de lignes sont exigés, comme c'est le cas pour d'importants réseaux haute tension, il est recommandé de poser des câbles non pupinisés qui permettent l'exploitation d'équipements téléphoniques multiplex à fréquences porteuses, par exemple avec 6 ou 12 voies

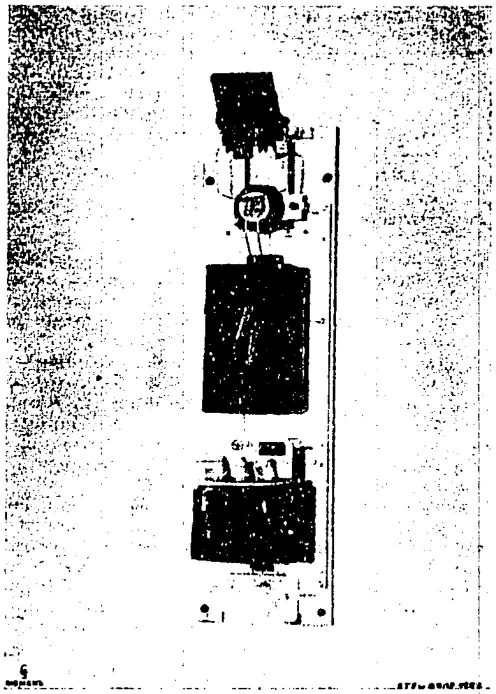

Fig. 1 — Équipement de protection pour une ligne aérienne contre danger de surtension

dans chaque direction et pour chaque paire de conducteur. Il est recommandé alors de veiller à ce que la tension longitudinale induite soit réduite en établissant le tracé des câbles à une distance aussi grande que possible de la ligne haute tension, ainsi que par une armature suffisante de la gaine du câble afin que, à part les transformateurs de terminaison de ligne dans les stations terminales et les stations intermédiaires, aucun autre transformateur ne soit à insérer dans la ligne.

On utilise également dans ce cas des équipements téléphoniques à fréquences porteuses, tels qu'ils sont en service pour les administrations des PTT à travers des câbles symétriques non pupinisés. Comme exemple, nous mentionnons le système à 12 voies pour une exploitation à 2 fils sur câbles qui transmet dans la gamme de fréquences comprise entre 6 et 54 kc/s dans une direction et dans la gamme comprise entre 60 et 108 kc/s dans l'autre direction, 12 voies téléphoniques avec un écart de fréquence de 4 kc/s. La largeur de bande BF s'étend de 0,3 à 3,4 kc/s. Le niveau d'émission au début de la ligne est en général dans ce cas de + 0,5 N et l'atténuation maximum admissible sans amplificateur intermédiaire de 6 N environ. En cas d'atténuations plus élevées, des stations de répeteurs doivent être insérées à une distance 30 à 60 km environ, suivant le diamètre des conducteurs utilisés et l'isolement du câble.

## 2. *Lignes haute tension*

La bande de fréquences utilisable pour la transmission des messages sur les lignes haute tension est déterminée par des prescriptions officielles dans de nombreux pays, et couvre souvent une gamme comprise entre 50 et 300 kc/s environ. Cette gamme est en même temps la plus favorable au point de vue technique.

Par beau temps, la courbe de l'atténuation des lignes par rapport à la fréquence suit une loi radicale en raison des pertes de dérivation réduites. L'atténuation kilométrique d'une ligne de 100 kV est, pour 300 kc/s, de 12 à 15 mN/km suivant le système de couplage utilisé. Par mauvais temps, en particulier par temps de givre, l'atténuation augmente en présence de fréquences élevées. Son allure par rapport à la fréquence se rapproche alors plutôt d'une loi linéaire.

Pour la transmission, on utilise souvent seulement un conducteur d'un système à courant triphasé et la terre comme ligne de retour. On parle alors de couplage unifilaire. Pour ce genre de couplage, c'est la valeur d'atténuation la plus élevée indiquée ci-dessus qui est valable. Malgré tout le couplage unifilaire est le plus employé, du fait que les équipements de couplage alors nécessaires offre la solution la plus économique. Si l'on utilise deux conducteurs d'un système à courant triphasé, on parle de couplage bifilaire et on obtient alors une atténuation réduite, mais les frais requis se montent au double. Des conditions semblables existent pour le couplage dit intermédiaire qui utilise un conducteur de deux systèmes à courant triphasé monté sur le même mât.

Les systèmes à fréquences porteuses sont couplés sur les lignes haute tension à l'aide de condensateurs avec une capacité de 1000 à 4000 pF environ, lesquels doivent être dimensionnés pour la pleine tension de service.

Plus la capacité des condensateurs de couplage est grande, plus la bande de fréquences transmise du filtre de couplage est large, et moins on nécessite de types de filtres de couplage pour couvrir la gamme complète de 50 à 300 kc/s. D'autre part, les condensateurs de couplage sont des éléments de construction très onéreux et l'on évite pour cette raison des valeurs inutilement élevées de capacité. Avec un montage approprié, ces condensateurs de couplage peuvent être également utilisés comme transformateurs de tension capacitifs pour des processus de mesure. Afin de transmettre une bande suffisante pour plusieurs voies à fréquences porteuses, on ajoute aux condensateurs de couplage et au transformateur de protection suivant d'autres capacités et l'on constitue ainsi des filtres passe-bande, appelés filtres de couplage.

Il ne suffit pas seulement d'insérer sur la ligne et de retirer les courants haute fréquence des équipements à fréquences porteuses à l'aide d'équipements de couplage. Il faut encore veiller à ce que ces courants s'écoulent seulement sur les lignes et dans la direction désirée. Des prolongements de lignes et des dérivations se trouvant sur le parcours doivent donc être bloqués pour les courants haute fréquence. On se sert alors d'inductances qui sont construites sous forme de bobines à air. Un point déterminant à observer lors de leur construction, est une résistance mécanique suffisante, car ces inductances n'ont pas seulement à supporter en permanence un courant de service de quelques 100 A, mais elles doivent également ne pas être endommagées par des courants beaucoup plus élevés provenant de court-circuits. La valeur de ces inductances est différente suivant les cas.

Si seule une liaison téléphonique est établie sur une ligne, des circuits bouchons de résonance peuvent être prévus, Fig. 2. Des inductances de 0,2 mH environ sont accordées avec des condensateurs d'accord pour verreuiller les deux bandes de fréquences utilisées. Les condensateurs d'accord doivent résister également aux augmentations de tension résultant de courants élevés occasionnés par des courts-circuits. Les circuits bouchons sont suspendus dans les installations de commande, comme le sont les condensateurs de couplage.

Si plus de deux bandes vocales sont à verouiller, il est recommandé d'utiliser des circuits bouchons toutes ondes. Ce sont des inductances de 2 mH environ dont l'impédance est suffisamment grande dans toute la gamme comprise entre 50 et 300 kc/s pour éviter un écoulement des courants porteurs dans des directions indésirables. Ces bobines sont tellement grosses et lourdes qu'on ne peut plus les suspendre, mais qu'on doit les poser sur le sol.

Ces deux modèles de circuits bouchons protègent certes les différentes voies de communication contre des pertes de puissance qui provoqueraient une augmentation d'atténuation. Les circuits bouchons ne sont cependant pas suffisants pour protéger les voies téléphoniques fonctionnant avec la même fréquence porteuse et situées de chaque côté des circuits bouchons contre une diaphonie perturbatrice. On doit donc renoncer à exploiter sur une ligne haute tension des voies téléphoniques utilisant la même fréquence porteuse et placées au voisinage les unes des autres. Si cette solution devait être cependant adoptée du fait du manque d'ondes résultant d'un trafic intense, il faut envisager la construction de circuits bouchons de diaphonie qui entraînent des frais considérables. Quelques bobines ne suffisent pas. Il est nécessaire d'aménager des qua-

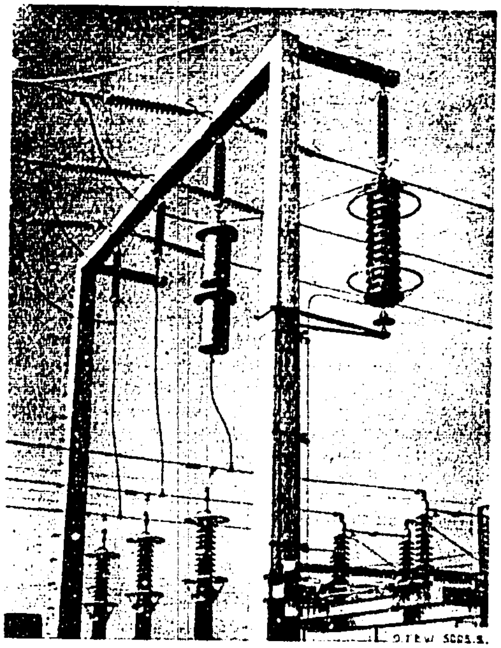

Fig. 2 — Dispositif d'accouplement d'une ligne H.T. pour l'exploitation d'equipements a frequences porteuses

dripôles sous forme de bobines type circuits bouchons toutes ondes et de condensateurs type de condensateurs de couplage. Des recherches approfondies ont montré que les frais restent dans des limites admissibles si l'on renonce au blocage de la gamme comprise entre 50 et 300 kc/s, c'est-à-dire si l'on dimensionne les éléments de construction, de telle façon que l'atténuation de blocage nécessaire n'existe que dans la gamme comprise entre 100 et 300 kc/s.

Les équipements à fréquences porteuses nécessaires à la transmission des messages sont raccordés aux lignes haute tension à travers des équipements de couplage. Originairement on ne nécessitait qu'une liaison téléphonique entre les différentes stations du réseau haute tension. Les équipements à fréquences porteuses furent donc d'abord envisagés sous forme d'équipements à une voie. Le procédé de modulation était une modulation en amplitude avec transmission de deux bandes latérales. Fig. 3

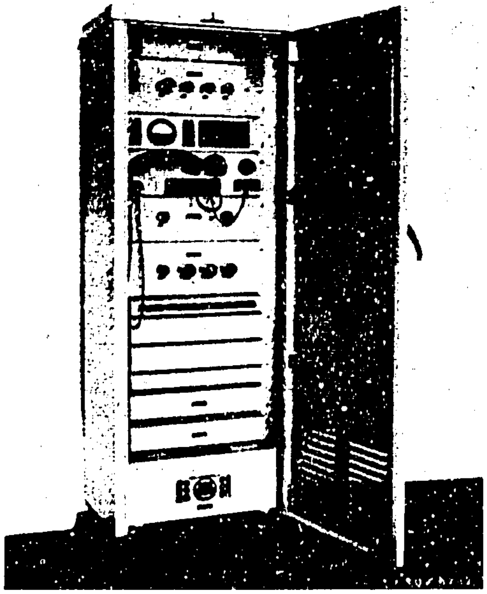

Fig. 3 — Équipement de téléphonie H.F. à bandes latérales doubles

Les deux directions de conversation utilisaient différentes fréquences porteuses. On échangeait souvent les fréquences porteuses lors de l'établissement d'une liaison. De tels équipements sont encore aujourd'hui exploités dans une grande mesure.

Suivant la largeur de bande BF désirée, ces équipements couvrent une bande de fréquences de largeur différente. Pour une bande BF comprise entre 0,3 à 2,4 kc/s, 5 kc/s sont nécessaires. Pour une bande BF comprise entre 0,3 et 3,4 kc/s, on utilise 8 kc/s. Afin de permettre un fonctionnement exempt de perturbations des différentes voies, la bande comprise entre 50 et 300 kc/s disponible fut subdivisée en des bandes de 5 kc/s de large. Dans les réseaux comportant des systèmes à fréquences porteuses de 8 kc/s de large, on a prévu en conséquence des bandes de 8 kc/s. L'atténuation de ligne maximum admissible est fixée la plupart du temps à 6 N, éventuellement à 7 N afin de limiter le niveau de bruit.

Habituellement, les récepteurs sont pourvus d'un circuit de réglage qui permet de régler les fluctuations du niveau de réception résultant des variations d'atténuation sur les lignes haute tension. La gamme de réglage de ce circuit est de 4 N.

Au lieu d'être occupées avec la téléphonie, ces bandes de fréquences peuvent être occupées également avec un plus grand nombre de voies de télécommande de 80 c/s de large. Il est rationnel de générer des porteuses avec des fréquences qui doivent être transmises sur la ligne à l'aide d'oscillateurs à quartz et l'on manipule ces porteuses avec les messages provenant des équipements de télécommande. Sur le côté réception, les voies sont déplacées par transposition de fréquences dans une position telle, qu'elles peuvent être séparées et reçues à l'aide des filtres utilisés normalement dans la télégraphie harmonique.

Lors de l'utilisation de bandes de 8 kc/s de large, on peut limiter les bandes téléphoniques entre 0,3 à 2,4 kc/s et superposer dans la bande de fréquences restante plusieurs voies de 80 c/s de large. De cette façon, on peut obtenir dans beaucoup de cas un nombre suffisant de voies de télécommande en plus des voies téléphoniques. Les besoins toujours plus grands en voies téléphoniques ont suscité dans les réseaux haute tension déjà existants une pénurie sensible des bandes de fréquences disponibles. C'est pourquoi on a essayé avec succès de réduire de moitié le besoin en bandes de fréquences par l'utilisation d'une modulation à une bande latérale, Fig. 4. On obtient ainsi en plus un intervalle favorable entre le niveau utile et le niveau de perturbation, car d'une part les perturbations se produisant dans la bande réduite de moitié sont également réduites de moitié. D'autre part, seule la bande latérale qui contient tout le message est transportée par la puissance débitée. Finalement, une écoute non autorisée des conversations à longue distance à l'aide de postes récepteurs de radio est rendue difficile en présence d'un service à une bande latérale et de la suppression de la porteuse.

En plus de la modulation en amplitude avec transmission des deux bandes laterales ou d'une bande latérale seulement, on a également recherché à determiner si une modulation en frequence pouvait offrir des avantages. Un tel essai presentait un certain intérêt du fait qu'il ne se produisait non seulement des bruits perturbateurs dans les voies téléphoniques par suite de l'effet de couronne (effet corona), mais également une modulation des messages au rythme de 100 c/s. Les effets de cette modulation corona pourraient être facilement supprimés par l'utilisation de la modulation en fréquence. Il faudrait alors qu'une bande de fréquences plus large soit disponible pour une deviation de frequence suffisante. Si l'on doit conserver les largeurs de bandes prevues jusqu'à présent, la coupure des bandes latérales provoque de plus grandes distorsions avec

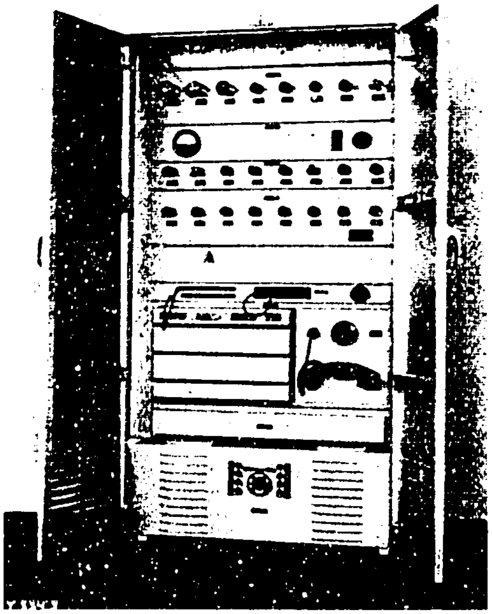

Fig. 4 — Equipement de telephonie H.F. a bande laterale unique

une modulation en fréquence, que la modulation corona avec une modulation d'amplitude. Le procédé le plus rationnel est donc une modulation en amplitude à une bande latérale.

Lors de l'aménagement de nouveaux réseaux haute tension, il est souvent plus avantageux de prévoir non pas des équipements téléphoniques à une seule voie, mais des équipements à plusieurs voies, semblables à ceux utilisés par la technique de la téléphonie à fréquences porteuses sur lignes aériennes, par exemple la technique des administrations des PTT. De tels systèmes transmettent par exemple 6, 12 ou 24 voies et occupent une large bande de fréquences qui doit être protégée contre la diaphonie des autres troncons de lignes du réseau. Les frais occasionnés par les circuits bouchons quadripôles nécessaires dans ce but se répartissent cependant sur de nombreuses voies, si bien que les frais à couvrir par voie téléphonique sont beaucoup plus réduits pour un tel système que pour un système à une voie. Particulièrement en cas de trafic intense, un tel procédé présente de grands avantages.

Pour toutes les liaisons de télécommunication traitées jusqu'à présent, il s'agissait d'établir entre les différents points d'un réseau de distribution d'énergie des faisceaux plus ou moins importants. Il se présente cependant des cas pour lesquels des commandes doivent être transmises à partir d'une centrale vers de nombreux points du réseau, par exemple dans les grandes villes où l'on doit simultanément connecter des consommateurs répartis sur toute une ville. On parle dans ce cas d'une installation de commande centrale.

Dans ces cas, les lignes haute tension ne sont pas des lignes aériennes, mais souvent des câbles qui ont une atténuation beaucoup trop élevée pour les fréquences porteuses élevées utilisées sur les lignes aériennes. On est alors obligé de prévoir pour la transmission des signaux des fréquences vocales. Pour la sélection d'une fréquence vocale spéciale, un compromis doit être établi:

D'une part, les harmoniques de la haute tension doivent être si réduits qu'ils puissent être séparés de la fréquence porteuse de signalisation par de simples circuits de filtres, ce qui est d'autant plus facile à réaliser que la fréquence porteuse est plus élevée. D'un autre côté, l'atténuation pour la fréquence porteuse qui augmente en même que la fréquence, ne doit pas être trop élevée. Quelques firmes qui construisent de telles installations utilisent des fréquences voisines de 1000 c/s.

Dans de telles installations, la centrale doit générer de grandes puissances de porteurs pour le réseau haute tension, en particulier si les récepteurs doivent être construits simplement par exemple sans utilisation de tubes amplificateurs. Ce point de vue est déterminant surtout si l'on doit envisager l'aménagement d'un grand nombre de récepteurs.

### 3. *Liaisons radio-électriques*

Il existe des cas où ni l'utilisation de la ligne haute tension, ni celle de lignes de communication spéciales ne fournissent la solution adéquate satisfaisant aux problèmes de transmission à résoudre, mais où l'exploitation de liaisons radio-électriques semblent être indiquée.

De tels cas se présentent si l'on veut communiquer en radio-trafic avec des stations téléphoniques mobiles dispersées autour d'une centrale, par exemple des troupes de dépannage. Le service omnidirectionnel qui fonctionne uniquement sans fil offre alors de grands avantages.

Même pour l'aménagement de faisceaux téléphoniques entre deux ou plus points fixes, on peut envisager des liaisons radio-électriques avec les moyens dont dispose la technique des faisceaux hertziens, en particulier si la bande de fréquences disponible sur les lignes haute tension pour les porteuses est déjà occupée.

Dans la recherche d'un domaine de fréquences approprié au service des usines de répartition d'énergie, est éliminé de prime abord le domaine des ondes longues, moyennes et courtes car d'une part ces domaines de fréquences sont déjà occupés et des bandes de fréquences ne sont pratiquement plus disponibles, et d'autre part en cas d'ondes longues et d'ondes moyennes surtout, les installations d'antenne nécessaires seraient trop onéreuses.

Les équipements les plus économiques seraient obtenus avec des ondes ultra-courtes. La gamme des ondes métriques est appropriée avant tout pour un service omnidirectionnel vers des stations mobiles, alors que pour des ondes encore plus courtes, des liaisons hertziennes peuvent être aménagées. Il faut naturellement veiller pour des liaisons fonctionnant sur de telles fréquences, à ce que des obstacles tels que des chaînes de montagnes ne se trouvent pas entre les stations radio-électriques afin de garantir une propagation parfaite des ondes.

Il n'est pas nécessaire de développer des systèmes radio-électriques spécialement pour le service des usines d'énergie. On peut envisager pour le radio-trafic et les liaisons hertziennes des systèmes déjà existants, par exemple des systèmes pour 12 ou 24 voies avec modulation des impulsions en position (PPM) ou avec modulation de fréquence. Du fait que la plupart de ces systèmes permettent de transmettre des bandes vocales jusqu'à 3 kc/s environ, une ou deux voies de télécommande peuvent être encore superposées en limitant la bande vocale à 2,4 kc/s. Si l'on nécessite un nombre encore plus important de telles voies de télécommande, les bandes vocales peuvent être occupées avec des voies de télégraphie harmonique. Pour une exploitation sur des systèmes radio-électriques dans le domaine des ondes centimétriques, il suffit d'envisager le système de télégraphie harmonique avec modulation en amplitude, alors que dans le domaine des ondes métriques, on prévoit de préférence un système à variation de fréquences.

## C) POINTS DE VUE À ENVISAGER POUR LE PROJET DU RÉSEAU

Pour une usine de répartition d'énergie, la sécurité de service de l'installation de télécommunication est le point de vue le plus important du projet à considérer. Pour la téléphonie, la disponibilité des équipements est exactement aussi importante que la sécurité de service, car une voie téléphonique occupée est aussi inutilisable qu'une voie en dérangement. Il s'agit donc d'établir le projet aussi bien avec une sécurité technique maximum qu'avec un nombre suffisant de liaisons.

Les facteurs pouvant limiter ces tendances sont de nature économique. L'établissement du projet de télécommunication envisageant non seulement les besoins actuels, mais également l'extension du réseau de répartition d'énergie, se heurte à des considérations économiques qui déterminent les limites de l'extension à prévoir pour cette installation.

### 1. *Sécurité de service*

La sécurité de service d'une installation de télécommunication dépend non seulement du fonctionnement des équipements, mais aussi de la sécurité de leur alimentation en courant et de la sécurité de leurs lignes. Les équipements ainsi que leur alimentation sont prévus de telle façon, qu'ils fonctionnent avec une sécurité suffisante, même dans les voies de transmission critiques comme pour le téléréglage ou la protection du réseau. Il s'agit seulement d'entretenir rationnelement les appareils et leur équipement d'alimentation afin de garantir cette sécurité de service pendant plusieurs années.

La sécurité de service des lignes est décisive pour la sécurité de toute l'installation de télécommunication. Des câbles souterrains posés loin de la ligne haute tension sont en règle générale les lignes de communication les plus sûres. Les frais des câbles posés exclusivement pour les usines électriques augmentent rapidement avec la distance de transmission franchie, si bien que des lignes aériennes ou des câbles aériens a plusieurs paires de conducteurs posés sur les mâts des lignes haute tension sont préférables. Les lignes haute tension elles-mêmes représentent comme voies de communication des moyens de liaison sûrs, du fait que leur construction mécanique est favorable et qu'elles ne se trouvent pas exposées au même danger d'endommagement que les lignes aériennes de télécommunication. Les liaisons radio-électriques ne peuvent être considérées comme voies de communication sûres, que si elles sont projetées avec beaucoup de soin, ce qui requiert parfois un matériel assez important.

En général, les voies de communication sont aménagées parallèlement aux lignes haute tension. Aussi longtemps qu'il s'agit de lignes de communication placées à proximité immédiate des lignes haute tension, les équipements de protection haute tension suffisent pour éloigner des équipements de communication tout danger de surtensions. La rupture des fusibles dans les équipements de protection provoque cependant une interruption des liaisons que l'on essaie de limiter par des mesures spéciales à un délai de temps aussi court que possible. Lorsque les lignes haute tension sont utilisées pour les liaisons de télécommunication, le couplage est prévu de telle façon, que des tensions destructrices ne puissent parvenir aux équipements de télécommunication. Des fusibles interromptant les liaisons ne sont pas prévus dans ce cas. Pour les lignes spéciales de télécommunication ainsi que pour les lignes haute tension, il faut s'attendre à une rupture des conducteurs. Sur les lignes spéciales de télécommunication, cette rupture des conducteurs a pour conséquence une interruption des liaisons. Ce n'est pas le cas pour les lignes haute tension. Si un conducteur haute tension se rompt, les autres conducteurs du système à courant triphasé transportent les fréquences porteuses à travers les capacitances existantes, de sorte que la rupture ne provoque qu'une augmentation d'atténuation. En raccordant des liaisons de communication à 2 conducteurs d'un système à courant triphasé au lieu d'un seul, la sécurité de la ligne peut être considérablement augmentée.

Des liaisons radio-électriques qui fonctionnent dans le domaine des ondes métriques ou décimétriques ne sont pas perturbées par le service haute tension.

## 2. *Extensions*

On peut construire une installation de télécommunication avec les frais les plus réduits si l'on ne tient pas compte des extensions futures éventuelles. Si l'on évalue la durée d'existence des équipements à 15 ans, il est indiqué de toujours contrôler si des extensions sont à envisager pendant cette période, afin de ne pas devoir éliminer des équipements dont la capacité n'est pas plus suffisante. Ceci est particulièrement important pour la détermination du nombre des conducteurs dans les câbles de télécommunication, car les frais de pose sont les plus considérables et ne doivent pas être renouvelés au cours d'une extension. Pour des liaisons à fréquences porteuses à travers des lignes haute tension, la possibilité d'extension dépend du plan des fréquences dans lequel des réserves suffisantes doivent être prévues pour l'aménagement de nouvelles liaisons.

Lorsque des extensions sont effectuées à de longues intervalles de temps, si bien que les anciens systèmes puissent être remplacés sur les lignes principales par de nouveaux systèmes de plus grand rendement, et que les équipements ainsi libérés soient utilisés sur les lignes secondaires, la mobilité des installations de télécommunication est décisive. Les lignes spéciales de communication ne peuvent pas être déplacées et doivent être soit renouvelées avec des frais élevés, soit rénovées pour des faisceaux de voies plus importants. Par contre, les liaisons à fréquences porteuses à travers des lignes haute tension ou des liaisons radio-électriques ne sont reliées qu'aux équipements terminaux dont on peut modifier le lieu d'aménagement sans grands frais. Les deux dernières techniques sont pour cette raison particulièrement appropriées pour les réseaux haute tension dont la structure se modifie rapidement.

### 3. *Considérations économiques*

Une question qui a été longtemps discutée est celle concernant la valeur des installations de télécommunication par rapport à la valeur d'une installation courant fort, sans que ces installations perdent leur caractère de moyens auxiliaires au service des usines de répartition d'énergie. Parfois, on essaie encore de limiter les frais lors de l'acquisition des équipements sans penser quels sont les désavantages et quelles sont les pertes qui peuvent en résulter dans le service courant fort, si le réseau de télécommunication est insuffisant. Dans les réseaux importants des pays industriels, on évalue actuellement la valeur des installations de télécommunication à un maximum de 3% de la valeur des installations courant fort respectives et on s'efforce d'augmenter ce rapport en faveur des moyens de télécommunication pour augmenter la sécurité et la rentabilité du service haute tension. Un rapport de 7% environ devrait représenter environ un maximum technique et économique.

Il n'est pas possible d'établir des règles sur lesquelles on puisse se baser pour chaque cas particulier, à savoir si l'aménagement de lignes spéciales, l'utilisation de lignes haute tension ou de voies radio-électriques pour la télécommunication détermine le minimum de frais. Souvent, les trois variantes doivent être projetées, les deux autres points de vues, c'est-à-dire sécurité de service et possibilité d'extension devant être mis en valeur. Pour un réseau important, une combinaison des trois types de moyens de transmission est souvent rationnelle, les parcours particulièrement importants étant aménagés parfois en double, avec deux moyens de transmission différents.

## RÉSUMÉ

Il est incontestable que des liaisons de communication sont absolument nécessaires à l'exploitation des usines et des réseaux de répartition d'énergie. En premier lieu ce sont les liaisons téléphoniques qui présentent le plus d'importance pour assurer la communication entre les différentes stations du réseau. D'autre part, les liaisons télégraphiques par téléimprimeurs se développent de plus en plus. Les liaisons de télémesure, de télécomptage et de téléréglage sont appropriées spécialement aux besoins des usines d'énergie. Enfin, on utilise des voies de télécommunication pour la protection du réseau, dans le but de supprimer rapidement les dérangements éventuels. Les exigences techniques requises pour les moyens de communication ainsi que pour la coordination de ceux-ci ont été exposées en détail.

Comme voies de transmission, il faut mentionner de prime abord les lignes aménagés spécialement dans ce but. Il est à noter que des surtensions peuvent se produire sur de telles lignes en raison de la proximité des lignes haute tension. Des mesures spéciales sont à envisager pour éliminer le danger que présentent les surtensions pour les équipements de télécommunication. D'ailleurs, les lignes haute tension elles-mêmes peuvent être exploitées pour la télécommunication. On utilise alors des fréquences porteuses comprises entre 50 et 300 kc/s. Dans ce cas, les équipements de télécommunication sont reliés aux lignes haute tension à l'aide d'organes de couplage. Des circuits bouchons sont à insérer aux points de dérivation des lignes haute tension afin d'éviter des pertes de porteuses défavorables. On a également la possibilité d'envisager des systèmes radio-électriques, soit des faisceaux hertziens pour la liaison entre des stations fixes, soit des radiateurs omnidirectionnels pour la communication de stations mobiles entre elles, par exemple troupes de dépannage.

Pour chaque cas particulier, un de ces moyens de communication doit être choisi, en tenant compte des conditions techniques et économiques. Il faut considérer en même temps la sécurité de service ainsi que les possibilités d'extension d'une installation projetée suivant les besoins momentanés.

## SUMMARY

It stands to reason that communication means are a vital consideration in the proper functioning of large electric power distribution systems. Among all the available media, telephone communication takes a prominent place in the transmission of intelligence between the individual power stations of such a system. On the other hand, teleprinter communication is also making considerable headway in this field. Telemetering, telecounting, and remote control facilities lend themselves particularly well for the supervision and control of such distribution systems. Moreover, as they permit the easy location and rapid elimination of trouble, they are also utilized for protecting the distribution network. The technical demands placed on these media, as well as on their interoperation, have already been set out in detail.

The primary communication paths are, of course, the lines that are installed for this purpose. It should here be noted that the proximity of the high tension lines exposes these circuits to possible overvoltages. Special measures must therefore be taken to counter the resultant hazards, i.e. to prevent the communication equipment from being damaged by overloads. The high tension lines themselves can also be used for communication purposes, carrier frequencies ranging from 50 to 300 kc/s here being assigned. In this case the communication equipment is connected to the high tension lines by means of coupling devices. The tapping points of high tension lines have to be provided with wave traps so as to avoid undesirable carrier leakage. There is, furthermore, the possibility of providing radio communication systems operating either as radio links for establishing a connection between fixed stations, or as omnidirectional radiators for establishing connections between mobile stations, e.g. trouble-shooting gangs.

For each particular application the choice of communication media should be governed by the prevailing technical and economic conditions. At the same time service reliability and the possibility of expanding an installation projected on the basis of initial requirements should also be taken into account.

## RESUMEN

No creemos sea necesario decir que los enlaces de comunicaciones son indispensables para la explotación, tanto de las usinas eléctricas como de las redes distribuidoras de energía, pero si queremos realzar la importancia tan grande que corresponde a la telefonía, pues es ella la que permite comunicar las diferentes estaciones de la red. Por otra parte, la técnica de teleimpresores se encuentra en un estado de desenvolvimiento continuo. De particular aplicación en las redes distribuidoras de energía son los enlaces de telemedición, telecómputo y telecontrol. No por último, las vías de telecomunicación se emplean para establecer una proteción eficiente de las redes, a los efectos de poder suprimir averías en un tiempo lo más corto posible. Las exigencias que la técnica requiere y que pone a los medios de comunicación, así como a la cooperación de los equipos, han sido detalladamente expuestas.

Como vías de transmisión será necesario mencionar en primer orden las líneas que se tendieron a tal fin. No debemos dejar de observar que en estas líneas pueden ocurrir sobretensiones a causa de la proximidad de las líneas de alta tensión, por lo cual habrá que tomar las medidas pertinentes para eliminar el peligro tan grande que suponen sobretensiones en los equipos de telecomunicación. En cambio, las líneas de alta tensión se podrán utilizar también para la telecomunicación. A este fin se utilizan frecuencias portadoras entre 50 y 300 Kc/s. En este caso, los equipos de telecomunicación se empalman con las líneas de alta tensión por medio de elementos de acoplo. En los puntos de derivación para las líneas de alta tensión habrá que insertar circuitos de bloqueo, con el fin de evitar pérdidas de portadora desfavorables. Igualmente existe la posibilidad de prever sistemas radioeléctricos para formar enlaces entre estaciones fijas, o de erigir antenas reflectoras omnidireccionales para enlazar con estaciones móviles, por ejemplo, cuadrillas para averías.

Para cada caso en particular, se elegirá uno de estos medios de comunicación, teniendo en cuenta las condiciones técnicas y económicas. Al mismo tiempo no sólo habrá que considerar la seguridad del servicio, sino también las posibilidades de ampliación de una instalación proyectada para servir a las exigencias del momento.

The last station for tropical areas supplied by Telefunken with a short-wave radio transmitter yet during the last war was Lourenço Marques in Portuguese East Africa. It required no repair-work during the 15-year period of operation despite heavy strains it was subjected by tropical temperatures and high atmospheric humidity. The extraordinary strain which in December 1939 was imposed by a tremendous locust's plague upon the antennas, reflectors, and aerial feeders was overcome without causing failure. The footnote refers to the tropical countries [1], which since 1904 were supplied by Telefunken with the most varied types of shockexcited —, quenched spark-transmitters, HF-alternators, electronic transmitters, receiving stations and aerial installations.

Recent equipment in use, however, has undergone considerable changes when compared with that formerly installed in tropical regions. By changing from low radio frequencies to very high frequencies, the mitigation of the most dreaded natural atmospheric statics especially prominent during tropical thunderstorms was fully accomplished. The use of beam antenna arrays in place of omnidirectional antennas in connection with the employment of ultra high frequencies and frequency modulation, resulted in a considerably higher reliability in operation and besides to a very high degree in freedom from intended wireless interferences. Concentrating the wireless stations at a few points only, made it easy to protect them against natural disturbances and acts of sabotage, whereas wirelines can hardly be guarded against well-prepared acts of sabotage, not even in most densely populated areas. By substituting telegraphy by telephony and teletype, the radio links can easily be operated by everybody without previous training.

The power companies, therefore, have taken special interest in the development of wireless communication systems and in particular that of radio links; they have already applied this modern means of intelligence transmission on extensive networks as in the case of the Bonneville Power Administration [1]. Similar systems are in the course of preparation in Germany. Ultra high frequency technique offers the following advantages:

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1) ASIA

Philippines
Borneo
Celebes
Ceram
Java
Sumatra
Timor
Thailand
South-Sea Islands

AFRICA

Congo
Egypt
Cameroons
Liberia
Nigeria
Sierra Leone
Portuguese Guinea
and East-Africa
Southwest-Africa
Tanganyika
Togo

AMERICA

Mexico
Honduras
Guatemala
Nicaragua
Cuba
Costarica
Salvador
Columbia
Venezuela

Dutch West-India
Dutch Guaiana
Brazil
Ecuador
Peru
Bolivia
Chile

[redacted]

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WORLD POWER CONFERENCE

Título 2
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SECTIONAL MEETING
Rio de Janeiro – 1954

KIRSTAEDTER (I.)
ROESSLER (E.)
Alemanha

# RADIO COMMUNICATION EQUIPMENT FOR THE POWER COMPANIES

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Like all enterprises servicing a large area the electric power companies are in need of efficient and reliable communication systems.

In *densely populated countries*, open wire-lines and underground cables of the postal authorities or of private communication companies are available and are being used to the highest possible extent. However, in case of failure of the electric power supply they cannot establish as rapidly as required reliable inter-communication between the parties concerned. Just in such cases the communication requirements are extremly heavy. Besides, these conventional communication systems cannot ensure proper synchronization of travelling-wave recording instruments required for fault-localisation on E.H.V. transmission lines or for telemetering.

In tropical areas as well as in undeveloped countries in general, no telephone and telegraph lines are existing so that the necessary communication means must first be set up along with the construction of a power plant in such areas. It is then desirable so employ such means which, along the route, cannot be affected by acts of nature or men. This is provided for by radio links.

To the power companies apply the same viewpoints which in the earliest stages of colonial countries have led to the utilization of wireless telegraphy. It should be recalled that as early as 1904, e.g., the first Telefunken stations with ranges of 200 kilometers were set into operation in Africa. Stations in Montevideo, Peru, Mexico, the Netherland's Indies and on the South Pacific Islands followed. In 1913 a radio network was commissioned in South America (Pará – Manaus – Santarém – Iquitos – Lima – Callao), covering a distance of 3,300 kilometers. The power supply units for most of the equipments delivered to tropical countries were manufactured by A.E.G.

1. Radio links can be established and used prior to the installation of high-voltage transmission lines, i.e., during construction of retaining dams, power generating stations and substations.
2. Elements of the power utility system located remotely from the high-voltage lines, such as brown coal mines or feeding points of retaining dams, may be included in the communications network (Fig. 1).
3. Contact with mobile telephone stations (vehicles of linepatrols or helicopters employed for inspecting the power lines) may be readily established by the use of radio telephony.
4. The vehicles, on their part, may communicate with portable VHF-sets, so considerably facilitating cooperation between the individual construction teams along the power lines or in large plants.
5. Pulses for localizing faults on E.H.V. transmission lines can be readily transmitted with great exactness by the medium of radio links.

## I. RADIO LINKS

As early as 1936 Telefunken has started with the development of radio links and contributed important pioneer work in this field, e.g. by introducing the pulse phase modulation (PPM) system. Prior to the

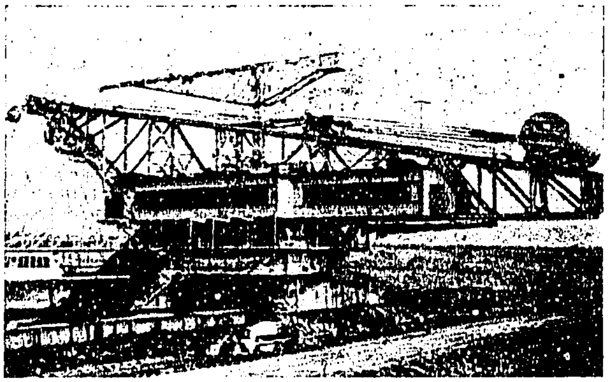

Fig. 1 — VHF Omnidirectional Antenna for Horizontal Polarization on an Excavator of the opencast mine Helmstedt (West Germany).

latter phase of development, a communications network covering a total distance of approximately 70,000 km had been set up by means of the frequency-modulated Telefunken UHF-links "Michael" and "Rudolf" which ensured utmost reliability in intelligence communication over a distance of 5,000 kilometers and above [2].

After the war, Telefunken concentrated its development on increasing the number of channels feasible for such radio links [3]. The number of transmission channels ranges between 60 and 600 at present. At the end of 1952, e.g., an UHF-wide-band radio link connecting Hamburg with Cologne was put into operation (Fig.2) [4].

The objection will be that such a great need for intelligence transmission exists only between the long distance exchanges but not between the generating plants and substations. This objection applies, however, to European conditions only. In undeveloped areas the exploitation of natural power resources and the transmission of electrical energy over long distance often represent the first steps made before the actual settlement of people and the establishment of industrial enterprises takes place. Experience shows that then the desire for communication with the outside world rises rapidly. In the course of the foundation of such settlements develops in many instances an unusual social structure. Foodstuffs and consumer goods which in Europe can be procured in the immediate vicinity have to be transported over very great distances. Family members are separated and live far away from each other. The rapid growth of the community results in an unusual increase of municipal and governmental activities.

In planning a radio link system for a power company operating in an undeveloped area, consideration therefore should be given to the possibility of extending the communications services beyond the operational requirements to meet also private and official needs for communication which may be expected in the future.

## I. *General Planning of Radio Link Networks*

From the electronic point of view, the frequency ranges of VHF and UHF waves (approximately 30...4000 Mc/s) are particularly suitable because of their propagational qualities. Under normal conditions waves within these ranges are not subject to ionospheric reflection so that objectionable fadings are eliminated due to the existence of various paths of propagation, that may greatly differ in length and hamper the transmission of higher modulation frequencies in the HF-range. Further, the use of VHF and UHF waves causes no special complications in producing the directional effect. Especially for UHF, the required beam antennas are so small that they may be mounted on existing buildings, roofs and high chimneys. The frequency-bands available are so wide that various "audio-channels" can be simultaneously transmitted in one "HF-channel". For this reason, a great number of such frequency-bands

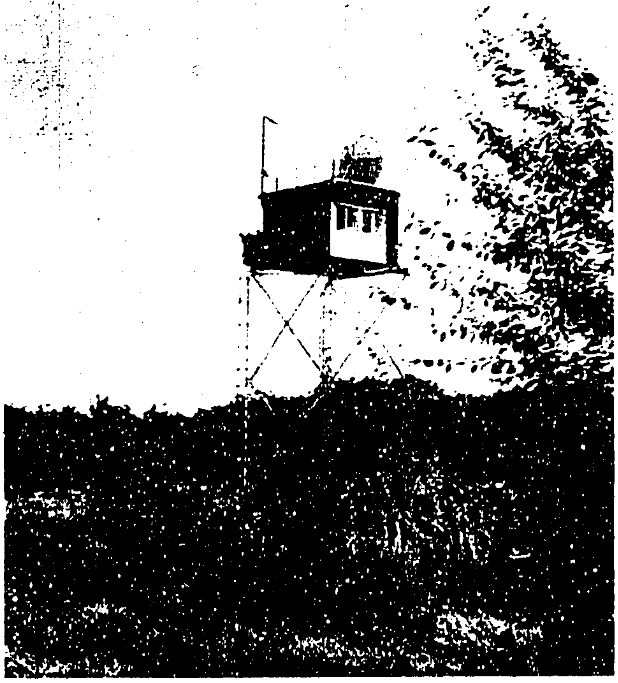

Fig. 2a — Terminal Station of Wide-Band transmission Link Hamburg-Koln (5 W, 2000 Mc/s, bandwidth 20 c/s – 5 mc/s) at Transmitter Station Langenberg.

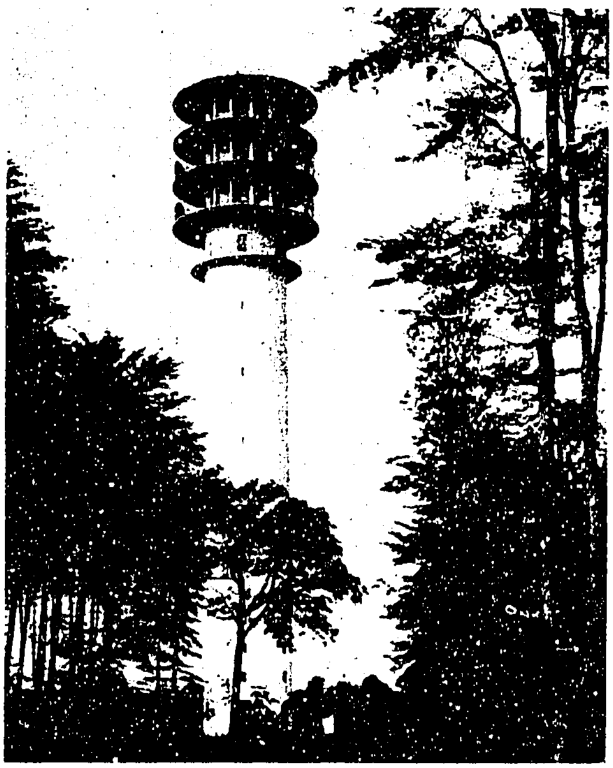

Fig. 2b — Communications Tower with a Relay Station for the Wide-Band Link Hamburg-Koln.

within the aforementioned ranges was assigned to radio-link operation at the Atlantic City Conference in 1947, so that the power companies will not encounter any restrictions in opening radio links as is the case in the medium-frequency range.

Another advantage of the VHF and UHF ranges is that they permit the use of frequency-modulation (FM) or pulse phase modulation (PPM). Radio links employing such modulation can be operated in the immediate vicinity of high-voltage lines without any interference [5].

Because of limited reach of UHF due to curvature of the earth, radio links covering a longer distance are usually sub-divided into several sections; however, in most instances it will be possible to adjust these sub-sections to the general requirements of the power grid. Much longer ranges are possible in mountainous regions, e.g., between two high mountains.

In the VHF-region, the range of a sub-section of a radio-link may be far beyond the line of sight provided that a sufficient expenditure in transmitting power and antenna gain is accepted. The type of equipment which has been successfully installed by Telefunken to connect Berlin with West Germany ("Funkbrücken = Radio-bridges") will be applied to great advantage where the installation of relay stations is difficult, as in cases where sections of oceans [6] or inaccessible tracts of land have to be bridged [7] [8]. These equipments are supplied not only as fixed stations (Fig. 3) but also as mobile or transportable units (Fig. 4) [9], so making possible operation prior to the determination of the final erection site, e.g., for surveying. It is quite natural that these stations during operation must be fixed with respect to the height of their masts and to insure the directional effect of the antennas.

The transmitting quality of the Telefunken radio links meets the highest requirements so that practically any number of sub-sections (relay stations) may be operated in succession. The links permit to branch off or add one or more groups of 6 audio-channels each at any relay station. This, however, necessitates certain additional facilities at the relay stations. If desired, these "Funkbrücken" may be equipped with automatic devices for testing, switching-over on standby units and fault-localisation. In selecting the appropriate HF-band between 30 and 1000 Mc/s due consideration should be given to the maximum number of channels required and to the existing topographic conditions. For distances reaching beyond the line of sight, lower frequencies are more favorable since they can be received beyond the horizon.

The range safely covered by UHF is given in approximation by the formula for the optical horizon as viewed from the transmitting antenna in relation to the earth curvature,

$$D_{(km)} = 3{,}57\ (h_{1(m)} + h_{2(m)})$$

where $D_{(km)}$ = distance between two stations, $h_{1(m)}$ and $h_{2(m)}$ = antenna heights. Exact calculation is based on the condition that the so-

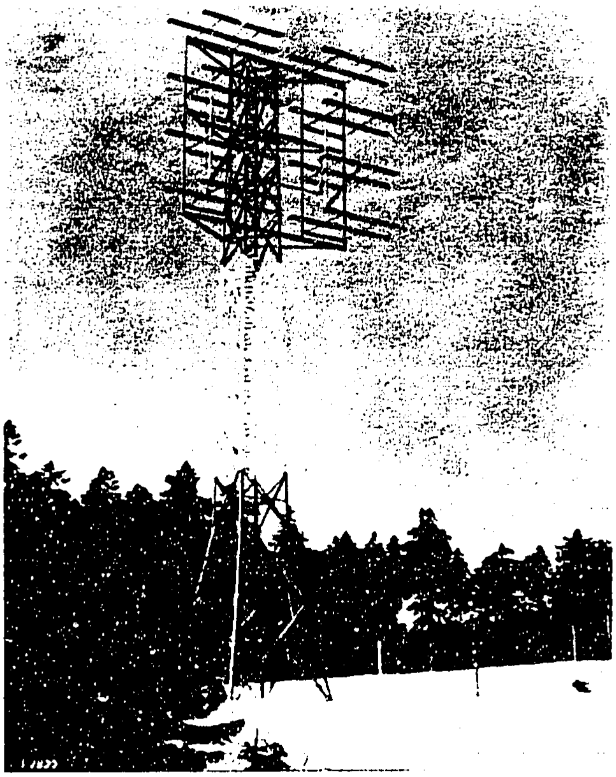

Fig. 3 — Beam Antenna of Multichannel Link Berlin-West Germany (250/1000 W, 60 Mc/s, FM ± 500 kc/s deviation, covering 200 kilometers without relay station.

called 1st Fresnel-zone 2)) is free of any obstacles. The resulting exact distances must not be exceeded, particularly with regard to intermediate mountainous regions.

Considerably longer distance, however, can be bridged by using VHF. For detailed and exact planning, a number of particulars [10] have to be taken into consideration which, if discussed here, would exceed the scope of this paper.

## 2. *Viewpoints specific to the power companies*

A very important point in planning radio links is the determination of the necessary number of audio-channels to be assigned to the individual links of the power company's communication network. The number results from the various requirements in communication listed below.

a) Audio-Channels

In general, one to three direct channels exclusively used for audio-transmission from the dispatching office of a E.H.V. transmission system to each larger sub-station will be needed. In addition it is practical to provide a number of so-called "Omnibus-channels", e.g. one omnibus-channel being assigned to any larger sub-station, and one or two such chanels each to groups of smaller sub-stations, etc. Furthermore, direct channels are needed for connecting the dispatching offices of interconnected E.H.V. transmission systems.

b) Telemetering channels for load control etc.

c) Supervisory-control channels for unattended sub-stations and similar purposes.

d) Teletype channels.

e) Channels for automatic localisation of faults, especially of short duration.

As is generally known, in fault-localisation use is made of the fact that travelling waves are running along the high voltage line to either end from the point of fault. Depending on the location of the fault relative to both ends of the line, these two travelling waves arrive at different instances in the terminal stations, where the instances of their arrival can be recorded. In order to determine for fault-localisation with sufficient accuracy the difference in time between the instances when the travelling waves arrive at the terminal stations, a reliable means for

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2) This is a space enclosed by an ellipsoid of rotation with the terminal stations as foci, in which the difference between the direct and the reflected beam does not exceed one half wave length.

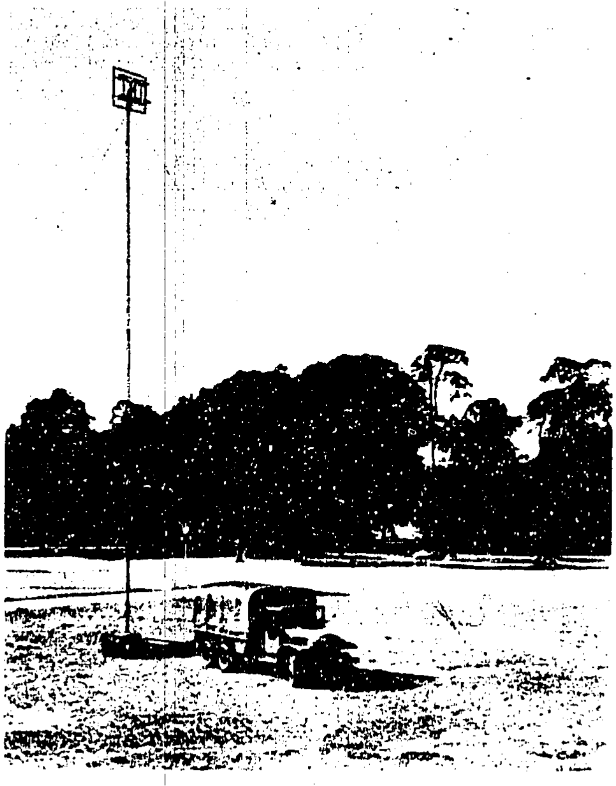

Fig. 4 -- Mobile Multi-Channel Link (50 W, 300 Mc/s, FM 300 kc/s deviation, 60 audio-channels.

time comparison is needed at both terminal stations. Time comparison can readily be achieved by the medium of pulses transmitted by radio link. This method enables not only to trace sustained faults on the E.H.V. transmission line, but also to discover short-time spark-overs. Thus defective insulators may be readily located and replaced before resulting in a break down of the transmission system.

The determination of the number of channels required for each section of the E.H.V. transmission system, mostly results in relatively high numbers of channels for transmission-trunk lines and in less numbers for the transmission feeders. For this reason, the VHF and UHF channel equipment will in the first line find its application on the trunk lines.

Fig. 5 — "Teleport II" — set Operating on a Large-Scale Construction Site.

## II. MOBILE AND PORTABLE RADIO TELEPHONY EQUIPMENT

Use of this equipment (Fig. 5) will cut down the time required for repair work on transmission lines considerably and will greatly reduce the loss in revenue resulting from failure of the power supply. Already when constructing the lines or similar extensive plants, work can be substantially sped up so as to reduce the initial costs. The RHEIN-ELEKTRA, e.g., has made use of the Teleport II equipment for maintaining contact between construction teams erecting transmission lines, thereby ensuring proper paying-off the cables. BETON and MONIER-

BAU uses this portable equipment to assist in the construction of generating stations by establishing contact between the crane operators. BEWAG, Berlin, and FELTEN & GUILLEAUME, manufacturers of cables, apply portable radio telephony equipment when laying high-voltage power cables and coaxial television lines. The operation of the portable TELEFUNKEN sets, on such projects in the 160 Mc/s band, will not be interfered by nearby 200 kV transmission lines.

The German power companies are united in the "Vereinigung deutscher Elektrizitätswerke" (VDEW), which is planning a joint power utility radio network throughout Germany. Thus it will be prevented that mutual interferences will arise between the individual power companies' communication services owing to the expected increased use of the frequency-bands available. This plan provides for approximately 250 fixed radio communication centres throughout West Germany (Fig. 6). Each centre shall be equipped with from 3 to 20 mobile stations, depending on local requirements. The following points merit consideration:

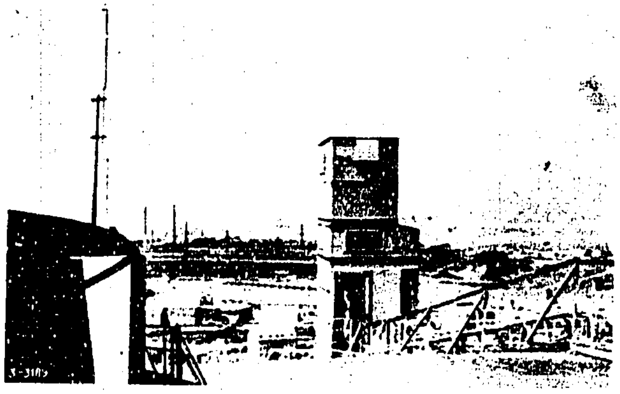

Fig. 6 — Radio Communication Centre Antenna in Idustrial Area.

a) Some radio networks must meet *supra-regional* requirements, when the radio-cars have to drive over great distances to service the installation of different power companies, involving primarily transmission systems operated at 110 kV and above. According to the German plans, the radio networks are designed to operate in a frequency range covering 72.35 to 72.75 Mc/s and 82.35 to 82.75 Mc/s respectively. Other radio networks will be restricted to service a *local region* only to which the VHF bands of 159.1 to 159.3 Mc/s and 163.6 to 163.8 Mc/s are allocated. Both these systems of networks are of the duplex type to establish communication in both directions simultaneously so that the parties concerned can talk and listen at the same time without manipulation of any switch (two-way-radiotelephony). This type of operation is necessary for connecting the radio communication networks with the wire-lines of the individual power companies. In accordance with the general planning of such duplex radio communication networks, the separation between transmitter and receiver frequencies is 10 Mc/s on the 80 Mc/s-band and 4.5 Mc/s on the 160 Mc/s-band. In addition for *portable equipment* one-way channels ranging between 162.9 and 163.4 Mc/s have to be provided. These connections are made by transmitting and receiving on the same frequency in either direction so that by means of a switch, either the transmitter *or* the receiver may be switched on at each station.

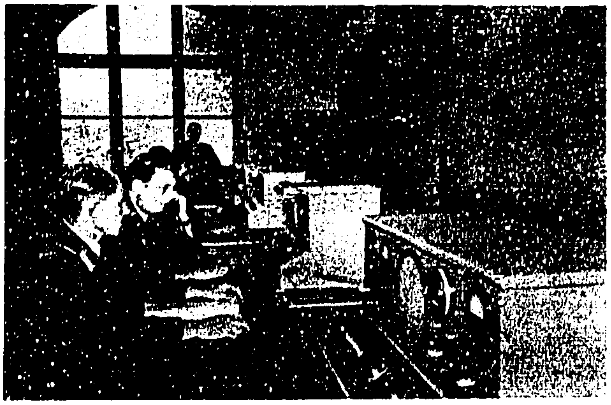

Fig. 7 — Police Radio Communication Headquater in a Large City.

b) The radio communications centres, which frequently are located close to each other, must be prevented from interfering each other. It is therefore not always advisable to install the *stationary equipment* at the highest altitude of the area concerned but to select a site the location of which is of such a nature that only the associated area may be covered and that in adjacent areas the field-strength will not exceed a certain threshold level.

c) The frequencies available will have to be allocated in such a way that the existing *radio communications equipment* of other power companies will not be interfered by networks equipped with modern equipment working on channels separated by 50 kc/s.

The power companies shall use the same equipment as in Germany has already stood the test in radio communication for police, fire-brigade, railroad, highway, and harbor authorities [11] [12] (Fig. 7)

Fig. 8 — Inside of Emergency Car Equipped with Radio Communication Sets.

The equipments in question have the following outstanding features:

1. *Mobile Equipments* (Fig. 8)

   a) Adjustable for operation on 1 or 7 channels
   b) Duplex operation
   c) Possibility of connecting to a wire line network
   d) Range: approximately 30 km
   e) Selective signal for calling a specific vehicle out of the total number of mobile stations. The calling signal may operate the "Bosch" horn of the vehicle so that also work teams occupied in some distance of the vehicle can be summoned

### 2. *Portable Radio Communication Sets*

- a) Operation frequency within 160 Mc/s band
- b) Simplex operation
- c) Range on level ground: 3 km
- d) The audio signal shall be audible at the called station over a distance of 5 meters. If required, the audio range may be extended to 30 meters by means of additional devices.

## III. TECHNICAL DESIGN FEATURES

Telefunken equipment is not only simple to handle but also all parts are easily accessible (Fig. 9). All equipment is housed weather proofed (Fig. 10). Individual units can be pulled out of the rack (drawout type, Fig. 10) or readily inspected when opening the doors (cabinet type, Fig. 11). Smaller units are accessible from all sides upon removal of the protective covers.

### 1. *Stationary Equipment*

The drawout-type is particularly advantageous because individual components can be readily replaced in case of trouble. The cabinet type is fit above all for UHF equipment since a separate housing of the individual components would be impractical because of the coaxial lines used in this type of equipment.

Of special importance for stationary equipment is the power supply which must ensure continuous operation and complete independence of the local distribution system, if used.

If a local distribution system is available, it is good practice to tap the high voltage line and step down to 220/380 volts 50 c/s. The low voltage will be supplied to two independent station networks, non-regulated and regulated, if necessary on account of the voltage fluctuations on the high voltage side. The non-regulated network feeds all load circuits when voltage fluctuations are of minor concern as in lighting. All radio communication equipments are connected with the regulated network so that they will not be affected by greater voltage fluctuations on the H.V. side. A storage battery is continuously charged by a rectifier to ensure continuation of operation immediately upon failure of the local power supply. The battery capacity is amply rated to ensure safe operation for four hours.

Contrary to amplifier stations which are usually powered directly from batteries the voltages required por operating radio communication equipments are derived from the 50 c/s constant-voltage system. When the local network fails, the voltage is supplied by a DC/AC motor gene rator set operating on the battery. This set is kept running also when power from the distribution system is taken to prevent even the shortest service interruption when changing over from local to battery operation. The AC generator of this set supplies constant AC voltage to the regulated network and covers the full load only upon failure of the local supply. Owing to the flywheel effect of the rotating parts of the MG set a period of about 1 second that is required for changing over from local to battery supply is bridged without causing any interruption.

When the normal supply fails for more than 5 minutes, the diesel emergency generating set automatically starts up to cover the power requirements. The diesel driven AC-generator supplies the regulated as well as the non-regulated network and constantly charges the battery via the AC/DC-motor-generator set.

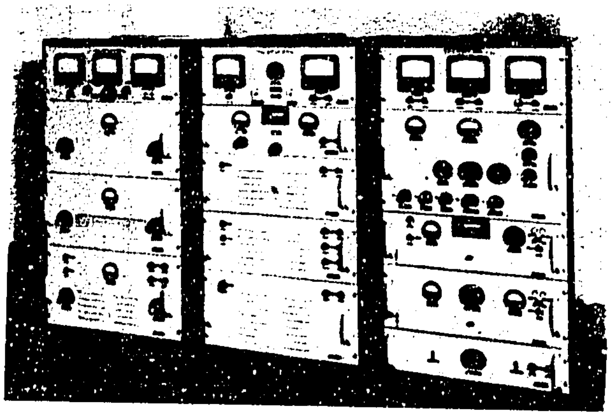

Fig. 10 — Transportable Transmitter-Receiver Equipment for 300 Mc s Multi-Channel Radio Link.

Should the diesel engine fail without the normal supply voltage having recovered, an alarm system will become operative and summon the local attendants or those of the nearest attended station. During the four hours for which operation can be maintained by the battery, it will mostly be possible to ensure continuous power supply by using a mobile emergency generating set.

Supplying power to relay stations located in sparsely inhabited areas often is so difficult that the entire project of radio links may be jeopardized. Under certain circumstances supplying power over long distances may be too expensive just as is the transport of diesel fuel or gasoline up inaccessible mountains (transport by mules). In such cases the use of wind-driven generating plants is the most favourable solution. Since storage batteries are provided in any relay station and an emergency generating set driven by a combustion motor is available, the wind-driven generator takes the place of the normal power supply. With no wind available the power is taken from the battery, which in such a case may be of a somewhat larger capacity (giving e.g. 8 to 12 hours discharge time). Since in coastal areas and on mountains generally more wind is

Fig. 11 – Relay Station of Television Transmission Link Hamburg-Koln.

Fig. 12 — 10 m Diameter Wind-Wheel Generator, built by Messrs. ALLGAIER, Uhingen Wuertt. (Germany).

available in the mornings and evenings, during the intermediate time power may be supplied by the storage battery, to economize in fuel. In all probability the utilisation of the wind-driven generating plant will be very high since on the mountains plenty of wind will be available and because the wind wheels are installed on the top of the antenna towers, which are outside the whirlwind-zones experienced near the ground. This also results in an improved performance. Fig. 12 shows a wind wheel built by Messrs. ALLGAIER.

## 2. *Transportable Radio Links*

Radio link equipment which permits easy transportation can be taken apart into components (Fig. 10) that can be readily lifted on any truck or trailer or carried into buildings, barracks or tents by four men. The components are connected by non-interchangeable plugs with each other, to the power supply (single-phase A.C.) and to the antenna. Upon removal of the rear covers of the transport case they are ready for operation irrespective of their place of installation on vehicles or inside of buildings. Unless already available for other purposes an appropriate power supply has to be furnished in the form of gasoline or diesel generating set. It is sufficient to protect the equipment during operation by a weather proof cover against ingress of water. During the transport the front and rear covers of the transport case protect the equipment against rain.

Yagi antennas mounted on a telescopic mast of 20 meters in height (Fig. 13) may be used for transportable radio links. Higher masts are not recommended because of their heavy weight and the difficulties involved in their erection. The equipment is designed for quick availability for operation. Practical tests have shown that five men, after some training, are able to set up the equipment ready for operation in about two hours and to dismount it in half the time.

With transportable relay stations, separate transmitting and receiving antennas have to be used which must be erected at a certain distance from each other and directed in such a way that interaction is minimum. Elimination of interaction can be easily accomplished by making appropriate use of the high inherent selectivity of the receivers.

Using separate antennas for transmitter and receiver offers the additional advantage that units provided for a relay station can also work separately from each other thus establishing an independent radio link.

In the case of stationary radio links, transmitter and receiver are frequently connected to a common antenna and separated by filters.

### 3. *Mobile Radio Telephony Sets*

The mobile sets are generally sub-divided into a number of units so that they can easily be mounted on any vehicle (Fig. 14). Transmitter and receiver are connected to a common antenna through a filter. The antenna may be so inconspicuously mounted that the vehicle can not be recognized as a "radio car".

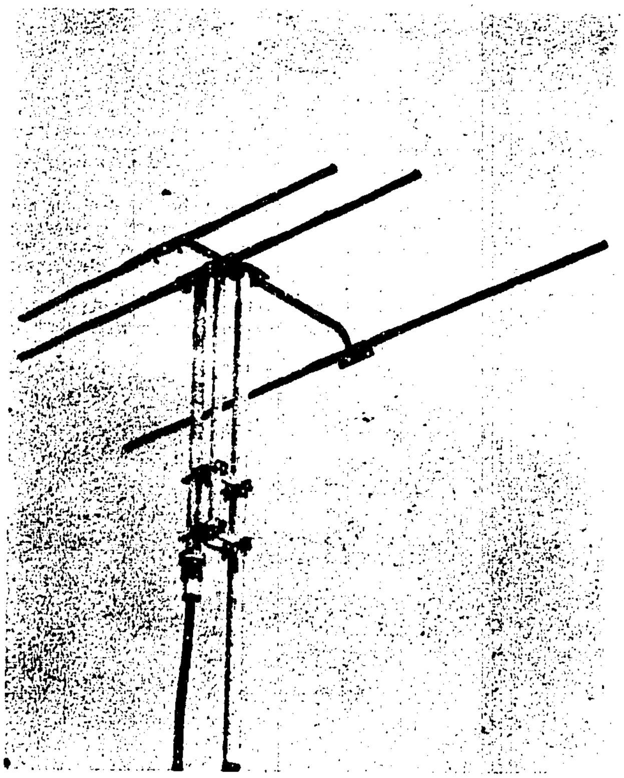

Fig. 13 — Plain Yagi-Antenna for Mobile Radio Links.

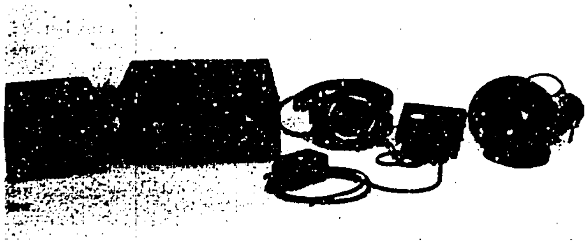

Fig. 14 — Individual Components of Mobile 7 Channels Radio Telephony Equipment. From left to right: Power-Supply; Transmission-Receiver; Telegraph Key; Telephone Set; Supervisory Instrument and Channel Selector Switch; Loudspeaker.

The individual channels are selected either by pressing the associated push-keys (Fig. 15) or selected by manipulating a rotary switch. The system shown on Fig. 14 permits the selection of seven channels. Thus no tuning is required but only simply operating the appropriate key or switch.

The telegraph key noticeable on Fig. 14 may be used for transmitting morse signals or any other signals operating the buzzer used for call

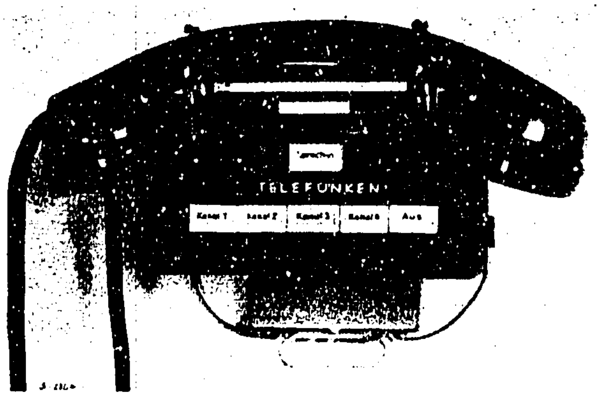

Fig. 15 — Cradle Set of Radio Telephony Equipment. Push-keys permit selection of for channels.

ing. This is particularly practical when short orders are transmitted because one need not hold the phone close to the ear all the time, since the calling signal can be heard even at some distance of the ear.

The loudspeaker shown on the right-hand side of Fig. 14 may be mounted on the fender when used for transmission of orders from the car and covers a distance of between 50 and 100 meters depending on the external noise level.

These mobile equipments are supplied with power from a 12 V or 6 V battery, via a vibrator.

### 4. *Portable Radio Telephony Sets*

This type of equipment may be carried on back (Fig. 5) or by hand (Fig. 16). It is designed as one-channel and 12-channel equipment (Te-

Fig. 16 — Portable radiotelephone sets in which but little heat in generated internally are not so much affected by the high outdoor temperatures of the tropics as by the stresses of cold in arctic areas and high mountains. "Teleport II" stood a special test and proved its adequacy on the Nanga-Parbat expedition. In heights up to 6,000 meters and at lowest temperatures, the equipment established communication between the different camps and while on route; it has being appreciated by all participants as an indispensable aid.

leport II and III respectivily). One storage battery for operation and another one as standby unit are arranged in the lower part of the set and can be easily removed. Thus it can also be charged remote from the equipment.

Telephone and microphone can be combined in a single unit just like a normal cradle set. It is also possible to use them separatly buckling the microphone with a strap to the chest of the operator and by fastening the head-phone with a ribbon to his head or fitting it into a cap. Thus both hands are free for other work while communicating. This is of special importance for work on transmission line towers.

### 5. *Tropicalisation, Resistivity against vibration and shock*

For equipment to be used in the tropics the inside is treated with a sponge lacquer in addition to the usual and well known treatment. Due to its fungicide effect this lacquer prevents the formation of fungi even in the presence of high humidity and heat.

In the Telefunken laboratories, the newest plastic materials, impregnating compounds, oils, etc. are continuously tested with respect to their application in high-frequency equipment. As a result of these tests, the most practical materials can be used for the individual parts of the equipment so that in many cases considerably higher temperatures can be permitted than formerly, e.g., by applying silicones.

All equipments are carefully tested also in mechanical respect, particularly to their resistance to shock and vibration during transport, so that they safely withstand rough handling and transport on vehicles over pathless tracts of land. When mounted, the equipment can take shocks corresponding to ten times the earth acceleration. This is tantamount to accelerations which result from driving on streets in poorest condition. The stresses experienced due to shocks while driving over cobble stones at a speed of 50 to 60 kilometers per hour is about 3 to 4 times as large as the earth acceleration. The equipment is protected against periodic vibration by eliminating all constructional elements which give rise to resonant vibration.

### SUMMARY

The great need for power utility communication subject to special conditions may be met not only by wire-line telephone systems, but can also be satisfied by radio service. The latter has many advantages since wireless connections are not bound to fixed stations but can also be readily established between mobile stations. This paper deals with VHF and UHF radio links, their importance and applicability to electric power supply systems, particularly to fast and reliable fault-localisation on EHV transmission lines; it also discusses the application of using mobile and

portable radio communication sets. The technical features inherent to this type of equipment are shown at hand of various patterns for use under normal and tropical conditions.

## Résumé

La necessité urgente de communications dont les entreprises de distribution d'électricité ont besoin peut être satisfaite par des lignes téléphoniques et également par des liaisons h.f. Les équipements h.f. permettent l'établissement rapide de liaisons entre des station fixes aussi bien qu'entre des stations mobiles. Cette flexibilité est un des grands avantages des liaisons h.f. On donne une analyse des applications possibles des câbles hertziens métriques et décimétriques ainsi que des équipements radiotéléphoniques portatifs et mobiles aux problèmes de télécommunications des entreprises de distribution d'électricité. La technique courante est décrite, en outre la localisation rapide et sûre de dérangements d'une ligne à haute tension et la possibilité de la tropicalisation du matériel.

## Resumo

A necessidade de comunicações urgentes que experimentam os serviços de distribuição de eletricidade, pode ser satisfeita pelas linhas telefônicas e, também, por serviço de rádio. Este último oferece muitas vantagens, desde que as comunicações sem fio não sejam sujeitas a estações fixas, mas possam, também, ser estabelecidas, prontamente, entre estações móveis. A presente monografia trata das ligações hertzianas VHF e UHF, sua importância e aplicabilidade aos sistemas elétricos de distribuição de energia, particularmente à fixa e segura localização de defeitos nas linhas EHV de transmissão de fôrça elétrica. Examina, também, a aplicação do emprêgo dos aparelhos móveis e portáteis de rádio-comunicação. Mostra os característicos técnicos próprios dêsse tipo de equipamento junto aos vários modelos para o uso sob condições normais e tropicais.

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CONFERÊNCIA MUNDIAL DA ENERGIA
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Titulo 3
Assunto 3.4

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro – 1954

SCHMIDT (F.)
EGGERSGLUESS (W.)
Alemanha

# PRODUCTION OF HIGH POWERED GAS FROM AGRICULTURAL WASTES OR OTHER ORGANIC MATTER

By FERDINAND SCHMIDT
and DR. WALTER EGGERSGLUESS

NATIONAL COMMITTEE OF THE GERMANY FEDERAL REPUBLIC

Until now gas has not been produced efficiently and profitably in a biological process from organic matter except in municipal sewage plants. It has been known for a considerable time especially from investigations by Buswell (USA), and proved in laboratory pilot plants, that methane gas can be obtained from farm wastes or other organic material. In 1947 we have designed a plant to use any agricultural wastes, manure, straw, vegetable residues etc. as a source of energy.

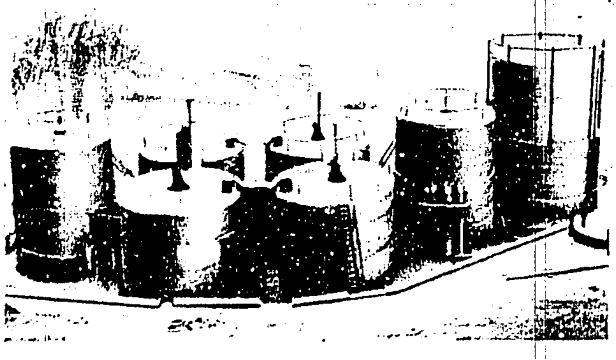

Figure 1 — BIHUGAS PLANT BREITENBURG — 4 fermentation tanks, 2 storage tanks for manure and a gasholder

If fibrous material is used in this biological process an accumulation of it takes place and forms a thick floating layer. The main problem was to destroy this layer in order to get a good fermentation by the methane bacteria in agricultural gas plants. The normal installation of sewage plants cannot be used in larger agricultural gas plants because in full operation floating layers of a thickness of several yards will form very soon. The problem of loosening the solid floating layer has been solved by using a penetrating jet of liquid drawn from the bottom of the fermentation chamber. The procedure has been improved in practical use.

In western Germany there are a number of agricultural biological humus and gas plants (called Bihugas plants) in use today. The biggest one shown in figure 1 has a total fermentation silo capacity of 720 cubic meters (25,500 cu.ft.). The average daily output of gas is 650 cubic meters (23,000 cu.ft.). The gas produced in these plants is used for cooking, boiling and heating on the farm, in green-houses and for tractor driving.

Bihugas normally has a content of 62 % methane and 38 % carbon dioxide. Only traces of nitrogen, oxygen, hydrogen and hydrogen sulphide are present. The gross heating value of this gas is 5,900 Kcals./cubic meter (≈ 660 BTU/cu.ft.).

The content of hydrogen sulphide differs according to the raw material used. Normally it is approximately 200 grams per 100 cubic meter (88 grains per 100 cu.ft.). In a simple cleaning box the sulphur is entirely removed, so there is neither unpleasant smell nor corrosion. This biologically produced gas is extremely good for driving cars or tractors because the octane figure is about 115. Investigations have been made on tractors which have run on Bihugas for years. In figure 2 such a 28 B.H.P. DEUTZ tractor is shown. It was stated by experts of the manufacturing firm that the gas driven tractors were worn out far less than the Diesel driven ones. The main reason for this is that Bihugas is free of sulphur, hence Diesel oil used in western Germany has a sulphur content of 0,5 to 1.0 percent in weight.

On bigger plants it is useful to wash out the carbon dioxide because the gross heating value can be increased up to 9,000 Kcals./cubic meter (1,000 BTU/cu.ft.). By this the radius action of the tractors is enlarged too. Two steel cylinders whose total content is big enough to keep the tractor running for about 9 hours are fitted. Bihugas is compressed by a compressor into large high pressure storage tanks up to 350 atm (5,000 p.s.i.). The two steel cylinders fitted to the tractor have a pressure of 200 atm (2,840 p.s.i.).

Compressed Bihugas does not follow the ideal gas law. In fact the content in gas at a pressure of 350 atm is about 10 % higher than it should be according to the gas law. The content of the steel cylinders on tractors with 200 atm is 25 % higher. Petrol engines can be driven by Bihugas without any difficulty. Diesel engines need an installation for ignition. Two well known German tractor firms (Deutz and Hanomag) deliver their normal tractors if required as gas tractors. A number of tractors of varying horse power rating are already running on several farms. All of them have turned out extremely well. Even if the carbon dioxide is not washed out Diesel tractors had no loss in power running on gas. Naturally it is possible to use this valuable Bihugas for many purposes. The entire output of gas of a Bihugas plant in Bavaria is, for instance, used for generating electricity. A gas generator is running for breaking the peaks in the consumption of electricity during working hours.

On a farm in Germany carrying 100 cows the production will be approximately 350 cubic meters (12,400 cu.ft.) of gas per day, providing that 10 kg of chopped straw is used for litter per cow daily. The production of gas for one year in such a plant amounts to 126,000 cubic meters (4,450,000 cu.ft.). This amount equals 95,000 ltr (25,000 US gals.) of petrol. The comparison with Diesel oil gives an equivalent of 70,000 kg. About 30 % of the total amount of gas produced is used for heating and machinery driving inside the plant. Under warmer climatic conditions the amount used for heating the fermentation silos is comparatively lower. On a normal German farm about 20-40 % of the gas production is used for tractor driving, the remaining gas is available for

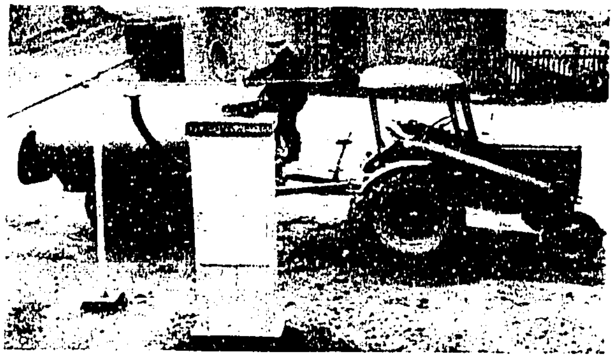

Figure 2 — 28 B.H.P. DEUTZ TRACTOR — driven by Bihugas tows a special trailer for distribution of manure, just being filled with manure from the storage tanks. In the foreground gas filling station from behind

other purposes. A farm with such a Bihugas plant is self sufficient in fuel and does not need any other supplies of energy. If Bihugas is used for cooking and heating purposes slight alterations of the gas-burner are necessary on account of the difference in velocity of flame compared with normal coal-gas. These special burners can easily be obtained. Gas plants in Germany are not only built because of the power producing aspects. Many agricultural advantages are given by such a Bihugas plant. Though production of gas is the main interest in this report several points of high agricultural importance should be mentioned here:

1. Handling of the manure on a farm is entirely mechanized that means from the byre to the fields. The distribution is done by special sludge trailers.
2. Fermentation takes place in airtight containers so there is no loss in manurial value especially nitrogen. Therefore this manure is of higher quality than normal manure. This has been proved by many tests and field trials.
3. During fermentation the loss in organic matter is smaller than on a normal manure heap. Therefore also the quantity of manure available is higher than before.
4. During fermentation weed seeds will be entirely destroyed.

The above mentioned advantages are sufficient to recover the total costs of a Bihugas plant in a short time. From the agricultural point of view Bihugas is a real byproduct and costs nothing.

In western Germany, according to the latest statistics, about 5,000,000 tons of cellulose and 350,000 tons of nitrogen are decomposed and lost per year from the manure heaps. This figure shows that in every country sufficient raw material is available and therefore gas plants are of great interest for the political economy. Out of the above mentioned figure of 5,000,000 tons of cellulose about 4,500,000,000 cubic meters of Bihugas can be produced. This annual amount of gas is equivalent to 3,400,000,000 ltr (900,000,000 US gals.) of petrol.

In western Germany much larger quantities of waste material are available as potato haulms, maize straw, reeds etc. Moreover organic wastes of certain industries like slaughter-houses, destilleries, yeast factories etc. can also be used in Bihugas plants. In the tropics enormous quantities of organic wastes are obtainable to produce gas and valuable manure. Fermentation tests have, for instance, been made recently on sisal wastes in a Bihugas plant. It was proved by our investigations that sisal waste has to be regarded as a first class material for fermentation, even better than manure. On a normal medium sized farm in Kenya or Tanganyika an average amount of about 10 tons of dry sisal waste would be on daily disposal. It was proved in many tests, that from 1 ton of sisal waste 400 cubic meters of gas can be produced. This gives a daily production of 4,000 cubic meters of Bihugas on a normal sisal farm. This equals 3,000 ltr (800 US gals.) of petrol per day or 1,080,000 ltr (290,000 US gals.) per year. It is obvious that this quantity of gas is far higher than the average consumption on a sisal farm including electricity. These figures show that Bihugas plants are of high importance in the tropics because, far away from any supplies and power sources, fermentation of organic matter opens up new resources of power which annually replenish themselves. This power can be obtained from raw material which so far was regarded as a real waste and was burned or thrown away.

Studies have been made by us for years on fermentation of agricultural wastes. It must be pointed out, however, that Bihugas can be produced without manure of any kind. In this case the fermentation liquid can be obtained by addition of special nutritive salts to water. These salts must contain, like artificial fertilizer, nitrogen, potash, phosphate etc.

Though the development of the Bihugas process was not started before 1947, a good number of plants in western Germany are running already. For instance to-day a tractor can be supplied with Bihugas from the different plants over a distance of more than 1000 km from north to south of western Germany.

The Bihugas process takes no energy from stored supplies as coal or oil but from organic material which annually is growing afresh. It presents a new way to sources of energy which now have been made accessible.

## SUMMARY

A plant has been constructed in which, similar to sewage plants, methane gas is produced by fermentation of all other kind of organic matter. The development is completed so far that a number of so called Bihugas plants are already running on several German farms. The produced gas is sufficient to supply the total need in energy for the whole farm. The gas is used for domestic appliances, tractor driving and generating electricity. All kind of organic matter can be used in the Bihugas process i.e. manure, straw, vegetable wastes and also organic wastes of certain industries. In the tropics huge amounts of organic material are available for this process. Sisal waste has been proved to be an ideal raw product for fermentation. On a normal sisal farm in Africa the possible output of gas equals 1,080,000 ltr (290,000 US gals.) of petrol per year. The Bihugas process takes no energy from stored supplies but from material which annually is growing afresh.

## RÉSUMÉ

On a construit une installation au moyen de laquelle on extrait — comme dans les clarificateurs pour eaux d'égouts des grandes villes — du méthane qui se dégage de matières en putréfaction. Le système et l'outillage se sont tellement perfectionnés qu'un grand nombre de ces installations nommèes "Bihugas" ont pu être mises en usage sur les propriétés agricoles d'Allemagne. Le gaz ainsi produit suffit à tous les besoins en énergie d'une exploitation rurale. On l'emploie pour la consommation domestique, pour actionner des tracteurs, pour la production d'énergie électrique. Le procédé "Bihugas" prête à l'utilisation de toutes sortes de substances organiques, du fumier, de la paille, des déchets de légumes ainsi que des déchets de quelques industries manufacturières. Enfin les régions tropicales sont abondamment pourvues de matières organiques prêtant à la production de ce gaz. Les déchets de sisal, par exemple, donnent un produit de base excellent. En Afrique la production annuelle de gaz sur une plantation moyenne de sisal équivaut à la quantité de 1.080.000 litres d'essence. Le procédé "Bihugas" permet d'exploiter des ressources d'énergie nouvelles reposant dans des substances organiques qui se régénèrent d'année en année.

## RESUMO

Construiu-se uma instalação pela qual — como nos clarificadores de águas de esgôto das grandes cidades — metano (gás dos pântanos) é produzido pela fermentação de tôda espécie de matéria orgânica. O aparelhamento se tornou de tal forma completo que grande número das chamadas instalações "Bihugas" foram logo sendo usadas nas propriedades agrícolas da Alemanha. O gás assim produzido é suficiente para suprir as necessidades totais em energia duma exploração rural. É usado para fins domésticos, para acionar os tratores e para a produção da energia elétrica. Tôda espécie de matéria orgânica pode ser usada no processo "Bihugas", isto é, estrume (adubo), palha, resíduos vegetais (legumes) e também resíduos orgânicos de certas indústrias. Nas regiões tropicais, enormes quantidades de matérias orgânicas se prestam à produção do gás em questão. Os resíduos de sisal têm provado ser um produto não trabalhado (agreste) ideal para a fermentação. Numa propriedade agrícola de sisal na África a produção possível de gás chega a 1.080.000 ltrs. (290,000 gals. norte-americanos) de petróleo por ano. O processo "Bihugas" não retira energia de materiais em depósito, mas de material que, anualmente, cresce ou regenera-se.

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# L'EXPLOITATION PRÉSENTE ET FUTURE DE L'ENERGIE SOLAIRE

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## 1. QUE PEUT-ON DIRE AU SUJET DE L'ÉCONOMIE DE L'EXPLOITATION DE L'ÉNERGIE SOLAIRE?

Au cours de ces dernières années, la question de savoir si et comment la génération future sera en mesure de couvrir ses besoins d'énergie qui ne cessent d'augmenter, est devenue un problème qui intéresse aussi les régions tropicales et subtropicales 1) 2) 3).

Bien que les conditions présentent de grosses différences dans tous les pays, la tendence générale montre que la demande directe de combustibles solides augmente à peine, tandis que celle qui s'adresse aux sources d'énergie plus évoluées accuse une montée vertigineuse. C'est la raison pour laquelle on s'occupe sérieusement de la question de savoir pendant combien de temps il sera possible d'assurer l'approvisionnement de l'humanité principalement en gaz et en courant électrique, en ayant recours aux méthodes de production actuelles. Autant qu'on en puisse juger et dans la mesure où il n'est pas obtenu sous la forme de gaz naturel, le gaz continuera à être produit à partir des combustibles solides ou liquides. Pour le courant électrique toutefois, il sera possible et même nécessaire dans un délai plus ou moins rapproché de se rendre indépendant des stocks limités de combustibles et des réserves également limitées de force hydraulique naturelle. A cette effet, deux possibilités se présentent: l'exploitation de l'énergie nucléaire et des énergies naturelles issues du soleil.

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1) Mueller H. F.: Grundzüge der Energieabsatzwirtschaft 1942.

2) Mueller H. F.: Das Arten — und Sortenproblem als ein Grundproblem in der Energiewirtschaft. Praktische Energiekunde 1952/53, Heft 2.

3) Mueller H. F.: Kosten, Werte und Preise in der Energiewirtschaft. Praktische Energiekunde 1952/53, Heft 3.

Si elle gagne en importance, cette seconde voie le fera surtout dans les régions tropicales et subtropicales. Des essais remarquables ont déjà été effectués à ce sujet et il semble qu'il soit nécessaire d'y accorder tout l'intérêt voulu. La deuxième partie de cet exposé s'occupe dès lors de la restitution du niveau atteint aujourd'hui par l'exploitation de l'énergie solaire et de ses possibilités techniques.

On ne peut pas encore dire grand chose au sujet de l'économie du développement des divers procédés à décrire. Le profit de l'examen pourrait être anéanti s'il n'était pas possible d'indiquer au moins les facteurs qui déterminent l'économie dans le cadre du développement attendu. On ne tardera pas de constater que les conditions pour une marche économique des installations destinées à l'exploitation de l'énergie solaire ont pris un tout autre aspect ces derniers temps et pourraient encore subir certaines modifications à l'avenir.

D'une façon générale, certains auteurs prétendent encore que de telles installations ne peuvent être prises en considération pour les régions tropicales et les zônes limitrophes, pour des raison d'économie. Néanmoins, chaque état se trouve aujourd'hui devant la question de savoir comment il pourrait se rendre maître du besoin d'énergie si ce dernier continue à suivre le même cours que pendant ces dix dernières années. On ne peut donner de réponse d'application générale à cette question si les conditions pour le développement dans tous les pays et, à plus forte raison, dans diverses zônes géographiques, présentent des différences considérables. On doit donc examiner pour chaque région séparément quels sont les facteurs qui déterminent le développement.

En premier lieu, on peut dire d'une façon générale que des distinctions strictes sont à faire entre le besoin d'énergie et le besoin de sources d'énergie. L'énergie, c'est ce que l'humanité doit et veut avoir sous les formes les plus diverses; les sources d'énergie, ce sont le charbon, l'huile minérale, le gaz et le courant électrique. L'homme n'en a pas besoin d'une façon directe, mais elles lui sont nécessaires car elles lui permettent d'obtenir de l'énergie sous la forme désirée. Il faut encore y ajouter le besoin de générateurs d'énergie qui sont les appareils et les machines dans lesquels doit s'effectuer la transformation de l'énergie et sans lesquels l'homme ne peut tirer parti des sources d'énergie à sa disposition.

Pour ce qui est des deux points suivants, il est nécessaire de décrire en détail et d'analyser la demande et l'offre, et de précieuses indications à ce sujet sont données dans le présent alinéa. Une importance particulière revient aux débours que le consommateur prend ou doit prendre à sa charge pour couvrir un certain besoin d'énergie. Ils dépendent des prix des sources d'énergie, de ceux des transformateurs d'énergie et de ceux du capital. Ce n'est qu'après addition qu'ils donnent les frais invisibles en soi et souvent difficilement estimables entraînés pour l'utilisation de l'énergie et que nous appellerons "prix de revient de l'énergie". Si, comparé au pouvoir d'achat de la monnaie, le niveau général des prix de revient de l'énergie est élevé, le besoin prend une importance et une tournure autres que s'il est bas. On en a pas tenu compte jusqu'à présent à l'occasion de la plupart des discussions relatives à cette question. On peut constater des différences analogues si les prix de diverses sources d'énergie dans un pays déterminé se comportent entre eux autrement que dans un autre, ou si les prix des appareils et du capital diffèrent sensiblement les uns des autres. Ceci devra également être illustré par des exemples. Des relations comparables des prix de revient de l'énergie n'ont cependant, en aucune façon, pour conséquence des développements similaires. Le climat, les matières premières et le caractère de la population exercent une influence considérable sur le besoin d'énergie. Celui-ci agit sur l'offre tout comme les prix de l'offre ont une influence sur le besoin. C'est précisément cette influence réciproque aux aspects les plus variés qui détermine l'économie des divers procédés dans le cadre du développement général.

Un quatrième groupe de facteurs, à savoir le développement du pays, de sa population et de son économie, est également d'une importance capitale pour la solution de ces questions. Naturellement, le besoin futur d'énergie dépend lui-aussi de tous ces facteurs, des tournures prises par la situation économique, etc. Un examen sur le plan économique peut, à vrai dire, donner certains renseignements sur l'influence de ces facteurs mais non sur leur développement au cours des années futures. Ce serait plutôt du ressort de l'étude des conjonctures, des disciplines biologiques, géologiques et autres. On s'abstient en général de toute prédiction concrète. Ceci devrait être pour l'économiste un avertissement l'invitant à ne pas émettre de pronostics économiques comme il le fait fréquemment. L'économie de l'énergie a uniquement à établir comment se développe le besoin d'énergie dans des conditions données et de quelles conditions dépend une satisfaction suffisante et économique du besoin en question. Elle n'est pas compétente pour trancher la question de savoir si telle ou telle condition sera donnée sous une forme ou sous une autre.

## 2. LE PROBLEME DES SORTES

Si, dans deux pays, on constate une consommation de beurre très différente par ménage, on peut à peine imaginer que le beurre puisse être destiné à des usages autres que l'alimentation et on pourra rendre le bien-être d'un peuple responsable de sa consommation de beurre. Il en va tout autrement pour le besoin d'énergie. Il existe ici des possibilités très différentes pour l'utilisation de l'énergie, possibilités qui ont [illegible]ns ou n'ont même aucun rapport entre elles comme, par exemple, la lumière pour éclairer ou irradier (plantes), la force motrice pour les communications, pour remplacer le travail humain ou pour tous les procédés possibles de façonnage, la chaleur pour fondre, rougir, chauffer, cuire, etc. Nous les appelons "sortes d'énergie".

Les différences dans le besoin d'énergie peuvent donc se présenter sous deux aspects: il peut s'agir de consommation importante ou minime d'une seule et même sorte ou de consommation de sortes absolument différentes (différences de quantité et différence de forme du besoin et de la consommation). Ces questions essentielles de l'économie de l'énergie ont également été quelque peu négligées jusqu'ici.

Pour les régions tropicales et subtropicales, la sorte d'énergie "chauffage des locaux" ne sera quantitativement pas aussi importante que pour d'autres régions; la demande d'énergie "éclairage" sera, d'une part, autre que dans les zônes nordiques en raison du peu de différence entre l'été et l'hiver, et accusera, d'autre part, une augmentation sensible dans les nuits d'été là où il est presque impossible de travailler le jour pendant les chauds mois d'été 4) 5) 6) 7).

Toutefois, de telles différences conditionnent aussi l'estimation des sortes. Afin de favoriser la croissance des plantes par irradiation, on sera prêt à certains sacrifices dans les pays nordiques, alors que ceci n'offre aucun intérêt dans les régions tropicales; mais pour voir dans l'obscurité, on sera prêt partout à des débours relativement élevés. Il est évident que les sortes d'énergie qui sont peu estimées, ne sont pas utilisées si le niveau du prix de l'énergie est élevé. Elles n'apparaissent pas "sur le marché"; nous ne le remarquons que plus difficilement que dans le cas d'autres biens économiques, car il n'existe pas de "marché" visible pour l'énergie, mais uniquement pour les sources et les transformateurs d'énergie dont il faut tirer les conséquences que l'ont applique au marché de l'énergie. Certaines branches entières de l'industrie, telles que par exemple la production de l'aluminium, ne pourront jamais se développer dans les pays qui ont des prix trop élevés pour le courant, faute de force hydraulique bon marché. La consommation d'énergie de la population peut, pour de simples raisons de ce genre, être beaucoup plus basse que dans d'autres pays, sans que ceci veuille dire chose qui a déjà été maintes fois répétée — que le standing est inférieur ou que la technique est moins developpée. La consommation d'énergie se limite toutefois aux sortes qui sont de plus grande valeur et dont on utilise des quantités moins considérables.

D'autre part, il peut arriver que dans les pays où, pour des raisons naturelles, le besoin de certaines sortes d'énergie est moins élevé que dans d'autres, l'unité d'énergie pour ces sortes est estimée à un niveau supérieur. Dans les pays nordiques, le besoin de chaleur pour le chauffage des locaux est généralement très élevé et on n'accorde que peu de

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4) Linge K.: Die Wärmepumpe im Rahmen der Energiewirtschaft. Zeitschrift des VDE, Bd. 88, H. 5/6, 1944.

5) Die Wärmepumpe als Energiekonsument Elektrizitätsverwertung 1951/52, Heft 1.

6) Diesse W.: Thermodynamische Grundlagen der Wärmepumpe. Energie, Bd. 5, H. 3.

7) Erichson C. R.: Die Wärmepumpe. Das Gas- und Wasserfach 1949. Wohnraumheizung mittels Wärmepumpe. Brennstoff — Wärme — Kraft (B W K) Bd. 2 (1950) S. 143.

valeur à l'unité de chaleur de la sorte "chauffage", de sorte qu'on ne peut avoir recours qu'à des combustibles bon marche. C'est la raison pour laquelle on est obligé d'accepter un certain "inconfort" du chauffage.

## 3. LE PROBLÈME DE L'ÉTABLISSEMENT DU PRIX

Ce sont donc des objets de natures très diverses (sortes d'énergie) qui sont utilisés à cet effet. Les marchés pour tous ces biens, qu'ils soient visibles ou invisibles, sont également très différents. Cette diversité est fréquemment négligée car seuls quelques rares marchés, indépendants l'un de l'autre à première vue, attirent l'attention en général. On rencontre ici des formes de marché avec un caractère de monopole à côté d'autres où régne la libre concurrence. En vérité, ils sont très étroitement liés l'un à l'autre. Pour l'éclairage électrique, le consommateur dépend dans une large mesure des services d'approvisionnement officiels alors qu'une libre concurrence règne en ce qui concerne les lampes. Une libre concurrence régne pour la préparation de l'eau chaude, également en ce qui concerne les sources d'énergie. Une offre favorable de courant et de gaz pose comme conditon primordiale que l'on éclaire avec le courant et que l'on cuise avec le gaz. Les prix de l'offre dépendent donc d'une façon unique en son genre des formes industrielles appliquées pour répondre aux besoins de sortes d'énergie souvent très différentes au moyen d'une ou des plusieurs sources d'énergie. Ceci a pour conséquence particulièrement intéressante que l'établissement du prix pour l'éclairage, par exemple, obéit plutôt aux conditions des marchés libres que des marchées monopolisés.

Il en résulte que le niveau général des prix pour l'énergie a accusé, par rapport au pouvoir d'achat au cours de ces dernières dizaines d'années, une tendance à la baisse dans la plupart des pays. La demande d'énergie a dès lors augmenté quantitativement et on constate une tendance marquée à l'abandon des sources et transformateurs d'énergie de peu de valeur au profit des sources et transformateurs d'énergie de qualité. On en arrive ainsi au fait, déjà mis en relief au début, que la demande de combustibles solides est à peine touchée directement par l'augmentation du besoin et que, par contre, la demande qui s'adresse aux combustibles plus évolués – en particulier le gaz et le courant électrique – prend des proportions inquiétantes. Ceci doit provoquer des phénomènes de rarification et partant une modification du niveau des prix et des relations des prix entre eux sur les marchés de lénergie. D'une façon générale, l'énergie devra devenir plus chère absolument et relativement au pouvoir d'achat, et les sources d'énergie évaluée dont le prix a baissé dans certains pays au cours de ces dernières années par rapport aux combustibles solides, vont voir leur valeur relative augmenter. Lors de l'exploitation de nouvelles sources d'énergie, les points de vue de la concurrence n'auront plus de valeur décisive dans le sens qu'on leur attribuait auparavant. Le point capital sera la question de savoir si les frais d'installation qui semblaient indiscutables jusqu'ici, peuvent être encore plus économiques en raison de la demande accrue de sortes d'énergie de valeur.

## 4. LA POMPE CALORIFIQUE À TITRE D'EXEMPLE DES PARTICULARITÉS ÉCONOMIQUES PRÉSENTÉES PAR LES RÉGIONS TROPICALES ET SUBTROPICALES DANS LE DOMAINE DE L'ÉNERGIE

Le rendement de la pompe calorifique dépend principalement du niveau de température qui doit être vaincu. Si on exige que la température soit portée de 10 à 80° C environ, la pompe calorifique travaille dans des conditions bien plus défavorables que si on ne demande qu'une température de 40° C. On sait en outre que l'utilisation de la pompe calorifique se heurte fréquemment aux frais élevés occasionnés par la construction de l'installation. Une longue durée d'utilisation est donc la première condition d'économie. Outre l'emploi pour le chauffage des locaux et la préparation de l'eau chaude, on prendra donc aussi en considération l'utilisation de la pompe calorifique pour la réfrigération. On construira également l'installation de façon à couvrir la charge de base, tandis que les pointes de froid éventuelles devront être couvertes par des chauffages supplémentaires. Toutes ces conditions peuvent être remplies dans les régions tropicales et subtropicales bien plus aisément que dans d'autres.

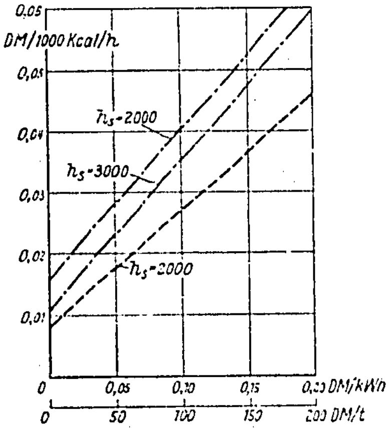

Fig. 1 — Comparaison des frais généraux pour un chauffage central et une installation de pompes calorifiques

La fig. 1 donne une comparaison entre les frais généraux d'exploitation ramenés à 1000 unités caloriques/heure pour un chauffage central et une installation de pompes calorifiques avec un rendement de 1 million d'unités caloriques/heure. Ici et dans l'exemple suivant, on a admis, pour la pompe calorifique, un point d'évaporation de l'ordre de 0° C et une température de liquéfaction de 40° C. On a prévu également, pour le dégagement de la chaleur, des radiateurs constitués de tuyaux à ailettes. Les frais d'installation du chauffage central ont été supposés s'élever à DM 110.000.—, ceux de la pompe calorifique à DM 220.000.—, le service du capital à 15%, le rendement du chauffage central à 80% et le chiffre de rendement effectif de la pompe calorifique à 4,7. Les résultats doivent être compris, en premier lieu, dans leur ordre de grandeur et dans leur relation entre eux. La fig. 1 permet de constater que les frais totaux s'élevent à Dpf 1,75 pour 1000 unités caloriques/heure pour le chauffage central si on prend pour base une durée d'utilisation de 2000 heures et un prix de DM 50.— pour la tonne de charbon; on arrive au même résultat pour 1000 unités caloriques/heure avec la pompe calorifique si le prix du courant est inférieur à Dpf 1/kWh. Mais avec le prix actuel du charbon qui s'élève à DM 125.— la tonne dans de nombreuses régions peut encore être considéré comme trop favorable, un prix équivalent de DPf 7/kWh pour le courant serait encore supportable.

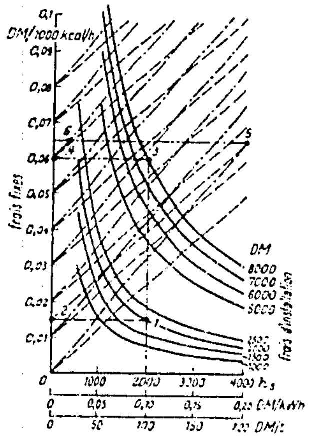

Fig. 2 — Installation de 10.000 unités caloriques/heure

Un calcul analogue a été effectué dans la fig. 2 pour des installations de 10.000 unités calorifiques/heure seulement. De nombreuses pompes calorifiques de cette importance sont en service aux U.S.A. Il y aurait lieu de dire ici que les frais entraînés par les installations de pompes calorifiques avec des rendements aussi réduits (petites maisons) sont quatre fois plus élevés que ceux résultant du chauffage central à eau chaude; ils sont 2,5 plus élevés pour 100.000 unités caloriques/heure et 2 fois plus élevés pour 1 million d'unités caloriques/heure. Dans la fig. 2, on a pris pour base un rendement de 60%, un chiffre effectif de 3,64, un service du capital de 15%. La comparaison peut être effectuée pour différentes hauteurs des frais d'installation et de la durée d'utilisation, en prenant aussi en considération la possibilité (même si elle n'est que conditionnelle) d'employer la pompe calorifique pour la réfrigération. Le diagramme de la fig. 2 montre:

Au-dessus de la durée d'utilisation, par exemple de 2000 heures, les ordonnées coupent d'abord la courbe des frais de capital d'un chauffage central; pour des frais d'installation de DM 2.000.—, soit donc au point 1. Les frais fixes pour 1000 unités caloriques/heure s'élevent dans ce cas à Dpf 1,5 (point 2). Le même rendement entraîne en cas d'utilisation d'une installation de pompes calorifiques coûtant DM 8.000.—, des frais fixes s'élevant à Dpf 6.— (points 3 et 4). Avec un prix de DM 200.— la tonne de charbon, on arrive à un débours total de quelque Dpf 6,5 pour 1000 unités caloriques/heure (point 5 se trouvant sur la droite pointillée donnant la montée des frais d'exploitation totaux pour 1000 unités caloriques/heure en fonction du prix du charbon); cette dépense limite le prix du courant équivalent à Dpf 1,5 environ le kWh (point 6 se trouvant sur la droite en "trait-point" donnant la montée des frais d'exploitation totaux pour 1000 unités caloriques/heure en fonction du prix du courant). Il est aisé d'extraire du diagramme des conditions plus favorables ou plus défavorables. Sous ce rapport, le point important n'est pas constitué par les relations des prix charbon/courant ou petite installation/grosse installation, mais par la dépendance existant entre l'économie et le taux d'intérêt. Si on prenait pour base, au lieu de 15%, un service du capital de 14%, les hyperboles des frais fixes auraient une marche absolument différente. Le point 2 se trouverait à Dpf 1,4, le point 5 à Dpf 6,4, le point 6 à Dpf 5,6 et le point 6 au-delà d'un prix du courant de l'ordre de Dpf 2,4 le kWh, c'est-à-dire de 60% plus élevé que précédemment. En d'autres termes, une installation d'énergie qui est inrentable sur un marché avec de la "monnaie chère", peut être économique sur le même marché avec de la "monnaie bon marché".

## 5. CONCLUSION

Nous avons ainsi trouvé un point de départ pour répondre à la question de savoir si et dans quelle mesure de tels procédés peuvent être économiquement rationnels pour la production de courant, procédés qui n'ont pas ou n'ont été qu'à peine pris en considération jusqu'ici. Les faits suivants sont déterminants:

1. la constitution qualitative et quantitative du besoin de sortes d'énergie,
2. la constitution qualitative et quantitative de l'offre de sources d'énergie et de transformateurs d'énergie,
3. le rapport des prix des sources d'énergie au prix du capital,
4. le rapport du prix de l'énergie en résultant au pouvoir d'achat ou à la productivité.

Il a été démontré que ces facteurs pouvaient, dans certains cas, avoir dans les régions tropicales et subtropicales une importance absolument différente de celle qu'ils auraient dans d'autres zônes.

Le maintien de la vie sur la terre nécessite de l'énergie et celle-ci trouve son origine dans le rayonnement solaire qui, depuis des millions voire même peut-être des milliards d'années, résulte presque sans variations de la naissance de l'hélium à partir de l'hydrogène.

Chaque mètre carré de la surface du soleil émet constamment une puissance de 62.000 kw 8). Un demi-milliardième seulement de cette énergie totale atteint la terre. Le courant d'énergie qui arrive sur l'hémisphère s'élève à $174.10^{12}$ kw. En d'autres termes, le rayonnement solaire est de 1,35 kw par mètre carré d'atmosphère extérieure en cas d'incidence verticale. Si on prend en considération le chiffre de population actuel de $2,32.10^{9}$, ceci représente 75 kw par habitant. Une grande partie en est toutefois perdue par réflexion et absorption dans l'atmosphère terrestre. Dans des conditions favorables, la surface terreste en Europe Centrale – par exemple durant les claires journées de juin – ne reçoit plus que de 0,8 à 0,9 kw de radiation par mètre carré. Si on effectue le calcul pour une année entière, on arrive cependant à un rayonnement par mètre carré encore dix fois plus petit en moyenne, car la nuit et les conditions atmosphériques défavorables doivent aussi être prises en considération. Chaque individu dispose donc d'une façon directe et constante de quelque 7,5 kw. Pour couvrir ses besoins d'énergie, il a toutefois recours à des sources indirectes plus accessibles telles que le charbon, les gisements de combustible, la force hydraulique et le vent. Sans cette énergie solaire historique que constituent le charbon et les gisements de combustible, le niveau actuel de la civilisation ne pourrait être conservé dans la plupart des pays. Il serait intéressant de savoir si la mise à profit intégrale de l'énergie solaire directe est possible et si elle est en mesure de porter remède à la carence de l'énergie solaire historique. C'est le but de l'exposé ci-après.

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8) Grassmann P.: Die Erschliessung der Energiequellen der Erde. Brennstoff-Wärme-Kraft (BWK) Bd. 1 (1949) S. 5/9.

## 6. LA CONSOMMATION D'ÉNERGIE DE L'HOMME

Elle comprend l'alimentation, la chaleur et la force motrice et est toujours exprimée ci-après en chiffres sous forme d'énergie électrique en kw.

En ce qui concerne l'alimentation, l'homme a besoin en moyenne d'environ 0,12 kw à l'heure, ce qui représente 2.400 à 3.000 calories en vingt-quatre heures, soit 3 à 4 kwh. Son besoin de force et de chaleur varie en fonction de la position sur la terre, du modus vivendi et du niveau de civilisation. Des 2,3 milliards d'individus qui constituent la population du globe, $0{,}3 . 10^9$ sont nomades, $1{,}3 . 10^9$ vivent dans des habitations fixes et $0{,}2 . 10^9$ dans des huttes. Dans les zônes centrales à la population la plus dense qui donnent asile à quelque $1{,}5 . 10^9$ habitants, la consommation peut — si on prend pour base le niveau de culture actuel — s'élever à 2 ou 3 kw par heure et atteindre une valeur moyenne de 60 kw par vingt-quatre heures, ce qui représent en chiffres ronds 20.000 kw par heure, soit une consommation totale d'énergie de $1{,}5 . 10^9 . 20.000 = 30 . 10^{12}$ kwh. A l'heure actuelle (1950), on dispose de $2 . 10^{12}$ kwh d'énergie électrique proprement dite, le reste étant fourni par le charbon, l'huile et le gaz. En considérant le niveau du développement atteint aujourd'hui, on peut s'attendre à ce que ces sources s'épuisent un jour et à ce qu'on en soit vraisemblablement réduit à l'exploitation de lénergie solaire directe transformée en énergie électrique. La préférence accordée à l'énergie électrique par le monde civilisé qui délaisse le charbon dans une mesure croissante, est une raison supplémentaire pour s'attacher à la transformation de l'énergie solaire en électricité.

De nombreux calculs ont été effectués par H. Steiner 9) et autres sur l'accroissement rapide de la consommation d'énergie électrique et les résultats en sont repris dans le tableau suivant.

TABLEAU I

ESTIMATIONS DE L'ACCROISSEMENT DE LA CONSOMMATION EN KWH PAR HABITANT ET PAR AN

| | *Probable* | *Possible* |
|---|---|---|
| Mines | 200 | 500 |
| Métallurgie | 2.000 | 8.000 |
| Matériaux de construction | 300 | 2.000 |
| Commerce et industrie | 2.000 | 2.500 |
| Autres branches de l'économie | 6.000 | 10.000 |
| Transports | 500 | 10.000 |
| Eclairage, cuisine et appareils ménagers | 1.000 | 2.000 |
| Chauffage et installations frigorifiques | 3.000 | 10.000 |
| | 15.000 | 45.000 |

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9) Steiner H.: Tendenzen der Stromverbrauchsentwicklung. Elektrizitätswirtschaft. Vol. 52. (1953) page 283.

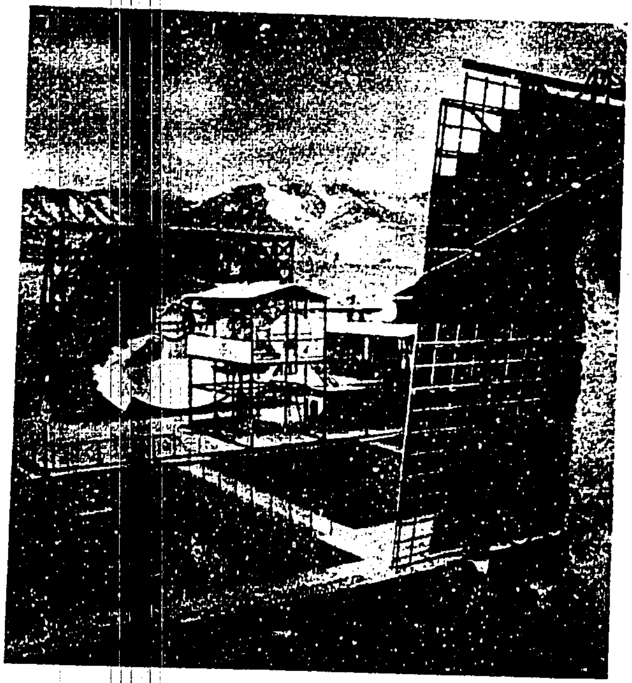

Fig. 3 — L'installation d'énergie solaire de 75 kw sur le Mont Louis dans les Pyrenées

Steiner a également calculé que la consommation d'énergie électrique augmente de 7,2% par an depuis quelque 50 ans, c'est-à dire de 100% en 10 ans. Aux U.S.A., la consommation d'énergie électrique s'élève actuellement à 2.500 kwh par individu et par an. Elle est de 6.000 kwh dans les pays scandinaves et de 1.200 kwh en Allemagne.

## 7. ESSAIS PHYSIQUES SUR L'UTILISATION DE L'ÉNERGIE SOLAIRE

### a) *L'installation du Mont Louis.*

Depuis des années déjà, des centrales à vapeur à miroirs ardents ont été construites dans certaines régions privilégiées, par exemple en Egypte et sur le Mont Wilson. Ces centrales purent sans contredit être mises en service, mais elles ne furent pas rentables car elles n'offraient aucune possibilité d'accumulation. Les circonstances sont essentiellement plus favorables dans le cas de la station d'essai de rayonnement solaire de 75 kw construite dans les Pyrénées [10] [11] fig. 3, et équipée d'un miroir parabolique de 120 mètres carré. Cette énergie est utilisée pour produire des températures particulièrement élevées destinées à des fusions spéciales

TABLEAU II

FORCE THERMO-ÉLECTRIQUE ET L'ÉNERGIE CALORIQUE

PROPERTIES AND PERFORMANCE OF POSSIBLE THERMO-ELECTRIC SYSTEMS

| | Couple | Electrical Resistivity ohm-cm. | Thermal Conductivity Watts/°C.-cm. | Thermo-electric Power Micro-volts per °C. | Calculated Efficiency | Observed Efficiency | Temperature Range |
|---|---|---|---|---|---|---|---|
| 1. | Constantan | $49 \times 10^{-6}$ | 0.33 | 73 | 0.96% | 0.92% | 20–500°C. |
| 2. | Chromel P. | $78 \times 10^{-6}$ | 0.22 | | | | |
| 1. | Bismuth | $185 \times 10^{-6}$ | 0.095 | 111 | 1.0% | — | 20–260°C. |
| 2. | Antimony | $86 \times 10^{-6}$ | 0.205 | | | | |
| 1. | 91% Bismuth 9% Antimony | $212 \times 10^{-6}$ | 0.073 | 123 | 1.31% | — | 20–260°C. |
| 2. | Antimony | $86 \times 10^{-6}$ | 0.205 | | | | |
| 1. | Zinc-Antimony (35% Zn. to 65% Sb.) | $7200 \times 10^{-6}$ | 0.014 | 250 | 2.7% | 2.7% | 20–420°C. |
| 2. | Constantan | $49 \times 10^{-6}$ | 0.33 | | | | |
| 1. | Zn-Sb (35%-65%) with small amounts of tin or silver | $2700 \times 10^{-6}$ | 0.015 | 250 | 5.6% | 5.7% | 20–420°C. |
| 2. | Constantan | $49 \times 10^{-6}$ | 0.33 | | | | |
| 1. | Zn-Sb (35%-65%) with small amounts of tin or silver | $2700 \times 10^{-6}$ | 0.015 | 390 | 10% | 7.0% | 430 C. |
| 2. | Lead Sulphide with excess lead | $13000 \times 10^{-6}$ | 0.015 | | | | |

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[10] Solar Power in the Pyrenees. Life, 23 mars, 1953 (International Edition) page 49 et suivantes.

[11] Die Sonnenenergie-Anlage in Frankreich. Naturwissenschaftliche Rundschau. Vol. 6 (1953) page 199 et suivantes.

et usages analogues. L'installation est à même de fonctionner 250 jours par an environ et travaille avec des températures pouvant atteindre 3.000° C.

b) *Essais portant sur la force thermo-électrique*

Une mise à profit de le rayonnement solaire appliquée depuis longtemps déjà dans certains appareils expérimentaux est sa transformation en énergie électrique par l'intermédiaire de thermo-éléments. La difficulté réside ici dans le fait que la différence de tension électrique par cellule est très réduite, de l'ordre de quelques micro-volts par degré centigrade. C'est la raison pour laquelle seules peuvent être prises en considération les machines dans lesquelles plusieurs milliers de points de soudure sont disposés en série. Il en résulte toutefois simultanément l'inconvénient d'une résistance relativement élevée qui provoque la perte de la majeure partie de l'énergie électrique en cas de court-circuit. Des savants américains[12]) ont démontré récemment dans des essais qu'il était possible de produire des forces thermo-électriques de 200 à 700 micro-volts par degré centigrade en ayant recours à des alliages appropriés (Tabl. II et III). Malheureusement, la conductibilité électrique donne une courbe généralement parallèle à celle de la conductibilité calorique, bien que des essais aient permis de démontrer également ici que des forces thermo-électriques de 200 à 300 micro-volts par degré centigrade procurent des effets utiles de 6 à 10 % de l'énergie calorique introduite, ce qui correspond au rendement effectif de la machine à vapeur en 1900 ou à celui de la locomotive moderne. Mentionnons avant tout ici l'ouvrage de M. Telkes[13]). (Fig. 4)

TABLEAU III

LES EFFETS UTILES DE SEMI-CONDUCTEURS

PROPERTIES OF SOME USEFUL SEMI-CONDUCTORS

| Material | $\rho$ Electrical resistivity at room temperature ohm-cm. | $k$ Thermal conductivity $\frac{\text{Watts}}{\text{C. cm.}}$ | Thermo-electric power referred to copper $\mu$V/ C. |
|---|---|---|---|
| Stannic Oxide | 0.17 | 0.01 | -200 |
| Zinc Oxide | 0.02 | 0.01 | -400 |
| Lead Sulphide (pure) | $10^1$ | 0.01 | 700 |
| Lead Sulphide with excess lead | 0.013 | 0.015 | -300 |
| Lead almost pure | 3.3 | 0.01 | 530 |
| Titanium Sulphide | 7.0 | 0.01 | -500 |
| Cuprous Sulphide | 0 05 | 0.01 | 280 |
| Cuprous Sulphide with excess copper | 33.3 | 0.01 | 620 |
| Cuprous Sulphide with excess sulphur | 0.005 | 0.01 | 80 |

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[12]) Griffith Miriam V.: Thermo-Electric Generation of Useful Power. Direct Current (1952) page 10 à 13.

[13]) Telkes Maria: The Efficiency of Thermo-Electric Generators. Journal of Applied Physics (1947) 18 pp. pages 1.116 à 1.127.

### c) *Accumulateurs de chaleur*

Aux U.S.A., une série de services et instituts scientifiques, s'occupent de l'accumulation de la chaleur solaire et de son utilisation pour la climatisation des habitations ainsi que pour certaines applications dans l'industrie chimique. La difficulté réside principalement dans l'obtention d'une accumulation, sans pertes exagérées, d'une quantité de chaleur suffisamment grande pendant des semaines et des mois. On y arrive d'autant plus aisément que plus élevé est le pouvoir d'absorption de la substance accumulatrice et que plus grandes sont les dimensions de l'accumulateur lui-même. Le sulfate de sodium ($Na_2SO_4 + H_2O$) a particulièrement fait ses preuves à cet effet. Au-dessus de 32° C, cette solution possède, à l'égard de la chaleur, un pouvoir d'absorption huit fois plus élevé que celui de l'eau. Des maisons ont déjà été équipées d'accumulateurs de chaleur au sulfate de sodium de ce genre et, autant qu'on a pu en juger jusqu'ici, ces installations donnent entière satisfaction. Certaines publications spécialisées dans ce domaine affirment que 10% des habitations seront équipées de cette manière d'ici une vingtaine d'année[14].

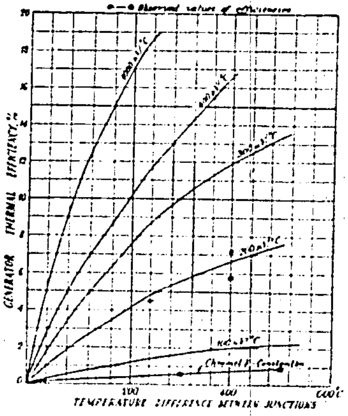

Fig. 4 — Variation de l'effet utile thermo-électrique

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[14] Solar Energy, ACEN Staff-Report, Chemical and Engineering News, Vol. 31 (1953) n. 20, pages 2056 à 2060.

L'équipement des canots de sauvetage de dispositifs transformant l'eau salée en eau potable sous l'effet de la radiation solaire, représente une autre application intéressante et importante de l'énergie solaire.

## 8. ACCÉLÉRATION DES PROCESSUS BIOLOGIQUES PAR L'ÉNERGIE SOLAIRE

L'ensemble de la vie sur la terre repose sur la production d'hydrates de carbone à partir des éléments purs. Ce processus biologique peut, en principe, être expliqué par la formule $6\,CO_2 + 6\,H_2O \rightleftharpoons C_6H_{12}O_6 + 6\,O_2$, soit donc acide carbonique + eau $\rightleftharpoons$ hydrate de carbons + oxygène ./. petites calories. Il a pu être établi qu'on se trouve ici en présence d'un processus de quanta au cours duquel ces 112.000 petites calories par molécule doivent être utilisées sous forme d'énergie solaire ou lumineuse irradiée.

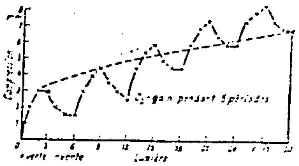

Fig. 5 — Courbe ascendante de l'energie solaire en cas d'alternance "lumiere-obscurité"

Il s'agit ici d'un double phénomène de quanta pour lequel, d'une part, la lumière est nécessaire pour fixer l'hydrate de carbone et, d'autre part, le processus complet n'a pas besoin de lumière, de la chaleur étant libérée par la séparation de l'oxygène qui produit alors les 112.000 calories/molécule. Ce second processus se déroule dans l'obscurité et il peut être suivi d'une façon particulièrement aisée si on fait et supprime la lumière alternativement (Fig. 5). Il s'est avéré que ce processus pouvait, en vases de réaction appropriés et dans des conditions biologiques adéquates, être conduit d'une façon considérablement plus économique que lorsqu'il se déroule normalement dans la nature et on a déjà réussi, dans des stations expérimentales spéciales, à produire 125 tonnes d'algues par hectare. La question de savoir si cette méthode est la plus rationnelle pour produire des produits alimentaires ou fourragers ou encore du combustible, n'a toutefois pas encore pu être éclaircie 15) 16).

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15) Burk D. et Warburg O.: Ein-Quanten-Reaktion und Kreisprozess der Energie bei der Photosynthese. Zeitschr. f. Naturforschung. Vol. 6 b (1951) pages 12, 134, 285, 417.

16) Warburg O.: Energetik der Photosynthese. Die Naturwissenschaften. Vol 39 (1952) page 337.

## RÉSUMÉ

Il ressort de l'exposé ci-dessus qu'il existe une série de processus utilisant directement la radiation solaire. Le transport de l'énergie du lieu de production au lieu de consommation peut, le cas échéant, se faire au moyen de lignes à tension constante. On peut aussi emmagasiner l'énergie dans des accumulateurs ou la transformer sur place en énergie chimique. Cet exposé se bornera à mentionner quelques sources bibliographiques à ce sujet. Une importance beaucoup plus grande doit être attribuée au fait que la WPC (Conférence Mondiale de l'Énergie) s'est chargée de cette mission pour en faire une réalité dans un avenir plus ou moins rapproché.

## SUMMARY

There are a number of processes utilizing sun radiation direct. The transmission of the energy from the generator to the consumer may be made by means of d.c. lines. However, energy can also either be loaded on batteries or converted on the spot into chemical energy. This article will quote only a few literature references on the subject, while essential importance should be attributed to the fact that also the WPC concerns itself with this task in order to realize it within a reasonable lenght of time.

## RESUMO

A monografia em questão evidencia a existência de vários processos que utilizam diretamente a irradiação solar. A transmissão da energia do gerador elétrico ao consumidor pode ser feita por meio de linhas de tensão constante. Pode-se também acumular a energia em acumuladores ou transformá-la na ocasião em energia química. A monografia se limitará em mencionar algumas fontes bibliográficas sôbre o assunto. Uma importância muito maior deve ser atribuida ao fato de que a WPC (Conferência Mundial da Energia) se encarregou dessa missão para dela fazer uma realidade num futuro mais ou menos próximo.

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12) Griffith Miriam V.: Thermo-Electric Generation of Useful Pow. Direct Current (1952) page 10 à 13.
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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 2
Assunto 2.1.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro - 1954

ZEHNLE (J. P.)
Bélgica

# CONSIDERATIONS SUR LA CONCEPTION DES CENTRALES HYDRO-ELECTRIQUES EN PAYS TROPICAUX ET PARTICULIEREMENT AU CONGO BELGE

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## I) INTRODUCTION

Les problèmes posés par la conception d'une centrale hydro-électrique en pays tropicaux n'appellent pas de solutions radicalement différentes de celles que l'on envisage couramment au Nord ou au Sud de l'Amérique ou en Europe, par exemple; il n'en reste pas moins que ces solutions doivent souvent composer avec des sujétions inconnues dans les régions de climat tempéré.

C'est par l'examen rapide de ces sujétions à la fois géographiques et humaines que nous aborderons notre note; nous montrerons ensuite dans quelle mesure elles peuvent intervenir aux divers stades de la conception d'une centrale hydro-électrique.

La documentation et l'expérience qui sont à la base de nos remarques ont été surtout recueillies au Congo Belge; nous n'étendons donc pas systématiquement nos conclusions à tous les pays tropicaux.

## II) LES FACTEURS GEOGRAPHIQUES ET HUMAINS

Les régions que nous envisageons comportent, non seulement les zones tropicales, mais aussi les zones équatoriales, soit d'une manière générale, les zones comprises entre les deux tropiques et que nous appellerons intertropicales.

## A) LA GÉOGRAPHIE PHYSIQUE

### 1) *Le Climat*

Le climat est essentiellement régi par le mouvement apparent du plan de l'écliptique solaire; il en résulte une remarquable périodicité annuelle de tous ses facteurs dominés, domme on le sait par des températures généralement élevées et des pluviosités extrêmes. La physionomie du climat varie avec les latitudes, elle peut encore être modifiée par des conditions locales de situation par rapport à la mer, et de relief.

Précisons quelques éléments du climat susceptibles d'intervenir dans l'étude d'une centrale hydro-électrique.

Le tableau I donne diverses valeurs caractéristiques de la température de l'air pour des stations du Congo Belge. Il met en évidence des moyennes annuelles de 20 à 26° et des amplitudes moyennes de variation diurne pouvant atteindre 14°.

TABLEAU I

TEMPÉRATURE DE L'AIR AU CONGO BELGE (en degrés Celsius)

| Stations | Latitude | Altitude | Moyennes annuelles | Moyennes mensuelles | | Amplitude de variation diurne moy. | Maxima |
|---|---|---|---|---|---|---|---|
| | | | | max. | min. | | |
| Elisabethville | 11° 39' S | 1250 m. | 20 | 23 | 16 | 14 | 35 |
| Lusambo ... | 4° 85' S | 470 m. | 26 | 27 | 24 | 11 | 36 |
| Yangambi .. | 0° 46' N | 470 m. | 25 | 26 | 24 | 10 | 35 |
| Buta ....... | 2° 47' N | 437 m. | 25 | 26 | 24 | 11 | 40 |

Le régime des vents présente la régularité bien connue des alisés; les intensités ne s'éloignent généralement pas de celles observées en Europe, mais elles se manifestent par rafales. L'attention de l'Ingénieur doit cependant être retenue par l'existence de typhons qui ravagent les côtes des mers tropicales, on peut y mesurer des vitesses de 200 km/h, leur fréquence n'est pas encore bien connue.

Les vents et les températures conditionnent à leur tour les pluies et déterminent leur périodicité; on peut admettre en première approximation, que le maximum des pluies suit en chaque région, avec un certain retard le passage du soleil au zénith; il en résulte suivant les latitudes, une ou deux saisons des pluies séparées par autant de saisons sèches. Les intensités des pluies apparaissent au tableau II.

## TABLEAU II

### CÔTES UDOMÉTRIQUES AU CONGO BELGE (en millimètres)

| Stations | Latitude | Altitude | Moyennes annuelles | Moyennes mensuelles | | Nombre de mois s/ pluie | Maxima en 24 h. |
|---|---|---|---|---|---|---|---|
| | | | | max. | min. | | |
| Elisabethville | 11° 39' S | 1250 m. | 1223 | 272 | 0 | 4 | 160 |
| Niemba .... | 6° 50' S | 600 m. | 1140 | 195 | 4 | 2 | 106 |
| Luebo ..... | 5° 22' S | 450 m. | 1447 | 217 | 9 | 0 | 116 |
| Yangambi .. | 0° 46' N | 470 m. | 1816 | 245 | 97 | 0 | 134 |
| Buta ....... | 2° 47' N | 437 m. | 1484 | 208 | 26 | 0 | 75 |

L'humidité en dehors des zones désertiques et sub-tropicales est toujours très forte le matin où elle voisine les 100%, elle tombe dans l'après-midi s'il pleut; le tableau III donne quelques chiffres relatifs à trois stations du Congo Belge très proches de l'Equateur.

## TABLEAU III

### HUMIDITÉS RELATIVES AU CONGO BELGE (mesurées en 1950)

| Stations | Latitude | Altitude | Moyennes annuelles | Moyennes mensuelles | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | à 7 h. | | à 15 h. | | à 18 h. | |
| | | | | max. | min. | max. | min. | max. | min. |
| Eala .... | 0° 01' N | 320 m. | 82 | 97 | 95 | 77 | 61 | 90 | 82 |
| Nioka ... | 2° 09' N | 1800 m. | 68 | 95 | 83 | 71 | 38 | 87 | 47 |
| Yangambi | 0° 46' N | 470 m. | 78 | 99 | 96 | 71 | 58 | 87 | 73 |

Considérons à présent un facteur qui intéresse l'économie des réserves d'eau: l'évaporation. Ce phénomène est important en pays intertropicaux, mais sa mesure est délicate. Les résultats de quelques mesures effectuées au Congo Belge sont indiqués, sous toute réserve, au tableau IV.

TABLEAU IV

ÉVAPORATION AU CONGO BELGE (en mm. mesurés à l'appareil Piche)

| Stations | Latitude | Altitude | Moyennes annuelles | Valeurs journalières extrêmes | |
|---|---|---|---|---|---|
| | | | | Maxima | Minima |
| Elizabethville .. | 11° 39' S | 1250 m. | 970 | 7,4 | 0,3 |
| Lusambo ...... | 4° 85' S | 470 m. | 1110 | 5,8 | 6,8 |
| Thysville ..... | 5° 15' S | 750 m. | 680 | 5,2 | 0,3 |
| Yangambi ..... | 0° 46' N | 470 m. | 550 | 5,8 | 0,0 |
| Boketa ........ | 3° 11' N | 500 m. | 870 | 5,8 | 0,2 |

Nous admettons généralement au Congo Belge, en l'absence de mesure directe, que la hauteur annuelle d'évaporation sur une nappe d'eau libre est égale à la cote udométrique, mais l'évaporation présente dans l'année une répartition complémentaire de celle de la pluviosité.

### 2) *La morphologie et les sols*

Il peut paraitre paradoxal dans un exposé qui se veut général, d'évoquer les caractères communs de la morphologie de pays très éloignés, si ce n'est en latitude tout au moins en longitude.

Et pourtant, si l'on considère la géologie qui engendre la morphologie, l'on constate que l'Afrique au Sud du Sahara, Madagascar, l'Australie, le Sud de la péninsule indienne et le continent Sud Américain à l'est des Andes, ont un passé commun, qui a imprimé à ces pays leur caractère massif tout en permettant une érosion intense qui leur a donné un aspect de pénéplaines monotones coupées de failles, modelées en cuvettes, remblayées quelques fois par des formations plus récentes et bordées de plateaux et de bourrelets peu ondulés; les roches éruptives, métamorphiques ou en voie de métamorphisation y sont particulièrement abondantes.

Des exceptions importantes doivent être faites pour les régions des Graben Africains, les reliefs volcaniques, de l'Insulinde notamment, et le caractère alpin du massif andin.

Mentionnons aussi le caractère monotone et très altéré des sols tropicaux résultant d'une transformation des roches sous-jacentes beaucoup plus rapide qu'en pays tempéré, sous l'action de la chaleur et de l'humidité, et qui donne assez uniformément naissance, dans les zones à saisons sèches bien marquées, à des terrains peu fertiles, argilo-sableux ou latéritiques, à part quelques bandes alluviales et colluviales.

### 3) *Les caractères généraux de l'hydrographie*

Les débits présentent la même périodicité générale que les précipitations dont ils suivent les variations avec un décalage qui croît avec la superficie des bassins versants.

Le tableau V donne les valeurs caractéristiques des débits de quelques rivières intertropicales. Les irrégularités mises en évidence pour les grands bassins versants sont très faibles près de l'équateur, mais croissent lorsque l'on s'en éloigne; du point de vue des débits, la création de régularisations complètes se présente favorablement.

La considération des débits extrêmes n'appelle pas de remarque spéciale: les faibles durées d'observation font d'ailleurs que ces grandeurs sont encore mal connues.

Quelques caractéristiques des accidents présentés par les profils en long des rivières intertropicales intéressent aussi l'ingénieur: sans vouloir généraliser, signalons que la morphologie en compartiments coupés de failles de l'Afrique centrale, donne souvent naissance sur des rivières à grands débits, à des chutes verticales importantes ou à des zones de rapides à forte dénivellation sur de faibles distances. De tels sites peuvent s'accomoder d'un équipement relativement économique et ce d'autant plus que les gradins sont quelquefois surmontés de vastes plaines permettant la création d'importants bassins de retenues.

Pour illustrer ces observations, citons une centrale du Haut-Katanga qui, à MADINGUSHA sur la rivière Lufira, utilise avec un débit moyen annuel de 45 m$^3$/s une chute naturelle de plus de 100 m surmontée d'un barrage qui, pour une hauteur maximum de 12 m crée un lac d'accumulation de 1,4 milliard de mètres cubes d'eau.

### 4) *La flore et la faune*

La flore et la faune tropicales doivent, elles aussi, retenir l'attention, d'abord par les conditions de travail qu'elles créent pour les humains, et, aussi, par certains problèmes techniques qu'elles posent: de grands animaux sauvages tels les éléphants sont susceptibles de faire des dégâts aux installations et il faut s'en protéger; à l'autre extrémité de l'échelle, l'existence de quantités considérables d'insectes et micro-organismes favorise l'attaque des constructions en bois, provoque le blocage de certains organes mécaniques, le tapissage des conduites forcées et l'obstruction des grilles et petites tuyauteries.

## B) LES FACTEURS HUMAINS

Avant de passer ces facteurs en revue, soulignons que nos remarques trouvent surtout leur origine dans le sous-développement de bien des contrées intertropicales ouvertes tardivement à la civilisation mais il ne nous

## TABLEAU V

### CARACTÉRISTIQUES HYDROLOGIQUES DE QUELQUES COURS D'EAU

| Rivières | Bassins versants (catchment aréa) | Débits moyens annuels (average annual flow) | Débits mensuels extrêmes | | Crues maxima connues (max. recorded flood) |
|---|---|---|---|---|---|
| | | | maxima | minima | |
| Lufira à Kapolowe ..... | 13.100 $km^2$ | 43 $m^3/s$ | 197 $m^3/s$ | 8 $m^3/s$ | |
| Lualaba à Zilo ........ | 16.300 $km^2$ | 103 $m^3/s$ | 175 $m^3/s$ | 28 $m^3/s$ | 560 $m^3/s$ |
| Luvua à Piana ........ | 233.000 $km^2$ | 550 $m^3/s$ | 1.800 $m^3/s$ | 80 $m^3/s$ | ± 2.000 $m^3/s$ |
| Kiymbi à Makungu .... | 270 $km^2$ | 8 $m^3/s$ | ± 30 $m^3/s$ | 3,5 $m^3/s$ | ± 200 $m^3/s$ |
| Inkisi à Zongo ......... | 15.100 $km^2$ | 160 $m^3/s$ | 550 $m^3/s$ | 60 $m^3/s$ | 960 $m^3/s$ |
| Congo à Léopoldville .. | 3.650.000 $km^2$ | 39.000 $m^3/s$ | 65.000 $m^3/s$ | 25.000 $m^3/s$ | 75.000 $m^3/s$ |

échappe pas que certaines de ces contrées — et elles se font tous les jours plus nombreuses — offrent maintenant à l'activité humaine un cadre aussi complet que la vieille Europe par exemple.

### 1) *Populations autochtones et populations blanches*

En Afrique centrale tout au moins, la population indigène est peu dense: 4,2 habitants par km² au Congo Belge, exceptionnellement 24,5 en Nigérie; sa civilisation et son industrie, originales sont rudimentaires, son pouvoir d'achat généralement très faible de l'ordre du cinquième et quelquefois du dixième de celui de l'ouvrier blanc moyen. Du point de vue professionnel, on rencontre principalement des manoeuvres ou des travailleurs peu qualifiés, les artisans sont l'exception. Les prix de revient de cette main d'oeuvre sont corrélativement encore modestes.

En face de cette population autochtone se trouve une population blanche immigrée, peu nombreuse, engagée en majeure partie par contrat en pays tempérés et qui constitue une main d'oeuvre très coûteuse pour l'employeur qui doit, non seulement payer des salaires très élevés, mais encore faire face à des charges connexes pesantes dues aux conditions de vie parfois dures faites par le climat.

Il ne nous échappe pas que les coûts des mains d'oeuvre européenne et indigène ont tendance à se rapprocher en même temps que les qualifications, mais pour l'instant, il faut encore tenir compte d'écarts sensibles en bien des régions.

### 2) *Le problème des approvisionnements et des réparations de machines*

Une conséquence de la faible pénétration de la civilisation moderne dans la plupart des pays intertropicaux est la rareté des industries importantes de transformation, des magasins de grosses machines et des ateliers de réparation bien outillés.

Au Congo Belge presque tout l'équipement des centrales hydro-électriques à l'exception de certaines charpentes métalliques doit être commandé en Europe, en Amérique ou en Afrique du Sud; les centrales ne peuvent souvent compter que sur elles-mêmes ou sur les sociétés dont elle dépendent pour les réparations ou les pièces de rechange, sauf à faire venir ces pièces de leurs pays d'origine avec des délais prolongés. Au stade de l'exécution, les entrepreneurs se heurtent, mais à un degré moindre, aux mêmes difficultés.

### 3) *Longueur et difficulté des communications*

La création d'un réseau de transport à fort débit rapide et dense ne s'est pas encore justifiée dans les pays intertropicaux.

Si les humains trouvent à leur disposition de nombreux avions, les marchandises doivent encore emprunter, notamment pour gagner le centre du continent Africain, le rail et les voies d'eau. Une marchandise expédiée d'Europe ou d'Amérique peut ainsi mettre couramment 3 à 4 mois pour atteindre un petit poste au Congo Belge, après quatre à six ruptures de charge accompagnées d'abandons sur des quais non abrités.

Les gabarits des chemins de fer et l'équipement des quais limitent les dimensions maxima des colis; dans toute l'Afrique centrale on ne rencontre que des chemins de fer à voie métrique ou voie de soixante centimètres. Le transport de colis de plus de (3 x 3 x 12) m$^3$ est difficile; quant aux tonnages transportés, ils ne peuvent dépasser 30 à 50 t. par unité sur le rail, pour autant que l'on dispose des moyens de déchargement adéquats.

La densité du réseau fluvial et ferré reste faible et ces voies n'atteignent généralement pas les sites d'aménagement hydro-électriques il faut alors recourir aux transports routiers ou construire des embranchements ferrés spéciaux.

Les transports par route se généralisent en même temps que le réseau routier se développe, mais ils se heurtent à des prix prohibitifs résultant du mauvais état des pistes et des difficultés d'entretien des véhicules.

### 4) *L'insuffisance de la connaissance des pays tropicaux*

La mise en valeur des pays intertropicaux reste sporadique, il en est de même de la connaissance topographique de ces régions; elle ne se traduit généralement que par des levés à très grande échelle.

Quant aux dossiers hydrologiques détaillés, ils ne peuvent, le plus souvent, s'enrichir qu'à l'occasion de la mise en valeur d'une chute d'eau; il est vrai que des études systématiques commencent à être entreprises par certains organismes parastataux au Congo Belge et dans quelques territoires de l'Union française.

L'aménagement de chaque nouveau site doit donc être précédé d'une étude particulière de la topographie et de l'hydrologie; pour cette dernière, la brièveté de l'étude rend l'évaluation de certaines données pour le moins incertaines.

## III) LA CONCEPTION DES CENTRALES HYDRO-ÉLECTRIQUES EN PAYS INTERTROPICAUX

Pour étudier l'influence des facteurs géographiques et humains dont nous venons d'esquisser le tableau, sur la conception des centrales hydro-électriques, nous considérerons successivement la détermination des caractéristiques d'ensemble des aménagements, la conception des ouvrages de génie civil et, enfin, celle du matériel d'équipement, à l'exclusion du matériel électrique dont il n'est pas question dans cette note.

### A) LES CARACTÉRISTIQUES D'ENSEMBLE DES AMÉNAGEMENTS

### 1) *Les programmes de puissance*

La fixation des programmes de puissance se heurte à deux difficultés: d'une part, les lois du développement économique d'un pays ou d'un centre tropical sont très mal connues, étant fonctions directement ou indirectement de quelques activités polarisées; par ailleurs, les accroissements de consommation pendant une période d'amortissement disons de dix ans — après la construction d'une centrale — peuvent être faibles en valeur absolue et d'un ordre de grandeur bien inférieur à celui des puissances disponibles sur les chutes dont l'équipement peut être envisagé dans des conditions très économiques; c'est notamment le cas pour les centrales alimentant principalement des centres urbains abritant de petites industries. L'absence d'interconnexion généralisée multiplie encore le problème par le nombre de centrales ou de groupes de centrales indépendants.

La construction d'une centrale, surtout pour alimenter le secteur public, peut donc poser un problème délicat d'amortissement et s'accompagner d'un grand risque financier.

Pour atténuer ces inconvénients, on envisage alors des exécutions en plusieurs étapes; il n'en reste pas moins que les investissements doivent tenir compte du fait que certains ouvrages, tels que barrages, galeries d'amenée, doivent, dès l'origine, être conçus pour le stade final.

Le projeteur devra chercher à limiter les immobilisations de première étape; au Djoué près de Brazzaville, en A.E.F., seuls le barrage et la prise d'eau intéressant le stade final, tous les autres ouvrages n'étant exécutés que pour la moitié de la puissance finale; à Zongo, près de Léopoldville au Congo Belge, les conduites forcées et l'équipement de la centrale proprement dite seront réalisés en plusieurs étapes.

Ces considérations conduisent aussi à la création de centrales à groupes assez nombreux; pour la réserve, on installe généralement un groupe, les interconnexions lorsqu'elles existent ne sont pas encore suffisamment développées pour permettre de concevoir des centrales sans réserves.

Il est vrai que, dans la pratique, la notion de réserve a tendance à être perdue de vue dans les centrales dépendant d'une industrie privée; lorsque la consommation croît et que les conditions hydrauliques le permettent, on n'hésite pas à mettre en service les groupes de réserve. Nous connaissons une centrale qui a ainsi fonctionné sans incident pendant une dizaine d'années sans réserve; l'entretien approfondi des groupes en a évidemment souffert.

Sans aller aussi loin, on peut remarquer que la régularité des débits permet des accroissements saisonniers des puissances produites par utilisation du groupe de réserve, les revisions étant systématiquement effectuées en saison sèche et la consommation organisée en conséquence.

### 2) *L'implantation des ouvrages*

La puissance à produire une fois définie approximativement, il convient de rechercher un site d'aménagement adéquat.

Cette recherche, vu le manque de documentation et les difficultés locales peut nécessiter une véritable exploration; elle utilise d'abord les méthodes de levers rapides; mesure des dénivellations à l'altimètre et au clisimètre, estimation des distances au pas. L'ingénieur chargé de cette étude doit donc pouvoir estimer sur des bases assez fragiles, les possibilités du site et les grandes lignes des aménagements les plus intéressants. En pratique, ce n'est que pour ces derniers que l'on pourra ensuite entreprendre les travaux topographiques détaillés, nécessaires à létablissement des projets, puis des études d'exécution. Ces travaux peuvent être longs: pour l'étude topographique complète relative à une centrale de 2500 kW dans une région d'accès difficile, nous avons dû utiliser onze mois de topographe, y compris les restitutions; pour l'étude d'avant-projet d'une centrale de 10.000 kW dans des conditions plus faciles, nous avons encore dû utiliser 5 mois de topographe.

Il semble que certaines des difficultés évoquées ici puissent, en partie, être évitées par l'utilisation de levers aérophotographiques préalables restitués par courbes de forme, puis pour les détails, par des levers photographiques terrestres avec triangulation des repères. Pour les petites installations cependant, le coût de missions aérophoto graphiques peut être excessif; en zone de grande forêt, il est difficile d'y recourir.

En ce qui concerne les fondations des ouvrages, on ne perdra pas de vue les possibilités d'altération très profondes des sols; l'organisation de campagnes de sondages est presque partout nécessaire et représente une source de dépenses accrue par les difficultés d'accès et de ravitaillement.

### 3) *Les études hydrologiques*

Ici encore tout est généralement à faire, à commencer par des mesures sur le terrain; les méthodes sont les mêmes qu'en Europe, mais l'absence de statistiques force souvent le projeteur à s'appuyer sur des chiffres incertains, que ce soit pour les débits d'étiage ou de crue, obtenus par la considération des éléments du climat, les traces des plus hautes eaux, etc...

Il s'indique, dans ces cas, de prévoir des dispositifs d'évacuation des crues susceptibles de surcharge sans grand dommage; déversoirs avec revanches suffisantes notamment.

Les possibilités de créer de grandes réserves d'eau en Afrique Centrale sont très fréquentes et facilitées par le fait qu'elles ne nécessitent que peu d'expropriations; ces réserves interviennent pour régulariser totalement ou partiellement les débits, la notion d'usine de pointe n'existant pas encore. La topographie en cuvettes fait que les réservoirs sont souvent peu profonds, la considération de l'évaporation devient très important. Ainsi la centrale de Madingusha au Katanga présente un réservoir de 1,1 milliard de mètres cubes utiles pour une superficie maximum de 446 km², la perte par évaporation est estimée en année moyenne à 0,5 milliard de mètres cubes pour un rapport total de la rivière de 1,82 milliard de mètres cubes; le rendement de la régularisation ne peut donc dépasser ici 72%.

## B) LA CONCEPTION DES OUVRAGES DE GÉNIE CIVIL.

### 1) *La conception en fonction des conditions de service*

La surveillance des installations étant confiée à un nombre limité d'agents blancs, ceux-ci doivent pouvoir accomplir leur téche avec facilité et efficacité. On mettra à leur disposition, le maximum de possibilités de contrôles; il convient que, des locaux de commande, ils puissent surveiller directement la salle des machines et y accéder très rapidement. Il se justifiera souvent de climatiser les salles de commande et de les pressuriser pour éviter l'entrée des poussières.

Autre aspect de l'influence des conditions de service, les sollicitations des ouvrages. Elles ne diffèrent de celles admises en Europe que par l'absence d'efforts dus à la neige et à la glace, pour les barrages, et par l'amplitude des variations thermiques au sujet desquelles nous avons donné quelques chiffres. Les normes belges sont d'application au Congo Belge pour les efforts dus au vent.

En ce qui concerne plus particulièrement les ouvrages hydrauliques, il est prudent d'envisager l'obstruction complète des pertuis de grilles par des corps flottants et de prévoir par ailleurs des dispositifs d'évacuation pour les îlots d'herbes dont la formation fréquente dans les grandes retenues à faible tirant d'eau, est favorisée par les oscillations du niveau d'eau. Ces masses d'herbes flottantes peuvent s'étendre sur quatre à cinq hectares. Pour les évacuer, on peut, soit les diriger vers des passes de crues surfaces; elles se déchiquettent sur les coursiers, mais les îlots se reforment dans la retenue d'une centrale aval s'il en existe; dans ce cas, il paraît préférable de les haler sur les rives et de les brûler en saison sèche. Nous étudions aussi la destruction des îlots par des herbicides, mais n'avons encore fait aucune expérience satisfaisante. La protection des ouvrages de prise d'eau contre l'introduction de ces îlots est souvent complétée par des avant-grilles flottantes.

### 2) *La conception en fonction des moyens d'exécution*

Nous estimons que les bonnes entreprises sont techniquement capables de réaliser en pays intertropicaux les constructions les plus compliquées et les plus audacieuses avec toute la sécurité voulue, mais les prix de revient peuvent s'en ressentir.

Le problème économique que nous évoquons est dominé par la rusticité de la main d'oeuvre indigène et les coûts et délais d'importation élevés pour les produits qui ne peuvent se trouver sur place. Des travaux simples peuvent être confiés à des indigènes, des travaux compliqués nécessitent un pourcentage élevé de main d'oeuvre européenne. En comparant les coûts de travaux identiques en Belgique et au Congo Belge, on remarque notamment que les coffrages et armatures sont relativement coûteux; les bois disponibles en Afrique sont d'ailleurs souvent sujets à déformation. On a donc intérêt à limiter l'importance des constructions en béton coulé en place, fortement armées et à grandes surfaces de coffrages; dans ce but, on peut envisager souvent les solutions suivantes:

- remplacement des coffrages par des parements de maçonneries de moëllons ou de blocs de béton préfabriqués incorporés dans la construction, ou par des blindages métalliques dans le cas des aspirateurs de turbine, convergents précédents ou suivant des vannages, etc...
- préfabrication de passerelles, dalles, petites poutres.
- réalisation d'éléments portants métalliques, colonnes, poutres de pont roulant, fermes de toiture, poutres de plancher de bâtiments, les hourdis étant seuls en béton armé.

Lorsque les coffrages subsistent, on a plus, qu'en Europe, intérêt à recourir à des éléments métalliques, étayages en tubes, plaques standard de surface; le projeteur peut être amené à tenir compte des caractéristiques de ce matériel.

La plus ou moins grande distance des cimenteries, l'entrainement des maçons indigènes et la qualité des roches disponibles posent le problème de la substitution de la maçonnerie de pierres hourdées à de grosses masses de béton; il n'y a pas de solution unique, mais la résolution économique du problème se pose; nous pouvons citer l'exemple de la centrale BIA au Katanga où les huit cents mètres du canal d'amenée présentent des parois latérales en maçonnerie de moëllons.

A l'opposé, des techniques nouvelles comme celles de la précontrainte, la fabrication de bétons sous vide, n'ont pas encore semblé pouvoir être économiquement introduites en Afrique centrale, mais il ne s'agit que d'une situation provisoire largement dépassée en d'autres pays tropicaux.

Il nous semble d'ailleurs que les méthodes d'exécution évoluent en ce moment très vite et qu'après la période héroique on passera très vite à la mécanisation à la manière américaine, sans s'arrêter au stade de l'artisanat méticuleux qui ne peut se concevoir avec des travailleurs indigènes comme ceux de l'Afrique centrale; dans le domaine qui nous occupe, il en résultera sans doute une floraison de barrages en terre ou en enrochements, la présence fréquente de sols argileux et, par ailleurs, de terrains de fondations souvent altérés favorise économiquement ce type de barrages.

### 3) *Remarques concernant l'organisation des travaux*

La périodicité annuelle des pluies et des débits des rivières est de nature à simplifier l'organisation des travaux et à la rendre moins aléatoire; dans ce domaine, deux remarques intéressent le projeteur.

Les débits maxima à dériver pour la mise à sec des fouilles de barrages ou de centrales peuvent être limités par exemple au débit médian de la rivière considérée si les mises à sec ne doivent durer que six mois axés sur un saison sèche, : le risque de submersion des batardeaux est minime pour les rivières à grands bassins versants.

L'existence de longues saisons sans pluies est favorable à l'exécution d'ouvrages en terre compactée, surtout si celle-ci doit être partiellement asséchée avant mise en oeuvre.

## C) L'ETUDE DU MATÉRIEL

### 1) *La conception du matériel en fonction des conditions de service*

L'éloignement des grands centres de réparation et le coût élevé des travaux d'entretien sur place justifient l'installation de matériel simple et robuste offrant les plus grandes garanties de bon fonctionnement.

Dans cet ordre d'idées, nous avons renoncé, après un essai à l'automaticité de la mise en route et de la commande des groupes turbo-alternateurs; il nous paraît préférable de s'en tenir aux manoeuvres directes, mais de centralise les commandes et contrôles essentiels dans des salles de tableaux bien équipées; pour plus de sécurité, les manoeuvres d'urgence peuvent encore être effectuées en d'autres emplacements judicieusement choisis; des dispositifs de sécurité permettent d'exécuter ces manoeuvres, même en cas de manque de courant.

Pour les vannes de barrage et de prise d'eau, nous prévoyons de même des commandes manuelles de secours.

Nos observations relatives à la robustesse du matériel visent plus particulièrement les turbines; nous avons noté des recharges par soudure d'aubages de roues et de blindages érodés par cavitation, de tourillons de distributeurs usés; après réparation par apport d'acier inoxydable, au lieu et place d'acier ordinaire, les érosions et usures ne se sont pas reproduites; il eut été préférable, dans de tels cas, de prévoir, dès l'origine, des qualités de métal suffisamment résistantes.

Il n'en reste pas moins que les centrales des pays intertropicaux doivent être pourvues d'ateliers très bien outillés avec d'importants stocks de pièces de réserve; il est indiqué d'installer ces ateliers avant le montage des groupes plutôt que de prévoir pour le montage des outillages spéciaux venus d'Europe ou d'Amérique.

La conception des organes mécaniques appelle encore quelques remarques de détail.

Les mécanismes devront être protégés contre l'intrusion des insectes et notamment, d'une sorte de guêpe — la mouche maçonne — qui au Congo Belge, bloque souvent des mécanismes en y construisant des nids en matériau argileux très dur.

La présence des termites fait proscrire l'usage du bois pour les étanchéités de batardeaux, charpentes, etc...

Pour les systèmes de réfrigération par eau, on tiendra compte par mesure de sécurité, de températures maxima de l'air de l'ordre de 50° et de l'eau de 20 à 30° suivant les régions; les micro-organismes contenus dans les eaux ont tendance à se déposer dans les petites tuyauteries et à les obstruer; les échanges calorifiques en étant diminués, on est amené à prévoir, soit un nettoyage périodique ou une alimentation en eau épurée en circuit fermé ou ouvert.

A une échelle plus grande, il est presque toujours utile de munir les grilles fines des ouvrages d'amenée, de rateaux dégrilleurs efficaces.

### 2) *La protection contre la corrosion*

La corrosion des vannes, batardeaux, grilles et, surtout, conduites forcées, sous l'effet de l'eau et des agents atmosphériques est assez rapide en pays tropicaux, elle parait encore activée par les dépôts de micro-organismes.

Nous avons observé sur une conduite forcée, simplement grattée et peinte à la mise en service, des piqures pouvant localement atteindre 3 mm. de profondeur après vingt ans de fonctionnement.

Nous avons l'habitude dans ces conditions, de faire donner par les constructeurs, à tous les équipements hydrauliques, des sur-épaisseurs générales de 2 mm. puis de sabler les fournitures et de les revêtir de deux couches de peinture bitumineuse en atelier; après montage, les raccords nécessaires sont effectués et une troisième couche est appliquée: nous admettons que la protection ainsi réalisée reste efficace pendant une dizaine d'années.

Nous envisageons de faire des essais de protection par métallisation au zinc.

Pour les glissières de vannes ou batardeaux scellées sous eau et inaccessibles pour l'entretien, nous envisageons des constructions entièrement en bronze ou en acier inoxydable, mais, pour l'instant, nous n'avons tenté encore aucune expérience dans ce sens.

### 3) *Les sujétions dues aux conditions de transport*

La limitation des dimensions et du tonnage des colis peut nécessiter un fractionnement inusité de certaines pièces de machines — bâches de turbines par exemple. Elle peut même conditionner les caractéristiques de certaines parties d'équipement.

Ainsi, pour les conduites forcées des centrales DELCOMMUNE et LE MARINEL au Katanga, nous avons été amenés à limiter le diamètre à trois mètres environ (soit au-dessous du diamètre économique théorique); il a été ainsi possible d'exécuter les soudures les plus sollicitées — c'est-à-dire les soudures longitudinales — des éléments de conduite, en atelier et l'on a finalement pù réaliser une économie substantielle sur les dépenses de montage tout en accroissant la sécurité.

La longueur des transports, le nombre élevé de ruptures de charge impose enfin une protection efficace contre les chocs et, si nécessaire, contre l'humidité de toutes les pièces de fournitures mécanisées, par crêtes, caisses solides; des précautions doivent également être prises contre la déformation des éléments de blindages métalliques et de conduites forcées: on veillera entre autres à rendre, impossible l'introduction de colis dans les éléments de conduite, nous avons fait l'expérience malheureuse de déteriorations de peinture pour avoir négligé cette précaution.

## IV) CONCLUSION

Nous avons esquissé très rapidement, sur base de caractéristiques géographiques générales, quelques un des problèmes spéciaux posés par la conception des centrales hydroélectriques en pays tropicaux.

Nous désirons souligner, pour terminer, que la résolution de ces problèmes exige des exécutants de grandes qualités humaines. Tout d'abord, elle suppose dans chaque cas particulier, une analyse détaillée des conditions locales; ce travail incombe à une mission de prospection sur place qui doit être soigneusement préparée et confiée à un personnel connaissant tous les aspects de l'étude d'une centrale hydroélectrique.

Le projet d'aménagement sera ensuite dressé à une distance souvent considérable du site d'aménagement, c'est dire que les rapports de la mission de prospection devront apporter au projeteur tous les renseignements dont il aura besoin.

Au stade des études d'exécution enfin, le bureau d'études devra remettre au chantier des études et plans très détaillés, toute explication verbale étant le plus souvent exclue; en fait, le bureau d'études et le chantier ne seront généralement en rapport que par correspondance écrite et celle-ci devra être rédigée avec grande précision.

Les travaux ne pourront donc bénéficier de l'avantage que procure la meilleure adaptation aux conditions locales et aux moyens d'exécution, que par un effort commun et organisé des services d'étude et d'exécution.

## RÉSUMÉ

Cette note commence par un brefrappel des caractéristiques générales de la géographie des pays tropicaux, soit:

- du point de vue physique: le climat, la morphologie, l'hydrologie, la faune,

- du point de vue humain: les populations, les moyens de communication, le développement technique et l'état des connaissances générales sur les pays considérés.

Les incidences de ces données sur la conception des centrales hydro-électriques sont ensuite passées en vue aux stades:

- de la détermination des caractéristiques d'ensemble des aménagements, puissance, implantation des ouvrages, débits caractéristiques,
- de l'étude des ouvrages de génie civil, compte tenu des conditions d'exploitation et de construction,
- de celle du matériel d'équipement hydromécanique.

## Summary

This paper begins with a brief reference to the general characteristics of the geography of tropical countries, namely:

- from the point of view of physical geography, morphology, fauna, climate and hydrology.
- from the human aspect; population, communications, technical development and the general state of knowledge of the countries considered.

The influence of the above factors on the design of hydro-electric power stations are then considered in the following stages:

- determination of the general features of the scheme, installed capacity, location of the works, characteristic flows,
- studies of the civil engineering works taking into account servicing conditions and conditions of construction.
- study of the hydro-mechanical plant and equipment.

## Resumo

Esta monografia começa com uma breve referência às características geográficas gerais dos países tropicais, principalmente:

- sob o ponto de vista físico: clima, morfologia, hidrologia, fauna;
- sob o ponto de vista humano: populações, meios de comunicação, desenvolvimento técnico e estado de conhecimentos gerais sôbre os países considerados

As incidências dêsses dados sôbre a concepção das centrais hidro-elétricas são, em seguida, passadas em revista sob os aspectos:

- da determinação das características de conjunto das instalações, potência, situação das obras, vazões características;
- do estudo das obras de engenharia civil levando-se em conta as dições de servidão e construção;
- do estudo do material de equipamento hidro-mecânico.

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Titulo 4
Assunto 4.2

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro - 1954

DUQUENNOIS. H
(Algéria)

# ASSOCIATION DE GROUPES ANÉMO-ÉLECTRIQUES AVEC LES USINES HYDRO-ÉLECTRIQUES RÉGULARISÉES.

## CAS PARTICULIER DE PRODUCTIONS COMPLÉMENTAIRES. DÉTERMINATION DE LIMITES ÉCONOMIQUES.

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COMITE NATIONAL ALGÉRIEN

1 — L'accroissement continu des besoins en énergie électrique a pour conséquence la réadaptation périodique de la puissance des moyens de production. Le problème se pose donc constamment du choix des moyens de production à installer en vue de suivre l'évolution dans le meilleures conditions techniques et économiques. Le choix est d'autant plus difficile que les moyens possibles sont plus nombreux et plus différents les uns des autres soit par leur nature soit par leurs garanties techniques soit enfin par leurs charges financières dans lesquelles l'amortissement joue un rôle très important prêtant toujours à discussion.

Soit un complexe régional d'une certaine importance pouvant, dans son ensemble, être considéré comme autonome. Chaque usine du complexe remplit un rôle que l'on peut traduire par une puissance maximum d'émission p, une production e, un nombre d'heures de fonctionnement h ramené à la puissance maxima p tel que $e = p\,h$, et un prix de revient de l'énergie à l'unité d'énergie, C, comprenant une part équitable des charges relatives aux lignes et postes d'interconnexion; C est en général une fonction hyperbolique décroissante de $h : C = \varphi\,(h)$, par contre p est à peu près indépendant de h.

En supposant h fixé pour chacune des usines du complexe le prix moyen de l'énergie $C_0$ est donné par:

$$C_0 = \frac{\Sigma\, p\, h\, \varphi\,(h)}{\Sigma\, p\, h}$$

La détermination du minimum de $C_o$ pour un complexe dans un état donné se fait relativement facilement en faisant appel d'abord aux moyens donnant les minima des produits p h $\varphi$ (h) pour des valeurs de h de l'ordre de 7.000 ou 8.000 heures puis progressivement aux moyens les moins couteux pour des h décroissants pour atteindre finalement les moyens très coûteux des h de l'ordre de 1.000.

Supposons que, à partir du complexe ainsi défini, on veuille réaliser un nouveau palier de puissance. Parmi tous les moyens susceptibles de satisfaire aux conditions de puissance et de production avec une égale garantie on choisira évidemment ceux qui donneront le $\Delta C_o$ optimum.

Le problème est infiniment complexe car la redistribution des valeurs particulières de h est à faire à nouveau et dans des combinaisons très variables.

Il faut s'assurer en outre que lors de la réalisation des futurs paliers la combinaison retenue aura une grande probabilité de rester économique. Le cas peut se poser en effet d'une combinaison incontestablement plus économique pour un premier palier et qui se révèlerait dix ou quinze ans plus tard comme un choix malheureux.

2 — L'introduction d'une énergie électrique nouvelle par la nature de l'énergie primaire avant transformation ne peut économiquement se justifier que si l'on s'astreint à opérer comme il est dit ci-dessus. Le problème est simplifié, tout au moins en première approximation, lorsque les conditions techniques de la production de l'énergie nouvelle sont telles qu'une association puisse être faite avec des productions d'un nombre restreint d'usines du complexe; il devient très simple si l'association peut être faite avec une seule usine du complexe et de façon telle que l'énergie de l'association ait les mêmes caractéristiques techniques et économiques que celles de l'usine retenue pour l'association.

3 — Avant d'aborder le problème de l'intégration dans un complexe de production de groupes électrogènes actionnés par le vent (groupes anémo-électriques) nous exposerons le cas de l'augmentation de la production d'un aménagement hydro-électrique par la dérivation, vers cet aménagement, d'un cours d'eau secondaire.

Soit un aménagement hydro-électrique caractérisé par:

| | |
|---|---|
| un barrage réservoir de capacité | R |
| un débit d'équipement | Q |
| une puissance d'équipement | P |
| un volume moyen annuel d'apport | V |

On suppose que la régularisation est convenable c'est-à-dire que, grâce à une capacité R suffisante, la production est étalée régulièrement sur l'année et faite aux heures les plus convenables de façon que le crédit $\varphi$ (h) soit maximum.

Le cours d'eau secondaire dérivé va apporter dans le réservoir un volume annuel supplémentaire $\Delta$ V. Si l'on maintenait R, P et Q aux mêmes valeurs la production correspondant à $\Delta V$ aurait le caractère d'une production différentielle au delà de h et ne pourrait avoir la valeur de la production de l'aménagement.

Supposons que R, Q, P soient majorés de telle façon que:

$$\frac{\Delta R}{R} = \frac{\Delta Q}{Q} = \frac{\Delta P}{P} = \frac{\Delta V}{V}$$

Dans ce cas la production supplémentaire a même valeur que la production initiale. Les charges financières et d'entretien relatives à $\Delta R$, $\Delta P$, $\Delta Q$ doivent être évidemment supportées par la dérivation.

En Algérie les possibilités d'aménagements hydro-électriques sont limitées de sorte qu'il est logique et économique de faire aux hydrauliques les hauts des diagrammes de charge. On force donc l'équipement en puissance de ces usines dont la production est émise entre 2.000 et 3.000 heures par an. Seule la Petite Kabylie, région montagneuse et très arrosée, offre des possibilités d'équipements hydro-électriques d'une certaine importance. Dans cette région le cas se présente souvent de rivières qui n'offrent pas d'intérêt pour un équipement propre mais qui peuvent être dérivées vers un aménagement possible. L'étude économique est alors faite en déterminant les dépenses de la dérivation proprement dite, celles relatives à l'augmentation proportionnelle de R, Q, P et en comparant le résultat au crédit procuré par l'énergie supplémentaire.

Pour 1 kwh supplémentaire les charges annuelles de suréquipement sont approximativement les suivantes en Petite Kabylie:

$\Delta R =$ 1 Fr,20
$\Delta Q + \Delta P =$ 1 Fr,50 pour $h = 2.500$ heures
soit au total 2 Fr,70

L'énergie garantie de 2.500 heures valant environ 8 Frs par kwh la dérivation est justifiée si les travaux proprement dits de dérivation ne créent pas des charges excédant 5 Frs par kwh garanti.

4 — Nous pouvons maintenant aborder le problème de l'association d'une production anémo-électrique avec celle d'un aménagement hydro-électrique régularisé.

La partie de la production anémo-électrique pouvant entrer dans le diagramme journalier de production de l'usine hydro-électrique aura la valeur de la production hydraulique considérée seule si h n'est pas changé en définitive. Pour cela il faut, si l'on désigne par $\Delta V$ l'équivalent en volume d'eau de la production anémo-électrique, prévoir des augmentations de P et Q telles que:

$$\frac{\Delta Q}{Q} = \frac{\Delta P}{P} = \frac{\Delta V}{V}$$

La modification à faire subir à R est fonction de la distribution saisonnière relative des régimes de l'hydraulique et du vent. Si les courbes représentatives ont leurs cloches décalées dans le temps $\frac{\Delta R}{R}$ est évidemment plus faible que $\frac{\Delta V}{V}$. Il se peut même que dans des conditions favorables $\frac{\Delta R}{R}$ soit négatif.

Nous donnons en figure I la représentation graphique valable pour la Petite Kabylie des variations des modules mensuels de l'hydraulicité et de l'énergie de jour du vent intégrable dans la production hydraulique. On voit que les énergies naturelles hydro-électriques et anémo-électriques sont remarquablement complémentaires l'une de l'autre. Ceci n'est pas une pure coincidence. Les vents dont il s'agit son engendrés par les différences d'échauffement des masses d'air d'une part au dessus de la mer, d'autre part au dessus du continent. Les courants de densité qui prennent naissance empruntent de préférence les sillons les plus creux que sont les vallées. Les différences d'éechauffement sont d'autant plus grandes que le ciel est plus clair, l'atmosphère plus calme, l'insolation plus forte. Il est donc tout à fait normal que les vents de vallée soient des vents de jour et présentent un maximum d'énergie en saison sèche. Ils ont d'ailleurs en cette saison des régularités horaire et énergétique étonnantes.

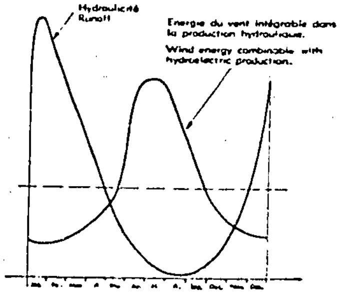

Fig. I — Régimes saisonniers de l'Hydraulique et des vents de vallée en Petite Kabylie (Algérie)
— Seasonal variations of runoff and valley winds in "Petite Kabylie" (Algeria)

Du dépouillement de deux années d'observations il résulte que non seulement il n'est pas nécessaire d'augmenter R mais qu'on pourrait réduire R suivant une loi linéaire:

$$R = R_o \left( 1 - 0{,}5 \frac{\Delta V}{V} \right)$$

ou $R_0$ représente la capacité de régularisation nécessaire à l'hydraulique seule et ou $\frac{\Delta V}{V}$ représente le rapport entre les productions du vent et de l'hydraulique.

Le rapport $\frac{\Delta V}{V}$ ne peut excéder une certaine valeur en raison de la nécessité de régulariser l'émission de puissance du vent par une émission conjointe de l'hydraulique pour respecter à tout instant le programme imposé par le dispatcheur à la production associée. Compte tenu des particularités des courbes de la fig. I le rapport $\frac{\Delta V}{V}$ ne doit pas excéder 1/3. On pourrait peut-être augmenter encore ce rapport mais on risquerait de diminuer la proportion d'énergie intégrable dans le diagramme correspondant à $h = 2.500$.

Jusqu'à la valeur 1/3 du rapport $\frac{\Delta V}{V}$ les productions suivantes peuvent être fournies annuellement par les génératrices anémo-électriques placées dans les vallées: 1.100 kwh/kw intégrables dans la production de 2.500 heures et 300 kwh/kw en production différentielle hors programme, dont les valeurs sont respectivement 8 Fr et 2 Fr.

Le crédit annuel total est donc:

$$1.100 \times 8 + 300 \times 2 = 9.400 \text{ francs}$$

Les charges $\Delta P + \Delta Q$ applicables seulement à la production dans le programme sont de 1 Fr,50 par kwh soit 1.650 Frs au total par an.

Le crédit annuel pour les charges du générateur anémo-électrique et son raccordement au poste d'émission hydraulique est d'environ: 7.750 Frs.

Compte tenu des pertes par transformation on peut raisonnablement estimer que le crédit annuel au kw est de l'ordre de 7.000 Frs. Dans l'hypothèse de groupes de fonctionnement sûr, équipés pour une marche automatique et nécessitant très peu d'entretien et de renouvellement, le prix de la fourniture aurait pour limite économique environ 60.000 Frs par kw installé.

5 — Cette valeur limite peut être majorée si l'on tient compte du crédit relatif à la diminution de la capacité de régularisation. Il est nécessaire pour cela de préciser ce que sont les valeurs créditrices des tranches d'une capacité. Il est bien évident qu'au fur et à mesure que croit une capacité les crédits qui s'attachent aux tranches successives vont en diminuant sensiblement comme les probabilités d'utilisation. A l'origine la très petite capacité de régularisation journalière qui évite l'émission

de courant de nuit a une probabilité de service de l'ordre de 300 dans l'année et a une haute valeur (fig. 2). Pour des valeurs de $\frac{R}{V}$ grandes la probabilité de service dans l'année peut être très faible, devenir inférieure à I (régularisation interannuelle). La courbe "crédit" d'une capacité est donc une fonction continue, décroissante et la limite économique d'une capacité se détermine par l'intersection de la courbe "crédit" avec la courbe du coût des capacités différentielles qui, elle aussi, est une courbe continue décroissante mais décroissant moins vite que celle du crédit.

L'adjonction de groupes anémo-électriques aurait pour effet de rendre "disponible" une certaine capacité $\Delta R$ dont les crédits sont ceux de la tranche $\Delta R$ située immédiatement à droite du point $\frac{R_o}{V}$ (fig. 2).

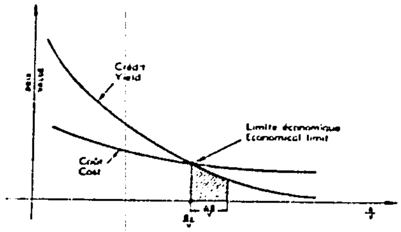

**Fig. II** — Cout et crédit des tranches différentielles de capacité d'un barrage réservoir — Cost and yield of additional capacities of a dam

Si le réservoir est menacé de comblement par la sédimentation, et c'est le cas à plus ou moins longue échéance dans les régions à saison sèche prolongée, la tranche $\Delta R$ se déplace vers la gauche et prend des valeurs de plus en plus grandes avec le temps. On ne doit donc pas négliger dans le bilan financier le crédit relatif à l'"économie" sur la capacité, qu'il s'agisse de réduction de capacité lors du projet ou d'usage de la capacité devenue disponible pour une régularisation plus poussée.

Dans le cas des associations des énergies hydrauliques avec vents de vallée en Algérie le crédit annuel complémentaire est de l'ordre de 1.000 Frs par kw. Le prix d'installation des groupes anémo-électriques pourrait être ainsi porté de 60 à 70.000 Frs par kw installé.

6 — Nous avons indiqué plus haut les raisons pour lesquelles, en Petite Kabylie, les énergies de l'hydraulique et du vent sont complémentaires saisonnièrement. Il est probable — ici les observations n'ont pas une durée suffisante pour que l'on puisse être absolument affirmatif — que ces mêmes raisons doivent avoir pour effet de réaliser une certaine compensation interannuelle. En effet une saison sèche prolongée, cause

d'une hydraulicité faible, sera aussi la cause d'une production anémo-électrique plus abondante. On peut donc espérer que sous l'angle de la garantie de production, l'adjonction de groupes anémo-électriques doit diminuer sensiblement les risques de pénurie grave en année exceptionnellement sèche.

7 — Pour terminer l'étude économique nous allons comparer les crédits obtenus par l'énergie des vents de vallée dans l'association avec les hydrauliques régularisées et fortement équipées en puissance avec ceux que l'on obtiendrait en utilisant l'énergie de vents soufflant régulièrement de nuit et de jour en toutes saisons. L'association de l'énergie de ces vents peut se faire soit avec des thermiques de base et dans ce cas les crédits sont constitués par l'économie différentielle de combustible (2 Frs par kwh), soit avec des hydrauliques de base auquel cas le crédit risque d'être nul aux périodes de hautes eaux. Pour atteindre les mêmes crédits que précédemment au kw installé il faudrait avoir une production annuelle de l'ordre de 4.000 à 5.000 kwh par kw chose assez improbable même dans les régions les plus fortement ventées du monde.

## Résumé

La production d'énergie électrique au moyen de générateurs actionnés par le vent est d'autant plus rentable que le régime du vent est davantage complémentaire de celui de l'hydraulique et que l'équipement en puissance des aménagements hydro-électriques régularisés est plus poussé. Dans le cas particulier de l'utilisation de l'énergie des vents de vallée d'Algérie en association avec les aménagements hydro-électriques régularisés on diminuerait les risques de pénurie grave d'énergie en année exceptionnellement sèche tout en retardant très sensiblement l'échéance du renouvellement des capacités soumises à la sédimentation. L'étude économique sommaire montre que, dans ce cas particulier, on peut tout en restant dans les limites de rentabilité, consentir pour l'installation de génératrices anémo-électriques des dépenses assez élevées, de l'ordre de 70.000 Frs par kw et cette conclusion peut être un encouragement donné aux inventeurs et constructeurs pour qu'ils réalisent des groupes de forte puissance, de fonctionnement sûr et d'entretien facile.

## Summary

The yield of the association of hydroelectric and anemoelectric generators is the greater, as the seasonal wind variations compense the runoff variations and as the regularized hydroelectric power equipment is steadily growing. In the particular case of the association in Algeria of valley winds energy, with regularized hydroelectric equipment, the risk of serious dearth of energy during very dry years is smaller and the date of renewal of capacity lost by sedimentation is very appreciably postponed.

The simplified economical study points out that it is possible, in this particular case, within the limits of a good yield, to allow high enough expenses, nearly 70.000 fcs/kw, for installation of anemoelectric generators, and this conclusion can encourage inventors to realize strong and reliable power plants of easy maintenance.

### RESUMEN

La producción de energia eléctrica por medio de generadores movidos por el viento, es tanto mas beneficiosa cuanto que el regimen de los vientos muede compensar el de la hydraulica y que los équipos en potencia de las instalaciones hitro-eléctricas regularizadas, tengan mayor desarrollo.

En el caso particular de la utilización de la energia de los vientos de vallados, en Argelia en asociación con las instalaciones hidraulicas regularizadas, se reducirian los riesgos de "penuria" grave de energia, en años de gran sequia, retardando muy sensiblement la necesidad de renovar la capacidad de los embalses, sujetos a "sedimendación".

Un estudio economico y sumario, nos demuestra que en este caso particular se puede, aun dentro de los límites de la *"rentabilidad"* llegar a la instalación de generatrices anemo-electricas, a gastos elevados, que no bajarian de unos 70.000 francos el kilowatio.

Tal conclusión constituiria un estímulo para los constructores e inventores, para la realización de grupos de gran potencia, de funcionamiento seguro, y de fácil entretenimiento.

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 1
Assunto 1.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro – 1954

BARROS (P.)
Portugal

# PLANEJAMENTO DA INDÚSTRIA DA ENERGIA ELÉCTRICA, VISANDO ATENDER AO PLANEJAMENTO COORDENADO DAS DEMAIS ACTIVIDADES ECONÓMICAS

Por **PAULO DE BARROS**

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**COMITÊ NACIONAL PORTUGUÊS**

1 — Entre as diversas fontes de energia, a electricidade ocupa, sob o aspecto quantitativo, um modestíssimo lugar, o mais modesto de todos, mesmo. Com efeito, a energia consumida na Europa e a sua repartição entre as diferentes origens, foi a seguinte nos anos de 1937 a 1949 (¹):

| | TOTAL | | Percentagem proveniente das diferentes origens | | | |
|---|---|---|---|---|---|---|
| | $10^{15}$ calorias | $10^{9}$ calorias por habitante | Combustíveis sólidos | Electricidade | Óleo | Gaz |
| 1937 | 4,448 | 11,0 | 79,7 | 3,3 | 6,7 | 5,6 |
| 1949 | 4,451 | 10,8 | 74,7 | 5,1 | 9,6 | 6,0 |

Embora se acuse nitidamente a tendência para o aumento relativo do consumo da energia eléctrica, nota-se que apenas 5,1% da energia total consumida provém da electricidade. Não deixa por isso de parecer paradoxal a importância fundamental que hoje em dia se atribui à energia eléctrica, a ponto de se lhe dar lugar de primazia em qualquer plano de fomento.

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(1) — Bibliografia n.º 3.

Tal facto deve-se, sem qualquer dúvida, à *utilidade* desta forma de energia, que permite, pelas suas múltiplas aplicações, dar à grei uma soma de bem estar e de comodidade que nenhuma outra lhe pode proporcionar.

Na época actual ninguém concebe a existência duma fábrica não electrificada ou de uma casa que não se ilumine a electricidade e que não utilise esta forma de energia nos usos domésticos.

O pesado trabalho dos homens é aliviado de maneira prodigiosa pelo emprego deste servo dócil, que obedece cegamente e mediante a prática de actos elementares, que não exigem qualquer esforço.

O seculo XIX foi a era da máquina a vapor, e, consequêntemente, do carvão; à potência carvoeira correspondia a potência industrial. E, assim, vimos a Inglaterra atingir nesse periodo a epoca áurea do seu poder e da sua prosperidade. Com o advento da electricidade o problema mudou de aspecto: o declínio da máquina a vapor é uma consequência do desenvolvimento de outras formas de energia, desde a que provém dos combustiveis liquidos até à que é produzida pela electricidade.

E os paises que se encontravam dependentes dos combustíveis sólidos de importação começaram a explorar as suas fontes nacionais de energia, até aí desaproveitadas, dando-se no mundo uma nova distribuição do poder industrial.

Podem-se considerar-se como indústrias chaves, além da electricidade, os combustíveis, o ferro, o aço e o cimento. Nem todos os países, porém, as podem ter e explorar, porque dependem dos recursos naturais. Mas todos os paises podem criar a sua indústria nacional de energia eléctrica, que se transformou num elemento essencial da politica económica dos Governos, não só pelas vantagens que confere, mas porque, além de ser um produto especificamente nacional é ainda a base da industrialização do pais.

2 — A posição de relevo ocupada pela electricidade no conjunto industrial dum pais é dada pela importância dos investimentos realizados: na Europa atingem cerca de 12% e 14% do total; nos Estados Unidos, alcançam os 20%; na Bélgica, em 1939, era a seguinte a distribuição de alguns investimentos (capital e fundos de reserva) em relação ao total (com excepção dos correios, telegrafos e telefones e caminhos de ferro): (2)

| | |
|---|---|
| Electricidade ................ | 13,8% |
| Texteis ........ .......... | 11,6% |
| Fabricações metálicas ........ | 9,7% |
| Carvões ............... .... | 8,8% |
| Alimentação ................ | 8,6% |
| Siderurgia ................ | 8,3% |

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(2) — Bibliografia n.º 11.

Em Portugal, segundo um inquérito particular realizado para um reduzido número de actividades, obtém-se os seguintes valores:

| | |
|---|---|
| Electricidade ................ | 49,2% |
| Navegação .................. | 35,1% |
| Moagens .................... | 6,6% |
| Cimento e Ceramica ......... | 5,8% |
| Tabacos .................... | 3,3% |
| | 100% |

Estamos em crer que as simples considerações produzidas permitem destacar com o relevo suficiente a razão de se atribuir à indústria da energia electrica um papel preponderante em qualquer planejamento económico.

3 — Os estudos estatísticos indicam que os aumentos de consumo se dão mais fortemente nos usos domésticos, e não se vislumbra a possibilidade de atingir a saturação em futuro mais ou menos próximo. Assim, por exemplo, o consumo doméstico na Europa, de 1938 para 1951, passou de 18% para 26%, ao passo que os consumos industriais e de tracção se reduziram respectivamente de 75% para 69% e de 7% para 5%. Em Portugal as coisas passam-se de maneira um pouco diferente. Com efeito, embora o consumo doméstico passe, entre 1927 e 1952, de 22% para 23,8%, o consumo industrial, em vez de diminuir, acusa um forte aumento, de 22,6% para 45,3%, denotando o esforço de industrialização do Pais; já na tracção se verifica a lei geral, reduzindo-se o consumo de 19,1% para 6,7%.

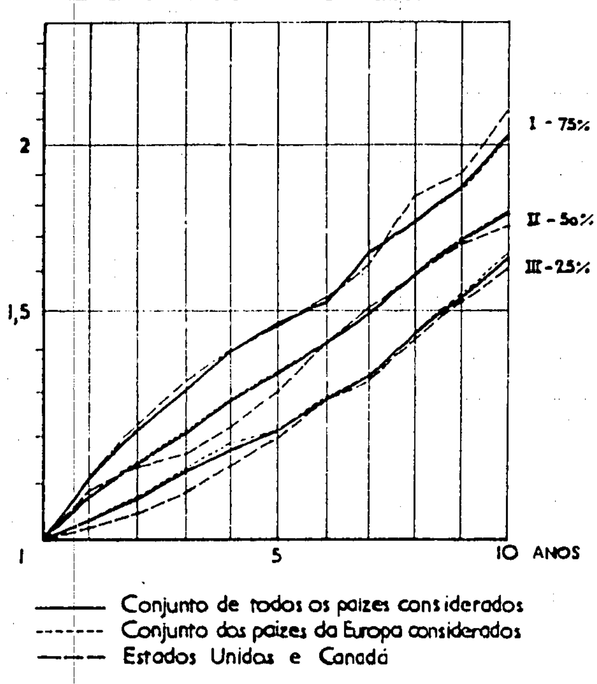
Se notarmos que o consumo doméstico específico por habitante europeu foi de 180 kWh em 1951, e que na Suissa atingiu 810 kWh, encontraremos motivo para pensar no enorme incremento que traria o simples facto de se alcançar na Europa este valor específico médio poderemos computa-lo em cerca de 267.000 milhões de kWh ou seja cerca de 90% do consumo total registado em 1951. Este número só atinge porém o seu verdadeiro significado, se nos lembrarmos que o consumo específico suisso não é de qualquer forma um limite (na América do Norte, por exemplo, é muito mais elevado) oferecendo por consequência largas possibilidades de aumento.

4 — Na elaboração de um plano de fomento devemos por consequência examinar primeiramente os problemas ligados com a indústria da energia eléctrica — produção, transporte e distribuição. Como fazer a relacionação de cada um destes estádios com as restantes actividades económicas ?

Ser-se-ia tentado, à primeira vista, em definir, como elemento base, a localização de todos os centros possíveis de absorção de energia, com as potências e os consumos respectivos. Cometer-se-ia porém um pesado

TENDÊNCIA DE EVOLUÇÃO DO CONSUMO DE ENERGIA ELÉCTRICA EM DIVERSOS PAIZES DO MUNDO.

I - ENVOLVENTE DE 75 % DOS CASOS
II - ENVOLVENTE DE 50 % DOS CASOS (curva média)
III - ENVOLVENTE DE 25 % DOS CASOS



erro, pois as omissões e as inexactidões seriam certamente numerosas, e o método, que aparenta um invejável rigor, facilmente redundaria em grosseira estimativa, a corrigir com o andar dos tempos.

O processo a seguir deverá por consequência ser outro: partindo do consumo existente estabelece-se a lei de variação ao longo do tempo, fazendo-se assim as previsões das necessidades que devem ser cobertas pela produção.

Segundo um estudo do Engº. Pierre Ailleret (8), o aumento do consumo pode ser considerado como a resultante de dois fenómenos diferentes:

a) Por um lado, a conjuntura económica influi sobre os consumos industrial e doméstico, que têm uma correlação estreita com o índice de actividade económica.

b) Por outro lado, o consumo apresenta uma tendência natural para o crescimento, independentemente da actividade económica, pelo simples facto da electrificação progressiva das indústrias e das casas, e que corresponde, afinal, à substituição progressiva pela electricidade de outras formas de energia.

O consumo poderá assim ser expresso por uma fórmula do seguinte tipo:

$$\text{Consumo eléctrico} = (\text{índice de actividade industrial})^{n} \times \\ \times \text{ exponencial do tempo.}$$

O exame estatístico permitiu concluir que será $n = 0{,}4$ e a exponencial do tempo tal que a duplicação do consumo se dará em 13 a 14 anos.

Em resumo, pode interpretar-se esta lei da seguinte forma:

a) O consumo tem uma tendência anual de crescimento igual a 5%, independente das variações da actividade industrial.

b) A esta tendência sobrepõem-se variações de ± 0,4% por cada 1% de variação para mais ou para menos na actividade industrial.

Na prática a solução do problema obtém-se facilmente, porque os consumos obedecem a uma inexorável lei de crescimento em progressão geométrica: duplicam em períodos compreendidos entre 8 e 10 anos, seja qual for o grau de industrialização do país.

Pode esta lei ser transitoriamente desrespeitada em regiões pouco industrializadas em que começam a aparecer as grandes indústrias electroquímicas e electro-metalúrgicas e em épocas de crise ou de excepcional

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(8) — Bibliografia n.º 6.

actividade económica: mas, por um lado, com o aumento global do consumo, estas influências vão-se diluindo progressivamente; e, por outro lado, sendo aquelas indústrias abastecidas com energia de carácter temporário, as próprias irregularidades climatéricas, dum ano para outro, se encarregam de atenuar estas diferenças.

Elementos estatísticos referentes aos países e periodos a seguir indicados (4)

| | |
|---|---|
| **Alemanha** | 1925 a 1943 |
| **Bélgica** | 1925 a 1939 e 1946 a 1950 |
| **Canadá** | 1927 a 1950 |
| **Espanha** | 1929 a 1934 e 1940 a 1950 |
| **E. U. A.** | 1925 a 1950 |
| **Finlandia** | 1930 a 1939 e 1949 a 1950 |
| **França** | 1925 a 1939 e 1946 a 1950 |
| **Holanda** | 1932 a 1939 e 1947 a 1950 |
| **Italia** | 1925 a 1941 e 1947 a 1950 |
| **Inglaterra** | 1925 a 1950 |
| **Noruega** | 1930 a 1939 e 1946 a 1950 |
| **Portugal** | 1927 a 1950 |
| **Suecia** | 1931 a 1950 |
| **Suissa** | 1931 a 1950 |

permitem concluir que em 10 anos, o consumo foi multiplicado

por mais de 2 em 25% dos casos
por menos de 1,65 em 25% dos casos também.

Os resultados obtidos para a Europa são perfeitamente comparáveis com os que se referem à América do Norte e ao Canadá. Com efeito, verifica-se pelo gráfico que as curvas são na realidade paralelas e que a probabilidade do consumo ser multiplicado em 25 anos por mais de 5 ou por menos de 3 é inferior a 1/4.

5 — Na Europa, devastada pela guerra, o consumo, de 1938 para 1951 (13 anos) aumentou 98% mas já em Portugal o incremento foi de 138%; teve influência nítida o período de hostilidades em que o consumo acusou regressão acentuada; basta notarmos que o aumento médio foi de 10% de 1932 a 1939, isto é, duplicação em pouco mais de 6 anos; nos Estados Unidos, porém e no período acima referido, o consumo passou de 100 para 302 e na U.R.S.S. de 100 para 257! Não se pode, evidentemente, verificar uma lei em tão curto espaço de tempo: o es-

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(4) — Bibliografia n.º 7.

forço da guerra nestes últimos países trouxe um forte aumento de consumo, originando assim singularidades na curva de evolução: ao longo dos tempos, porém, obtém-se a duplicação entre os 8 e os 10 anos.

Aliás, como as previsões a longo prazo são falíveis, como deve sempre haver uma margem duns 20% pelo menos entre as disponibilidades energéticas e o consumo, e como o tempo necessário para a entrada em serviço de novas fontes produtoras oscila entre 3 e 5 anos, há apenas que estabelecer previsões a praso curto, e, periodicamente, rever os programas para se realisar o ajustamento com as realidades.

6 — Um plano de fomento é, por consequência, de natureza eminentemente dinâmica; é uma verdadeira luta contra o tempo: tem de se adaptar às circunstâncias e acompanhar o desenvolvimento da nação, moldando-se às novas conjunturas económicas, sociais e financeiras.

O Parecer da Camara Corporativa sobre o Plano de Fomento Português (5) foca este aspecto com especial clareza ao afirmar: "vários indícios levam a supor que nem sempre é vista em verdadeira grandesa a necessidade sem fim de acrescentar sempre mais, em ritmo crescente, o equipamento nacional da produção, transporte e distribuição. E mais adiante: "A tendência não é para enfraquecer o ritmo das obras, mas antes para o aumentar, porque o consumo cresce em progressão geométrica. Um país não é susceptível de dar por finda a sua electrificação".

O Engº. Pierre Ailleret define este aspecto de instalações eléctricas da seguinte forma: "o carácter essencial desta arquitetura é não ser a de um monumento construído duma só vez para a eternidade: é uma arquitetura dinâmica, que tem de atender aos mesmos problemas que o urbanismo, num país novo em desenvolvimento rápido".

Os progressos técnicos actuam no mesmo sentido, pois novas formas de produzir energia ou melhorias substanciais de rendimento em meios existentes de produção, podem alterar por completo a fisionomia do plano: assim, por exemplo, a diminuição do consumo específico das centrais térmicas, que chega hoje a valores da ordem das 2.100 kilocalorias/kWh (6) põe de novo em equação o problema transporte de carvão comparado com transporte de energia, pois à diminuição de perdas no transporte da energia eléctrica pela elevação de tensão contrapõe-se a menor quantidade de combustível a transportar pela melhoria do rendimento da central.

A elevação de potência unitária das centrais térmicas é outro problema a considerar pela influência que pode ter na substituição antecipada do equipamento existente: a comparação feita por M. Ricar (7) entre a vantagem de concentrar, por um lado, a produção térmica, e, por outro lado, de aproximar quanto possível a produção do consumo, levou à conclusão que a potência unitária deve crescer um pouco mais

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(5) — Bibliografia n.º 2.
(6) — Bibliografia n.º 1.
(7) — Bibliografia n.º 5.

lentamente do que a raiz quadrada da densidade do consumo, ao passo que o número de centrais cresce um pouco mais ràpidamente do que essa raiz quadrada. Extrapolando esta regra e admitindo que os consumos duplicam em 10 anos, seríamos levados a prever a duplicação da potência das centrais todos os 23 anos e a duplicação do seu número todos os 18 anos.

As turbinas a gás, de menor custo, podendo ficar localizadas perto dos centros de consumo, por precisarem de pouca refrigeração, permitem resolver facilmente o problema das pontas e reduzem a extensão da rede de transporte.

As centrais nucleares, por seu lado, poderão trazer uma contribuição decisiva para a alteração dum programa a longo prazo, introduzindo novos elementos de apreciação de extrema importância.

A utilização efectiva da energia nuclear é já hoje uma realidade: o calor desenvolvido num reactor é utilizado para acionar um submarino e tanto a Inglaterra como a América têm já em construção, cada uma, um grupo gerador fixo cuja potência ultrapassará 50 MW.

É cedo ainda para se difinir a orientação em matéria de reactores nucleares; uma coisa porém é certa: afastou-se para muito longe o espectro duma eventual carência de energia no mundo, e introduziu-se um novo factor extremamente importante na localização das centrais. Com efeito, tendo o combustível da pilha atómica um volume muito reduzido, a central poderá ser localizada onde melhor convier, desde que tenha água de refrigeração suficiente.

O perigo das radiações atómicas impedirá, pelo menos por enquanto, que ela se construa junto às grandes aglomerações urbanas; mas poderá ficar suficientemente perto para reduzir os transportes de energia.

A central atómica é por consequência um elemento a tomar em consideração no estabelecimento das redes de transporte: estas devem ser limitadas ao optimo económico, sem grandes antecipações para necessidades futuras, porque a nova técnica trará fatalmente uma pausa nos transportes de energia a longa distância.

Finalmente o aumento específico do consumo vai reduzindo sucessivamente a zona de acção dos aproveitamentos hidroeléctricos, — o hinterland hidráulico, — de forma que as redes terão de transportar quantidades macissas de energia a distâncias cada vez mais curtas.

Em resumo, a tendência a ter em conta na transformação dinâmica dum plano de fomento eléctrico resume-se nos seguintes pontos:

a) Aumento do número e da potência unitária das centrais térmicas, e sua aproximação dos centros de consumo;

b) Diminuição do hinterland hidráulico;

c) Diminuição correspondente das distâncias de transporte e aumento da potência transportada;

d) Utilização das centrais atómicas.

É por isso que um plano de fomento não se elabora para servir de espelho a um narcisismo precioso: é uma simples orientação, a seguir dia a dia, para ser adaptada também dia a dia às necessidades da nação e aos progressos da técnica.

7 — Uma vez estabelecida a lei da variação do consumo, e conhecidas por consequência as necessidades em futuro próximo, importa definir primeiramente o programa de realizações em matéria de centros produtores de energia.

Cada país, naturalmente, começará por aproveitar, dentro do possível, os seus recursos próprios: o apetrechamento das fontes nacionais de energia é um imperativo político e económico a que ninguém hoje pode fugir. Podemos recorrer a duas origens principais: os aproveitamentos hidroeléctricos e as centrais termo-eléctricas. Não me refiro ao aproveitamento da energia das marés, da energia solar e dos ventos, que não poderá certamente produzir volumes de energia que sejam comparáveis com os provenientes de outras fontes, nem à energia atómica, que, como dissemos, levará ainda alguns anos a ser uma realidade industrial.

Em todos os países de recursos carboníferos abundantes, como os que estão incluídos na zona central da Europa, existe o predomínio da energia térmica: nos restantes países ou zonas, ao Norte e ao Sul, já a energia hidro-eléctrica tem a vantagem.

Os recursos hidráulicos, de carvão e de lenhite das 3 zonas encontram-se assim distribuídos: (8)

| | Recursos hidráulicos | Carvão | Lenhite |
|---|---|---|---|
| Zona Norte ........... | 35% | 0,1% | — |
| Zona Central ........... | 16% | 98,5% | 92% |
| Zona Sul ............. | 49% | 1,4% | 8% |

A relação entre a produção hidráulica e térmica tem-se mantido sensivelmente constante; com efeito:

| | | Térmica | Hídrica |
|---|---|---|---|
| Europa ....... | 1938 | 62% | 38% |
| | 1951 | 62% | 38% |
| U. S A. ...... | 1938 | 66% | 34% |
| | 1951 | 76% | 24% |
| U. R. S. S. .... | 1938 | 88% | 12% |
| | 1951 | 86% | 14% |

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(8) — Bibliografia n.º 4.

Esta permanência no índice (apenas na América acusa um aumento sensível) significa claramente que a política do aproveitamento das fontes de energia tem sido mantida com notável constância e em obediência aos imperativos de carácter económico e político já citados.

Definidos os recursos a utilisar, importa estudar a melhor localização das centrais: este problema interessa apenas às oficinas termo-eléctricas, pois a sua localização exige um acurado estudo comparativo entre os custos dos transportes da energia e do carvão: os parâmetros são muitos, mas chegar-se-á normalmente à conclusão que as lenhites ou os combustíveis muito pobres ( da ordem das 3.000 cal/kg.) se deverão queimar à boca da mina e que os carvões ricos (com mais de 5.000 cal/kg) se deverão utilisar junto dos grandes centros de consumo.

Cada caso terá de ser estudado separadamente, pois o simples facto de se tratar duma central de trabalho permanente, ou, pelo contrário, de uma central de apoio e de reserva pode alterar por completo as conclusões do estudo.

8 — Para projectar a rede de transporte já é indispensável conhecer a distribuição dos grandes centros de consumo para dimensionar e estruturar as linhas de alta tensão. Torna-se ainda necessário estabelecer as artérias de ligação entre zonas ou países diversos, de predomínio hídrico ou térmico, de diferente regimen hidrológico ou mesmo térmico (centrais de altos fornos, centrais de gases naturais, centrais de carvões mais ou menos ricos).

Neste capítulo de interligação, tanto entre zonas do mesmo país, como entre países diferentes, não devemos porém levar o nosso zêlo muito longe, porque, ao fim e ao cabo, as trocas são insignificantes. Basta, para tirar esta conclusão, examinar alguns elementos estatísticos. Assim, por exemplo, as percentagens de energia exportadas na Europa em relação à produção total são as seguintes: (9)

1937 — 1,3%
1938 — 1,1%
1948 — 1,3%
1949 — 1,3%
1950 — 1,3%

E não se julgue que o resultado índice apontado provém de dificuldades de fronteiras da velha Europa: nos Estados Unidos, por exemplo, apenas 4,5% da produção total foi exportada para fora das fronteiras dos diversos Estados.

A explicação do fenómeno é simples: a energia deve ser consumida o mais perto possível da fonte de produção, e, por isso, os transportes macissos de energia a distância longa são automaticamente reduzidos.

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(9) — Bibliografia n.º 4.

Por estas razões deve por-se de parte a ideia da criação duma super rede de muito alta tensão, à escala continental, sobrepondo-se às redes nacionais: as interligações far-se-ão progressivamente, à medida das necessidades, e só se passará dum nível de tensão para outro quando o primeiro se encontrar em vias de saturação e as potências e volumes de energia a transportar justifiquem tensão mais elevada.

9 — A rede de distribuição, finalmente, tem de se conceber para levar energia a todos os pontos, e deverá ser feita à escala da produção: isto é, se, por um lado, não faz sentido estrangular a produção, montando redes exiguas que não permitam o escoamento de tóda a energia gerada, por outro lado é um contra senso económico fazer redes dimensionadas com folga demasiada.

Os encargos de distribuição pesarão então de tal forma sobre o kWh distribuído, que o seu custo tornará impossível aumentar o volume das vendas, e, portanto, aproveitar a total capacidade instalada.

O equilibrio entre os diversos estádios produção, transporte e distribuição é condição sine qua non para o desenvolvimento harmonioso do conjunto. Os investimentos devem estar distribuidos de maneira que à produção caiba cerca de 50% e ao transporte e à distribuição outros 50%.

10 — O problema dos investimentos a fazer apresenta uma considerável importância; é preciso não sacrificar a eficiência das realizações a economias que não se compadecem com a verdadeira estrutura do plano; mas é preciso também não realisar investimentos inúteis, sob a idéia dum falso critério de segurança, e que vão onerar fortemente o preço de custo e diminuir por consequência as possibilidades de expansão económica. Uma solução de compromisso entre os dois extremos conduz justamente àquele equilibrio que só a experiência e o sentido das realidades permitem alcançar.

Isto é particularmente verdadeiro para o fomento da electricidade: o material eléctrico, grosso modo, tem uma vida média de 30 anos; neste período de tempo, na hipótese de duplicação em 10 anos, o consumo é multiplicado por 8. Se a instalação existente permitisse a satisfação deste consumo, no termo da sua vida física teria de ser substituida por uma outra com uma capacidade 8 vezes maior. Na realidade, isto não sucede assim, porque correspondia a ter um capital improdutivo durante muito tempo. E os investimentos fazem-se sucessivamente, sempre subordinados à lei do crescimento do consumo e as novas instalações entram em serviço antes do desaparecimento ou substituição das existentes.

Quer dizer, tem de se adoptar a solução intermédia entre poderosas instalações que dêem para largos anos ou pequenas instalações que cubram uns escassos dois a três anos.

Para escolher o tipo da central mais conveniente, devemos fazer um balanço energético dos investimentos a realisar, para se conhecer o preço da caloria útil.

Teremos portanto de entrar em conta com todos os encargos provenientes das instalações a montar, desde aquelas que se referem ao capital até às despesas de exploração, e, determinar, para várias hipóteses, o preço, *em moeda estável*, da caloria útil produzida. Obteremos assim a melhor solução económica (que não coincidirá porventura com a melhor solução política) e que pode aliás ser alterada no decurso do tempo.

11 — O Parecer da Camara Corporativa relativo ao Plano de Fomento Português dá justamente o necessário relevo ao problema da energia eléctrica, ao dizer logo de início: "O abastecimento de energia eléctrica do País, é, seguramente, a mais palpitante questão tratada no Plano, pelo seu carácter de exigência pública que não consente demoras, pela situação de insuficiência em que nos encontramos, apesar da obra já feita, e pelo grande volume de capitais que movimenta". Com efeito, dos investimentos previstos para a indústria, no total de 3.616 milhões de contos, destinam-se 2.736 milhões de contos (76%) para a electricidade.

O estudo das necessidades de consumo e das possibilidades de produção (em ano médio) levou aos valores a seguir indicados:

| | Produção | | Consumo | | Saldos | |
|---|---|---|---|---|---|---|
| | Permanente | Temporária | Permanente | Temporário | Permanentes | Temporários |
| | $10^6$ kWh | | $10^6$ kWh | | $10^6$ kWh | |
| 1953 ........ | 1.080 | 200 | 1.320 | 250 | — 240 | — 50 |
| 1954 ........ | 1.160 | 210 | 1.440 | 250 | — 280 | — 40 |
| 1955 ........ | 1.380 | 220 | 1.560 | 250 | — 180 | — 30 |
| 1956 ........ | 1.640 | 260 | 1.690 | 250 | — 50 | + 10 |
| 1957 ........ | 1.780 | 270 | 1.820 | 250 | — 40 | + 20 |
| 1958 ........ | 2.060 | 290 | 1.960 | 250 | + 100 | + 40 |
| 1959 ........ | 2.430 | 340 | 2.100 | 300 | + 330 | + 40 |

Precisamos de analisar atentamente estes números para lhes atribuir o seu exacto significado.

As produções referem-se a anos hidrologicamente médios, quer dizer, serão muito influenciadas pelas condições meteorológicas: e determinado ano, que no quadro acima apresenta um saldo positivo ou negativo, pode ver o saldo com sinal diferente, se o regimen de chuvas não corresponder à média.

Consideremos o ano de 1953, que vai ilustrar de maneira flagrante estas considerações. A produção total hidro-eléctrica deverá atingir os 1.000 milhões de kWh, contra os 1.280 milhões previstos no Plano; se considerarmos que todo o consumo electro-químico foi de energia temporária (ou, pelo menos, deve ser considerado como tal), teremos:

Energia permanente — 850 milhões de kWh
Energia temporária — 150 milhões de kWh

Em relação às previsões a quebra foi de

Energia permanente — 230 milhões ou seja 21,3%
Energia temporária — 50 milhões ou seja 25 %

Quer dizer, *um ano seco, como o de 1953*, altera por completo os números previstos pelo Plano, que adquirem assim o seu verdadeiro sentido, isto é, simples previsões correspondentes a determinadas hipóteses.

Vejamos agora o consumo; em 1953, segundo os números provisórios apurados, a produção total deve andar à volta dos 1.400 milhões de kWh, inferior por consequência em 170 milhões de kWh (10,8%) ao valor previsto no Plano. Considerando os consumos permanente e temporário obtemos os seguintes números:

Permanente — 1.250 milhões de kWh
Temporário — 150 milhões de kWh

E as diferenças em relação ao Plano serão então

Permanente 1.320 — 1.250 = 70 milhões de kWh ( 5,3%)
Temporário 250 — 150 = 100 milhões de kWh (40 %)

A quebra no consumo temporário é proveniente do mau ano hidrológico, e não merece por consequência qualquer comentário, visto os números do Plano se referirem a anos médios. No consumo permanente, dado que não houve restrições, porque a produção térmica supriu as faltas hidro-eléctricas, a ligeira diferença provém de se ter admitido para 1952 um consumo superior ao verificado, e, portanto, os consumos subsequentes serão influenciados por este facto: dentro da ordem das previsões, porém, os números do Plano estão certos, tanto mais que há sempre vantagem em prever com ligeiro excesso, para obter folgas que compensem anos hidrológicamente maus, crescimentos anormais do consumo ou eventuais atrazos na entrada em serviço de novos aproveitamentos.

Conclui-se assim que os saldos negativos previstos no Plano não correspondem a falta de energia: são deficits de produção hidroeléctrica, que serão cobertos pela prodação térmica.

A análise dos números inscritos no Plano como evolução do consumo permanente permite verificar que se adoptou uma taxa média de crescimento decrescente de 9,1% no primeiro ano a 7,1% no último, com o valor médio de 8%, ou seja, duplicação em 9 anos.

Em 1953, o consumo permanente acusou, em relação a 1952, um aumento de 10%. E nos últimos 20 anos (1933 a 1953) a produção total passou de 302 milhões de kWh para 1.339 milhões de kWh, isto é, foi multiplicado por 4,4% que corresponde à duplicação em cerca de 9,5 anos, taxa média de 7,8%.

Uma vez fixada a lei de evolução do consumo, e, por consequência, das necessidades, definiu-se o plano de constracão dos elementos de produção.

Para a escolha das centrais hidro-eléctricas a construir tiveram-se em conta os seguintes elementos: (10) "o preço de custo do kWh produzido, o grau de regularização, dependente de ser mais necessária em dada época a energia de inverno, a energia de verão ou a energia regularizada todo o ano; a potência instalada, subordinada ao volume das necessidades a suprir em potência ou energia; a continuidade da marcha dos estaleiros, aconselhando a construção sucessiva de centrais vizinhas; a melhoria que uma central construida a montante pode trazer sobre as centrais de juzante; o tempo de construção ou o avanço do projecto, quando haja urgência em conseguir rápidamente a entrada em serviço da nova unidade; por último, a localização, dependente da posição dos consumos a servir, porque o transporte mais curto é mais seguro e mais barato, sabido que sob esse aspecto a posição optima da fonte é o centro de gravidade dos consumos."

Foi em face destas considerações que se decidiu completar os aproveitamentos do Zêzere e do Cávado e iniciar os trabalhos do aproveitamento da bacia hidrográfica do Douro.

Este esquema será completado por uma central térmica a construir junto às minas de antracite do Norte do País, destinada a servir simultâneamente de apoio à rede primária em anos secos, e a garantir o consumo dos carvões pobres.

Quanto à rede de transporte, admite-se a necessidade de ampliar a rede actual a 150 kV, e sobrepor uma nova rede a 220 kV, imposta pelo aproveitamento do Douro Internacional, pois, as quantidades de energia a transportar e as distâncias aos centros de consumo exigem uma tensão mais elevada.

No que se refere à distribuição o Plano considera a necessidade de ampliar e remodelar as redes actuais, de forma a garantir o escoamento da energia produzida.

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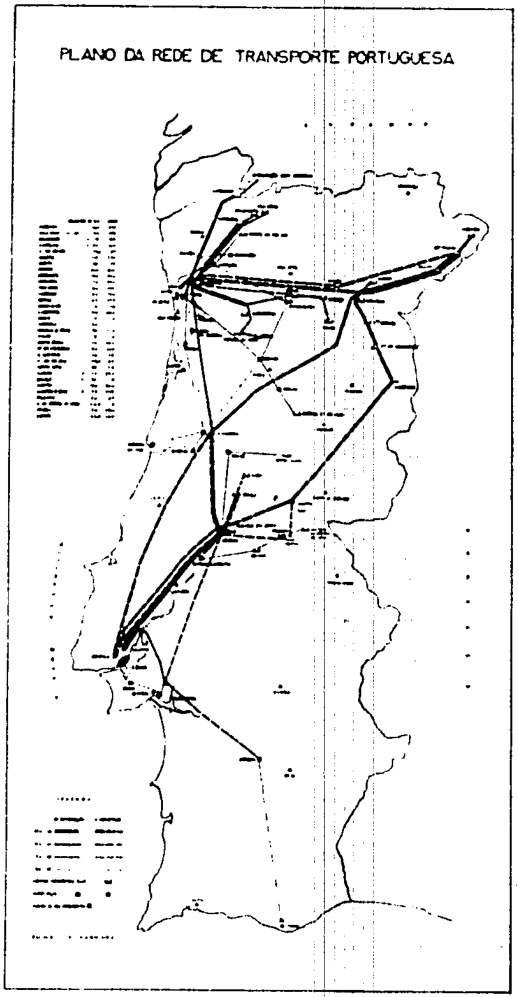
(10) — Bibliografia n.º 2



PLANO DA REDE DE TRANSPORTE PORTUGUESA

Na carta junta representamos as centrais já construidas e a construir em obediência ao Plano, e o ante-projecto da rede de transporte que deve interligar os centros de produção com os centros de consumo.

12 — O Plano de Fomento Português, estabelecido para o periodo 1953-1958, considerou toda a actividade económica da nação, examinando as necessidades e a evolução futura da agricultura, das minas, da energia eléctrica, da siderurgia, da refinação de petróleos, dos adubos azotados, da folha de Flandres, da celulose e papel e das comunicações e transportes.

Neste balanço total a energia eléctrica tem um papel de relevo, pois, justamente, se entendeu ser ela a chave da abobada do edificio industrial que se pretende erigir e completar.

Em 1901, escrevia Anselmo de Andrade: "não há erro económico mais perigoso do que a industrialização de um país, quando nele faltam apropriadas condições. Onde as matérias primas faltam e onde o carvão de pedra não existe, as indústrias só podem medrar à sombra de protecções caras."

A energia eléctrica veio alterar este condicionamento, criando as "condições apropriadas" para o desenvolvimento industrial.

Desta forma, países de fracos recursos em matérias primas, como Portugal, puderam, não transformar-se em grande potência industrial, mas adquirir uma certa independência económica, aquela independência que consiste em cada um valorisar os seus recursos próprios, podendo assim elevar o nível de vida da sua população e libertar progressivamente o indivíduo da dura servidão dos trabalhos pesados. Esta é a missão civilizadora da electricidade.

## RESUMO

Entre as diversas fontes de energia a electricidade é a menos importante de todas sob o aspecto quantitativo, representando apenas 5,1%.

Tem porém papel de relevo no mundo de hoje, pela sua utilidade, constituindo a base de industrialização de qualquer país; os investimentos nesta indústria representam a percentagem mais elevada.

Os consumos aumentam sempre, em progressão geométrica, e não se vislumbram quaisquer indícios de saturação. Na elaboração dum plano de fomento deverá por consequência atender-se a esta lei de crescimento, e ainda todas as inovações de carácter técnico que possam surgir. Por isso, se tem de encarar um Plano de Fomento como sendo de natureza essencialmente dinâmica, devendo adaptar-se a todo o momento à conjuntura.

Para a escolha do melhor sistema de produção de energia deve-se determinar o preço da caloria útil e fixar a localização das centrais térmicas; as redes de transporte e de distribuição devem ser projectadas to mando em conta a localização das cargas, com folga suficiente para não estrangular a produção, mas não tão elevada que o kWh transportado e distribuido apresente um custo proibitivo.

Os números referentes à produção de energia eléctrica incluidos no Plano de Fomento Português, comparados com os valores de 1953, mostram que as previsões foram feitas com ligeira folga, o que tem a maior vantagem.

A energia eléctrica criou em Portugal o clima propício à industrialização, que segue em ritmo acelerado.

## Résumé

Parmi les différentes sources d'énergie, l'électricité est celle qui a la moindre importance sous l'aspect de quantité, car elle correspond seulement à 5,1%. Mais sous l'aspect de l'utilité, le problème est tout à fait différent, parce que l'énergie électrique est la base de l'industrialisation de tous les pays; les investiments dans l'industrie électrique représentent le pourcentage le plus élevé.

La consommation augmente toujours, en progression géometrique, et il n'y a pas de raison pour penser que la cadence de developpement va s'affaiblir. Quand on prépare un Plan Economique on doit respecter cette loi de croissance et aussi toutes les inovations techniques qui peuvent apparaitre.

C'est pourquoi un Plan Economique est de nature dynamique, devant toujours s'adapter à la conjoncture

Pour faire le choix du meilleur système de production d'énergie, on doit calculer le prix de revient de la calorie utile et fixer l'emplacement des centrales thermiques; les réseaux de transport et de distribution doivent être capables d'alimenter les centres de consommation avec une marge suffisante pour ne pas étrangler la production, mais pas si élevée que le prix de revient du kWh ne devienne prohibitif

Les chiffres se rapportant à la production de l'energie électrique du Plan Economique Portugais comparés à ceux obtenus en 1953 montrent que les prévisions dépassent légèrement la réalité, ce qui a le plus grand avantage.

L'énergie electrique a donné au Portugal le climat necéssaire pour l'industrialisation, qui ne poursuit sans cesser

## Summary

Quantitatively, electricity is the least important of the various sources of energy. It represents only 5,1% of the total

From the standpoint of utility, the position is quite different. Electric power is the foundation of industry in all modern countries, where the investments in the electrical industry are of a very high order.

The consumption of electric energy is steadily increasing in a geometric progression, with no sign of a saturation of demand.

An Economic Program must respect this geometric law as well as consider the technical progress that may occur in the industry.

Consequently, an Economic Program must be essentially dynamic and adapt itself to changing conditions.

In the choice of a system of power production, the cost price of the useful calorie must be calculated and the locations of thermo-electric stations must be determined; the transmission and distribution systems must be so developed that they may properly supply the consumers, with a sufficient margin to meet increasing production, yet commensurated with a reasonable price per kWh.

The figures of the production of electric power in the Portuguese Economic Program compared with those actually realized in 1953 show that the previsions have exceeded reality. This may be considered a highly satisfactory condition.

Electric power has given to Portugal an increasingly favorable atmosphere for industry.

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# DEVELOPMENT OF INTERNATIONAL WATER POWERS IN EUROPE

## SOME EXPERIENCES OF RECENT DATE

By LEONHARD WOLF

NATIONAL COMMITTEE OF THE GERMANY FEDERAL REPUBLIC

The steadily increasing demand for electric power throughout the world has brought about a growing interest in the development also of water powers belonging to two or more countries (international water powers). Frequently, large rivers lending themselves to an economical exploitation are involved. One reason for the favored harnessing of these rivers was the not unfounded hope, in a post-war Europe lacking capital, that these international projects would be given preference over national projects in regard to the release of financing capital from international funds. At the same time, a practical contribution was thus made in Europe towards European cooperation. Both the European Council, which is studying the possibilities of so-called European companies with view to the economic integration of Europe, and the United Nations Economic Commission for Europe (ECE) in Geneva have taken as pattern the forms evolved in recent times out of the development of boundary waterways.

It is therefore with justification that this suject was selected for a report to the next World Power Conference. In this connection, it cannot be the aim to present generally valid rules but rather a short summary dealing with various experiences derived from recent European developments. These findings might be of general usefulness, especially also in the countries outside of Europe, in harnessing international water powers.

### I.

The waters under consideration are either rivers or lakes belonging to several States. The former, in turn, are classified differently according to whether the border line runs along their course (contiguous waterways) or whether the border line bisects their course, meaning that they flow through the territories of one or more States in succession (successive waterways). It often occurs that one and the same river constitutes a contiguous waterway in one part of its course and a successive waterway in another part. The classification, as will be shown in the following, is of extreme importance in relation to the procedure governing the development.

The special features inherent in the development of international waterways lie not in the technical field but arise from the legal situation. Therefore it is advisable to start with a short description of the legal problems resulting from such construction projects. The questions calling for solution fall under private law, public law and international law.

*Question of private law* arise from the juxta-position of two national legal systems. In general, the solution thereof does not involve special difficulties and calls for no extraordinary measures, as the principles of law of each individual State concerning the conflict of laws (inadequately termed international private law) are entirely sufficient for this purpose; particularly as regards private law it is possible almost without any restriction to arrive at corresponding accords between the parties to an agreement.

More difficult is the question of the concurring regulation of the *public law* of several States. Public law for the greater part is compulsory law that cannot be excluded by agreement between the parties to an agreement. In regard to some questions the governments may conclude treaties concerning the implementation of legal measures lying within the discretion of the authorities, a point of view which has become very important for the course of procedure. There are questions, moreover, which, if open to solution at all, can be solved only by amending the relevant legislation. In general, this course is not resorted to, as the agreements to be reached require ratification by the legislative bodies and are thus exposed to an examination under political points of view.

Of primary importance although in the development of waterways owned by several States are the rules of *international law,* which is designated in this sector also as international water law. Just as the remainder of international law was not codified -- excepting some individual sectors -- so also international water law has not been submitted to codification. Its principles must be gleaned from international legal practice (especially international treaties), from scientific theory, and from scarce quasi-international case law. Two basic opinions oppose each other in international water law: The principle of territoriality and the principle of integrity. According to the principle of territoriality, each State is entirely free in relation to other States to dispose of the waters within its territory and is not restricted in its measures concerning its water regime by any consideration whatsoever for other States. The principle of integrity declares that a State may not take any measures in its water courses or allow such measures to be taken as might result in appreciable inconvenience or detriment to another State, excepting this State has given prior consent.

Since the exploitation of water power for the generation of electric power has reached practical significance, the attempt repeatedly has been made to arrive at an international convention concerning questions of international water law, the tendency — corresponding to the much older international navigation law — always being in direction towards the principle of integrity. A concrete result, however, has not been achieved so far. The Convention of Geneva signed within the scope of the work of the League of Nations in 1928 (which also advocated the principle of land, Siam, Uruguay and Yugoslavia, it was ratified only by the following States: Austria, Belgium, Bulgaria, Chile, Denmark, France, Free State of Danzig, Great Britain, Greece, Hungary, Italy, Lithuania, Poland, Siam, Uruguay and Jugoslavia, it was ratified only by the following States: Austria, Danzig, Denmark, Egypt, Great Britain, Greece, Iraq, Panama and Siam, meaning only by such States as did not have a common boundary. This fact rendered the convention practically ineffective. It is remarkable, furthermore, that between the preliminaries for an attempt of this sort by an international conference of jurists in Madrid in 1911 and the most recent work of the ECE in Geneva, the rules propounded have become steadily more lenient and moderate. Developments in this sector of international law have clearly shown that although rules of international law can be drawn up on paper, they are dependent in their implementation, owing to their unenforcibility on a general basis, on the political situation of power and on the particular interests of the States involved, and that they only have a chance to be complied with if (as for instance in international navigation law) at least a certain degree of reciprocity is guaranteed. This sobering conclusion is confirmed by the differing treatment accorded contiguous and successive waterways.

Regarding *contiguous waterways* there generally exists a close union of interests between the concerning States resulting from the very nature of these water courses. No one State may utilize the water power without the participation of the other. In practice this resulted as a matter of course in the treatment on an equal basis of all problems of development and crystallized into the principle that each of the two parties should dispose of half of the gross water power, irrespective whether the frontier line follows the deepest navigational channel at low water (the so-called Thalweg) or runs through the middle of the water surface. In individual cases the solutions arrived at on the basis of this principle might differ: for instance, joint construction of a frontier power station or subdivision of a boundary river in such wise that each State receives a section of the common border stretch for exclusive development and exploitation.

Regarding *successive waterways*, on the other hand, which in most cases do not evoke parallel interests as in the case of contiguous rivers but frequently give rise to considerable conflicts of interests between upstream and downstream riparians on the utilization of the water power, opposing standpoints are still being maintained today. The upstream State usually advocates the standpoint of territorial sovereignty assuring it the free disposal of its water power without consideration for the downstream riparian, whereas the downstream State conversely endeavors by holding to the principle of integrity to safeguard itself against the diversion of water or other impairment of the utilization of the river by the upstream riparian. The controversy still unsettled today concerning the diversion of water from Lake Michigan and the harnessing of St. Lawrence River shows that it is extremely difficult to achieve an agreement between upstream and downstream riparians on questions of water diversion, even if a State treaty as was concluded between the USA and Canada in 1909 is extant. On the other hand, the agreement signed by Austria and Bavaria in 1948 relating to the diversion of the mountain creeks Rissbach and Dürrach, both flowing from Austria into Bavaria, demonstrates that also successive water courses are open to agreements, even though both parties maintain their opposing legal standpoints.

## II.

Most recent experiences in the harnessing of international waterways in Europe relate to the construction of power stations on Salzach and Inn Rivers, on the Danube and on the Rhine, which come under the classification of *contiguous rivers*, as they form the frontier between Western Germany on the one side and Austria and Switzerland, respectively, on the other. The following remarks will deal with the most important regulations concerning organisation, construction and operation in regard to the essentially similar developments on Inn and Danube Rivers; experiences gained in the harnessing of the section of the Upper Rhine from the Lake of Constance to Basle will be the subject of a Swiss report to be submitted separately.

For the construction of the *hydro power stations on Inn and Salzach Rivers* (1) as well as for the *Jochenstein power plant on the Danube* (2), the Austrian an German government offices concerned concluded an

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(1) On the Lower Inn (as far as the river forms the boundary between Germany and Austria), power station Braunau, with a potential capacity of 90 MW and an average annual generation of 513 million KWh, is under construction at present. Projects on this river section call for two further generating stations with a total potential capacity of 161 MW and an overall average annual generation of 973 million KWh. Seven frontier power stations, with a potential capacity of 133 MW and an average annual generation of 780 million KWh, are projected on Salzach River.

(2) The Danube hydro-electric station Jochenstein, under construction at present, has a potential capacity of 140 MW and an average annual generation of 920 million KWh.

agreement on the foundation of special joint stock companies whose duty it is to construct and operate certain hydro-electric stations on the waterways common to both States. The principle generally acknowledged in international water law, that the power generated on a contiguous waterway belongs to each of the two States by half, was once again expressly upheld in the agreement. The diversion by halves was not made in such manner that the exploitable sites were distributed among the partners for exclusive development and operation, but rather it was agreed upon that a group of shareholders of each of the two States take a fifty percent interest in the joint stock company, and that each group can claim delivery of half of the power generated by the undertaking at any time. In the first of the two cases it would have been necessary, using the head as basis, not to divide by halves but by unequal portions, as the backing-up of water into the territory of the one State would have resulted in a higher head in its favor. This was compensated for by deepening the tailwater channel of the power station in the territory of the other State, so that this increase in head balanced the effects.

Mention should be made of the fact that a solution involving the operation of a joint power station, the energy of which is to be divided equally among both partners, may give rise to difficulties in case the generating units installed in the plant do not feed into a common busbar. The control of the units, which should be adjusted to the waterflow at all times, cannot then be effected uniformly for all machine sets. In consequence, the optimum utilization of the waterflow is no longer assured. On the other hand, the division of the boundary waterway into sites ceded to one or the other of the two States for exclusive development, will also lead to considerable difficulties. Modern crest operations (3) which alone render possible the optimum utilization of water by several power stations situated on one river section, require a uniform management embracing the whole chain of generating stations, which may not always be possible if the power sites are apportioned between the two riparian States.

The advantage of an agreement between the governments concerning the establishment of a company was to be found particularly in the fact that this step opened the way to binding accords relating to questions of public law, a procedure that cannot be followed by a private foundation. It became possible, for instance, to insure in this way that all technical problems would be solved only from a standpoint of usefulness, just as if there were no border line and the undertaking lay entirely in the territory of one State. In the part of the agreement governed by public law the principle was laid down that the public authorities

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(3) Crest operations involving a run-of-stream plant or chain of power stations are defined as the regulation of operating water made possible by short-time storage of flow, in order to meet demand fluctuations.

of both States would apply the relevant legislation in such manner as to further the aims of the company as much as possible. Subsequently, the questions were cleared among others of grants and concessions under water law, including the procedure to be followed; questions of fishing and hunting laws; questions of taxation (property tax, trade tax, turnover tax, corporation tax, company tax, tax on real estate transactions); questions of reciprocal legal assistance regarding taxation; questions of customs, import and export; treatment under foreign exchange law of capital payments, transfers of profits, salaries and wages to employees and workmen of the company living on the other side of the frontier; questions dealing with the sojourn as well as the exit and entry permits of persons employed in the construction and operation of the power stations.

Owing to the possibilities created by the government agreements, construction work was started, the blank provisions of the agreements providing the necessary leeway for the practical execution. As an example, the provisions of the agreements stipulating that such articles as are required for construction, operation and maintenance of the respective power station shall be exempt from import and export duties in accordance with laws in effect on either side of the frontier, were implemented as follows: The entire construction site has been fenced off on the territory of each of the two States as a sort of customs-exempt area. Goods may be taken into this area from both sides of the border free of duty, but, in case they are not used in construction (for instance, constructing equipment) or consumed otherwise, they are exempt from custom duties only if returned to the land of origin. In order to achieve an effective control, all goods brought into the barred zone are therefore registered. This enclosed construction area may be entered by all persons in possession of a special permit. These persons, however, may leave this area only on the side of the border from which they came. Checking is rendered fairly simple by the use of permits of different colors. To make possible the provisioning of construction personnel on the site, without continuously having to issue foreign exchange authorizations, a special canteen money was coined. This money can be acquired by the workmen in the currency of their own country and enables them to make purchases in the canteens within the fenced construction site. It is not permissible to take any other kind of money into the barred zone.

Orders for construction were placed in each of the two States on a basis of equality in accordance with the government agreements and to the extent permitted by the technical and economic interests of the undertaking. The same parity was maintained in the employment of labor.

Financing in one case was effected in such a way that each group of shareholders granted the company loans in their own currency in the amount of the expenditures of the company accrued in the territory of their own State. The loan claims will later be converted into stock capital. Regarding foreign capital, the principle applies that it shall be raised by both sides to a fairly similar extent.

It is important furthermore that the proceedings required by the water and trade laws of the two countries be executed simultaneously and in mutual agreement.

As regards operation, it has been stipulated that both of the two groups of shareholders are entitled in general to take delivery of half of the power generated at any time. In case, however, one group does not raise the full half of the financing capital it is obliged to, it has a claim to power supply only in proportion to its actual share in the financing. For power delivered, the company is to be paid at cost plus an adequate interest on own capital. To assure that unequal taxation in the two States also affects power rates, and that higher taxes in the one State do not encumber the rates for the partner of the other State, the company first of all receives from each customer a compensation for the taxes and duties levied on the company in the territory of his State. Each customer pays his compensation to the branch office of the company in his own State in local currency. The company on its part is obliged to adjust its production costs insofar possible in such manner that they accrue half and half in each of the States. Finally it is provided that the shareholders can pass, with three-quarters majority, binding directives concerning the determination of production costs, and also exclude interest on own capital.

All disputes arising from the agreement regarding foundation, construction and operation of the company shall be submitted to a court of arbitration. In consideration of the fact that the board of directors, the board of supervisors and the general meeting have been constituted on a basis of strict parity, so that a decision cannot be rendered in cases of dispute with a majority vote, it has been stipulated in regard to such cases in which these bodies cannot reach a decision, that an internationally recognized expert be called upon, provided the two governments do not themselves come to an agreement in the matter.

The provisions governing a possible liquidation of the company likewise were drawn up on a basis of parity, but provide at the same time that the constructed installations be maintained as an operational unit, if in any way possible.

In part, the development of the Upper Rhine followed a different pattern. Of the exploitable total of 11 sites on the international section of the Rhine from the Lake of Constance to Basle, seven power stations are already in operation and two are under construction at present. Details about this international group of power stations are included in a report submitted by Switzerland.

Worth mentioning, finally, is the harnessing of the river Doubs which, in part of its course, forms the frontier between France and Switzerland. In 1930, these two States concluded a Convention concerning the utilization of the water power of the Doubs, the Convention containing stipulations regarding the division by equal parts of the electric power generated on the frontier section, as well as provisions relating to inlet and outlet operations upstream and downstream. On the basis of the Convention, concession for the harnessing of this section of the Doubs was granted to a Swiss syndicate and the Electricité de France in 1947, and the year of 1950 saw the beginning of construction work on the Châtelot power station. This concession once more stipulated the equal division of the electric power between France and Switzerland. Also the stock capital was divided equally between Switzerland and France; likewise, the principle of equality was maintained in placing orders in the two countries. Each of the two countries is entitled, during the period of construction and also later during the period of operation, to appoint a commissioner to supervise the activities of the management.

Regarding the development of *successive waterways* through international cooperation, no extensive experiences of recent date are on record. Worth mentioning is the agreement reached a short time ago between Austria as upstream riparian and Yugoslavia as downstream riparian concerning the operation of the power stations on the Drave. On this river, power stations were erected both on the upstream Austrian section and on the downstream Yugoslavian section. As a result of modern water regulation at these run-of-stream stations, the upstream plants turbined the water stored in the headwater at peak load periods, the released water then arriving at the downstream riparian at such a time as did not permit him to effectively utilize this water. This example shows that the water schedule of the upstream riparian can in such cases lead to inconveniences to the downstream riparian. Therefore it has been the aim in recent times to place such a chain of power stations into the hands of one undertaking, in order thereby to assure a uniform management as well as the best possible utilization of the water. This is also the reason why the power sites on various contiguous rivers are not distributed between the riparians for exclusive development, but rather developed and operated jointly. In the case of Yugoslavia and Austria, an agreement was arrived at, which will assure an economic operation of all power stations on the Drave.

Still in the stage of preliminary negotiations are the plans for the harnessing of the Upper Inn, with inclusion of the Spölbach in the Italo-Swiss frontier area. Two Swiss groups, the Konsortium für Engadiner Kraftwerksprojekte (KEK) (Syndicate for Engadine Power Projects) and the Konsortium Innkraftwerke A. G. (KIK) (Syndicate Innkraftwerke A. G.), have presented international projects, i.e. projects which can only be solved by inclusion of Swiss and Italian territory in the construction scheme. Italian companies are either participating or interested in both syndicates. A special feature is the fact that a third State, namely Austria, is also directly interested in these projects as downstream riparian on the Inn, as the planned diversions of water to Italian territory affect Austrian development schemes on Inn River. Therefore, agreements will have to be concluded between the three above mentioned States in order to realize the harnessing of the Inn, if it is to be carried out on an international level.

Plan of the mentioned Hydro Power Developments.

Neither in international water law nor in practical international cooperation in the construction of power stations was the question taken up hitherto, whether the downstream riparian may be called upon to render compensation if he is benefited by construction measures of the upstream riparian. In view of the characteristics of European Alpine rivers, with their summer floods and the decrease of flow in winter, the construction of a storage reservoir by the upstream riparian is to the advantage of the downstream riparian insomuch as the reservoir stores dangerous summer flood water and, at the same time, improves valuable winter flow.

The harnessing of international waterways has certain points in common with the development of national water powers on an international basis. This conception was brought to life again in Europe in recent times by the United Nations Economic Commission for Europe (ECE) in connection with the development of Yugoslavian water power resources, and by the Studiengesellschaft für Alpenwasserkräfte in Österreich (Interalpen) (Society for the Study of Alpine Water Powers in Austria). Both cases involve the problem of developing water powers for export which far exceed the own requirements of a given country, and of carrying out this development on an international basis, because investment capital cannot be raised in the exporting country proper. This task gives rise to a variety of technical, economic, legal and financial questions which, for a beginning, are to be studied in international cooperation.

The "*Interalpen*" was established by French, Austrian, Italian, and German power supply undertakings in Innsbruck on 1 December 1952. Their goal is to study and prepare a future international harnessing of Alpine water powers in Austria. To start with, four committees were set up, namely a committee each for hydro-technical, hydro-economic, legal, and financial problems. Final results by these committees are not yet available and it is not possible therefore to give details about this work already today. Similarly, studies are being carried out at present within the scope of the work of the ECE concerning the possibilities of constructing *power stations in Yugoslavia for the export of electric energy*. The studies are being undertaken by four committees for technical, economic, legal, and financial problems, respectively, the chairmen of which in turn constitute a coordinating committee. In these committees are represented, by equal numbers, the countries of Yugoslavia, Austria, Italy and the Federal Republic of Germany. The work also of these committees is still in full swing, and no details are as yet available on practical experiences.

As individual study of a similar nature, the ECE in recent years took up the examination also of the *Our project* which had been the subject of several studies already before the last war. The basic conception of the project is to create a centrally located pumping station within the Belgian, Luxembourg, German, French, and Dutch industrial districts by making use of the River Our. The Our would be backed up in the valley between Vianden and Stolzenburg and the water pumped up 300 m into a basin on the Nikolausberg. Electric power for pumping is to be supplied by brown coal power stations, the storage basin to be utilized for the generation of peak energy. Apart from the State of Luxembourg and the Town of Vianden, French, German, Luxembourg, Dutch and Belgian undertakings are participating in the Société de l'Our founded in Luxembourg in 1951. This demonstrates the intensive interest the Our project has aroused in international circles. At the present time, the draft of a treaty is being prepared jointly by representatives of Luxembourg and Germany. The treaty will contain provisions regarding the question of granting concessions for the project and will embrace stipulations relating to other questions connected with construction and operation to be solved by the authorities of each country. Practical experiences are not yet available, however, as it has not been possible so far to start carrying out this project.

## Summary

The harnessing of international waterways is steadily gaining in importance, as rivers are frequently involved which promise a highly economic exploitation. The problems raised in this connection are primarily those of private law, public law, and international law.

Of special significance regarding the development of international waterways are the rules of international law, in this field termed international water law. Here we find two principles opposing each other: the principle of territoriality grants each State an unrestricted right to dispose of its water powers without consideration for neighboring States, and the principle of integrity declares that no State may, without consent of the neighboring State, take any steps, or allow such steps to be taken, which might lead to an appreciable inconvenience or impairment of that State. Attempts hitherto of arriving at multilateral conventions in the field of international water law have not matured into practical significance. Actual practice has shown although that bilateral agreements on certain projects were possible in all cases involving given parallel interests. This is the rule in regard to waterways forming the boundary between two States (contiguous waterways) as in opposition to waterways bisected by the frontier (successive waterways).

The report deals mainly with the construction of individual power stations on the Inn and on the Danube as contiguous waterways and shows up the solutions arrived at in recent times. In addition, constructions on successive waterways are outlined. Finally, mention is made of the studies in course at present concerning the international development of national waterways.

## RÉSUMÉ

L'exploitation des cours d'eau internationaux gagne d'importance progressivement comme il s'y agit souvent des forces hydrauliques qui méritent particulièrement d'être exploitées. Il s'y présentent spécialement des problèmes juridiques, tel que le droit privé, le droit public et le droit international.

Le droit international — appelé dans ce cas "législation internationale sur les cours d'eau" — est d'une importance particulière pour l'exploitation des eaux internationales. Voici d'abord le principe territorial qui donne à tout état un droit de disposition illimité sur ses forces hydrauliques sans égard aux états voisins et voilà le principe d'intégrité, d'après lequel un état n'a pas le droit de prendre ou d'admettre des mesures quant à ses eaux, qui causeraient une importunité considérable ou un passe-droit d'un autre état en tant que celui-ci n'a pas donné son consentement. Jusqu'à ce jour l'essai de parvenir à des conventions multilatérales dans le cas de la législation internationale sur les cours d'eau n'obtint pas d'importance pratique. Cependant la pratique a prouvé que des conventions bilatérales sur de certains projets étaient possibles partout où des intérêts naturels et parallèles existent; c'est ordinairement le cas concernant les eaux qui forment la frontière entre deux états (des eaux partagées par la frontière en longueur) au contraire des eaux qui sont traversées par la frontière (des eaux partagées transversalement).

Le rapport traite surtout l'aménagement de quelques centrales électriques situées sur l'Inn et sur le Danube étant des eaux partagées en longueur et montre les solutions qu'on a trouvées dans les derniers temps. En outre on fait allusion à des constructions concernant des eaux partagées transversalement. Finalement les études sont mentionnées dont on s'occupe à présent à cause de l'aménagement international des eaux nationales.

## RESUMO

O aproveitamento dos cursos d'água internacionais se torna tanto mais importante quando se trata, freqüentemente, de fôrças hidráulicas que apresentam particular interêsse em sua exploração. Aí se apresentam, especialmente, problemas jurídicos, tais como o direito privado, o direito público e o direito internacional.

O direito internacional — nesse caso chamado "legislação internacional sôbre os cursos d'água" — apresenta importância especial no aproveitamento das águas internacionais. Veja-se logo, a propósito, o princípio territorial que dá a todo Estado um direito de disposição ilimitada sôbre suas fôrças hidráulicas sem atenção aos Estados vizinhos, a par do princípio de integridade, segundo o qual um Estado não tem direito de tomar ou de admitir medidas relativamente às suas águas, que seriam consideràvelmente importunas ou injustiça de um outro Estado, sem o

consentimento do vizinho. Até hoje a tentativa de chegar-se a convenções multilaterais para o caso da legislação internacional sôbre os cursos d'água, ainda não resultou em importância prática. Entretanto, a prática provou que convenções bilaterais em certos projetos eram possíveis nos casos em que interêsses naturais e paralelos existiam; sendo, ordinariamente, o caso em relação às águas que delimitam a fronteira entre dois Estados (águas divididas pela fronteira em comprimento), contràriamente ao das águas que são atravessadas pela fronteira (águas divididas transversalmente).

A monografia trata, sobretudo, de usinas geradoras individuais situadas sôbre os rios Inn e Danúbio com águas divididas em comprimento e mostra as soluções que se encontraram nos últimos tempos. Além disso, faz-se alusão a construções que interessam às águas divididas transversalmente. Finalmente mencionam-se os estudos que se ocupam, no presente, do aproveitamento internacional das águas nacionais.

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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 7
Assunto 7.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

URBAN (E.)
VAZ (O.)
Áustria

# AUSTRIA'S EXPERIENCES IN INTERNATIONAL HYDRO-ELECTRIC DEVELOPMENTS

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AUSTRIAN NATIONAL COMMITTEE

The discussions concerning the legal and economic problems arising from the utilisation of the water power of rivers running through or bordering two or several states have increasingly been intensified with the progressing exploitation of hydro power.

The discussions between neighbour states concerning the utilisation of watercourses of common interest have centered around two opposite principles, viz., The territorial principle according to which any country, by virtue of its unlimited sovereign rights, was entitled to exploit the section of a watercourse within its territory without regard to any detriment inflicted thereby on other countries and the principle of integrity according to which any country must, even on its sovereign territory, abstain from any interference in the natural waterflow of watercourses which is bound to result in prejudicing the interests of another state. Austria and her neighbour states have to an ever increasing degree realized that rigid adherence to either of these principles would not promete their relations in the field of water economy.

Similar to Switzerland the territory of the Austrian Federal Republic lies in the central part of the main European mountain range, viz. the Alps, of which it comprises the eastern part. It extends over 500 kilometers in a west-east direction, its larger part lying north and the smaller part south of the main chain. Whereas in the case of Switzerland the watercourses flow from the highest elevations within the state territory in all directions beyond the borders and thus make Switzerland the model of an "upper" state in respect of water economy. in the case of Austria several important watercourses coming from higher areas in the west and south are entering her territory. Since the southern borders of Austria are formed by mountain ranges there are no rivers flowing off southward. but several flowing off northward where the respective watersheds lie south of Austria's northern borders.

Among the watercourses which are shared by Austria with other countries there are both successive and contiguous waters. the term "successive" being used in relevant literature for waters which. coming from one state territory. enter another state territory. flow through the respective countries successively and cross their borders while by "contiguous" or border rivers such are understood whose watercourses from the boundary between two states.

In view of the existing geographical conditions which have resulted in making Austria in one case an "upper" state (i.e. a state which holds the upper courses of rivers) and in another a "lower" state (i.e. a state holding the lower courses of rivers) with the concomitant problems arising therefrom it is understandable that already early this country has felt prompted to seek new ways and means for settling its relations with other countries in the field of water economy. These attempts have had the effect that more emphasis has been placed on economic and technical considerations and that rigid adherence to purely legal principles has been more and more abandoned. Increasing importance has been attributed to the idea of optimum utilisation. i.e. the viewpoint has been largely adopted that without regard to the division of watercourses by political boundaries the optimum technical and economic solution is to be attempted and jointly to be utilised.

The principle of joint optimum water power utilisation. so to say. forces itself upon one's mind in the case of contiguous waters and thus has received more attention than in the case of successive waters. But even in respect of successive waters arrangements have been made between Austria and her neighbour states which go far beyond the principles of notification and consultation as recommended by the Electricity Committee of the UN Economic Commission for Europe (cf. Recommendation No. 3).

Optimum utilisation is meeting with considerable difficulties even where no political boundary lines are involved. which difficulties quite naturally are increasing greatly in respect of waters where there is a joint interest. Furthermore. cooperation in the field of water economy between the countries concerned requires for the practical development of projects special solutions particularly in the field of finance and customs legislation as well as in the field of labor legislation and other fields of public administration.

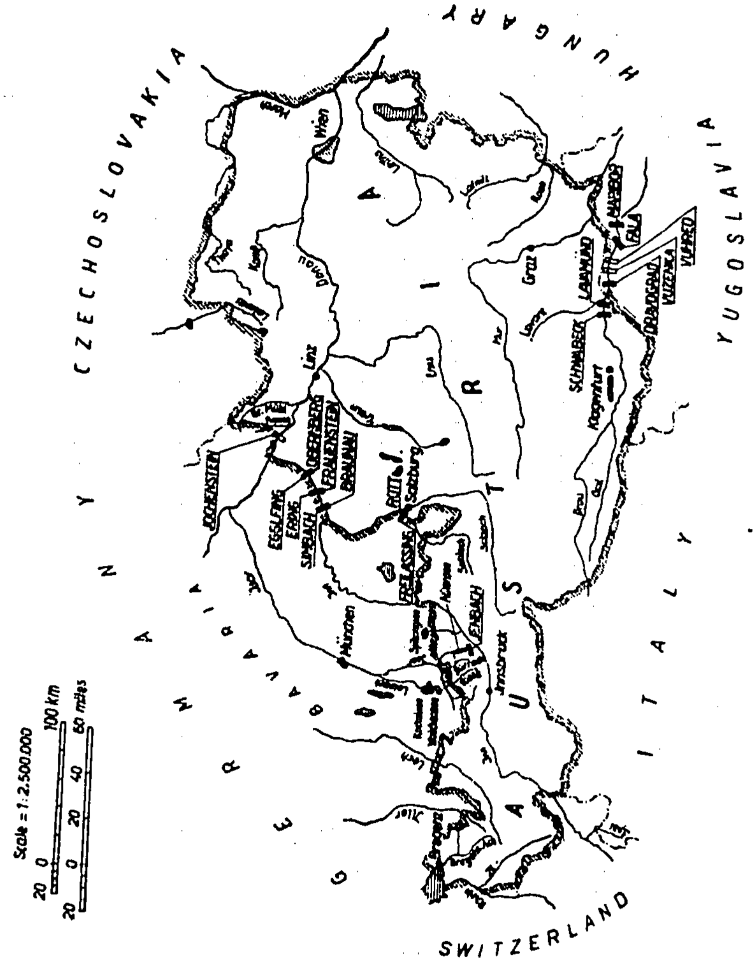
The first hydro power project which prompted Austria to enter into intergovernmental negotiations was the development of the Achensee (Achen lake) in the Tyrol carried out during 1924 and 1927. The Achensee though wholly located on Austrian territory discharges its water by way of the Walchenbach into the Isar on Bavarian territory. It lies 400 meters above the Inn-river valley little less than 4 kilometers distant and its development by Austria into a storage reservoir with concomitant utilisation of the existing gross head suggested itself. The net storage capacity of the lake (87 million cu.m.) is not utilised by raising but by lowering its surface level by 12.5 meters at the utmost; the natural efflux was interrupted and the catchment area enlarged by various river diversions. 188 million cu.m. water from a catchment area of 155 squ.kilometers the natural run-offs of which would join the Isar-river are diverted to the Inn-river by way of the power plant (capacity : 83.000 KW, production : 145 million kWh, net head : 360 meters). Thus the Isar lost at the confluence point of the Walserbach about one sixth of its catchment area. Although the waterflow of the Isar is in Bavaria thereby strongly reduced, Bavaria has not stuck rigidly to the principle of integrity and given up resistance against the blocking of the Walchen area as the natural run-off area, while on the other hand Austria has not adhered unyeldingly to the territorial principle. A solution was found in connection with a long-term supply contract whereby a large part of the electric energy produced by the Achensee plant has been ensured to the Bavarian company for public supply at a favorable price and which, with various subsequent additions, is still in force. In this manner the Achensee Power Plant has been recognized as the optimum means of utilisation of the respective waters and the advantages of this utilisation have been shared with the "lower" state, in this instance the idea of joint optimum utilisation of a successive watercourse appears thus realized.

Since the catchment area of the Achensee Power Plant does not suffice in years with an unfavorable water supply for filling the net storage volume of the Achensee Austria has after the second World War envisaged an extension of the existing plant by diverting other Isar tributaries originating on Austrian territory, viz. the Rissbach and the Dürrach whose catchment area lies higher than the maximum water level of the Achensee. At the same time Bavaria was planning to divert the Rissbach into the Walchensee for improving the Walchensee Power Plant. These two hydro power projects excluded each other. If Austria had diverted the run-offs of 50 squ.kilometers of the Rissbach catchment area to the Achensee the Rissbach diversion would have been reduced to one half of its water afflux and thus lost its profitability.

In recognition of the importance of the Rissbach diversion for the Walchensee Plant Austria has abandoned the planned diversion of the Rissbach to the Achensee Plant. Bavaria, on the other hand, agreed to the diversion of the Dürrach having a catchment area of 63 squ.kilometers and an average waterflow of 70 million cu.m. (yielding an additional power production of 55 million kWh per year), both parties resigning any claim for indemnification.

Viewed purely from the aspect of electrical and hydro power economy, the diversion of the Rissbach to the Achensee would have had the same effect because the net head of the Walchensee Plant amounts to only one half of that of the Achensee Plant and the annual waterflow of the Rissbach at its confluence point is twice as large as at the point where it could have been diverted to the Achensee. In consequence of the diversion of the Rissbach to the Walchensee, however, about the double amount of water is being utilised over a head of 200 meters only instead of over a head of 400 meters. Yet, when considering the special economic requirements of the two countries concerned also this solution may be termed to comply with the principle of optimum utilisation.

Whereas in the case of the power plants discussed thus far we have been dealing with the utilisation of whole catchment areas in mountainous regions, the stagger scheme on the Drau-river concerns a certain section of that river where it forces its way from the Völkermarkt basin in the west to the Maribor basin in the east. This section is about 100 kilometers long and provides a head of about 120 meters. On this section the first Drau hydro plant was erected as a run-of-river storage plant during the first World War near Fala. As a result of the new border lines drawn in 1918 this power plant came to Yugoslavia and this section was cut into an Austrian and a Yugoslavian part at a point about 45 kilometers above the Fala Power Plant and about 4 kilometers east of the town of Dravograd, the Drau-river forming the border between the two states in a length of about four kilometers. At the upper end of this river section on genuinely Austrian territory the Drau-river Power Plant Schwabeck (capacity: 60.000 kW, production: 350 million kWh/per annum, gross head: 22 meters) was erected in the years 1938-1942. In 1941 when Yugoslavia was occupied by Germany and the boundaries had temporarily disappeared an overall power scheme was elaborated for the whole above-mentioned section of the Drau-river including the Fala Plant and the construction of the Power Plants Lavamünd, Dravograd and Maribor initiated. In this connection the Power Plant Maribor (with a head of 16 meters) was to provide the complementary reservoir for the intermediate reservoir of the Schwabeck Plant. It was intended to regulate operations in the whole power plant group from this intermediate reservoir. After the old boundaries of 1938 had been re-established in 1945 the Power Plants Schwabeck and Lavamünd remained with Austria while the Power Plants Dravograd and Maribor came to Yugoslavia to which also the Power Plant Fala was returned. Within this power plant group construction of the Power Plant Vuze-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Klagenfurt
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Bregenz
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EGGLFING
ERING
SIMBACH
OBERNBERG
FRAUENSTEIN
BRAUNAU
RIEDT
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nica was begun in 1951 and more recently of the Power Plant Vuhred; it is intended to utilise the remaining head up to the back water of Fala by another power generating station.

At the time being certain links in the whole chain of power plants are still missing, but even for this incomplete chain optimum hydro power utilisation can be achieved only by way of regulated intermediate storage operations which, however, are rendered difficult due to the existing conditions on the border. Negotiations conducted between Austria and Yugoslavia in 1952 and 1953 have led to the establishment of a joint operational scheme for the two adjacent Power Plants Schwabeck (on Austrian territory) and Dravograd (on Yugoslavian territory) whereby intermediate storage at Schwabeck has been regulated. In that both Austria has taken account of the Yugoslavian interests in respect of the subsequent power plants and Yugoslavia of the Austrian requirements in respect of the Power Plants Schwabeck and Lavamünd the two countries have attempted to approach an optimum with regard to an economical utilisation of this watercourse by considering the entire range of power plants involved.

Genuinely contiguous waters are concerned by the agreements concluded between Austria and Germany on the utilisation of the rivers Saalach, Salzach, Inn and Danube which for 155 kilometers form an uninterrupted wet border between the two states. The Saalach joins the Salzach below the city of Salzburg and the latter river the Inn above Braunau which has its confluence point with the Danube at Passau. At this border stretch where during Austria's occupation by Germany the boundaries had been eliminated the Inn-river Power Plant Ehring-Frauenstein as well as the Power Plant Egglfing-Obernberg were erected by the Innwerk A. G. while on the Saalach-river the Power Plant Freilassing was commenced by the Municipal Power Company of the City of Salzburg. Whereas after the re-establishment of the German-Austrian border the Power Plant Rott-Freilassing remained as a whole in the possession of the City of Salzburg by which it was completed the installations of the Inn-river Plant Ering and Obernberg have, as far as they are located on Austrian territory, come under the so-called German property in Austria and thus their status has remained unclarified. The installations of the two Inn-river power plants are at present under public Austrian administration.

Their unclarified status, however, proved no obstacle for the conclusion of an agreement between the two Governments concerned on the joint development and the joint utilisation of hydro power resources of the Austro-Bavarian border rivers such as the Inn and Salzach in particular. On the basis of the intergovernmental agreement concluded on October 16, 1950, a special company, the "Österreichisch-Bayrische Kraftwerke A. G." has been formed to that effect of which one half of the shares is in the hands of an Austrian and the second half in the hands of a Bavarian group. Likewise half of the members of the board of directors and of the managing board of this joint stock company are delegated by each group. The accounting operations are subject to supervision by the public auditing agencies of the two Governments concerned.

Each group of shareholders is responsible for the financing of one half of the building requirements: consequently each is entitled to one half of the electric power produced by the joint company and obliged to refund one half of the primary costs accruing. After a decision has been reached on the so-called German property in Austria the existing two Inn-river Plants Ering and Obernberg will be included among the assets of the company.

The required licences and other official authorisations in respect of the plants are granted independently by each of the two countries on the basis of existing legislation after consultation with the other; they should be issued simultaneously, contain similar provisions and conditions and not be in contradiction to each other.

All legally permissible taxation privileges are extended by both countries to the company for which equal treatment in respect of taxation is attempted; for setting unavoidable additional taxation charges occurring on one side special provisions have been set up.

In respect of transports between the two countries the goods imported or exported which are to be used or consumed by the company are exempt from the payment of customs and duties; to that effect a free zone has been created around the power site in cooperation between the fiscal agencies of the two Governments. Also the granting of foreign exchange permissions has been provided for in the respective intergovernmental agreements.

In regard to the employment of labor, the placing of orders and similar matters the interests of both countries are to be considered equally. As far as feasible labor is to be granted the required permits for residence, employment, entrance into and departure from the other state territory as well as for a free transfer of wages.

The frontier between the two states has not been affected by the intergovernmental agreement so that the existing border line will remain unchanged even if the existing valley route should be modified.

The first result of this intergovernmental cooperation where the principle of optimum utilisation has been applied most effectively and where all related problems in the field of finance, customs duties, labor and all other administrative questions have been solved in an exemplary manner has been the initiation of the Power Plant Braunau (capacity : 96,000 kW, production : 513 million kWh per year, gross head : 11.5 meters) above the Inn-river Plant Ering which will be put to operation in October 1953.

While the Power Plant Braunau was still in the project stage a joint projecting committee has been set up by the German "Rhein-Main-Donau A. G." and the Austrian "Elektrizitätswirtschafts A. G." which elaborated the plans for the projected Power Plant Jochenstein to be erected on the Austro-German border section of the Danube.

The first plans for the Jochenstein Power Plant date from the year 1918 when the Bavarian Canal Construction Office drafted its first schemes for the large waterway Rhine-Main-Danube; these plans were later set aside because development of the Kachlet Plant above Passau which for navigation is by far more important was decided upon in Bavaria and carried out in the years 1922-1927 by the "Rhein-Main-Donau A. G." The erection of a power plant at Jochenstein has repeatedly been envisaged under the various overall development schemes for the Danube.

On the basis of the agreement concluded on February 13, 1952, between the Governments concerned the joint "Donaukraftwerk Jochenstein A. G." has recently been founded whereby the joint erection and use of that power plant (capacity: 140,000 kW, production: 940 million kWh/per annum, gross head: 10.15 meters) appears assured in a similar manner as has been done in the case of the above-described development of the Inn-river. Also in this instance production and financial outlay will be jointly shared by both riparian states although the embankment area made use of is for its larger part situated on German territory. The equal distribution ratio was ensured in that Austria has made available part of the gross head below Jochenstein for the power plant and the corresponding head was obtained by deepening the bed of the river. As the Danube is a navigable river and is, moreover, in respect of navigation subject to international agreements the interests of navigation had to be considered which formed one of the most difficult problems to be solved. In spite of the fact that a twin lock with a usable length of 230 meters and a free width of 24 meters each must be erected the entire building costs which are borne by the company are in the case of the Jochenstein Power Plant but little higher than those for the Braunau Plant. At the beginning of 1955 the first generating unit of the Jochenstein Power Plant will be put to operation.

The countries participating in this joint development of the Inn and Danube may note with satisfaction that in no other case an agreement has been reached within such a short time on the development and the execution of a hydro power project on a contiguous water. The arrangements made have set a model for the joint development of border rivers and thus have been used as a basis for the respective Recommendation No. 2 by the Electricity Committee of the UN Economic Commission for Europe.

In the immediate future some other joint hydro power projects are awaiting solution. In this connection the development plans for the Bregenzer Ache on the border between Vorarlberg and Bavaria and the exploitation of the Inn-river on Swiss territory may be mentioned.

The general development scheme for the Bregenzer Ache provides for diversions from the catchment areas of the Iller and Lech whereby these two rivers which in Bavaria are largely utilised for hydro power production are affected though only to a limited extent. In this instance Austria is the "upper" state.

In the second instance, viz. the utilisation of the Inn-river by Switzerland, Austria is the "lower" state. The projects for the area of the Upper-Inn-river which have been under consideration for some decades and are promoted by two competing groups provide for the diversion of a considerable portion of the waterflow of the Inn-river to Italy. Thereby the hydro economy of the Inn-river in Austria is considerably affected. Its catchment area mounts to 1945 squ.kilometers at Martina on the Swiss-Austrian border. The annual waterflow varies at this point between 20 and 40 l/s.squ.kilometers and to 30.0 on the average, the average waterflow for the last years being 58.3 cu.meters/sec. During the same period the average annual waterflow varied between 1240 million cu.meters (minimum) and 2,460 million cu.meters (maximum). The Swiss-Italian plannings envisage the creation of storage reservoirs with an overall water content of 330 to 360 million c.meters of which 260 million cu.meters are to be diverted to Italy while the remaining waterflow of the Inn will be utilised on its natural course. As a result the water supply of the Inn would be shifted to a great extent from the summer to the winter months while the waterflow on Italian territory during the winter months would be increased.

It is to be hoped that also in these cases negotiations between the countries concerned will not be frustrated by rigid adherence to juridical principles but that technical and economic considerations will prevail and lead to solutions which take account of the requirements of the countries concerned within the frame of an equitable program of hydro power utilisation.

## SUMMARY

In the report of the Austrian National Committee the results are indicated which Austria in cooperation with her neighbour states has achieved in the solution of problems arising in connection with the establishment of joint power plants. These positive results are primarily to be attributed to the fact that in their relations in the field of hydro economy Austria and her neghbour countries have more and more discarded the principles rigidly applied before (the territorial principle and the

principle of integrity) in respect of successive and contiguous waters. These principles have increasingly been replaced by technical and economic considerations and the concept of joint optimum utilisation has been accepted to an ever higher degree.

## RÉSUMÉ

Le rapport fait ressortir les résultats que l'Autriche a pu atteindre en coopération avec ses pays voisins on ce qui concerne la solution des problèmes soulevés par la construction de centrales hydro-électriques communes. Ces résultats positifs sont principalement dus au fait que. dans leurs relations sur le plan de l'économie hydraulique. l'Autriche et ses pays voisins ont commencé à abandonner les attitudes rigides qui. dans le passé. ont servi de règle dans le cas des eaux successives et contigués (principes de territorialité et d'intégrité). Au contraire. des considération techniques et économiques ont été substituées dans une mesure de plus en plus grande à ces principes inflexibles. et les pays intéressés ont adopté l'idée de l'exploitation commune assurant un effet optimum.

## RESUMO

A monografia evidencia os resultados a que a Austria pôde chegar em cooperação com os paises seus vizinhos no que diz respeito à solução dos problemas surgidos com a construção das centrais hidro-elétricas comuns. Os resultados positivos se devem. principalmente. ao fato de que no dominio da economia hidráulica. as relações da Austria com os paises vizinhos já começaram a abandonar as atitudes rigidas que. no passado. serviram de regra nos casos das águas sucessivas e contiguas (principios de territorialidade e de integridade territorial). E muito ao contrário. considerações técnicas e econômicas vão substituindo. cada vez mais. aquêles principios inflexiveis. e os paises interessados adotaram a idéia da exploração conjunta da qual resultaram os melhores efeitos.

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PROF. DR. TECHN. EMIL MOSONYI:

# HYDRO-ELECTRIC DEVELOPMENT IN HUNGARY

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# HYDRO-ELECTRIC DEVELOPMENT IN HUNGARY

By

Prof. Dr. Techn. EMIL MOSONYI

## I. Potential Water Power

According to former detailed investigations by the author, potential water power in Hungary may be estimated at a capacity of 960 000 kW and at an output of 7500 million kWh per annum when taking into consideration the discharges of 50% duration on an average. It is characteristic for the hydrological condition of Hungary's river system that the values belonging to 95% duration discharge amount to 462 000 kW and 4050 million kWh respectively. The flows in this country are feeding two major rivers, the Danube and the Tisza, thus constituting the two water systems of Hungary (Figure 1.). Only 16% of the above mentioned water power is being carried by the Tisza system, the remaining 84% belongs to the Danube and its tributaries. It is characteristic that the Danube — Europe's second largest river — by crossing Hungary carries all alone 67% of the country's total potential water power, while the Danube tributaries and the Tisza system together represent merely the remain-

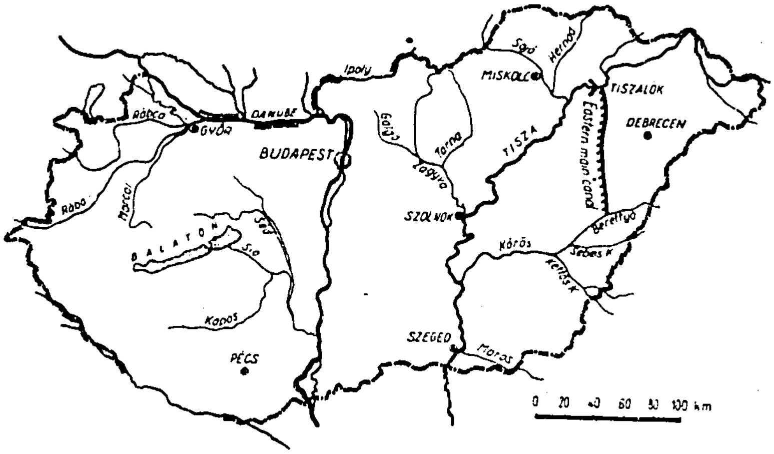


Figure 1.

ing 33 per cent. The Danube carrying the bulk of potential water power flows across a lowland of small slopes and the same must be said about the Hungarian stretch of the Tisza and its tributaries as well. Only quite a few of the minor tributaries of both the Danube and Tisza spring from the hilly regions of the country where more significant downstream slopes can be found. Establishing high heads and setting up reservoirs are completely excluded by topographical and settlement conditions. It is rendered evident by these circumstances that mainly low-head run-of-river plants can be designed in this area.

The hydro plants are to be constructed either in the river bed itself or in the short cuts improving the river bends. A system with longer deviation canals is advisable merely on the upper reaches of the Danube and on some minor flows where slope conditions are more favourable.

However, only a considerably reduced portion of the water power in question can be developed as regards energy generation. This fact is due to three reasons :

*a)* Losses in energy conversion ;

*b)* At the time of great floods the low-head hydro plants are either completely out of action or their operation is considerably reduced.

*c)* Topographical and settlement conditions on the Hungarian plains do not permit everywhere the best utilization of potential water power and, what is more, certain shorter river stretches have to be left inutilized.

According to recent examinations the capacity utilizable in view of energy generation amounts to some 500 000 kW. With this installed capacity an average annual output of 3300 million kWh can be estimated. The capacity of plants which would be most economic and are therefore primarily advisable for construction totals 250 000 kW with an annual output of 1700 million kWh.

Unfortunately the development of hydro-electric plants in Hungary was greatly neglected in the past and so the projects constructed so far represent a total capacity of only 16 000 kW. This slight figure, however, as we have seen does not give the right idea of what energy lays unexploited in the river systems of the country. Considering that Hungary's territory consists mainly of plains and only in a small portion of hills or mountains, it is obvious that here the possibilities for hydroelectric development are less favourable and less valuable than in the neighbouring mountainous countries. Yet the situation is far better than if judged from the insignificant output of hydro plants constructed so far.

## II. Hydro Electric Plants As Parts of Multi-purpose Utilization

Utilization of water power in Hungary is closely to be connected with flood control, drainage and irrigation. The headwater elevation of hydro plants is to be fixed at a height not imperiling the safety of flood control and not requiring excessive costs for drainage, or else the accessory expenses will render water power development irrentable. The importance of this point becomes plausible when bearing in mind that 46 500 km² i.e. roughly 50% of Hungary's territory is drainage area out of which 23 000 km² (some 25% of the country) has such a low elevation that this area has often been flooded prior to the construction of dikes.

These flood controlled plain-land regions are highly suitable for irrigation. Investigations have proved that in Hungary it is rentable to envisage the irrigation of an area totalling some 800 000 hectares out of which over 100 000 hectares will be prepared for irrigation by the end of 1954.

Considering that the majority of areas to be irrigated are situated along the Tisza, the construction of dams has been launched on this river, although it is much poorer in hydro-energy than the Danube. In the meantime careful surveys, planning and scale model tests concerning water power development of the Danube are in progress. With the hydro plants on the Danube power generation is the point but here, too, the requirements of irrigation must not be disregarded. Photo 1 was taken at night of an experimental measurement of flow on the Danube. The course of lighted floats was photographed to observe surface flow. This test is of great importance as in this sharp curve specific condi-

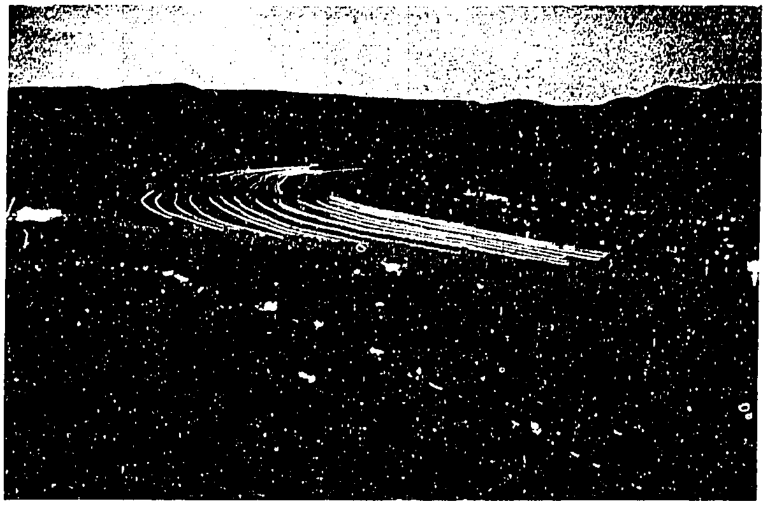


Photo 1. Float test to determine current direction in River Danube

tions of flow prevail. In several sections discharge measurements have also been made. Comparison of discharge measurement to photogrammetrical evaluation of float tests gives a right picture of the so called secondary flow, swire formation, eddies, etc. The results of these tests have been used in controlling the scale model of the Danube stretch in question.

The scale model (Photo 2) has been built in the garden of the Budapest Technical University: size: 50 m × 5 m. Scale of length and width 1 : 500, scale of depth 1 : 80 giving a torsion of 1 : 6,25.

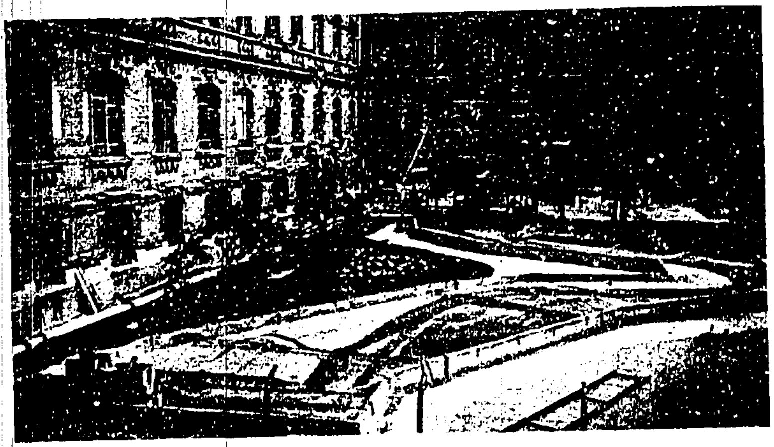


Photo 2. Scale model of a Danube stretch in the garden of the Budapest Technical University

## III. Description of the Tiszalök Hydro-electric Plant Under Construction

Serving the purposes of irrigation, the first dam built on the Tisza River was put into operation in May 1954. The water for irrigation is to flow in a 100 km long canal crossing the Hungarian Plain. A 63 km stretch of this navigable main canal is now completed.

Plant 1 under construction at Tiszalök, together with the rest of the projects to be constructed in the course of the Tisza canalization, will serve a fourfold purpose:

*a)* direct irrigation of the Tisza-valley and its surroundings;
*b)* feeding of fish ponds and plain-land reservoirs;
*c)* generation of water power;

*d)* improvement of navigation on the Tisza and the river system connected with it.

Beside the dam, foundation of and machine house for the power station on one side are now completed, and the ship lock on the other is under construction. Installation of machinery is in progress.

The dam has been built in a cut of a river bend. (Fig. 2.) By this solution the safety of building process has largely been increased, though building operations were carried out inside the flood control dikes but outside the river bed.

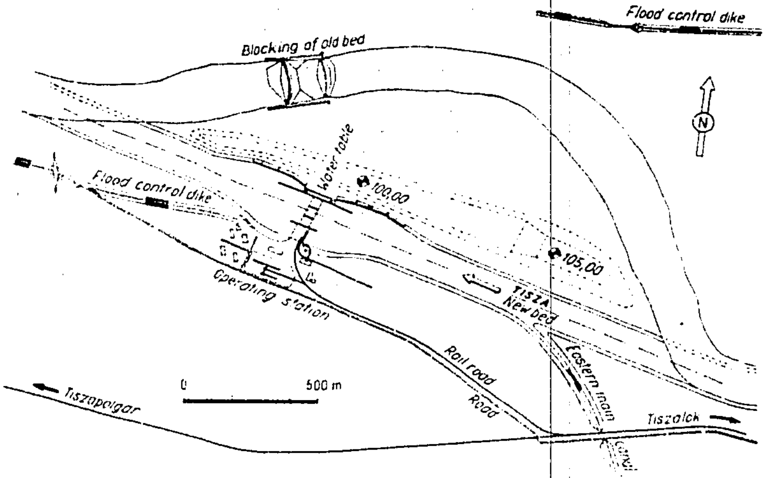


Figure 2.

The excavation for foundation could be protected against water overflooding the river bed by a circular dike outside the main flow. Proper arrangement excluded every possibility of icing and the decrease in vertical section did not affect the safety of run-off of floods.

Building in the natural river bed would have been extremely complicated. The foundation blocks and piers should have been erected on caissons and the construction work could have been carried out only gradually, in many parts, under the protection of sheet piles. All this would have meant higher costs and longer time for construction.

Locating the dam in the cut inside the river bend has brought with it simpler, cheaper and more rapid construction. An additional advantage is that all the works are located in a straight stretch. General arrangement is shown in *Fig.* 3. Foundation is laid on sand soil.

*The Tiszalök project* includes three movable gates of vertical-lift type with deeply located sills. Each distance between the piers is 37 m, giving a total free outlet of 111 m. Each gate is a skin plated steel framework with three girders supplied at the upper edge with a separate hinged-leaf plate. (System Dortmunder Union A. G.). The gates are 38,5 m long and 6 m high each. When raising hinged-leaf plate the total height of steel construction reaches 8 m.

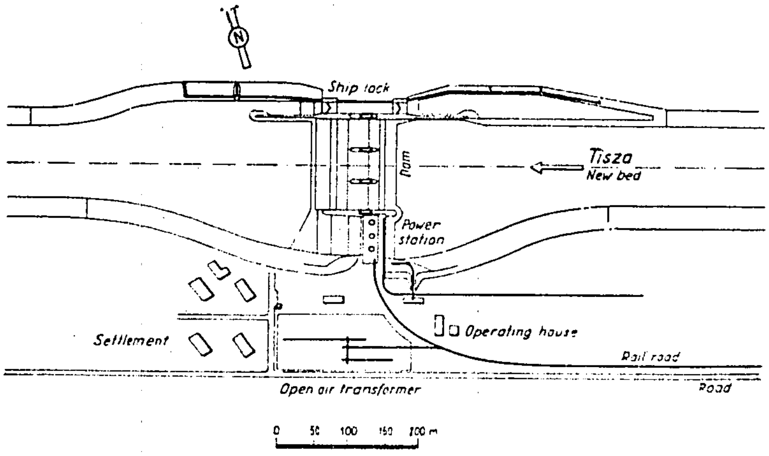


Figure 3.

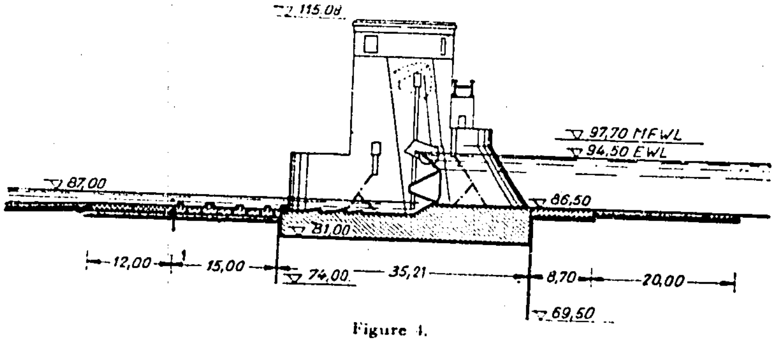


Figure 4.

To incresae seepage route, at the upstream face of dam a reinforced concrete apron has been constructed. In accordance with the results of scale model tests, following the dentated stilling basin, concrete blocks, stone filled rolls and farther off stone lining protect the bed. (Fig. 4.).

*The power station* will be furnished with three Kaplan turbines of 4,80 m in diameter with a maximum capacity of 100 $m^3$/sec each. Heads vary 0 to 7,5 m. *(Fig. 5.)* Overall capacity of the three units in the hydro-electric plant totals 12 000 kW.

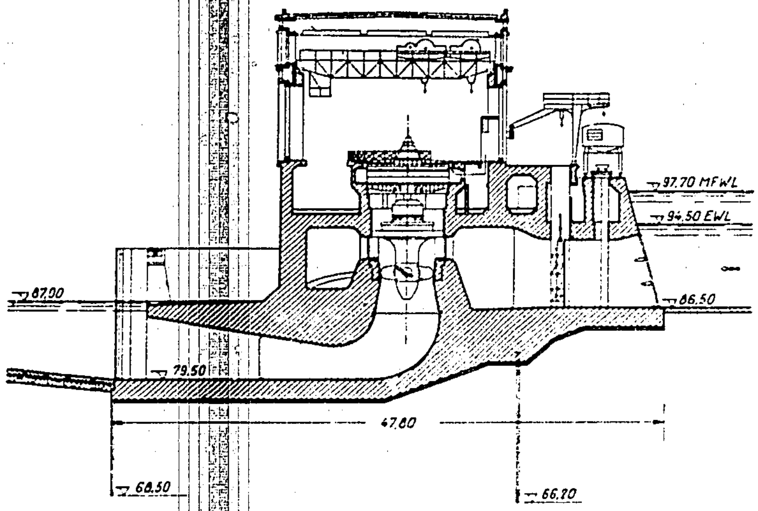


Figure 5.

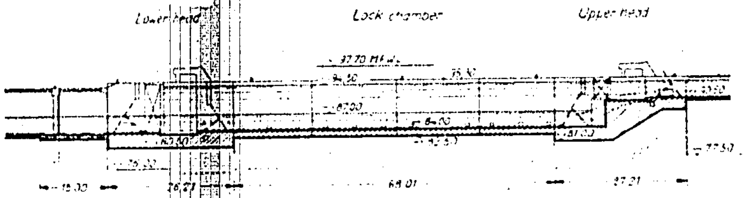


Figure 6.

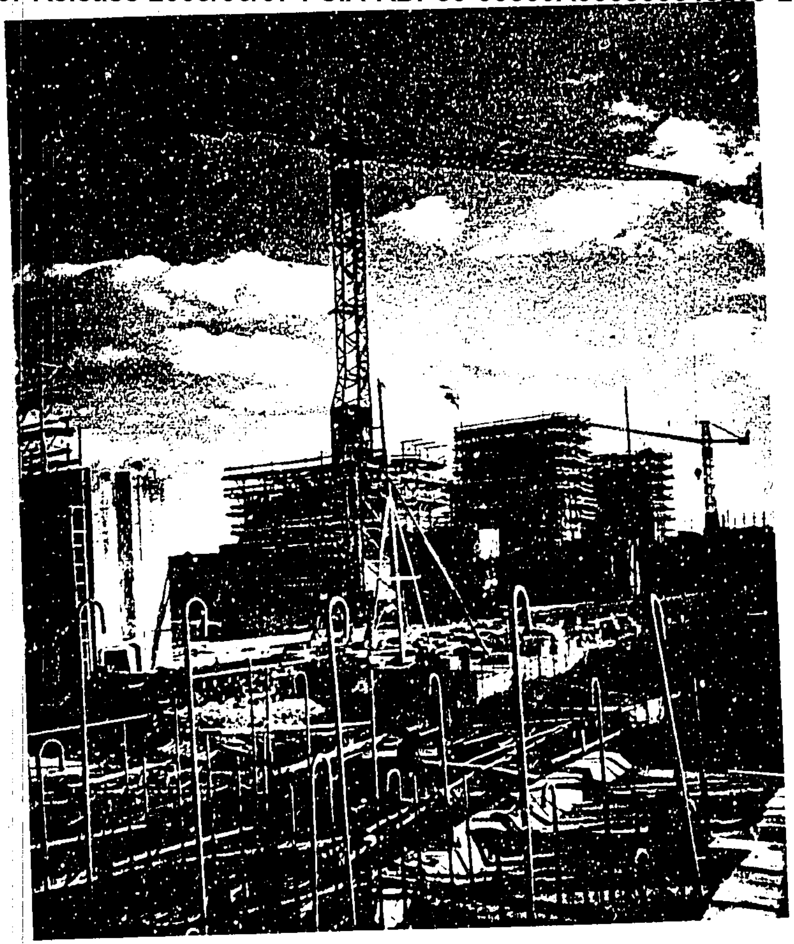


Photo 3. Tiszalok project under construction as viewed from tail-water direction

*The ship lock* will span a 85 m distance between the gates and its inside width will be 17 m. Even in case of minimum tailwater elevation a 3 m water depth is secured. With these measures the lock will be navigable to 1000 – 1200 ton barges and the Tisza steamers alike. *(Fig. 6.)*

### IV. Special Problems of Foundation in Constructing the Tiszalök Project

Despite many advantages of the Tiszalök dam site, one difficulty has not yet been overcome and that is : de-watering work site. Below and around the work site medium and small size sand strata are embedded in the ground at a depth which cannot be reached even by walls of sheet piles. The diameter of medium size sand varies 0.05 to 0.3 mm. while the larger grains can be found in the lower sub-stratum. Filtration coefficient varies $1.5 \cdot 10^{-5}$ cm sec to $1.5 \times 10^{-3}$ cm sec.

De-watering of the 20 000 $m^2$ work site was carried out by way of lowering ground water level. The deepest point of the basic concrete plate of the power station is 13 m below average ground water level. Two methods of lowering

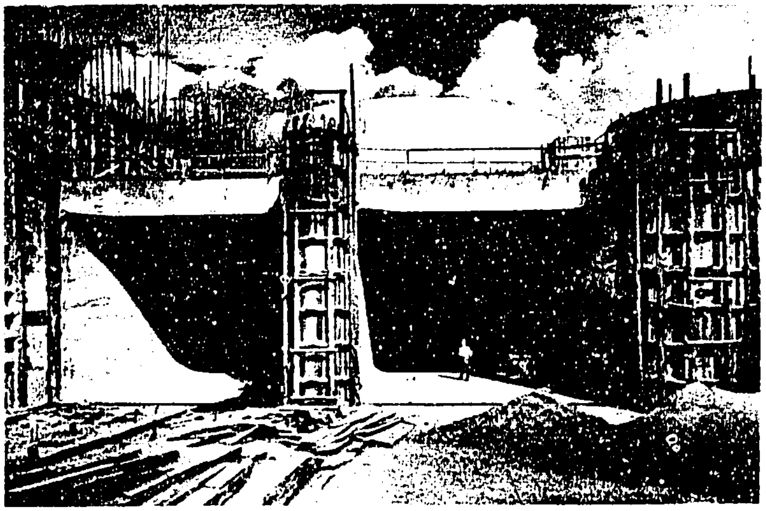


Photo 4. Hydro plant of the Tiszalök project. Outlet of reinforced concrete draft tube of one of the Kaplan turbines

groundwater level were taken into consideration *a)* drilling of few, low-bottom wells with a depth of 20—30m each. *b)* drilling of shallow wells on different ground elevations. The scientific evaluation of test pumping carried out at work site has proved the disadvantages of method *a)*, as wells penetrating deep into the subsoil of larger grains of sand would have largely increased discharge. Lowering ground water level by wells on different ground elevations appeared to be most suitable and the correctness of this assumption has been actually justified by the successful completion of work.

Lowering of ground water level has been carried out by drilling altogether 215 wells on three different ground levels gradually. Based on careful preliminary calculations the lowering system was designed for a discharge of 2,5 to 3,0 lit/sec with each well. In practice, however, maximum discharge for one well hardly exceeded 2 lit/sec, while average discharge was 1,5 lit/sec. In the course of foundation work in constructing the Tiszalök project, maximum lowering effect was achieved in August 1951 when the level of lowered ground water was 11,5 m below natural ground water level.

## V. Mechanic Equipment of the Tiszalök Project

Discharges on the Tisza are highly variable. Values vary 100 $m^3$/sec to 1500 $m^3$/sec in general but extreme floods of about 4000 $m^3$/sec have already been observed on the one hand, and discharge has more than once fallen to as low as 50 $m^3$/sec on the other. Head is equally varying from 0 to 7 m (exceptionally 7,5 m). In accordance with these conditions, installation of Kaplan turbines has been foreseen which, within wide limits of head, can be operated with the highest possible efficiency. Furthermore, considerations of economy and other have led to the requirement that, owing to the considerably low degree utilization (200-day duration : 300 $m^3$/sec), the units should provide the utilization of maximum possible water quantity and operation should cease at the lowest head only. With these requirements, so typical of Hungary's plainland rivers, the nearly 100-year-old Hungarian turbine manufacturing industry had to face an interesting and new task. Investigations and model tests have led to two noteworthy statements :

1. With rivers of little slope, where heads vary between wide limits, it is not expedient to strive at too high specific speed as it is essentially limited by operation required also at low heads on one hand, and by costs on the other, which would go up owing to increased foundation depth caused by decreased draft head. These costs would have largely exceeded savings arising from the installation of high speed units.

2. Great discharge required at very low heads calls for not only runners of great specific discharge but also for special draft tubes. Draft tubes are to be

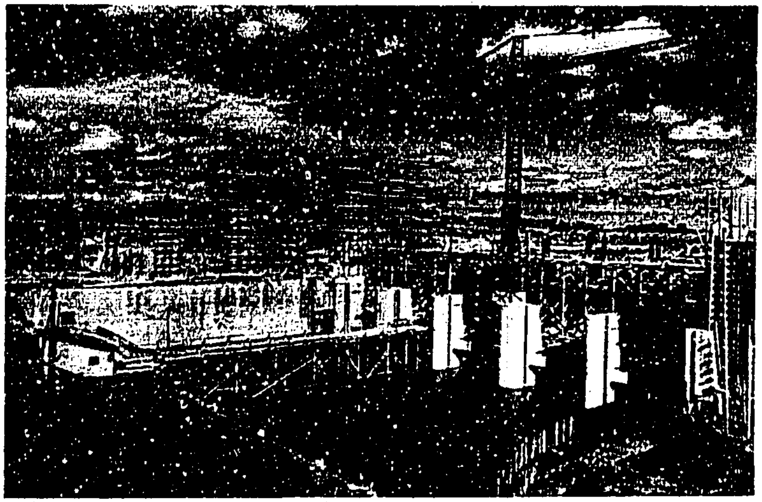


Photo 5. Hydro plant of Tiszalök as viewed from tail-water direction

designed within economic limits of size so, that energy conversion be performed with good efficiency even at the highest specific discharge.

Based on model tests directed mainly to designing draft tube and carried out with air in the Hydro-Mechanic Laboratory of the Budapest Technical University, the Hungarian industry (Ganz Turbine Works, Budapest) has initiated the construction of three Kaplan turbines. The construction of turbines is before completion and foundation and speed rings have been installed simultaneously with building power house.

Fundamental data of the turbines are as follows :

| | |
|---|---|
| Nominal output at a 4,8 m head ... | 4650 hp |
| Maximum output ................. | 6000 hp |
| Maximum discharge .............. | 100 $m^3$/sec |
| Speed........................... | 75 rpm. |

Arrangement of turbines is normal but certain special solutions deserve mentioning. The thrust bear is not mounted to the upper bearing bridge but directly to top plate. The advantages of this solution are well known : direct transfer of weight of the rotating parts to foundation through top plate and the columns of speed ring ; equalization of axial hydraulic thrust by water pressure

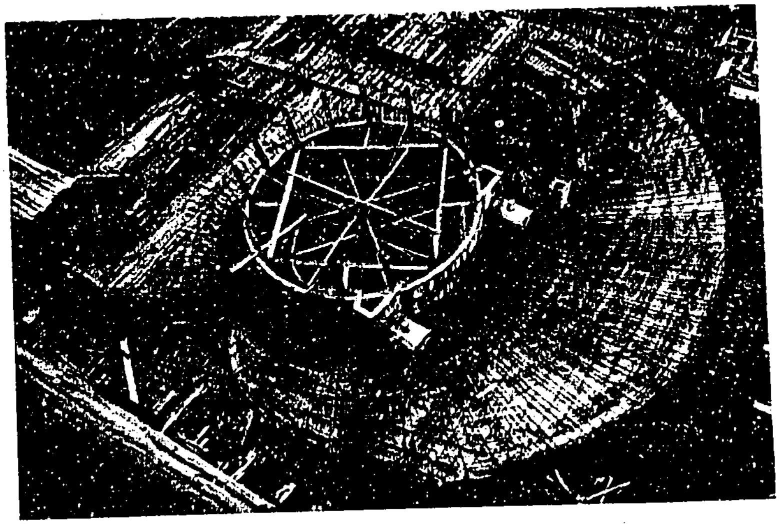


Photo 6. Reinforcement of spiral case, Tiszalök plant

to top plate through turbine shaft and thrust bearing: accessibility to thrust bearing. Further advantages: when dismounting generator for cleaning windings and air gaps, the dismounting of the rather sensible thrust bearing is unnecessary and last but not least the power house will be lower. Moderate regulating power due to proper types for runner blades and low head has made it possible to instal servo-motor in the rotor hub of generator. This solution has again further advantages, namely inside the generator-rotor sufficient space is at our disposal: extra size shaft coupling flanges are rendered unnecessary: the servo-motor is easily accessible without dismounting shaft because only the oil supply head is fixed above it. An additional advantage is that the turbine shaft could have been divided right inside the thrust bearing house so, that the upper flange of the lower shaft constitutes the thrust collar which, in this case, carries the rotating pivoted shoes of the self-lubricating thrust bearing.

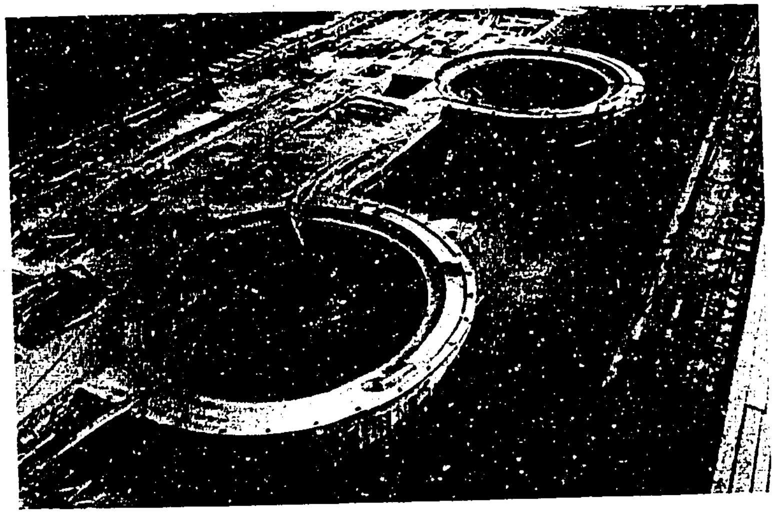
From the point of view of constructional solution the runner blades and guide vanes are to be mentioned. The four runner blades of the 4,8 m diameter runners have been specifically manufactured, i. e. an ordinary steel framework has been attached to the runner blade stem. The framework is covered by a properly shaped plating of special steel. By this method a light and smooth

Photo 7. Inside of spiral case, Tiszalök plant

plate has been obtained by using little special material. The guide vanes are 2,2 m high without stems and can be produced at a low cost. They are made completely of welded steel plates.

*The Tiszalök project* is to operate as a run-of-river plant in Hungary's energy system and therefore its task is to most efficiently utilize the discharge of the river. Owing to lack of higher pondage possibility the discharge of units must be in keeping with run-off. In our case this problem will be solved by an automatic device governed from head-water level with regard to highest efficiency in operation. To give protection against the 210 rpm runaway speed of the turbine a separate oil pressure system has been installed storing and supplying high pressure oil for the servo-motors. Adequate pressure cares for stopping the units in safety in case of runaway. The mechanism of the power station will be automatic and putting into operation will be carried out by press button system.

As to generators which are produced also by home industry we have to be satisfied with listing the most important data. It must be noted that contrary to general rule, owing to low speed, the exciter is not directly connected with the turbine unit but constitutes a separate electro-aggregate with a speed of 1460 rpm.



Phozo 8. Building of power house; supporting rings for generator, Tiszalök hydro-electric plant

*Generator data*

Connection Y, three-phase

| | |
|---|---|
| Nominal rating ............ | 5000 kVA |
| Tension .................. | 5250 V |
| Cycle .................... | 50 |
| Speed .................... | 75 rpm. |

As we have seen Hungary is far from being rich in hydro energy due to the exceedingly little slopes of its rivers. Therefore in the country's co-operating system the bulk of load will always be carried by thermo power plants while hydro plants will be able to participate not more than 10—12% in Hungary's overall capacity. It is obvious that hydro plants will continue to be of an auxiliary character and, due to highly variable hydrographical conditions, provisions are to be made for certain reserve plants as well. Yet water plants are of a great importance as far as economy in coal is concerned.

In conclusion several photographs illustrate phases of building process at the Tiszalök project described in this paper.

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Titulo 2
Assunto 2 1.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

GRISCOM (S.B.)
FERRAZ (O.M.)
Brasil

# THE ELECTRICAL PROBLEMS RESOLVED IN THE SYSTEM OF "CIA. HIDRO ELÉTRICA DO SÃO FRANCISCO"

By S. B. GRISCOM
Electric Utility Engineering — Westinghouse Electric Corporation, East — Pittsburg

and OCTAVIO MARCONDES FERRAZ
Technical Director — Stonemason Chief Foreman

BRAZILIAN NATIONAL COMMITTEE

As described in a companion paper, the Paulo Afonso Hydroelectric Station is located at a considerable distance from load and population centers. This situation is shown in Fig. 1. The two largest consuming centers are at Recife and Salvador, and it is expected that both initially and ultimately, the bulk of the power will be transmitted to those vicinities. However, there are many inland communities in need of low cost electric service. The area encompassed is very large, and many years must inevitably elapse before all the communities can be served. The initial steps involve bulk power service to Itabaiana and Angelim, whence subtransmission at 69 kv is being established to some of the larger communities in those districts.

The Paulo Afonso site is capable of 900,000 kilowatts ultimate capacity. The initial capacity is two 60,000 kilowatt hydroelectric generator units soon to be followed by a third. The initial non-coincident maximum loadings were estimated to be within the following figures:

| | |
|---|---|
| Recife | 25,000 kw (50 cycles) |
| Salvador | 20,000 kw |
| Itabaiana | 10,000 kw |
| Angelim | 10,000 kw |

## I. SELECTION OF TRANSMISSION VOLTAGE

The distances to Recife and Salvador are about 250 and 275 miles respectively. At these distances, the stable carrying capacity of transmission lines can be expected to be of the order of the "surge impedance" or "natural" loading. The realizable loading is influenced by factors such as the generator and transformer impedance, number of lines, number of line sectionalizing points, type of switching and relaying, synchronous condenser capacity, possible use of series capacitors, etc. Dependent upon those factors, the realizable loading for this distance might reasonably range from say 0.9 to 1.4 times surge impedance loading (SIL).

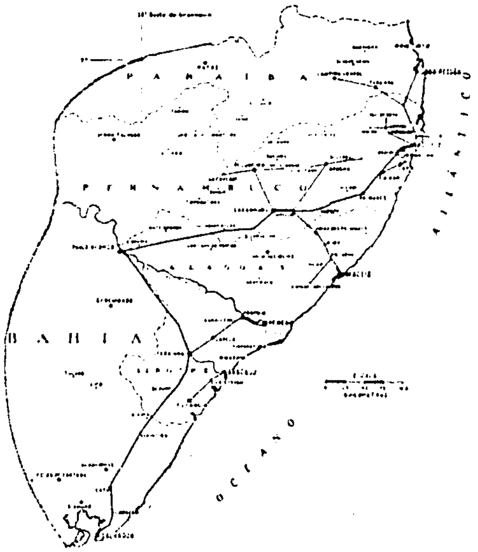

Fig. 1 — Geographic area served by the Paulo Afonso Project, and the routing of the transmission lines

Based on surge impedance loading, the carrying capacity per circuit at different operating voltage levels is as follows:

| *Operating Voltage* | *Load Capacity per circuit* |
|---|---|
| 138 kv | 48,000 kw |
| 161 kv | 65,000 kw |
| 230 kv | 132,000 kw |
| 287 kv | 198,000 kw |
| 330 kv | 272,000 kw |

This table shows that one 138 kv or 161 kv line each to Recife and Salvador would have been adequate for the first two or three generating units, but that additional circuits would have to be constructed as additional generating units were added. At the opposite end of the scale, two 330 kv circuits to each major load center would be adequate for the ultimate development, and probably most economic at that stage. However, the investment costs would be excessive for the initial development. This applies not only to the cost of the line, but also the extra cost of handling the high line charging kva.

It was considered that the initial transmission line installation must be capable of handling at least the maximum output of three generating units, or 200,000 kw. Further, that because of the uncertainty of the division of load between the two major receiving centers, it should be possible to transmit 2/3 this power over one line. Preliminary technical and economic studies had indicated 230 kv as the most suitable voltage.

## II. A-C CALCULATING BOARD STUDIES

To further establish the best transmission voltage and the receiver P. kva a study was made on the a-c Calculating Board. Some seventy individual power flow conditions were investigated. Fig. 2 is illustrative of one of the heavy load cases. The Recife line has a power input of 132,000 kw; the surge impedance loading. It will be observed that a total of 60,000 kva of synchronous condenser capacity is required at Recife, mostly to serve the R kva requirements of the load, since the R kva requirement of the line is practically zero at surge impedance loading.

Several essential facts for system engineering and equipment specification are ascertained from the data of Fig. 2 (supplemented by the other A-C Board Studies). These were:

1. The 230 kv level of operating voltage was necessary.
2. The initial Paulo Afonso generators could never be loaded to capacity at lower than 0.98 pf lagging (overexcited).
3. The generator step-up transformers should be wound for a low-tension voltage of 13,800 volts to best match the 13,800 volts generators. (13,200 volts is customary in most generating stations)

4. A maximum transformer tap (no load) of 225 kv would suffice (in conjunction with generator voltage control) to maintain a generating station bus voltage level in the zone of 220 to 240 kv, because of the high power factor operation.
5. With the conventional 10% tap range, the lowest tap could be made 202 kv which would be a decided asset in the initial operating period when only two generators were installed and one generator might occasionally be unavailable for service.
6. Complete data was afforded for selection of taps on the receiving 230 kv transformers, and the various transformers on the 66 kv subtransmission net. Data were made available for future use regarding synchronous condenser capacity for various loadings. This data is primarily for future system planning and is not of sufficient general interest to present here.

## III. LINE CHARGING REQUIREMENTS

The theoretical line charging kva at rated voltage of the lines is as follows:

| | |
|---|---|
| 230 kv Paulo Afonso – Recife .... | 65,000 kva |
| 230 kv Paulo Afonso – Salvador ... | 71,000 kva |
| Total ........ | 136,000 kva |

The total exceeds the initial generator capacity at Paulo Afonso.

Conventional calculations neglect the additional length of conductors due to sag and additional capacitances due to proximity effects of towers, etc. Experience has shown that the measured charging current frequently exceeds the calculated values. The ability to safely handle the charging kva of the long lines was considered an essential point of system design. In order to be on the safe side, the theoretical charging kva was arbitrarily increased by 7%, when determining the characteristics of the equipment for handling the lines. That is, the total charging kva of the lines to Recife and Salvador was taken as 145,000 kva at 230 kv. Calculations indicated that the charging kva of the 69 kv lines just about equalled the total transformer magnetizing kva.

## IV. THE LINE HANDLING PROBLEM

The initial development consisting of only two generators at Paulo Afonso, it was deemed prudent to base the system design on the contingency that one generator might be out of service from one cause or another (electrical, hydraulic, mechanical, control, or auxiliary trouble or maintenance). Unless the system were designed on that basis, if one generator were out of service, it would be necessary to disconnect one line and thereby interrupt service to either Recife or Salvador.

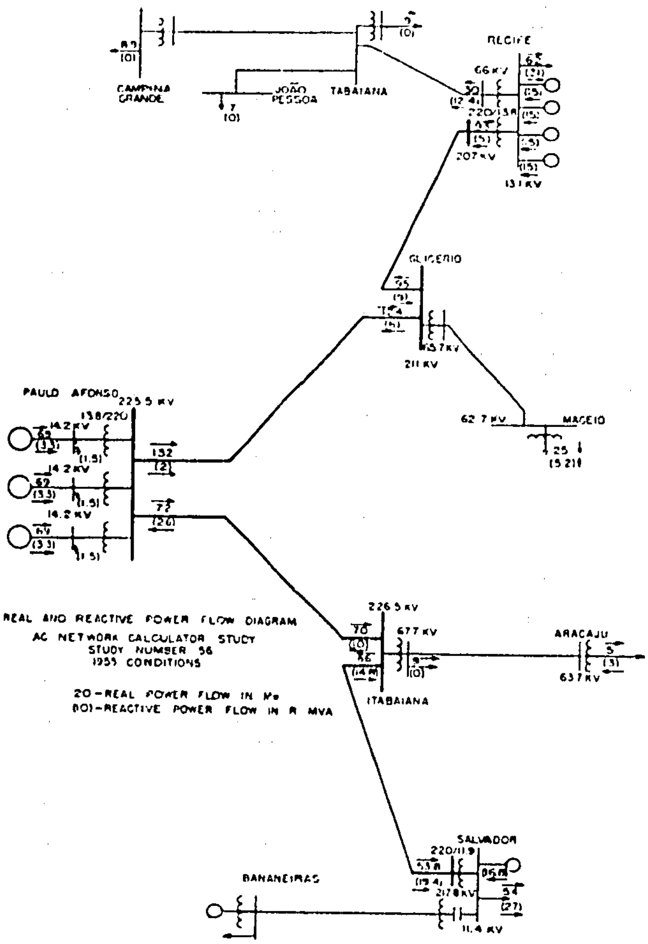

Fig. 2 — Load flow diagram of system in early stages showing voltage levels and reactive correction required

Therefore, the sum total of the line charging ability of one Paulo Afonso generator plus all other equipment must at least equal the line charging kva. This condition was met by the following equipment line charging abilities:

| | *Line Charging Ability* |
|---|---|
| 1 – Paulo Afonso Generator ........... | 96,000 kva |
| 2 – Recife Frequency Changer Motors .. | 22,500 kva |
| 2 – Recife Shunt Reactors ...... ..... | 10,000 kva |
| 1 – Salvador Synchronous Condenser ... | 10,000 kva |
| 2 – Salvador Shunt Reactors ........... | 10,000 kva |
| Total ............... | 148,500 kva |

This is slightly more than the line charging requirements, on the conservative basis stated earlier.

Merely providing the line charging requirements did not necessarily insure stable operation inasmuch as the reactive kva was being supplied from both ends of long transmission lines. There was the possibility of dynamic instability because of the long connecting lines, and all synchronous machines being operated at practically zero field excitation.

To verify this situation, the system was set up in miniature, using rotating synchronous machines, and the necessary resistances, reactances, and capacitances to simulate the lines on a scale proportionately. The scale was set by assigning a kva rating to the synchronous machine such that their synchronous reactance equalled that of the actual machines they were to simulate. The transient reactance was made to suit by adding external reactance if the miniature machine reactance was too low, or by subtracting some reactance from the lines and transformers if it was too low. Inertias were approximated by means of the various flywheel combinations available. The machines actually used in the test were of the salient pole type, and had a continuous capacity of 100 kva.

A set-up of this kind brings in the dynamics of the actual system with respect to power transfer between machines, their inertias, and their field time constants. In this instance, the field time constants were shorter than those of the actual machines, hence the results are conservative.

Voltage regulators for the synchronous machines were not available for these tests. While certain types of voltage regulators promise improvements in dynamic stability, it was deemed prudent to base the system design on hand control.

Fig. 3 shows the set-up of the miniature system.

Fig. 4 shows the results of one series of tests. Here, the capacitance kva, was varied as a percentage of the total available line charging kva. The Salvador line was connected, but the synchronous condenser was off, and there was no load at Salvador. The 100% charging kva point is the point where each synchronous machine is operating at its full line charging ability (zero field excitation), with no load delivered by the Recife frequency changers. To get the pull-out load for the frequency changer, a small load increment was applied. (In the actual set up, the "frequency changer" was a synchronous to d-c motor generator set, and the load on the d-c generator was controlled by excitation control of the d-c generator.) The voltages would thereupon drop slightly. The field excitations of each machine were then increased to restore normal voltage. Additional small load increments and excitation increases were applied until the "frequency changer" pulled out of synchronism. A similar procedure was used for lesser amount of capacitance kva, resulting in the curve of Fig. 4.

Fig. 4 may be used in a variety of ways. Two examples will be used.

Case 1. Assume the two 61,000 kva generators have line charging abilities to 61,000 kva each or 122,000 kva total. In accordance with USA practices, they would have an SCR of 1.25 to attain this ability. The Recife frequency changers and shunt reactors having combined line charging abilities of 32,500 kva, the total line charging ability would be

Fig. 3 — View of the miniature replica system used to investigate the effect of charging kva on steady state power limits

154,500 kva. With 145,000 kva actual requirements, the percentage to be used in Fig. 4 is $145/154.5 \times 100 = 94$. The frequency changers would therefore pull out of step if loaded to 10,000 kw — less than half their combined ratings.

Case II. Assume the two 61,000 kva generators have line charging abilities (short time) of 96,000 kva each, or 192,000 kva total. (SCR of 1.98) With the Recife ability of 32,500 kva, the total line charging ability is 224,500 kva. The requirement of 145,000 kva is 65%. From Fig. 4 the Recife frequency changers would pull out at 17,000 kw.

Certain other specific cases, all with no load at Salvador, were examined.

SCR = 1.25

| *Case* | | | *Pull-out load of Recife Frequency Changers* |
|---|---|---|---|
| III | 1 | Generator at P.A. no condenser at Salvador ........ | Inoperable due to overvoltage |
| IV | 2 | Generators at P.A. no condenser at Salvador .. ...... | 16,000 kw |
| V | 2 | Generators at P.A. 20,000 kva condenser at Salvador | 37,000 kw |

SCR = 1.98

| | | | |
|---|---|---|---|
| VI | 1 | Generator at P.A. no condenser at Salvador ........ | 31,000 kw |
| VII | 2 | Generators at P.A. no condenser at Salvador ........ | 50,000 kw |
| VIII | 2 | Generators at P.A. 20,000 kva condenser at Salvador | 52,000 kw |

Case III confirmed previous analyses that the Salvador line would have to be disconnected under these circumstances.

The other cases demonstrate that, having provided sufficient line charging ability in the Paulo Afonso generators, to operate with one generator out of service, a very valuable corollary was obtained. If both Paulo Afonso Generators were available for service, then any one other machine could be out of service, and electricity supply could still be made available over both lines. (Note: The Salvador condenser being larger than the Recife frequency changer motors, it was deduced that the loss of one frequency changer would be less serious, system-wise, than the loss of the Salvador condenser.)

## V. THE LINE SWITCHING PROBLEM

The previously discussed analyses show how the line charging problem was met. The line switching problem was still formidable. Lack of space precludes a full presentation of all the work which was done in connection with energizing a line.

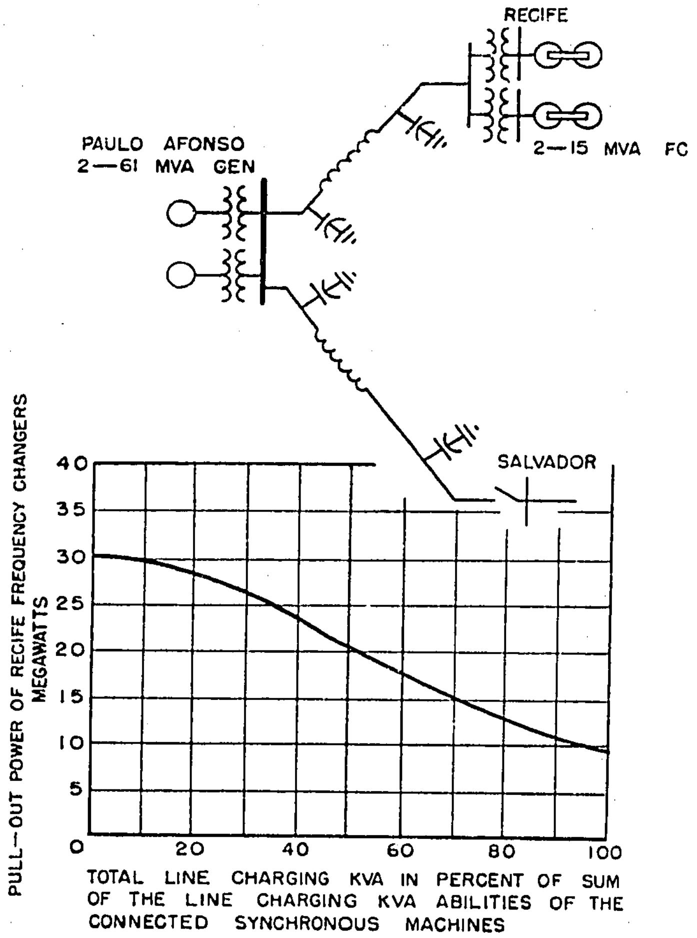

Fig. 4 — Steady-state pull out loads of Recife frequency changers as affected by total system charging kva

Each major load area is served by a single 230 kv line. When that line is tripped due to a fault, service is temporarily interrupted. The temporary interruption is tolerable. The problem is: How can the line be re-energized?

The following table shows the calculated voltages for several combinations of conditions when re-energizing the line to Salvador. In each case, it was assumed that the voltage of the Paulo Afonso generator was controlled by the automatic voltage regulator, and was operating at 12 kv terminal voltage (87% of normal) just prior to closing the high tension breaker to the Salvador line.

| | *Condition* | *Maximum RMS Voltage at Salvador* |
|---|---|---|
| a. | One PA generator, line open except for stepdown transformers ...................................... | 400 kv |
| b. | One PA generator, two 5000 kva shunt reactors at Salvador ...................................... | 325 kv |
| c. | Two PA generators, line open except for step-down transformers ...................................... | 285 kv |
| d. | Two PA generators, two 5000 kva shunt reactors | 240 kv |

The voltage values listed were calculated based on the voltage rise due to transient reactance plus a slight further rise due to alternator field flux increase until the voltage regulator obtains control.

The saturation effects of the transformers and reactors were not included in the calculations. If consideration is given to saturation, the calculated rms voltages would have been somewhat less. However, in other studies made with the Analog Computer of iron saturation in the presence of capacitance, it has been found that saturation greatly distorts the voltage wave form such that the crest voltage may be as much as 2.0 times the rms rather than 1.41 times for a sine wave. The voltages are therefore very dangerous and apt to cause failure of apparatus insulation.

If both PA generators were available for service, the situation could be readily met by allocating one generator to the Recife line and using the other generator for energizing (at reduced generator terminal voltage) the Salvador line. This procedure, while minimizing disturbances, postulates the continuous availability of both Paulo Afonso generators. A high availability of generating capacity can be foreseen, but the possibility of a generator being out of service could not be ignored. Consequently, means were sought to permit re-energization of either the Recife or Salvador line, even though only one Paulo Afonso generator was available for service.

This problem was solved by using the receiver synchronous machine (a frequency changer at Recife or the condenser at Salvador) at standstill, as a shunt reactor. This effect is achieved by connecting the machine across the low voltage receiver bus (without reduced voltage taps) before closing the transmission line breaker at Paulo Afonso. The machine therefore presents its "locked rotor impedance" substantially the sub-transient reactance, as a shunt reactor.

The equivalent size of shunt reactor afforded is as follows:

| | |
|---|---|
| 1 — Salvador Condenser ....... | 80,000 kva. |
| 1 — Recife Frequency Changer . | 75,000 kva. |

This procedure of connecting a standstill (or slowly rotating machine) is very effective in neutralizing the line charging kva. Actually, the machines give somewhat more compensation than needed, so that there is a voltage drop along the transmission line. This is actually desirable in that it minimizes the mechanical stresses on the windings by reducing the inrush current.

The actual voltage across the machine terminals is between 50 and 65% of rated voltage. The effect of the combination of the line and connected machine, as reflected at the sending end of the line is a load of about 13,000 kw, at practically unity power factor. The initial effect on the bus voltage at Paulo Afonso is therefore very small. There may be a slight rise, or a slight drop, depending upon the particular circumstances. This is in marked contrast to the sudden and large rise of voltage which would ensue upon energizing an open-circuited line.

It is possible to calculate fairly accurately the changes in voltages at Paulo Afonso and Salvador as the synchronous condenser comes up to speed. However, such calculations are quite complex, since they require a step-by-step process. Fig. 5 shows the approximate manner in which the Salvador condenser currents and voltages' are expected to vary during a full voltage start, from standstill. These curves are based on calculations for the initial and final conditions, with approximations of the effects due to the rotational inertia and field time constants of the condenser.

It will be observed that from standstill to pull in of the condenser, that the current and voltage change gradually, so that the voltage regulator on the Paulo Afonso generator can readily follow the changes. After the condenser pulls into synchronism, the condenser current drops off at a more rapid rate, due to rapid magnetization of the machine. Some slight temporary overshoot in voltage might occur, dependent upon the number of lines, generators and receiver equipment in service.

At the end of the time period depicted by Fig. 5, the condenser will be operating without field excitation. The machine will have pulled into step at random with respect to the field poles. Therefore, applying a given polarity of field excitation might either raise or lower the voltage. With one polarity of excitation, the automatic voltage regulator will work properly. With the other polarity of excitation, an increase of excitation will reduce the voltage, thus calling for more excitation. With the negative or wrong excitation polarity, the excitation current would be increased by voltage regulator action until the condenser slipped poles, at which time it would be positive excitation, and the terminal voltage would go considerably above normal, with violent oscillations in phase position.

To prevent this situation, a polarity determining device was provided to apply excitation of the proper polarity.

## VI. SPECIAL PROTECTIVE FEATURES

The electrical systems at the receiver ends of the system have very small amounts of synchronous machine capacity. As a consequence, they are completely inadequate to charge their respective transmission lines. Should the supply breaker open at Paulo Afonso with the receiving equipment connected, destructive overvoltages would be likely.

To guard against this possibility the line protection relays are arranged so that the tripping impulse is given to the receiving end breaker first, the tripping of the Paulo Afonso line breakers being delayed slightly. Also, the control of the Paulo Afonso line breakers are arranged so that if a line is tripped manually by the operator, the receiver end breakers are tripped first.

Further safety features are provided by overvoltage relays at all of the stations. These relays are for back-up purposes, in the event that the normal protective devices do not function for some reason. For example, should a receiver breaker be opened accidentally, there is no ideal way of detecting that fact. The generator frequency will increase, and with it the voltage. With the system otherwise operating normally, overvoltage relays is a satisfactory means of protection.

## VII. INSULATION LEVELS AND GROUNDING

The question of insulation levels for the 230 kv transformers and circuit breakers required careful consideration in view of the possibilities of dynamic overvoltages due to the long lines being handled. Electrical equipment is designed to operate at 105% of rated voltage continuously, and it is recognized that during switching, sudden loss of load, no-load operation and the like, the voltage of the system may rise temporarily above its rated voltage. No specific provision for these contingencies is provided in equipment designs. However, it is evident that designing a system which might have frequent and considerable overvoltages would be courting apparatus failure, or else a high level of apparatus insulation would have to be selected.

The philosophy adopted was to lay out the system so that overvoltages could be minimized, thereby allowing the use of normal apparatus insulation levels. So doing allowed a choice between the 196/230 Kv class and the full 230 kv class having, for transformers 60 cycle tests of 395 kv and 460 kv, and impulse tests of 900 and 1050 kv respectively.

The use of the 196/230 kv class is dependent on the system being effectively grounded, and the apparatus being protected to an impulse level below 900 kv. These provisions were met by the use of delta-wye transformers at all locations, the 230 kv windings being wye connected in each case, and solidly grounded. Lightning arresters rated at 195 kv afforded the necessary impulse protection.

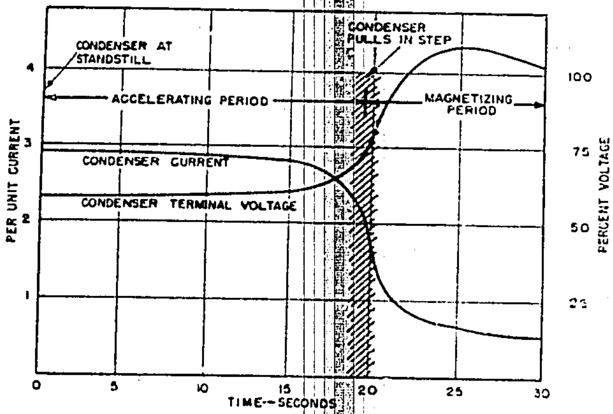

Fig. 5 — Calculated approximate terminal voltage and current in Salvador condenser during an across-the-line starting operation

As a consequence of the wye connection on the 230 kv side at Recife and Salvador, and the further requirement that the low side had to provide a ground current source, three-winding wye-delta-wye transformers were used. At Itabaiana and Glicerio the 66 kv side was delta, and zig-zag grounding banks were provided to ground the 66 kv system.

## VIII. STABILITY

Since there is only one line to each load area, a fault on that line interrupts service temporarily. Under these circumstances, there is no stability problem in the usual sense. However, additional transmission lines will be built as required by load demands, and at such time, it is anticipated that a faulted line section must be switched out without loss of stability to the system.

This requires high speed circuit breakers and relaying. The breakers are of 196/230 kv 3,500,000 kva rating and have a clearing time of 3 cycles (0.05 seconds). Carrier relaying is used to give rapid discrimination. In the initial phases of operation, the high speed relaying and tripping is advantageously used in a transfer tripping scheme to trip the receiver breakers ahead of the sending breakers to avoid overvoltages.

## IX. OPERATIONAL PROBLEMS

[illegible]

During the first few years of operation, the amount of synchronous machine line charging ability relative to line charging requirements is much smaller than on most systems. As additional generators are installed, the situation improves rapidly. In the meanwhile it is necessary that the system be operated very carefully to avoid dangerously high overvoltages. Based on engineering calculation, the operating personnel have received instructions as to the procedure to be followed when energizing the lines with various combinations of machines available.

Since initially there is but one transmission line in each direction, line tripouts will cause power interruptions. Following a line tripout, if both Paulo Afonso generators are in service, one machine may be temporarily disconnected from the system, and used to re-energize the line, and then re-synchronized with the system. If only one generator is in service, the tripped line must be re-energized with a synchronous machine connected to the receiver end.

Two 5000 kva shunt reactors were provided for each receiving substation. These were found by the A-C Calculating Board studies to be desirable for light load operation. Without them, the generator voltage would have to be lower than desirable, or the receiver voltage higher than desirable at light load. This situation could also have been corrected by the use of on load tap-changers. However, the extra line-charging ability obtained from the shunt reactors is of considerable value when the synchronous machines are out of service.

## CONCLUSIONS

1. The initial operations of the Paulo Afonso project required the handling of long transmission lines with relatively small amounts generating capacity. A-C Calculating Board studies indicated that the initial operation should be at about the design line voltage of 230 kv.

2. The system was designed on the premise that it must be operable with any one synchronous machine out of service. This required the ability to charge the lines with only one Paulo Afonso generator. The generators were designed to have a short circuit ratio of about 2.0 to make this possible.

3. A miniature replica of the system was set up using 100 kva machines. Based on generators of SCR = 2.0, the successful operation of the system was verified with one Paulo Afonso generator in service.

4. Re-energizing a tripped open-circuited line would cause dangerous overvoltages. To permit such re-energization, the receiver synchronous

machines are arranged for across-the-line starting. Their "locked rotor" reactance provides the equivalent of a large shunt reactor for a time sufficient for the voltages to be stabilized.

5. By providing means to minimize dynamic overvoltages, effectively grounding the system, and providing adequate impulse voltage protection, apparatus of the 196/230 kv class was possible, at a considerable saving in cost.

6. Close coordination between engineering and operation is necessary in the initial phases of operation.

## Summary

As a result of careful and thorough analysis of system requirements, the equipment installed at the Paulo Afonso generating station and main receiver substations will be adequate to supply the initial and future load conditions as planned for by the Cia. Hidro Elétrica do São Francisco.

This paper summarizes considerations given to the various technical features of the electrical design in the selection of the basic characteristics of the system and apparatus. AC Calculator Board studies proved that the use of line voltage of 230 KV would enable satisfactory operation with transformers using standard range of taps, not only for the initial operation but also for the future anticipated loads. In this type of system where kilowatts required for line charging are very large in comparison with the connected synchronous capacity, the initial operation condition is most critical. A study of the dynamics of the system on a miniature replica established the fact that generators of a short circuit ratio of 1.98 would have the desired characteristics in connection with all operating conditions to be encountered including the initial light loadings. Adequate voltage control is provided by synchronous equipment with automatic voltage regulators at the main receiving stepdown substations at Recife and Salvador. In order to simplify system operation these receiver synchronous machines are arranged for across the line starting as well as conventional low voltage starting. A brief description of the system grounding and special features which have been incorporated to safeguard system operation is also included.

## Résumé

Come résultat d'une analyse complète des nécessités du système, l'équipement installé à la centrale de Paulo Afonso et aux principales stations d'arrivée de l'énergie pourra répondre aux conditions de charge initiales et futures prévues par la Compagnie Hydroélectrique du São Francisco.

Cette monographie résume les attentions données aux différents aspects techniques du projet pour le choix des caractéristiques fondamentales du système et de son appareillage. Les études au tableau calculateur du courant alternatif ont démontré que l'usage d'un voltage de

ligne de 230 kV permettrait un fonctionnement satisfaisant avec des transformateurs à bornes standardisées, non seulement pour l'étape initiale mais aussi pour les charges futures prévues. Dans ce genre de système où les kilowatts exigés pour la charge de ligne ont une valeur très grande en comparaison avec la capacité synchrone branchée, la condition de l'opération initiale est des plus critiques. Une étude de la dynamique du système sur modèle réduit a montré que des générateurs d'un rapport de court-circuit égal à 1.98 présenterait les caractéristiques voulues par rapport à toutes les conditions d'opération qui devront se vérifier, y compris les charges initiales d'illumination. Un contrôle convenable de voltage est fourni par un équipement synchrone muni de régulateurs automatiques de voltage aux principales stations d'arrivée pour l'abaissement de voltage à Recife et Salvador. Afin de simplifier l'opération du système, ces machines synchrones réceptrices sont aménagées à travers le point de la ligne et celui du bas voltage convenu. La monographie contient aussi une courte description de la terre du système et des précautions spéciales qui ont été prises pour sauvegarder l'opération da système.

## RESUMO

Como resultado duma análise completa das necessidades do sistema, o equipamento instalado na central de Paulo Afonso e nas principais subestações poderá satisfazer às condições de carga iniciais e futuras previstas pela Companhia Hidro-Elétrica do São Francisco.

Essa monografia resume as observações feitas sôbre os vários aspectos técnicos do projeto para a escolha das características fundamentais do sistema e de sua aparelhagem. Os estudos no quadro calculador da corrente alternada demonstraram que o emprêgo duma voltagem de linha de 230 kV permitiria um funcionamento satisfatório de transformadores com bornes padrões de ligação, não só para a etapa inicial como para as cargas futuras previstas. Nesse gênero de sistema, no qual os quilovoltes necessários para a carga de linha têm um valor elevado em comparação com a capacidade sincrônica conectada, a condição da operação inicial é das mais críticas. Um estudo da dinâmica do sistema baseado no modêlo reduzido mostrou que geradores duma relação de curto-circuito igual a 1.98 apresentariam as características desejadas em relação a tôdas as condições de operação que deverão se verificar, incluindo-se as cargas iniciais de iluminação. Um contrôle conveniente de voltagem é fornecido por um equipamento sincrônico, munido de reguladores automáticos de voltagem nas principais subestações para o abaixamento de voltagem em Recife e Salvador. A fim de simplificar a operação do sistema, essas máquinas sincrônicas receptoras são ordenadas através do ponto inicial da linha e o da baixa voltagem convencionada. A monografia contém, ainda, uma rápida descrição do sistema de terra e das precauções especiais que foram tomadas para salvaguardar a operação do sistema.

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# SOME TECHNICAL AND ECONOMIC ASPECTS OF POWER TRANSMISSION IN BRAZIL

By Ing. F. P. DE MELLO

BRAZILIAN NATIONAL COMMITTEE

The problem of long distance power transmission will be encountered with increasing frequency in Brazil where the rapid growth of some regions creates a market for power which could be supplied from far away sites across vast tracts of relatively undeveloped land. Bulk power transmission across distances of a few hundred miles with no intermediate generation is one of the problems facing the transmission engineer who must strive to make such transmission economically and technically feasible.

This paper presents some technical and economic aspects of such transmission with particular reference to conditions in Brazil. The general philosophy of transmission design is discussed, based on particular problems which have been worked out. To limit the scope of this paper the discussion centers around a transmission distance of 200 miles which is more likely to be encountered than the longer distances. The basic approach to the problem however would be the same regardless of distance, the only difference being in the relative economic weight of the various factors.

## DESIGN CRITERIA

The transmission System with which we shall concern ourselves is one that links a remote power site to a metropolitan power system. The power received by such a metropolitan system from the remote plant represents a substantial fraction of the system capacity and hence the reliability of the supply has to be high.

The design of a transmission system is based on maintaining a certain degree of reliability in the continuity of supply. The classical design is the one that provides for stability through the most severe disturbances likely to be encountered, such as a 3 phase to ground or a 2 phase to ground fault on one circuit near the sending end bus. Fault durations of 4 cycles are assumed (1 cycle relay time and 3 cycles breaker time).

The conventional methods of achieving reliability in transmission by use of intermediate switching stations and series compensation have been well described in recent literature. The effects of low sending and receiving end reactances as well as of increased inertia of the sending end generators have also received due consideration. Each of these methods of improving the stability of transmission is limited and can be applied insofar as practical economic considerations permit. The possibilities of using a shunt braking resistor at the sending end, to be switched on immediately after the occurrence of a fault, are also considered as a supplementary means of maintaining stability. As will be shown, such a scheme makes possible some economies in transmission plant. The efforts towards making a transmission system stable, so far, have been mainly in the direction of smaller fault clearing times and greater post-fault synchronizing ability between the two ends. The direct results of these design measures have been (a) the reduction of the disturbing influence to a manimum by cutting down the time of fault duration and (b) the increase in the natural restoring synchronizing forces which, after clearing of the fault, would restore the sending end rotors to relative equilibrium with the receiving end. This latter effect is obtained through the reduction of the through impedance with series capacitor compensation, and by shortening, with the use of intermediate switching stations, the line sections which may tripout. Both these measures (a and b) can be used within limits.

The philosophy behind the use of shunt braking resistors is sound inasmuch as the switching on of the braking resistor is a shock treatment with exactly opposite effects to those caused by the fault. A fault causes a loss in electrical output of the sending end generators whose rotors are given accelerations proportional to the amounts of power lost. The braking resistor loads these generators and converts back into heat the excess energy stored in the rotor inertias helping them back into equilibrium with the receiving end. Basically the shunt resistor method of improving ability is a direct antidote to the cause of instability. These shunt resistors can be three phase water resistors for direct connection to the sending end high tension bus through a high speed breaker. The switching on of these resistors could be made within 6 cycles after occurrence of the fault by an instantaneous impedance relay calibrated to close on faults severe enough to warrant the stabilizing action of the braking resistors. The mechanism of the breaker controlling the braking resistor would have to be designed for close-open operation with an "on" interval of a required number of cycles. As will be shown this interval should be long enough to maintain stability on the most severe faults, without being detrimental to stability, due to overbraking, on the less severe faults.

The classical design permits the system to ride through a fault followed by the outage of a line section. High speed reclosing should not be considered in this case for the following reasons:

a) — reclosing is not by itself a measure which improves materially the stability limit of a transmission system because of the dead time limitations of 12 or more cycles after the fault period, during which time the restoring forces should play the greatest part in order to maintain stability.

b) — The possibility of the fault persisting is always present and, should this happen, rapid reclosure would reapply the fault and endanger stability rather than help it.

Frequently less severe design criteria are considered satisfactory. In view of the great reliability of modern transmission lines of 230 Kv and higher, which exhibit performance characteristics approaching the ideal lightning proof line, it is often considered acceptable to have a one circuit transmission system accepting the risk of generation loss in case of a fault on the line. For these cases a braking resistor at the sending end could be used to advantage together with high speed reclosing thereby avoiding the loss of the sending end plant except in those relatively rare cases where the fault is permanent.

## ANALYSIS AND COSTS OF 200 MILE TRANSMISSION

The following specific examples are used to illustrate transmission schemes and compare costs. They will establish the order of magnitude of the factors involved and give an idea of the economics of typical transmission schemes.

Let us examine the possibilities of transmitting 400 MW from a Power Plant to a Metropolitan System 200 miles distant using the classical design which permits operation with a line section out of service. The following assumptions are made:

1) — Generator transient reactance = 0.30 per unit on 400 MVA base.

2) — Sending end transformer reactance = 0.10 per unit on 400 MVA base.

3) — Generator inertia constant Hg = 3.0 on 400 MVA base.

4) — 230 Kv lines of 795 000 cm or 1113 000 cm ACSR with 31-1/2 ft. horizontal spacing or 287 Kv lines with 512 000 cm. hollow copper type HH with 32-1/2 ft. horizontal spacing.

5) — Receiving end consists of a 230 Kv network with a reactance = 0.20 per unit on 400 MVA base.

6) — Receiving end equivalent inertia Hm = 12.0 on 400 MVA base.

7) — For the case of 287 Kv transmission the additional reactance corresponding to 287/230 Kv auto-transformation at the receiving end = 0.08 per unit on 400 MVA base.

8) — Under normal conditions a 5% voltage drop is assumed between sending and receiving ends.

The first step would be to determine what arrangements are feasible to guarantee a steady state stability limit above the amount of power to be transmitted, considering one element of the line out of service due to a fault.

The following were the values obtained as steady state limits for various arrangements:

| | Maximum power received in per unit |
|---|---|
| 1) — Two 230 Kv circuits, normal (unity) short circuit ratio of sending end generators ..... | 1.08 |
| 2) — One 230 Kv circuit normal SCR .................... | 0.64 |
| 3) — Two 230 Kv circuits SCR 50% higher than normal ... | 1.15 |
| 4) — One 230 Kv circuit SCR 50% higher than normal .... | 0.67 |
| 5) — Two 230 Kv circuits normal SCR with one intermediate switching station and one line section out .............. | 0.89 |
| 6) — 2 x 230 Kv circuits, normal SCR, one switching station, 50% series capacitor compensation ................. | 1.35 |
| 7) — 2 x 230 Kv circuits, normal SCR, one switching station 50% series capacitor compensation, one line section out. | 1.05 |

| | |
|---|---|
| 8) — 3 x 230 Kv circuits, normal SCR .................... | 1.14 |
| 9) — 2 x 287 Kv circuits, normal SCR .................... | 1.39 |
| 10) — 1 x 287 Kv circuits, normal SCR .................... | 0.90 |

From steady state considerations alone and making allowances for the possibility of a line section outage, the following arrangements would have been possible, to give minimum requirements.

a) — 2 circuits of 230 Kv with one intermediate switching station and 50% series capacitor compensation.
b) — 3 circuits of 230 Kv with no series capacitor compensation.
c) — 2 circuits of 287 Kv with one intermediate switching station and no series capacitor compensation.

The second step is to examine the minimum requirements which would guarantee the stability of transmission following the tripout of a line section caused by a severe fault. An easy way of examining these requirements is through power angle curves and use of the equal area criterion.

Fig. 1 shows curves of the combined torque angle characteristics of sending and receiving end $\left( \frac{T1}{H1} - \frac{T2}{H2} \right)$ for the transmission arrangement described in (a). It is evident that with one switching station, any fault, no matter how light, which results in the tripout of a line section, causes loss of synchronism. With two switching stations 66.7 miles apart, and with 50% series capacitor compensation distributed between the two stations a line section outage is not so critical. However, severe faults like a $3\phi$ or a $2\phi$ — gnd fault near the sending end bus would still cause instability. For such cases use of a braking resistor of about one per unit resistance, to be switched on for about 12 cycles, would be sufficient to maintain stability. This would prove more economical than additional intermediate switching stations.

In fig. 2 are plotted the swing curves corresponding to the case under consideration. It is evident that stability can be maintained provided that the braking resister is switched on for about 12 cycles starting about 6 cycles after the instant the fault occurred. Reclosure of the open line section should be attempted within 1 second or more by which time the system should have settled to its new steady conditions. If the fault should persist this line section would trip out again and the braking resistor would be switched on for another 12 cycles and stability again maintained, as illustrated by swing curve B.

## 400 MW TRANSMISSION

Plot of $\left(\frac{T_1}{H_1}-\frac{T_2}{H_2}\right)$ in p u. versus angular displacement
for case of 2 circuits of 230 kv with
50% series capacitor compensation
and Braking resistor R=1.0 p.u

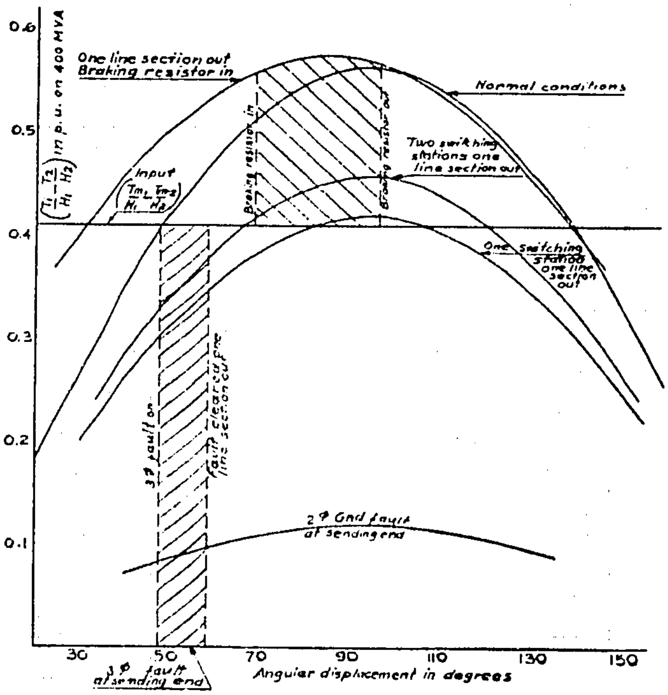


Fig. 1

### 400 MW TRANSMISSION OVER 2 CIRCUITS OF 230 kV WITH 50 % SERIES CAPACITOR COMPENSATION AND 2 SWITCHING STATIONS

*Swing curves of displacement angle $\delta$ versus time in cycles*

A – Threephase fault at sending end cleared in 4 cycles by tripout of one line section and followed within another 2 cycles by switching on of Braking Resistor for a period of 2 cycles.

B = Reclosure of line section with reestablishement of fault cleared within 4 cycles by tripout of line section Reapplication of Braking Resistor within another 2 cycles for period of 12 cycles.

C = Opening of line section not preceded by fault and followed within 6 cycles by switching on of Braking Resistor for a period of 12 cycles.

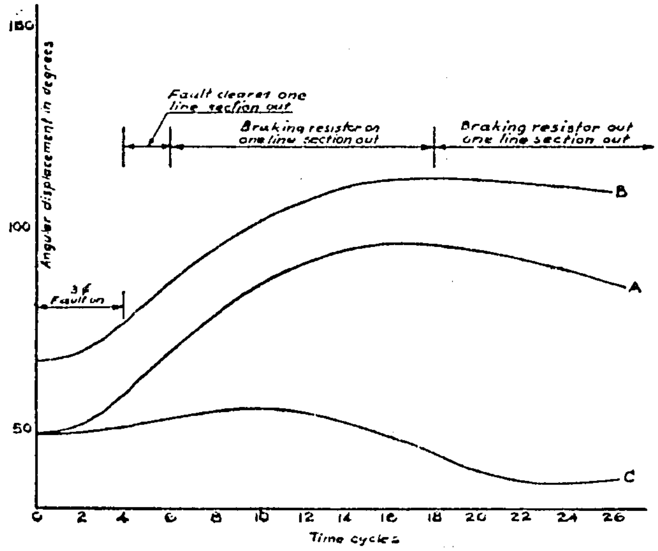


Fig.2

The use of the braking resistor should be limited to those cases where the fault is severe enough to require the braking action of the resistor. The possible adverse effects of having the resistor switched on for a very light fault can be judged from examination of the limiting case which would be the switching out of a line section not being preceded by a fault and followed within 6 cycles by the switching on of the braking resistor for 12 cycles. Curve C shows part of the swing which would result. The action of the braking resistor causes the angle to decrease to a minimum value of 36° and the subsequent swing would not be stable. This can be readily seen from the equal area criterion which gives the minimum angle for which stability may be preserved as about 39°. This angle is quite close to 36° and it is therefore concluded that in this particular application the relay calling for the action of the braking resistor could be set for relatively light faults without running the risk of over-braking and instability on the back swing.

The application of series capacitors and the particular problems involved in their protection has been covered in recent literature. We have in mind the series capacitor equipped for rapid reinsertion following a fault such as is described in reference (10).

In fig. 3 are plotted the power angle characteristics for the transmission scheme (b). From the curves it is evident that with no switching stations any fault, no matter how light, causing the trip out of a line would cause instability. With one intermediate switching station, the tripout of a line section caused by a light fault would not cause the two ends to fall apart. However, for any fault which causes an abrupt change in the electrical torque function $\left(\frac{T1}{H1} - \frac{T2}{H2}\right)$ of the order of 0.60 p. u., the systems will not stay in synchronism except through the stabilizing action of the braking resistor.

A low value of such a resistor although very effective on severe faults would result in over braking on light faults. A value of about 1 p. u. and a closed period of 12 cycles would appear satisfactory. Fig. 4 shows swing curves corresponding to conditions of this scheme.

Curve A shows the swing caused by a $3\ \phi$ fault at the sending end followed by the switching on of the braking resistor within 6 cycles of the start of the fault and for a duration of 12 cycles. System stability is preserved. Reclosure of the faulted circuit at the sending end, with the re-establishment of the fault, causes instability inspite of the re-application of the braking resistor for another period of 12 cycles, as is shown by swing curve B. With this reclosure however, a full $3\ \phi$ fault was assumed to appear again on the sending end bus. It would be a simple matter to make the reclosure firts from the end of the circuit remote from the plant in which case the severity of the fault would be greatly reduced and stability would not be lost.

400 MW TRANSMISSION

Plot of $\left(\frac{T_1}{H_1} - \frac{T_2}{H_2}\right)$ in pu. versus angular displacement

For case of 3 circuits of 230 KV with braking resistor R = 1.0

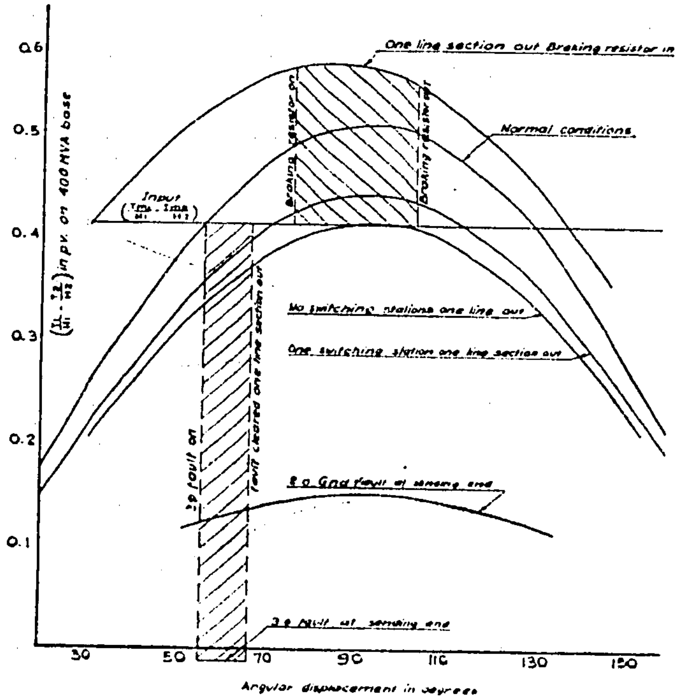
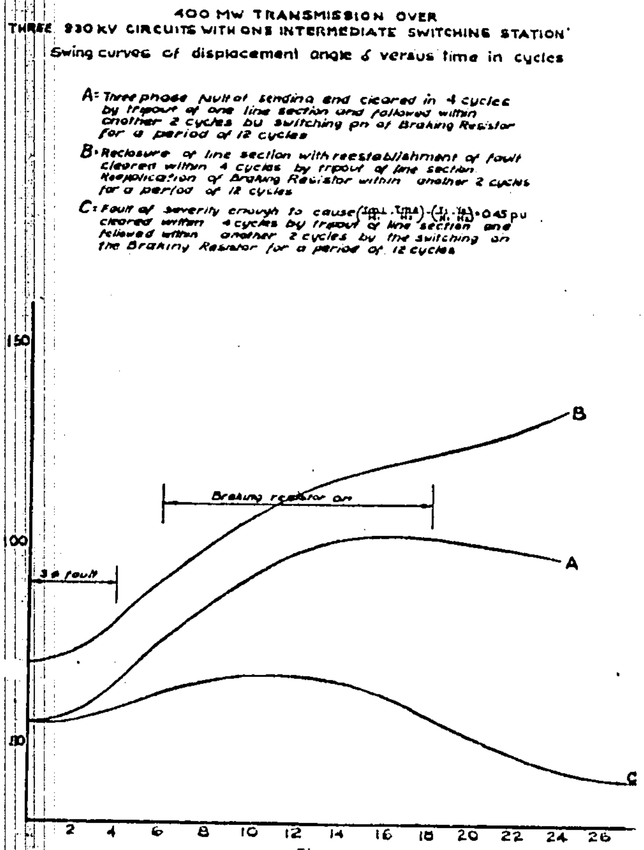


FIG. 3



400 MW TRANSMISSION OVER
THREE 330 KV CIRCUITS WITH ONE INTERMEDIATE SWITCHING STATION

Swing curves of displacement angle δ versus time in cycles

A: Three phase fault at sending end cleared in 4 cycles by tripout of one line section and followed within another 2 cycles by switching on of Braking Resistor for a period of 12 cycles

B: Reclosure of line section with reestablishment of fault cleared within 4 cycles by tripout of line section. Reapplication of Braking Resistor within another 2 cycles for a period of 12 cycles

C: Fault of severity enough to cause $\left(\frac{T_{m1}}{H_1}\cdot\frac{T_{m2}}{H_2}\right)-\left(\frac{T_1}{H_1}\cdot\frac{T_2}{H_2}\right)=0.45$ pu cleared within 4 cycles by tripout of line section and followed within another 2 cycles by the switching on the Braking Resistor for a period of 12 cycles

FIG 4

Curve C shows the swing resulting from a fault which would cause a change in the torque function ( $\frac{T1}{H1} - \frac{T2}{H2}$ ) of the order of 0.45 p. u. With the braking resistor applied for 12 cycles the over-braking is severe enough to cause instability on the back swing. It was stated that faults causing a change in this function of the order of 0.60 p. u. or greater would require some braking action to prevent instability. It is therefore evident that in this particular application the switching on time of the resistor should be graded in accordance with the severity of the fault.

The merits of the scheme of transmission described in (c) can be evaluated from the torque angle curves in fig. 5. With one switching station alone, the switching out of one line section due to no matter how light a fault would cause instability. With two switching stations there is no danger of instability due to the loss of a line section except on severe faults.

Approximately the same degree of stability could be achieved with one switching station and 20% or 30% series capacitor compensation. A braking resistor would then still be of advantage in case of 3 $\phi$ faults.

The following are the cost data which should be approximately representative of the conditions in Brazil and which will be used for the economic evaluation of the various schemes above.

TRANSMISSION LINE COST PER AVERAGE MILE IN $

| | Single Circuit Line | | Double Circuit Line | |
|---|---|---|---|---|
| | *ACSR Conductor Size* | | *ACSR Conductor Size* | |
| *Line Kv* | 795 *MCM* | 1113 *MCM* | 795 *MCM* | 1113 *MCM* |
| 230 | $50 000 | $55 000 | $75 000 | $82 000 |
| 287 | $55 000 | $61 000 | $82 500 | $91 000 |

Cost of right of way is assumed negligible.

| Voltage | Transformer cost $ per KVA |
|---|---|
| 230 Kv | $6.00 |
| 287 Kv | $9.00 |
| Auto-transformers | |
| 287/230 Kv | $7.00 |

| Cost of Breaker Position with *disconnect switches and structure* | *Voltage* |
|---|---|
| $160 000 | 230 Kv |
| $235 000 | 287 Kv |

Cost of series capacitors compensation at $15 per KVA.

| | |
|---|---|
| Water braking resistor with Breaker for 230 Kv | $200 000 |
| Water braking resistor with Breaker for 287 Kv | $294 000 |

Receiving end KVAR at $12 per KVAR.

## COST COMPARISON OF THE ALTERNATIVES IN 400 MW TRANSMISSION FOR 200 MILES

a (i) — 2 x 230 Kv with 2 switching stations and 50% series capacitor compensation on 2 single circuit lines of 1113 MCM ACSR.

| | |
|---|---|
| Two single circuit lines | $22,000,000 |
| Circuit Breakers (12 positions) | 1,920,000 |
| Series Capacitors | 1,900,000 |
| Sending end Transformation | 2,540,000 |
| Breaker & Braking resistor | 200,000 |
| | $28,560,000 |
| Reactive sources required at the receiving end for correction to unity power factor (45 MVAR) | $ 540,000 |
| Total | $29,100,000 |

Cost of transmission per KW received allowing for necessary correction to unity power factor and for sending end transformation — $77.

a (ii) — 2 x 230 Kv with 2 switching stations and 50% series capacitor compensation on one double circuit line of 1113 MCM ACSR.

| | |
|---|---|
| One double circuit line .............. | $16,500,000 |
| Circuit breakers (12 positions) ........ | 1,920,000 |
| Series Capacitors .................. | 1,900,000 |
| Sending end Transformation .......... | 2,540,000 |
| Breaker & Braking resistor ............ | 200,000 |
| | $23,060,000 |
| Reactive sources required at the receiving end for correction to unity power factor | 540,000 |
| Total .......... | $23,600,000 |

Cost of transmission per KW received allowing for necessary correction to unity power factor and for sending end transformation — $62.4.

b (i) — 3 x 230 Kv with one switching station and 3 single circuit lines of 795 MCM ACSR.

| | |
|---|---|
| 3 single circuit lines .................. | $30,000,000 |
| Breakers (8 positions) ............... | 1,280,000 |
| Sending end transformation .......... | 2,540,000 |
| Breaker & Braking resistor ........... | 200,000 |
| | $34,020,000 |
| Reactive sources required at the receiving end for correction to unity power factor (20 MVAR) ...................... | 240,000 |
| Total .......... | $34,260,000 |

Cost of transmission per KW received allowing for necessary correction to unity power factor and for sending end transformation — $91.

b (ii) — 3 x 230 Kv with one switching station and one double circuit line and one single circuit line.

| | |
|---|---|
| One double circuit one single circuit line | $25,000,000 |
| Breakers (8 positions) ............... | 1,280,000 |
| Sending end transformation .......... | 2,540,000 |
| Breaker & Braking resistor ............ | 200,000 |
| | $29,020,000 |
| Reactive sources required at receiving end for correction to unity power factor | 240,000 |
| Total .......... | $29,260,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor = $75.6.

c (i) 2 x 287 Kv with two intermediate switching stations and two single circuit lines.

| | |
|---|---|
| Two single circuit lines .............. | $22,000,000 |
| Breakers (12 positions) .............. | 2,820,000 |
| Sending end transformation .......... | 3,960,000 |
| Receiving end auto-transformation ..... | 3,080,000 |
| Breaker & Braking resistor ............ | 294,000 |
| | $32,154,000 |
| Reactive sources required at receiving end for correction to unity power factor | 0 |
| Total .......... | $32,154,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor = $82.8.

c (ii) — 2 x 287 Kv with two intermediate switching stations and one double circuit line.

| | |
|---|---|
| One double circuit line .............. | $16,500,000 |
| Breakers (12 positions) .............. | 2,820,000 |
| Sending end transformation .......... | 3,960,000 |
| Receiving end auto-transformation ..... | 3,080,000 |
| Breaker & Braking resitor ............ | 294,000 |
| | $26,654,000 |
| Reactive sources required at receiving end for correction to unity power factor | 0 |
| Total .......... | $26,654,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor = $68.

c (iii) — 2 x 287 Kv with one intermediate switching station and 30% series capacitor compensation with two single circuit lines (795 MCM ACSR)

| | |
|---|---|
| Two single circuit lines .............. | $22,000,000 |
| Breakers (8 positions) .............. | 1,880,000 |
| Sending end transformation .......... | 3,960,000 |
| Receiving end transformation ......... | 3,080,000 |
| Series capacitor compensation ......... | 700,000 |
| Breaker & Braking resistor ........... | 294,000 |
| | $31,914,000 |
| Credit for lagging reactive power received | 600,000 |
| Total .......... | $31,314,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor — $83.

c (iv) — 2 x 287 Kv with one intermediate switching station and 30% series capacitor compensation with one double circuit line (795 MCM ACSR)

| | |
|---|---|
| One double circuit line .............. | $16,500,000 |
| Breakers (8 positions) .............. | 1,880,000 |
| Sending end transformation ........... | 3,960,000 |
| Receiving end transformation ......... | 3,080,000 |
| Series capacitor compensation ......... | 700,000 |
| Breaker & Braking resistor ............ | 294,000 |
| | $26,414,000 |
| Credit for lagging reactive power received | 600,000 |
| Total .......... | $25,814,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor — $68.5.

A summary of the above results is shown on the table below:

400 MW transmission for
200 miles

| *Transmission Scheme* | *Cost per KW received* |
|---|---|
| Two single circuit 230 Kv. 1113 MCM ACSR lines with 2 switching stations and 50% series capacitor compensation | $77 |
| One double circuit 230 Kv line with 2 switching stations and 50% series capacitor compensation | $62.4 |
| Three single circuit 230 Kv. 795 MCM ACSR lines with one switching station | $91. |
| One double circuit and one single circuit 230 Kv. 795 MCM ACSR lines with one switching station | $75.6 |
| Two single circuit 287 Kv. 795 MCM ACSR (or equivalent) lines with two switching stations | $82.8 |
| One double circuit 287 Kv. 795 MCM ACSR (or equivalent) line with two switching stations | $68 |
| Two single circuit 287 Kv. 795 MCM ACSR (or equivalent) lines with one switching station and 30% series capacitor compensation | $83 |
| One double circuit 287 Kv. 795 MCM ACSR (or equivalent) line with one switching station and 30% series capacitor compensation | $68.5 |

For a fair comparison of costs, losses should be taken into consideration. To have the same losses the conductor cross section of the lines in scheme (a) were taken an about 50% greater than that of the lines in scheme (b).

The losses in scheme (c) are approximately equal to those in (b) when considering the additional losses due to the receiving end transformation.

The concept of surge impedance loading is very useful as a yardstick for estimating the capabilities of transmission for different voltages based on the capabilities of a transmission system of a given voltage.

For ready reference the Table below lists the surge impedance loadings of transmission circuits of different voltage levels.

400 MW TRANSMISSION

Plot of $\left(\frac{T_m}{H}-\frac{T_e}{H}\right)$ in p.u. versus angular displacement for case of 2 circuits of 287 KV

A: 2 × 287 KV with no compensation

B: 2 × 287 KV with one switching station and 20% series capacitor compensation

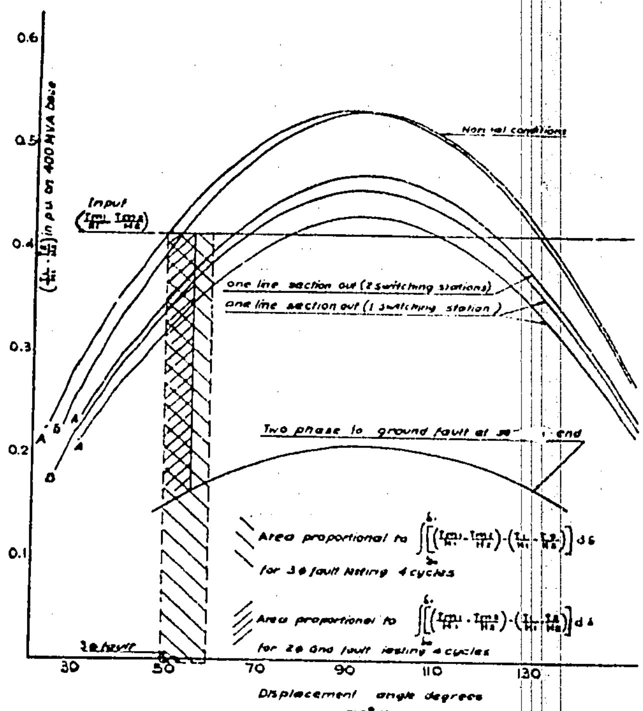


FIG.° 5

## SURGE IMPEDANCE LOADING PER CIRCUIT

| Line Kv | Single Conductor<br>*S.I.L.* | Dual Conductor<br>*S.I.L.* |
|---|---|---|
| 138 | 47.600 | |
| 161 | 65 000 | |
| 230 | 132 000 | 165 000 |
| 287 | 206 000 | 257 000 |
| 330 | 272 000 | 340 000 |
| 380 | 361 000 | 451 000 |

On the basis of the example which was worked out and within the assumptions outlined in the beginning it could be concluded that for a distance of 200 miles, a fully reliable transmission system of two lines with 50% series capacitor compensation, two switching stations and braking resistor at the sending end would be good for about 150% of surge impedance loading.

For the same distance a system of 3 transmission lines with one intermediate switching station would be good for 100% of surge impedance loading while one of two transmission lines with two switching stations or with one switching station and 30% series capacitor compensation would be good for almost 100% S.I.L.

For larger blocks of power to be transmitted over this same distance estimates can be readily made as follows:

| Power to be transmitted | Possible transmission Scheme for 100% reliability reliability |
|---|---|
| 600 MW | a) Three 230 Kv circuits with 50% series capacitor compensation one switching station, and Braking resistor.<br>b) Two 287 Kv circuits with two switching stations, 50% series capacitor compensation and Braking resistor.<br>c) Three 287 Kv circuits with one switching station and Braking resistor.<br>d) Two 230 Kv dual conductor circuits with two switching stations and Braking resistor.<br>e) Two 330 Kv circuits with one switch station 30% series capacitor compensation, and Braking resistor. |

| Power to be transmitted | Possible Transmission Scheme for 100% reliability |
|---|---|
| 800 MW | a) Three 287 Kv circuits with 50% series capacitor compensation, one switching station and Braking resistor.<br>b) Two 330 Kv circuits with 50% series capacitor compensation 2 switching stations and Braking resistor.<br>c) Three 330 Kv circuits with one switching station and Braking resistor.<br>d) Two 380 Kv dual conductor circuits with two switching stations and braking resistor.<br>e) Two 380 Kv dual conductor circuits with one switching station, 30% series capacitor compensation and Braking resistor. |

The first alternative in each case is based on the case worked out for 400 MW transmission with two lines of 230 Kv, two switching stations and 50% series capacitor compensation. With three circuits for 600 MW, one switching station would suffice for this arrangement.

We have no very reliable means of evaluating costs for 330 Kv and 380 Kv voltages. However, from estimates based on available literature we would expect the cost of a 330 Kv single conductor line to run about $68 000 per mile of single circuit line and about $102 000 per mile of double circuit line. Dual conductor lines might run in the order of $75 000 per mile of single circuit line. Circuit breaker costs may well be of the order of $300,000 per breaker position and transformation costs in the order of $10.5 per KVA for both sending and receiving ends.

Based on the above cost data, the following would be the costs of transmission and transformation per KW for the schemes above.

| | |
|---|---|
| 600 MW | (a) $75/KW for 3 single circuit 230 Kv lines with one switching station and 50% series capacitor compensation.<br>$65.5/KW for one single circuit and one double circuit 230 Kv line with one switching station and 50% series capacitor compensation.<br>(b) $70.2/MW for two single circuit 287 lines with two switching stations and 50% series capacitor compensation.<br>$59.5/KW for one double circuit 287 Kv line with two switching stations and 50% series capacitor compensation. |

(c) $82.4/KW for 3 single circuit 287 Kv lines with one switching station.
$72.5/KW for one single circuit and one double circuit 287 Kv lines with one switching station.

(d) $83.5/KW for two single circuit dual conductor 330 Kv lines with two switching stations.

800 MW

(a) $72/KW for three single circuit 287 KV lines with one switching station and 50% series capacitor compensation.
$63/KW for one single circuit and one double circuit 287 Kv line with one switching station and 50% series capacitor compensation.

(b) $66.5/KW for two single circuits 330 Kv lines with two switching stations and 50% series capacitor compensation.
$58/KW for one double circuit 330 Kv line with two switching stations and 50% series capacitor compensation.

(c) $83/KW for three single circuits 330 Kv lines with one switching station.
$74.5/KW for one single circuit and one double circuit 330 Kv lines with one switching station.

There will be some instances of remotely located Power Plants with moderate outputs for which the design of a double circuit transmission line or two single circuit transmission lines would not appear justified since these outputs might well be handled by one circuit and since experience has shown that a well built line in the 230 Kv and above class has a very low outage rate usually less than one per hundred miles per year. For such cases use of high speed reclosing together with a braking resistor at the sending end would materially improve the performance of the system since the greater part of the faults are bound to be of a temporary nature.

An interesting case is the transmission of 200 MW for a distance of 200 miles to a system which could afford an occasional loss of such generation. For such a case the use of a single circuit could be made with material reductions in cost. The alternatives would be based on having a circuit whose steady state limit exceeded the power to be transmitted by about 15%. Under the circumstances the following alternatives would be possible:

a) One 230 Kv line with the sending end generators of 50% higher than normal short circuit ratio.
b) One 230 Kv line with about 30% series capacitor compensation and standard SCR at the sending end generators.
c) One 287 Kv line with standard SCR at the sending end generators.

In the classical design based on preserving stability through a disturbance such as might be caused by a fault and trip of a line section the transient stability analysis is the important factor and invariably the steady state stability limits which correspond to a given design based on preserving stability as explained above, are well above the power limits set by transient stability considerations. In the classical design, therefore, the gains which are obtainable from an increase in short circuit ratio are only of a secondary nature.

A cost comparison of these alternatives gives the following results:

| | |
|---|---|
| a) One single circuit 230 Kv line with 1113 MCM ACSR conductors | $11,000,000 |
| Breakers (2 positions) | 320,000 |
| Sending end transformation | 1,270,000 |
| Extra cost of Generators for 50% higher SCR | 160,000 |
| Breaker & Braking resistor | 200,000 |
| | $12,950,000 |
| Reactive sources for correction to unity power factor at receiving end (40 MVAR) | 480,000 |
| Total | $13,430,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor = $71.3 (includes sending end transformation).

| | |
|---|---|
| b) One single circuit 230 Kv line with 1113 MCM ACSR conductors | $11,000,000 |
| Breakers (2 positions) | 320,000 |
| Sending end transformation | 1,270,000 |
| Series capacitor compensation | 850,000 |
| Breaker & Braking resistor | 200,000 |
| | $13,640,000 |
| Credit for lagging reactive power received (35 MVAR) | 420,000 |
| Total | $13,220,000 |

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor = $70.2

It need not be pointed out that for this case the third alternative would prove more expensive due to higher breaker costs and higher transformation costs. The costs of alternatives (a) and (b) are so close that the simplicity of a line without compensation would no doubt outweigh the small cost difference in favour of alternative (b).

The effectiveness of the Braking resistor in preserving stability can be readily appreciated from the power angle curves on fig. 6 and the swing curves of fig. 7. These curves are for the case of one 230 Kv circuit transmitting 200 MW and tripping out on a 3 $\phi$ fault followed by the switching on of the resistor within 6 cycles from the start of the fault. The circuit is reclosed after a dead time of 29 cycles and the Braking resistor switched off almost simultaneously after a "on" time of about 27 cycles. For this case the water resistor was assumed large enough to dissipate 400 MW.

Evidently the same type of one line transmission system could be used for higher blocks or power, with lines of higher voltages.

The following would be the possibilities of transmitting larger blocks of power for 200 miles over one circuit considering that 150% surge impedance loading is feasible as was shown for the case of one 230 Kv circuit.

300 MW — One single conductor 287 Kv circuit.
350 MW — One dual conductor 287 Kv circuit.
400 MW — One single conductor 330 Kv circuit.
500 MW — One dual conductor 330 Kv circuit.
650 MW — One dual conductor 380 Kv circuit.

We are not in a position to estimate costs of transmission for the higher voltages. The costs of transmission per KW should decrease as larger and larger blocks of power are transmitted over higher voltage circuits provided that the economy resulting from having one circuit out weighs the increase in cost of the terminal equipment. For 300 MW transmitted over one 287 Kv line our estimate of the cost per KW transmitted including sending and receiving end transformation gives $.... $68.20/KW. as follows:

| | |
|---|---|
| One 287 KV 1113 MCM circuit .................... | $12,200,000 |
| Sending end transformation .................... | 2,970,000 |
| Receiving end auto-transformation .................... | 2,300,000 |
| Breakers (2 positions) .................... | 470,000 |
| Breaker & Braking resistor .................... | 294,000 |
| Reactive sources at receiving end for correction to unity power factor at receiving end ........... | 240,000 |
| Extra cost of generators for 50% higher SCR ... | 960,000 |
| Total ............ | $19,434,000 |

### 200 MW TRANSMISSION

Plot of $\left(\frac{T_1}{H_1}-\frac{T_2}{H_2}\right)$ in p.u. versus angular
displacement for case of one 230 kv
circuit with Braking resistor R=1.00 p.u
(400 MVA base)

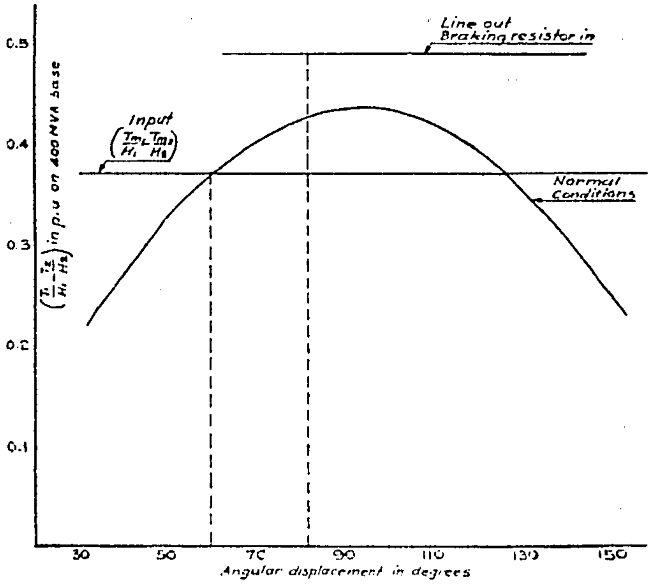


Fig. 6

200 MW TRANSMISSION OVER ONE 230 kW CIRCUIT

Swing curve of displacement angle between sending end and receiving end rotors versus time in cycles for condition of trip out of the line due to a fault, with application of the braking resistor for a period of 27 cycles and reclosure of the line after a dead time of 29 cycles

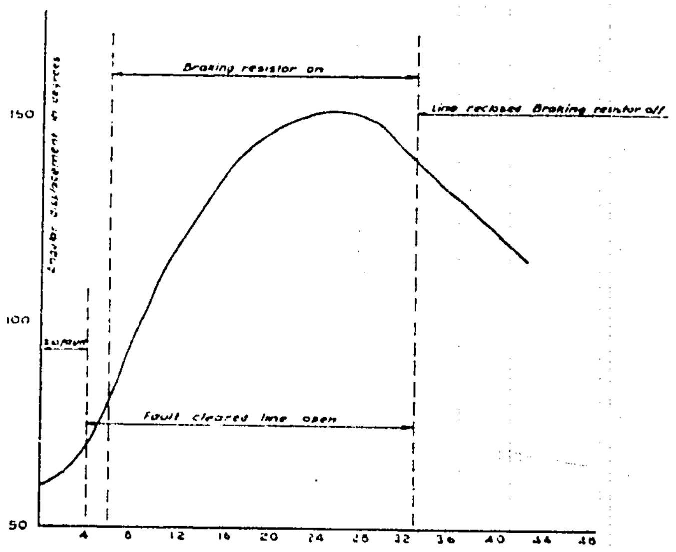


Fig. 7

Cost of transmission and transformation per KW received allowing for necessary correction to unity power factor = $68.20.

This cost per KW is very close to that of transmitting 200 MW over one 230 Kv circuit. It is therefore fairly evident that for the transmission of 400 MW over a distance of 200 miles there would be no economic advantage in having one 330 Kv circuit instead of two 230 Kv circuits especially where a double circuit 230 Kv line is used.

Naturally with just two 230 Kv circuits with no switching stations and no series capacitor compensation approximately the same degree of reliability would be obtained as with just one 330 Kv circuit, since the loss of the generation would be inevitable in case one of the 230 Kv circuits became faulted and did not stay when reclosed. When a transmission arrangement is made up of more than one circuit there is naturally the temptation to make it reliable enough to withstand the permanent outage of a line section following a fault. In such a case the design criteria are different as previously discussed. In the case of 400 MW transmission over two 230 Kv circuits it was shown that such reliability could be obtained with two switching stations and 50% series capacitor compensation and a braking resistor. With such an arrangement and two single circuit lines the cost per KW was shown as $77/KW while with one double circuit line this cost was only $61/KW.

If reliability considerations allow for the possibility of losing the generation for those rare cases where reclosure of the faulted line is not successful, then the costs of the particular transmission under consideration would be reduced to $71.3 per KW for two single circuit lines and $55.4/KW for one double circuit line.

Further, in the case of two circuits there is the possibility of avoiding the total loss of generation upon failure of one circuit to reclose by tripping out half of the generation as can be seen from the following sequence of events:

1) — Fault and tripout of one circuit, switching on of braking resistor, unsuccessful reclosure of faulted circuit, tripout of half of generation, switching off of braking resistor.
2) — Fault and tripout of both circuits, switching on of braking resistor, reclosure of both circuits, successful in one, unsuccessful in the other, tripout of half generation and switching off of braking resistor.

It should be noticed that in all the cases which have been discussed the design included the braking resistor at the sending end. The savings accomplished by having such a braking resistor can be readily appreciated from the torque angle curves. In order to obtain the same degree of stability by other means, the number of switching station or of parallel lines would have to be increased and the costs would be materially higher.

## SUMMARY

This paper deals with some technical and economic aspects of Transmission Design with particular reference to conditions in Brazil. The general phylosophy of Transmission design is discussed and the economics of alternative schemes have been worked out for the particular case of transmission over a distance of 200 miles.

The use of braking resistors has for a number of years been proposed as a means of increasing the stability of transmission systems, but has not gained much acceptance probably because there had been much more to be gained through other design improvements such as high speed relaying and fast faultclearing. In this paper the use of shunt braking resistors at the sending end is considered as an effective and economical design feature in conjunction with the other more conventional methods of increasing firm transmission capacity which have been developed practically to their limiting values.

## RESUMO

Êste trabalho descreve alguns aspectos técnicos e econômicos de transmissão de Energia aplicáveis a condições no Brasil.

Os critérios gerais de projetos de Transmissão são apresentados e os aspectos econômicos de várias alternativas são calculados para o caso particular de transmissão a uma distância de 200 milhas.

A aplicação de resistências para frear geradores tinha sido proposta já há vários anos como meio de se aumentar a estabilidade de sistemas de transmissão. Êsse método todavia não tem sido até o momento aplicado provàvelmente porque havia ainda muita margem no desenvolvimento de outros métodos de aumentar a estabilidade tais como relés e chaves interruptoras de alta velocidade.

Neste trabalho a aplicação de "resistências-freio" é considerada como um meio econômico e efetivo de se aumentar a "capacidade firme de transmissão" em conjunto com os outros métodos convencionais cujas possibilidades se acham desenvolvidas pràticamente ao máximo.

## RÉSUMÉ

Ce rapport décrit quelques aspects techniques et économiques concernant le transport d'énergie électrique, particulièrement sous les conditions rencontrées au Brésil.

La conception générale des projects de transmission est exposée ici et le problème particulier de transport a 320 Km a été étudié au point de vue économique.

L'utilisation des "résistances de freinage" a été proposée il y a déjà quelques années comme un moyen d'augmenter la stabilité des systèmes de transmission. Cette méthode n'a pas été acceptée. probablement car il y avait encore assez de possibilités de progrès dans d'autres méthodes plus interessantes telles que la protection ultra-rapide.

Dans le présent rapport l application des "résistances de freinage" au départ est considerée comme un moyen effectif et économique. apporté aux autres procédés d'augmentation de capacité de transmission plus conventionnels. que l'on a déjà dévelopés à leurs valeurs limites.

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**CONFERÊNCIA MUNDIAL DA ENERGIA**
**WORLD POWER CONFERENCE**

Título I
Assunto I I

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

BERENHAUSER Jr. (C.)
PEREIRA (N.)
Brasil

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# BALANÇO DOS SERVIÇOS DE ELETRICIDADE NO BRASIL

Por CARLOS BERENHAUSER JÚNIOR

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e NATÉRCIO PEREIRA

[illegible]

COMITÊ NACIONAL BRASILEIRO

## I. EVOLUÇÃO DOS SERVIÇOS DE ELETRICIDADE

A primeira usina elétrica instalada no Brasil data de junho de 1883. Tratava-se de uma pequena instalação termelétrica de 52 KW, montada em Campos, Estado do Rio de Janeiro.

A primeira central hidrelétrica foi a da Companhia Mineira de Eletricidade, em Juiz de Fora, Estado de Minas Gerais, instalada em 1889, e a segunda termelétrica, a de "The South Brazilian Railway Co. Ltd.", em Curitiba, Estado do Paraná, no mesmo ano.

A primeira grande instalação hidrelétrica foi levada a efeito em Parnaíba, no Rio Tietê, a 31 quilômetros da capital paulista, pela "The São Paulo Tramway, Light and Power Co. Ltd.". Essa usina foi inaugurada em 1901; sua potência cresceu ràpidamente a 27.379 KW.

No Norte do Brasil, as primeiras centrais instaladas foram térmicas: a de Cruzeiro do Sul no Acre, inaugurada em 1904, e a de Manaus e de Belém, inauguradas em 1905.

O Quadro 1 ilustra bem o desenvolvimento dos serviços de eletricidade no Brasil, desde 1883.

No Gráfico n.º 1 observa-se claramente a curva dêsse desenvolvimento, de 1900 a 1952. Esse Gráfico foi traçado com os elementos constantes do Anexo 1.

## QUADRO I
## RESUMO HISTÓRICO DA INDÚSTRIA DE ELETRICIDADE NO BRASIL DE JUNHO DE 1883 A 31-12-1952

| | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
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| [illegible] | | | | [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] |
| Total | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | | | | | | | |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Total | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

FONTE: Divisão de Águas do Ministério da Agricultura.
(*) Dados relativos a 1952.

O Anexo 2 fornece, para cada unidade da Federação, nos anos de 1930, 1940 e 1950, indicações completas relativas ao número de emprêsas de eletricidade, número e potência de usinas geradoras, fornecedoras e privativas, e estas segundo a fonte de energia primária.

## II — POTÊNCIA INSTALADA E PRODUÇÃO DE ENERGIA ELÉTRICA NO PERÍODO DE 31-XII-1939 A 31-XII-1952

O Quadro II mostra a evolução da potência instalada e da produção de energia elétrica, no período 31.XII.1939 a 31.XII.1952, com as taxas de crescimento anuais. São indicados no mesmo quadro os fatôres de utilização nos anos correspondentes.

## QUADRO II
## EVOLUÇÃO DA POTÊNCIA INSTALADA E DA PRODUÇÃO DE ENERGIA ELÉTRICA NO PERÍODO DE 31-12-1939 A 31-12-1952

| ANOS | POTÊNCIA INSTALADA — kW | | | Taxa de Crescimento Anual % | Produção Estimada kWh | Taxa de Crescimento Anual % | Fator de Utilização Anual % |
|---|---|---|---|---|---|---|---|
| | Usinas Termelétricas | Usinas Hidrelétricas | Total | | | | |
| 1940 | [illegible] | 1 009 396 | 1 243 877 | 1.40 | [illegible] 338.329 | 6.05 | 31.2[illegible] |
| 1941 | [illegible] | 1 035 015 | 1 261 226 | 3.64 | [illegible] 117.360 | 8.40 | 31.43 |
| 1942 | [illegible] | 1 080 666 | 1 307 666 | 0.59 | [illegible] 420.070 | 9.00 | 33.01 |
| 1943 | [illegible] | 1 067 065 | 1 315 698 | 1.43 | [illegible] 395.864 | 10.42 | 35.29 |
| 1944 | [illegible] | 1 076 969 | 1 334 246 | 0.56 | [illegible] 998.753 | 7.92 | 36.06 |
| 1945 | [illegible] | 1 079 427 | 1 341 633 | 5.03 | [illegible] 658.809 | 8.66 | 41.01 |
| 1946 | [illegible] | 1 154 245 | 1 414 961 | 8.42 | [illegible] 095.019 | 12.86 | 43.00 |
| 1947 | 282 975 | 1 251 160 | 1 534 135 | 5.94 | [illegible] 050.411 | 14.56 | 44.74 |
| 1948 | 291 [illegible] | 1 333 366 | 1 625 355 | 6.76 | [illegible] 998.648 | 11.54 | 44.96 |
| 1949 | 304 991 | 1 430 860 | 1 735 191 | 8.52 | [illegible] 339.880 | 5.82 | 50.06 |
| 1950 | 346 850 | 1 536 177 | 1 883 027 | 3.02 | 7 962 336.706 | 9.55 | 48.29 |
| 1951 | 355 190 | 1 584 756 | 1 939 946 | 1.81 | 8 722 458.002 | 6.70 | 51.32 |
| 1952 | 372 500 | 1 642 [illegible] | 1 975 [illegible] | | 9 306 995.723 | | 53.78 |

FONTES: A potência instalada foi obtida de estatísticas da Divisão de Águas do Ministério da Agricultura. A produção foi obtida diretamente de algumas emprêsas e estimada para as restantes.

Verifica-se do Quadro II que, enquanto o crescimento da potência instalada foi de 731 158 kW ou 58,8%, no período de 12 anos, a produção total elevou-se de 192%, no mesmo período. Em conseqüência, o fator de utilização, que era em 1940 de 29,25% passou a 53,78%. Tão elevado fator de utilização evidencia bem o grau de esgotamento das usinas geradoras brasileiras.

## III — POTÊNCIA INSTALADA EM 1952

A potência instalada em usinas geradoras pelas unidades da Federação em 1952 é indicada no Quadro III.

### QUADRO III

### POTÊNCIA INSTALADA EM USINAS GERADORAS PELAS UNIDADES DA FEDERAÇÃO — 1952

| Unidades da Federação | kW | | |
|---|---|---|---|
| | Térmica | Hidráulica | Total |
| 1 Guaporé | 703 | — | 703 |
| 2 Acre | 855 | — | 855 |
| 3 Amazonas | 5 780 | — | 5 780 |
| 4 Rio Branco | 20 | — | 20 |
| 5 Pará | 6 927 | 15 | 6 942 |
| 6 Amapá | 252 | — | 252 |
| 7 Maranhão | 2 192 | 99 | 2 291 |
| 8 Piauí | 9 031 | | 9 031 |
| 9 Ceará | 12 632 | 387 | 13 019 |
| 10 Rio Grande do Norte | 5 210 | | 5 210 |
| 11 Paraíba | 11 670 | 252 | 11 922 |
| 12 Pernambuco | 52 923 | 6,368 | 59 291 |
| 13 Alagoas | 11 336 | 2,842 | 14 178 |
| 14 Fernando de Noronha | 550 | | 550 |
| 15 Sergipe | 8 218 | 435 | 8 653 |
| 16 Bahia | 11 920 | 81 074 | 92 994 |
| 17 Minas Gerais | 12 333 | 243 537 | 255 870 |
| 18 Espírito Santo | 4 631 | 8 857 | 13 488 |
| 19 Rio de Janeiro | 29 560 | 95 579 | 125 139 |
| 20 Distrito Federal | 40 320 | 376 | 40 696 |
| 21 São Paulo | 22 770 | 836 763 | 859 533 |
| 22 Paraná | 10 786 | 39 388 | 50 174 |
| 23 Santa Catarina | 16 906 | 24 864 | 41 770 |
| 24 Rio Grande do Sul | 88 839 | 15 187 | 104 026 |
| 25 Mato Grosso | 4 537 | 2 994 | 7 531 |
| 26 Goiás | 344 | 7.639 | 7 983 |
| TOTAL | 372 388 | 1 602.627 | 1 975 015 |

FONTE: Divisão de Águas do Ministério da Agricultura.

A potência instalada nos principais sistemas elétricos, no ano de 1952, acha-se discriminada no Anexo 3.

## IV. PRODUÇÃO E CONSUMO DE ENERGIA ELÉTRICA EM 1952

Foram obtidos dados precisos da produção e do consumo de energia elétrica em 40 sistemas brasileiros, relativamente ao ano de 1952. A potência instalada nesses 40 sistemas era então de 1 452.189 kW, correspondendo a 73,5% do total instalado no País. Seus serviços foram prestados em 472 municípios, cuja população era de cêrca de 20.130.000 habitantes, representando 37% da população total estimada para o Brasil em 1952.

As instalações restantes totalizaram a potência de 522 826 kW. Na base dos fatôres de carga e perdas dos 40 sistemas informantes, cuja relação detalhada constitui o Anexo 3, foi estimada a produção e o consumo das instalações restantes.

Todos êsses dados foram reunidos no Quadro n.º IV, que apresenta um resumo das características dos serviços de energia elétrica em 1952.

### Quadro IV

### RESUMO DAS CARACTERÍSTICAS DOS SERVIÇOS DE ENERGIA ELÉTRICA EM TODO O BRASIL, NO ANO DE 1952

| | Unidade | Dados precisos de 40 sistemas com a população de 20.130.000 habitantes em 472 municípios | Dados aproximados das instalações restantes | Total estimado para todo o Brasil |
|---|---|---|---|---|
| Potência instalada | kW | 1.452.189 | 522.826 | 1.975.015 |
| Carga máxima horária | kWh/h | 1 377 637 | 365 504 | 1 743.141 |
| Fator de carga | % | 66,5 | 40,0 | 61,0 |
| Produção | $10^6$ × kWh | 8 022,8 | 1 284,1 | 9 306,9 |
| Perdas | % | 14,3 | 20,0 | 15,1 |
| Consumo | $10^6$ × kWh | 6 876,0 | 1 027,3 | 7 903,3 |

NOTA: — As estimativas para as instalações restantes obedeceram ao seguinte critério:

a) potência instalada — do total brasileiro fornecido pela Divisão de Águas, deduziu-se a dos 40 sistemas informantes.

b) carga máxima horária — adotado o valor de 70% da potência instalada.

c) produção — adotado o fator de carga anual de 40%, foi obtido pelo produto deste pela carga máxima horária.

d) consumo — estimado em 20% o total das perdas, deduziu-se este valor da produção.

## V. CLASSIFICAÇÃO DO CONSUMO DE ENERGIA ELÉTRICA POR CATEGORIA DE SERVIÇO

Com os dados dos 40 sistemas relacionados no Anexo 3, foi obtido o resumo da classificação do consumo de energia elétrica por categoria de serviço.

O resumo é apresentado no Quadro V.

QUADRO V

RESUMO DA CLASSIFICAÇÃO DO CONSUMO DE ENERGIA ELÉTRICA POR CATEGORIA DE SERVIÇO EM 1952

| | Unidade | Dados reais 40 sistemas | Dados estimados instalações restantes | Total do Brasil estimado |
|---|---|---|---|---|
| *Potência instalada* | kW | 1.452.489 | 522.526 | 1.975.015 |
| *Consumo* | | | | |
| Domiciliar | $10^6 \times$ kWh | 1.598,7 | 410,9 | 2.009,6 |
| Industrial | $10^6 \times$ kWh | 3.366,4 | 513,7 | 3.880,1 |
| Outros | $10^6 \times$ kWh | 1.910,9 | 102,7 | 2.013,6 |
| Total | $10^6 \times$ kWh | 6.876,0 | 1.027,3 | 7.903,3 |
| *Consumo industrial em porcentagem total* | % | 49 | 50 | 49 |

A estimativa do consumo industrial para o grupo designado "Instalações Restantes" justifica-se por incluir em sua totalidade as usinas geradoras privativas de indústrias, cuja produção é predominantemente utilizada para fins de fôrça motriz.

## VI. CONSUMO DOMICILIAR DE ENERGIA ELÉTRICA EM 1952

Para o consumo domiciliar de energia elétrica, foram obtidas informações precisas de 40 sistemas. Entretanto, o número exato de consumidores domiciliares sòmente foi possível conseguir de 19 daqueles 40 sistemas.

Destarte, só será possível analisar mais detalhadamente os dados, tanto de consumo como de número de consumidores domiciliares, dos 19 sistemas a saber: The São Paulo Tramway Light and Power Co. Ltd., Cia. de Carris Luz e Fôrça do Rio de Janeiro, Cia. Brasileira de Energia Elétrica, Cia. Energia Elétrica da Bahia, Cia. Fôrça e Luz de Minas Gerais, Cia. Fôrça e Luz do Paraná, Cia. Fôrça e Luz Nordeste do Brasil, Cia. Paulista de Fôrça e Luz, Cia. Energia Elétrica Riograndense, The Pernambuco Tramway, Light and Power, The Riograndense Light and Power Syndicate, Cia. Central Brasileira de Fôrça Elétrica, Cia. Sul Americana dos Serviços Públicos, Cia. Sul Mineira de Eletricidade, Cia. Fôrça e Luz Cataguazes-Leopoldina, Emprêsa Sul Brasileira de Eletricidade, Cia. Luz e Fôrça Santa Catarina, Serviços de Luz e Fôrça de Aracaju e Comissão Estadual de Energia Eletrica do Rio Grande do Sul.

Esses 19 sistemas apresentaram, em conjunto, no ano de 1952, 1.556.684 consumidores domiciliares ligados, cujo consumo total foi de 1.114,1 milhões KWh.

O consumo médio por domicílio foi, portanto, de 908 KWh. Em 1944, êsse valor era de 610 KWh em 13 sistemas, dentre os 19 para os quais foi possivel obter informações completas em 1952.

O consumo domiciliar, em 1952, variou nesses 19 sistemas de um máximo de 1.391 KWh a um mínimo de 257 KWh. O valor mais alto foi registrado no sistema de "The São Paulo Tramway Light and Power Co. Ltd." e o menor no sistema da Cia. Fôrça e Luz Nordeste do Brasil (Maceió e Natal), conforme esclarece o Anexo 4, com detalhe. No sistema da Carris, Luz e Fôrça do Rio de Janeiro Ltda. essa media foi de 756 KWh anuais por domicílio.

Excluidos os dois maiores sistemas ("The São Paulo Tramway Light and Power Co. Ltd." e Cia. Carris, Luz e Fôrça do Rio de Janeiro) o consumo médio anual por domicílio nos 17 sistemas restantes, que aliás servem 9 capitais de Estados, foi de 640 KWh em 1952. Em 1944 êsse valor era de 366 KWh para 11 sistemas, incluidos, todavia, aquêles que servem as citadas 9 capitais de Estados.

A fim de avaliar o consumo médio domiciliar em todo o Brasil, seria necessário estimar o número total de consumidores domiciliares existentes em 1952. Na base dos resultados dos recenseamentos gerais já realizados no Brasil, parece razoável admitir que o número total de domicílios existentes no País, em 1952, tenha sido da ordem de 10.900.000, correspondente a uma densidade domiciliar media de 6 habitantes por residência.

A vista disso, avaliou-se em cêrca de 2.940.000 o número de consumidores existentes no mesmo ano, correspondente a uma taxa de eletrificação domiciliar de 27%. Em 1944, segundo o relatório da Comissão da Indústria do Material Elétrico (C.I.M.E.), o número de consumidores domésticos foi estimado em cêrca de 2.000.000, sendo a taxa de eletrificação também de 27%.

Nessas condições, entre 1944 e 1952 houve o acréscimo estimado de 940.000 consumidores domésticos ou sejam 47,0% em 8 anos, o que parece razoável, pois corresponde à média cumulativa anual de 5,0%.

As localidades com iluminação pública ou domiciliar a eletricidade passaram de 3.145 em 1945, para 3.792 em 1950. Houve assim o aumento de 20% em 5 anos, correspondendo à taxa média cumulativa anual de 5%, o que confirma o valor acima.

A média brasileira estimada de consumo anual por domicílio aumentou de 405 kWh em 1944, para 683 kWh em 1952, correspondendo ao acréscimo de 14% em 8 anos. Esse valor também se harmoniza com o aumento estimado do número de consumidores.

As emprêsas do grupo da "Brazilian Traction, Ligh and Power Co." (Rio e São Paulo) e as 11 do grupo das Emprêsas Elétricas Brasileiras tiveram o número de consumidores aumentado de 873.957 em 1944 para 1.390.300 em 1952, ou seja um acréscimo de 59%; o consumo domiciliar aumentou de 532,8 milhões de kWh para 1.399,4 milhões de kWh, correspondendo ao acréscimo de 154%. O consumo específico anual por consumidor passou de 610 kWh para 970 kWh, correspondendo ao acréscimo de 59%. A capacidade geradora conjunta dêsses dois grupos passou de 893.700 kW em 1940 a 1.221.910 kW em 1952, representando o aumento de 37%.

Será interessante assinalar que a capacidade geradora de tôdas as demais emprêsas passou do mesmo período de 440.508 kW para 750.105 kW, tendo havido o aumento de 70%. Isso põe em evidência o fato de ser a crise de energia sentida com mais intensidade nos centros supridos por aquelas duas maiores emprêsas do País.

## VII. UTILIZAÇÃO DA ENERGIA ELÉTRICA PELA INDÚSTRIA NO BRASIL

No Anexo 5 é apresentado o sumário da fôrça motriz instalada nos estabelecimentos industriais, bem como o valor da respectiva produção, de acôrdo com o resultado apresentado pelo Recenseamento do Brasil em 1940 e 1950.

Para a devida apreciação do grau de eletrificação realizado pela indústria, será interessante estabelecer correlação entre a potência total e elétrica utilizada na mesma, a mão de obra empregada e o valor da produção industrial.

O Quadro VI foi preparado com as informações colhidas nas publicações dos Recenseamentos de 1920, 1940 e 1950.

QUADRO VI

### UTILIZAÇÃO DA ENERGIA ELÉTRICA PELA INDÚSTRIA NO BRASIL.

| **Anos dos Censos** | 1920 | 1940 | 1950 |
|---|---|---|---|
| 1. População do Brasil, habitantes | 30.635.605 | 41.236.315 | 51.944.397 |
| 2. Número de estabelecimentos industriais | 13.336 | 49.418 | 89.086 |
| 3. Número de operários empregados | 275.512 | 781.185 | 1.256.807 |
| 4. Percentagem da população empregada na indústria — % | 0,90 | 1,90 | 2,40 |
| 5. Potência total utilizada — HP | 310.361 | 1.186.358 | 2.667.017 |
| 6. Potência total por operário — HP | 1,13 | 1,51 | 2,12 |
| 7. Potência elétrica utilizada — HP | 146.500 | 885.926 | 2.350.000 |
| 8. Potência elétrica por operário — HP | 0,53 | 1,12 | 1,87 |
| 9. Percentagem de eletrificação — % | 47,50 | 76,00 | 85,00 |
| 10. Valor da produção industrial, milhões de Cr$ | 2.989 | 17.479 | 116.747 |
| 11. Valor da produção industrial, por operário — Cr$ | 10.800 | 22.400 | 93.100 |
| 12. Valor da produção industrial por HP total — Cr$ | 9.590 | 14.900 | 43.900 |

**NOTA:** — O valor da potência elétrica utilizada (item 7) em 1950 foi estimada. Conseqüentemente resultaram dessa estimativa os itens 8 e 9. Todos os demais valores foram colhidos nas publicações dos Recenseamentos ou resultaram de operações feitas com dados exatos obtidos nessas publicações.

Do exame do quadro supra verifica-se que, a despeito da inflação de preços verificada entre 1940 e 1950, houve um aumento apreciável do rendimento do operário. Na verdade, passou êle a contar, em média, com mais 40% de fôrça motriz disponível (1,51 em 1940 para 2,12 HP em 1950). Não fôsse a crise de energia elétrica, que há vários anos se verifica em todo o País, aquela média já seria bastante mais significativa. E seria também mais expressiva a taxa de eletrificação.

A evolução da potência total utilizada por operário e também o valor da produção industrial por HP disponível nos Estados mais industrializados do País poderá ser apreciada no Quadro VII:

### Quadro VII

## POTÊNCIA TOTAL UTILIZADA POR OPERÁRIOS E VALOR DA PRODUÇÃO POR HP DISPONÍVEL

| ESTADOS | HP POR OPERÁRIO |  | VALOR DA PRODUÇÃO |  |
|---|---|---|---|---|
|  | Censo de 1940 | Censo de 1950 | Censo de 1940 | Censo de 1950 |
|  |  |  | Cr$ por HP |  |
| São Paulo | 1,39 | 2,19 | 17.150 | 51.500 |
| Distrito Federal | 0,91 | 1,68 | 24.200 | 62.600 |
| Rio Grande do Sul | 1,31 | 2,35 | 15.700 | 52.700 |
| Minas Gerais | 1,15 | 2,00 | 11.150 | 36.900 |
| Rio de Janeiro | 1,83 | 3,78 | 8.550 | 25.000 |
| Pernambuco | 1,16 | 1,62 | 10.150 | 38.800 |
| Paraná | 1,40 | 2,99 | 9.750 | 38.900 |
| Santa Catarina | 1,22 | 2,08 | 9.150 | 42.500 |
| BRASIL (média) | 1,51 | 2,12 | 11.900 | 43.900 |

FONTE: — Recenseamento Geral do Brasil em 1940 e 1950. Publicação do I.B.G.E.
NOTA: — Os valores da produção industrial se referem aos anos de 1939 e 1949.

O valor de HP por operário no Estado do Rio de Janeiro, em 1950, apresenta-se bem mais elevado que nos demais Estados, devido à influência da Usina Siderúrgica de Volta Redonda e das indústrias satélites que se estabeleceram nas imediações.

A evolução do consumo de eletricidade pela indústria brasileira foi a seguinte, em números redondos:

| | |
|---|---|
| 1939 | 733.000.000 kWh |
| 1944 | 1.811.000.000 kWh |
| 1952 | 3.880.000.000 kWh |

O dado de 1939 é o do Censo de 1940; o de 1944 foi estimado pela Comissão da Indústria de Material Elétrico (CIME) em 1945; e o de 1952 consta do Anexo 3 dêste trabalho.

Estima-se que a potência elétrica total instalada na indústria, em 1952, tenha sido de cêrca de 2.000.000 kW ou 2.720.000 HP. Nessas condições, a relação média entre o consumo industrial e essa potência elétrica instalada foi da ordem de 1.940 kWh/kW. Esse valor parece razoável porquanto corresponde a um fator de utilização de 21%.

Será interessante assinalar que, em média, um HP instalado na indústria produziu, em 1950, 43.900 cruzeiros de produtos industriais, valor que corresponde a 59.500 cruzeiros por kW. É verdade que uma parte dessa produção é realizada sem o auxílio de máquinas motrizes elétricas. Em todo o caso, êsse valor permite fazer algumas considerações. Partindo, pois, da premissa que um kW instalado na indústria poderá produzir em média cêrca de 60.000 cruzeiros de bens industriais por ano, e admitindo um fator de diversidade de 2,5 entre o consumidor industrial e a usina geradora, conclui-se que um kW instalado em usina geradora poderá produzir anualmente 150.000 cruzeiros em bens industriais. O custo médio do kW, desde a usina geradora até o consumidor, é atualmente da ordem de 12.000 cruzeiros. Verifica-se, assim, que um kW instalado em usina geradora poderá produzir, em um ano, doze vêzes e meia o seu valor em bens industriais.

## VIII. TRANSPORTES URBANOS

O número de carros motores e extensão total de linhas em 28 cidades brasileiras, servidas por ferro-carris de uso público, foram obtidos no Anuário Estatístico do Brasil, Ano XIII — 1952.

Com base nestas informações e adotando as mesmas percentagens contidas no relatório da Comissão Executiva da Indústria de Material Elétrico (CIME), relativamente ao ano de 1914, estimou-se os demais valores, isto é, número total de motores, potência total dos motores e potência média por motor.

Nessas condições, o serviço tranviário no Brasil, em 1950, apresentou as seguintes características:

| | |
|---|---|
| 1) — número total de carros-motor ...... | 2.381 |
| 2) — número total de motores .......... | 5.967 |
| 3) — potência total dos motores ......... | 282.335 HP |
| 4) — potência média por motor ........ | 47,3 HP |
| 5) — extensão das linhas .............. | 1.903,0 km |

Para o ano de 1952 pode ser adotada a estimativa acima sem incorrer em grande êrro, porquanto o Serviço Tranviário no Brasil, nestes últimos anos, pouco se tem desenvolvido. A tendência tem sido para reduzir e até eliminar êsse serviço público.

O serviço de troleibus desenvolve-se ràpidamente em algumas cidades brasileiras. Constitui uma solução muito interessante para o tráfego urbano de superfície. Na verdade, o troleibus possui uma flexibilidade de movimentos muito maior do que os veículos sôbre trilhos, evitando o congestionamento da via pública. Além disso, se comparado com ônibus propulsionados por motores de combustão interna, o serviço de troleibus proporcionará uma economia na importação de combustíveis, especialmente quando a eletricidade é produzida em usinas hidrelétricas.

A cidade de São Paulo foi a primeira a inaugurar êsse serviço, sendo êle operado pela Companhia de Transportes Coletivos (CMTC). Atualmente a extensão das linhas simples é de 36.700 metros, cogitando-se elevar a extensão a 50.000 metros. Estão em operação 30 carros, dos quais 20 de fabricação "Westram" com motor elétrico de 140 HP, 6 de fabricação "Pullman" com motor elétrico de 140 HP e 4 de fabricação da "British United Transit Co." (BUT) com motor elétrico de 165 HP. A CMTC está adquirindo mais 50 carros alemães (Verdingen) grandes.

Em Belo Horizonte estão em funcionamento 8.000 metros de linha singela com 4 carros "Twin Coach", com motor Westinghouse de 140 HP. Estão em construção 3.200 metros de linha singela e em projeto 82.000 metros. O número total de carros será elevado a 84.

A cidade de Niterói já possui 15 carros "Vetia", fabricados na França, com motor de 130 HP cada um. Foi iniciada a construção de 41.600 metros de via singela.

A potência média de cada troleibus é de 140 HP. A potência total dos carros já em funcionamento no País é de 4.860 HP, elevando-se a 10.710 HP com o início de operação do serviço em Niterói. Com os novos carros programados para São Paulo e Belo Horizonte aquêle total se elevará de mais 18.200 HP, admitindo a potência média de 140 HP por unidade.

## IX. ELETRIFICAÇÃO FERROVIÁRIA

O consumo de combustível e energia elétrica pelas estradas de ferro do País no serviço de tração está indicado no Quadro VIII, para os anos de 1918 a 1952.

Quadro VIII

CONSUMO DE COMBUSTÍVEL E ENERGIA ELÉTRICA NO SERVIÇO DE TRAÇÃO FERROVIÁRIA, NO QÜINQÜÊNIO 1918-1952

| | 1948 | 1949 | 1950 | 1951 | 1952 |
|---|---|---|---|---|---|
| *Lenha*, 1.000 m³ | 12.593 | 11.439 | 11.219 | 11.669 | 10.042 |
| *Carvão de Pedra* | | | | | |
| Nacional, ton | 808.805 | 865.384 | 886.326 | 930.457 | 1 079.789 |
| Estrangeiro, ton | 419.185 | 385.785 | 310.906 | 317.298 | 197.097 |
| | 1.227.990 | 1.251.169 | 1.197.232 | 1.247.755 | 1 276.886 |
| *Combustível líquido* | | | | | |
| Óleo Diesel, ton | 21.634 | 29.509 | 32.908 | 33.350 | 38.769 |
| Outros, ton | 81.158 | 106.863 | 196.537 | 235.287 | 273.605 |
| | 102.792 | 136.372 | 229.445 | 268.637 | 312.374 |
| *Energia elétrica*, 1.000 kWh | 278.071 | 313.933 | 337.199 | 369.107 | 383.095 |

FONTE: Estatística das Estradas de Ferro do Brasil.
Principais dados relativos ao qüinqüênio 1948-1952 — Departamento Nacional de Estradas de Ferro.

A modificação do consumo de combustíveis e de energia elétrica, bem como a despesa total com essas fontes de energia pode ser apreciada no Quadro IX.

### QUADRO IX

## CONSUMO DE COMBUSTÍVEL E ENERGIA ELÉTRICA E RESPECTIVA DESPESA NO SERVIÇO DE TRAÇÃO FERROVIÁRIA, NO QÜINQÜÊNIO 1918-1952

NÚMEROS ÍNDICES

| | 1948 | 1949 | 1950 | 1951 | 1952 |
|---|---|---|---|---|---|
| Lenha ................. | 100 | 91 | 89 | 93 | 87 |
| Carvão estrangeiro ..... | 100 | 90 | 72 | 71 | 46 |
| Carvão nacional ........ | 100 | 107 | 110 | 115 | 134 |
| Óleo Diesel ............ | 100 | 136 | 152 | 151 | 179 |
| Outros líquidos ........ | 100 | 132 | 212 | 290 | 327 |
| Outros sólidos ......... | 100 | 8 | 0 | 132 | 49 |
| Energia elétrica ........ | 100 | 113 | 121 | 133 | 138 |
| Despesa total .......... | 100 | 103 | 105 | 129 | 115 |

**FONTE**: Estatística das Estradas de Ferro do Brasil — Principais dados relativos ao qüinqüênio 1948-1952 — Departamento Nacional de Estradas de Ferro.

Os serviços de tração elétrica vêm-se desenvolvendo progressivamente, embora em escala aquém da que é recomendada, face à necessidade imperiosa de restringir, tanto quanto possível, o consumo de lenha e de combustíveis líquidos importados.

O Quadro X indica a extensão das linhas eletrificadas em 1929, 1952 e outubro de 1953, bem como a tensão de operação das linhas de contacto e o ano inicial da eletrificação.

### Quadro X

## EXTENSÃO DE LINHAS ELETRIFICADAS, TENSÃO DE OPERAÇÃO E ANO INCIAL DE OPERAÇÃO

| ESTRADAS DE FERRO | EXTENSÃO DE LINHAS ELETRIFICADAS KM LINEARES | | | | TENSÃO DA LINHA DE CONTACTO Volts c. c. | ANO INICIAL DA ELETRIFICAÇÃO |
|---|---|---|---|---|---|---|
| | 1929 Em Tráfego | 1952 Em Tráfego | Outubro de 1953 | | | |
| | | | Em Tráfego | Em Construção | | |
| E. F. Corcovado | 4 | 4 | 4 | — | 750 | 1916 |
| E. F. Morro Velho | 8 | 8 | 8 | — | 500 | 1910 |
| E. F. Campos do Jordão | 47 | 47 | 47 | — | 750 | 1918 |
| Ramal Férreo Campineiro | 31 | 28 | 28 | — | 600 | 1920 |
| E. F. Votorantim | — | 11 | 11 | — | 600 | 1928 |
| Cia. Paulista de Estrada de Ferro | 286 | 451 | 451 | — | 3.000 | 1922 |
| Rêde Mineira de Viação | 73 | 181 | 333 | — | (1.500)<br>(3.000) | 1929 |
| E. F. Central do Brasil | — | 193 | 193 | — | 3.000 | 1937 |
| E. F. Sorocabana | — | 236 | 357 | — | 3.000 | 1944 |
| E. F. Santos Jundiaí | — | 87 | 174 | — | 3.000 | 1950 |
| Viação Férrea Federal Leste Brasileiro | | — | — | 245 | 3.000 | 1953 |
| Rêde Viação Paraná Santa Catarina | — | — | — | 110 | 3.000 | 1953 |
| TOTAL | 419 | 1.319 | 1.609 | 355 | — | — |

FONTE: Estatística das Estradas de Ferro do Brasil — Principais dados relativos ao qüinqüênio 1948-1952 — Departamento Nacional de Estradas de Ferro

O consumo de eletricidade pelos serviços de tração elétrica das principais estradas de ferro é indicado no Quadro XI, nos anos de 1948 a 1952.

### QUADRO XI

### CONSUMO DE ELETRICIDADE NO SERVIÇO DE TRAÇÃO ELÉTRICA — QÜINQÜÊNIO: 1948-1952

| | 1.000 kWh | | | | |
|---|---|---|---|---|---|
| | 1948 | 1949 | 1950 | 1951 | 1952 |
| Estrada de Ferro Central do Brasil | 86.766 | 108.806 | 113.016 | 106.250 | 95.019 |
| Estrada de Ferro Santos-Jundiaí | — | — | 10.008 | 27.496 | 35.579 |
| Companhia Paulista de Estradas de Ferro | 133.486 | 141.179 | 141.993 | 151.826 | 159.093 |
| Estrada de Ferro Sorocabana | 45.205 | 56.270 | 59.455 | 69.659 | 80.334 |
| Rêde Mineira de Viação | 6.092 | 5.606 | 5.754 | 6.533 | 5.262 |
| Viação Férrea Federal Leste Brasileiro | — | — | — | — | — |
| Rêde Viação Paraná-Santa Catarina | — | — | — | — | — |
| Estrada de Ferro Corcovado | 343 | 343 | 343 | 343 | 329 |
| Estrada de Ferro Morro Velho | 312 | 801 | 798 | 772 | 712 |
| Estrada de Ferro Campos do Jordão | 1.031 | 981 | 921 | 889 | 833 |
| Ramal Férreo Campineiro | 441 | 458 | 434 | 434 | — |
| Estrada de Ferro Votorantim | 4.398 | 4.184 | 4.477 | 5.105 | 5.904 |
| TOTAL | 278.074 | 318.933 | 337.199 | 369.107 | 383.[illegible]5 |

FONTE: — Estatística das Estradas de Ferro — Dados relativos ao Qüinqüênio 1948-1952 — Departamento Nacional de Estradas de Ferro.

As características das locomotivas elétricas em serviço nas principais ferrovias, em outubro de 1953, estão indicadas no Quadro XII.

O número e a capacidade do equipamento de conversão de corrente alternada para corrente contínua acham-se discriminados no Quadro XIII (Situação em outubro de 1953).

O serviço de tração por meio de locomotivas Diesel-elétricas vem se desenvolvendo apreciàvelmente, tendo a potência total das 411 locomotivas em tráfego atingido 438.081 HP em outubro de 1953.

O Quadro XIV indica o número e a potência das locomotivas Diesel-elétricas em tráfego no País, em outubro de 1953.

## QUADRO XII

## CARACTERÍSTICAS DAS LOCOMOTIVAS ELÉTRICAS DAS PRINCIPAIS FERROVIAS

| ESTRADAS DE FERRO | Quantidade de Locomotivas | Tipo | Pêso Total de cada ton. | POTÊNCIA UNIHORÁRIA — OUTUBRO/53 — HP | | Alimentação Volts |
|---|---|---|---|---|---|---|
| | | | | De cada | Total | |
| Estrada de Ferro Central do Brasil | 1 | B+B | 48 | 700 | 700 | 3.060 - c.c. |
| | 5 | B+B | 53 | 1.240 | 6.200 | 3.000 - c.c. |
| | 15 | 2-C+C-2 | 165 | 4.400 | 66.000 | 3.000 - c.c. |
| SUB-TOTAL | 21 | — | — | — | 72.900 | — |
| Trens unidades | 101 | — | — | 700 | 70.700 | 3.000 - c.c. |
| TOTAL | 122 | — | — | — | 143.600 | — |
| Estrada de Ferro Santos-Jundiaí | 15 | C+C | 120 | 3.000 | 45.000 | 3.000 - c.c. |
| Cia. Paulista de Estradas de Ferro | 17 | B+B | 56 | 662 | 11.254 | 3.000 - c.c. |
| | 2 | C+C | 106 | 1.620 | 3.240 | 3.000 - c.c. |
| | 8 | B+B | 89 | 1.665 | 13.320 | 3.000 - c.c. |
| | 8 | C+C | 107 | 1.650 | 13.200 | 3.000 - c.c. |
| | 4 | 2-B+B-2 | 107 | 1.665 | 6.660 | 3.000 - c.c. |
| | 3 | 1-B+B-1 | 129 | 2.160 | 6.480 | 3.000 - c.c. |
| | 1 | 1-C+C-1 | 101 | 2.160 | 2.160 | 3.000 - c.c. |
| | 9 | 1-C+C-1 | 135 | 2.485 | 22.365 | 3.000 - c.c. |
| | 1 | 1-D-1 | 123 | 3.180 | 3.180 | 3.000 - c.c. |
| | 22 | 2-C+C-2 | 165 | 4.260 | 93.720 | 3.000 - c.c. |
| | 5 | 2-D+D-2 | 246 | 5.125 | 25.625 | 3.000 - c.c. |
| TOTAL | 80 | — | — | — | 201.204 | — |
| Estrada de Ferro Sorocabana | 46 | 1-C+C-1 | 130 | 2.195 | 98.775 | 3.000 - c.c. |
| Trens unidades | 4 | — | — | 740 | 2.960 | 3.000 - c.c. |
| TOTAL | 50 | — | — | — | 101.735 | — |
| Rêde Mineira de Viação | 14 | B+B | 50 | 1.070 | 14.980 | 3.000 - c.c. |
| | 8 | B+B | 48 | 965 | 7.720 | 1.500 - c.c. |
| | 5 | B+B | 46 | 600 | 3.000 | 1.500 - c.c. |
| TOTAL | 27 | — | — | — | 25.700 | — |
| Viação Férrea Federal Leste Brasileiro | 10 | B+B | 50 | 1.070 | 10.700 | 3.000 - c.c. |
| Rêde Viação Paraná-Santa Catarina | 10 | B+B | 50 | 1.070 | 10.700 | 3.000 - c.c. |
| TOTAL GERAL | 314 | — | — | — | 538.639 | — |

FONTE: — Dados colhidos pelos autores.

## QUADRO XIII

## NÚMERO E CAPACIDADE DE EQUIPAMENTOS DE CONVERSÃO DE CORRENTE ALTERNADA PARA CORRENTE CONTÍNUA

| | RETIFICADORES | | MOTORES-GERADORES | | Capacidade total do equipamento de conversão kW |
|---|---|---|---|---|---|
| | Quantidade | Capacidade kW | Quantidade | Capacidade individual kW | |
| Estrada de Ferro Central do Brasil | 11 | 2.000 | — | — | 55.000 |
| | 6 | 2.500 | — | — | |
| | 6 | 3.000 | — | — | |
| Estrada de Ferro Santos-Jundiaí | 6 | 2.000 | — | ... | 12.000 |
| Companhia Paulista de Estradas de Ferro | | | 11 | 1.500 | 10.500 |
| | | | 6 | 2.000 | |
| | 1 | 3.000 | 3 | 3.000 | |
| Estrada de Ferro Sorocabana | 17 | 2.000 | 8 | 2.000 | 50.000 |
| Rêde Mineira de Viação | 1 | 250 | ... | ... | 12.500 |
| | 2 | 500 | — | — | |
| | 7 | 1.500 | — | — | |
| Viação Férrea Federal Leste Brasileiro | 5 | 1.500 | — | — | 7.500 |
| Rêde Viação Paraná-Santa Catarina | 6 | 1.500 | — | — | 9.000 |
| TOTAL | 71 | — | 28 | | 186.500 |

FONTE: — Dados colhidos pelos autores.

## X. ESTIMATIVA DO CRESCIMENTO FUTURO DOS SERVIÇOS DE ELETRICIDADE NO BRASIL

No Quadro I foi apresentado o desenvolvimento da indústria de eletricidade no Brasil, desde junho de 1883 até 31 de dezembro de 1952.

Com os dados relativos à capacidade instalada foi preparado o Gráfico I, onde também estão indicadas as razões de crescimento por decênio.

### QUADRO XIV

### NÚMERO E POTÊNCIA DAS LOCOMOTIVAS DIESEL-ELÉTRICAS, EM OUTUBRO DE 1953

| ESTRADAS DE FERRO | Quantidade de locomotivas | POTÊNCIA — HP | |
|---|---|---|---|
| | | De cada | Total |
| Estrada de Ferro Central do Brasil ...... | 120 | 1.600 | 192.000 |
| | 12 | 1.500 | 18.000 |
| | 38 | 1.000 | 38.000 |
| | 5 | 660 | 3.300 |
| TOTAL ........................ .... | 175 | — | 251.000 |
| Estrada de Ferro Santos-Jundiaí ......... | 10 | 1.000 | 10.000 |
| | 3 | 2.250 | 6.750 |
| Companhia Paulista de Estradas de Ferro .. | 12 | 1.600 | 19.200 |
| TOTAL ...... .......... .......... | 15 | — | 25.950 |
| Estrada de Ferro Sorocabana ...... ...... | 15 | 1.200 | 18.000 |
| | 42 | 600 | 25.200 |
| | 10 | 330 | 3.300 |
| TOTAL ......................... | 67 | — | 46.500 |
| Viação Férrea Federal Leste Brasileiro .... | 3 | 467 | 1.401 |
| | 8 | 380 | 3.040 |
| | 2 | 725 | 1.450 |
| | 15 | 660 | 9.900 |
| TOTAL ... .... .................. | 28 | — | 15.791 |
| Rêde Viação Paraná-Santa Catarina ...... | 6 | 150 | 900 |
| | 8 | 660 | 5.280 |
| | 16 | 1.400 | 14.000 |
| | 10 | 1.600 | 16.000 |
| TOTAL ......... .................. | 34 | — | 36.180 |
| Companhia Mogiana de Estradas de Ferro | 12 | 660 | 7.920 |
| Rêde Ferroviária do Nordeste . .......... | 13 | 1.000 | 13.000 |
| Rêde Viação Cearense .................. | 15 | 650 | 9.750 |
| Estrada de Ferro Vitória-Minas .......... | 9 | 1.100 | 9.900 |
| | 2 | 650 | 1.300 |
| TOTAL ............... .......... | 11 | 1.750 | 11.200 |
| Estrada de Ferro Leopoldina ............ | 1 | 650 | 650 |
| TOTAL GERAL .... ....... . | 381 | — | 427.941 |
| TOTAL PERTENCENTE A OUTRAS ENTIDADES | 33 | — | 10.140 |
| GRANDE TOTAL ............ | 414 | — | 438.081 |

FONTE: — Dados colhidos pelos autores.

Será interessante recapitular as razões médias cumulativas anuais do acréscimo da capacidade instalada nas usinas geradoras brasileiras:

| | |
|---|---|
| 1900 - 1910 | 29,5% |
| 1910 - 1920 | 8,4% |
| 1920 - 1930 | 7,8% |
| 1930 - 1940 | 4,9% |
| 1940 - 1950 | 4,2% |
| 1950 - 1952 | 2,5% |

Ressalta claramente da apreciação dêsses números o motivo da crise de energia elétrica verificada em todo o País, sobretudo no após-guerra, alcançando o seu ponto mais crítico no inverno de 1953. Em conseqüência, tiveram de ser adotadas medidas drásticas de racionamento no consumo de eletricidade, que causaram prejuízos imensos à economia e ao progresso do País, sem falar no desconfôrto impôsto às populações.

Essa crise prolongada de eletricidade, motivada sobretudo pela deficiência de capacidade geradora, é devida ao atraso sofrido, por causas várias, predominando a dificuldade de conseguir equipamento no após guerra, nos programas de obras das emprêsas de eletricidade, especialmente nos grandes sistemas.

Com efeito, o Grupo Light, cujo sistema supre os dois maiores centros econômicos do País, que se formaram em tôrno da Capital Federal e da cidade de São Paulo, havia programado (Plano Salte), para o período de 1947-1953, o acréscimo de capacidade instalada de 505.000 kW. No entanto, até dezembro de 1953, êsse aumento não passará de ..... 241.314 kW.

O Grupo das Emprêsas Elétricas Brasileiras havia programado para o mesmo período de 1947-1953, 204.000 kW de capacidade geradora adicional, tendo instalado apenas 66.036 kW.

No conjunto brasileiro a estimativa do Plano Salte previa o acréscimo de capacidade geradora instalada de 1.340.572 kW, entre 1947 e 1953. Entretanto, nesse período, o acréscimo não ultrapassará de ...... 583.000 kW.

Será oportuno mencionar que nos grandes sistemas a capacidade instalada cresceu em média de 25 a 30%, entre 1947 e 1953, ao passo que no conjunto das pequenas e médias emprêsas êsse acréscimo alcançou 50%.

Verifica-se daí que o atual "déficit" de capacidade geradora para atender às necessidades mais imediatas do País é da ordem de um milhão de kilowatts (1.000.000 kW).

Os programas de ampliação da capacidade instalada em usinas geradoras são apresentados no Anexo 7, para o período de 1953-1957. Em sua maioria, trata-se de obras em andamento, com grande probabilidade de serem executadas no período considerado.

No Quadro XV encontra-se o resumo dêsses programas de ampliação. No Gráfico I foram traçadas, para o qüinqüênio de 1953-1957, as curvas da estimativa do acréscimo da capacidade instalada.

Será feita a seguir uma referência suscinta aos principais programas de ampliação da capacidade geradora instalada, entre 1953 e 1957.

*Grupo Light* — A Cia. de Carris, Luz e Fôrça do Rio de Janeiro tem o seguinte programa:

a) instalação de seis geradores na Usina Subterrânea de Forçacava, com capacidade total de 330.000 kW, dos quais 70.000 kW (2 grupos de 35.000 kW) foram postos em operação em 1953 e os restantes quatro de 65.000 kW o serão durante o primeiro semestre de 1954.

b) construção da Usina Auxiliar de Lages, à jusante das Usinas de Fontes e Forçacava, com a capacidade entre 90.000 kW e 150.000 kW. Início de operação previsto para 1957.

c) Construção das barragens de regularização no Alto Paraiba para assegurar o volume d'água suficiente às usinas de Fontes e Forçacava, bem como a construção do segundo estágio de ampliação da Usina de Fontes e a Usina de Fio D'água, no Rio Paraiba, à jusante de Santa Cecilia.

A São Paulo Light and Power Co. Ltd. e companhias aliadas têm o seguinte programa de obras:

a) Construção de uma seção subterrânea com o total de seis grupos geradores de 75.000 kVA cada, na Usina de Cubatão, estando prevista a entrada em serviço de duas unidades em cada um dos anos de 1955, 1956 e 1957.

b) Construção da Usina Térmica Piratininga e que contará inicialmente com dois grupos geradores de 80.000 kW cada um, estando seu funcionamento previsto para o segundo semestre de 1954.

c) Obras de regularização dos cursos d'água que alimentam as usinas do sistema.

*Grupo das Emprêsas Elétricas Brasileiras* — O Grupo das Emprêsas Elétricas Brasileiras tem programado o adicional de 179.500 kW de capacidade geradora para o qüinqüênio 1953-1957, elevando a mesma de 266.837 em 1952 para 446.337 em 1957. A obra mais importante é o aproveitamento hidrelétrico de Peixoto, no Rio Grande, Estado de Minas Gerais. Esta usina será interligada ao extenso sistema da Cia. Paulista

## QUADRO XV

## PROGRAMAS DE AMPLIAÇÃO DA CAPACIDADE GERADORA NO QÜINQÜÊNIO 1953-1957

| USINAS | 1952 CAPACIDADE INSTALADA kW | ESTIMATIVA DE ACRÉSCIMO DA CAPACIDADE GERADORA — kW | | | | | |
|---|---|---|---|---|---|---|---|
| | | 1953 | 1954 | 1955 | 1956 | 1957 | TOTAL |
| Hidrelétricas | 1.602.627 | 86.300 | 518.650 | 224.000 | 424.825 | 428.550 | 1.682.325 |
| Termelétricas | 372.388 | 18.995 | 216.000 | 40.000 | 20.000 | 45.000 | 339.995 |
| TOTAL | 1.975.015 | 105.295 | 734.650 | 264.000 | 444.825 | 473.550 | 2.022.320 |
| Total acumulado do acréscimo | — | 105.295 | 839.945 | 1.103.945 | 1.548.770 | 2.022.320 | 2.022.320 |
| Total acumulado da capacidade instalada | 1.975.015 | 2.080.310 | 2.814.960 | 3.078.960 | 3.523.785 | 3.997.335 | — |
| Percentagem de acréscimo sôbre o ano anterior | | 5,1 | 35,3 | 9,4 | 14,4 | 13,4 | — |

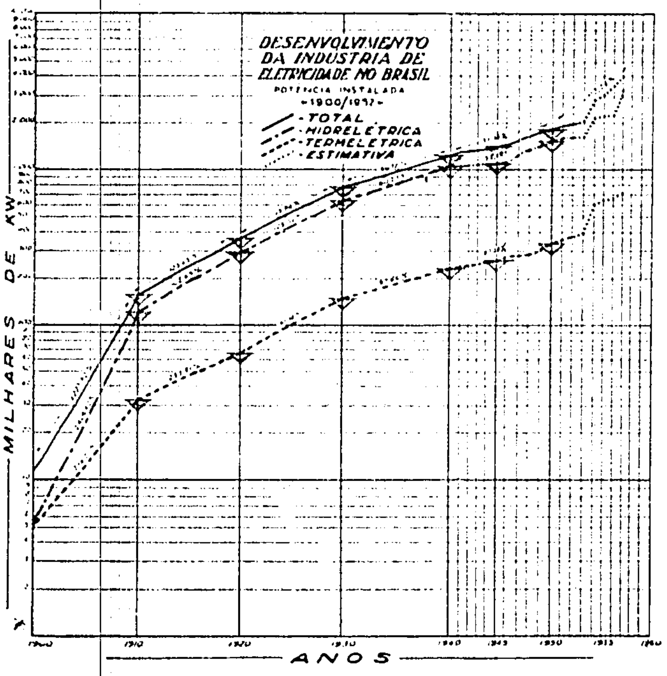
FONTE: — Dados colhidos pelos autores.

de Fôrça e Luz, no Estado de São Paulo. A potência total disponivel nesse aproveitamento é de cêrca de 400.000 kW, sendo inicialmente instalados 2 grupos de 40.000 kW, que deverão estar instalados em 1956.

No Estado de São Paulo está em final de construção a usina termelétrica de Carioba, com capacidade inicial de 30.000 kW, cuja operação está prevista para 1954.

No Estado do Paraná a capacidade adicional prevista é de 25.000 kW e no Estado do Rio de Janeiro de 20.000 kW.

*Estado de Minas Gerais* — No Estado de Minas Gerais, entre as obras a cargo das Centrais Elétricas de Minas Gerais, destacam-se: a Usina Hidrelétrica de Salto Grande com a potência total de 100.000 kW, sendo



50.000 kW na primeira etapa programada para estar concluída em fins de 1954, e a segunda etapa com mais 50.000 kW prevista para 1957; as obras da Usina Hidrelétrica de Itutinga com a capacidade total de 24.000 kW em duas etapas de 12.000 kW, sendo a primeira para fins de 1954 e a segunda para fins de 1956.

O total da capacidade geradora prevista para ser instalada entre 1953 e 1957 é de cêrca de 130.000 kW.

*Estado do Rio Grande do Sul* — No Rio Grande do Sul, as obras mais importantes, a cargo da Comissão Estadual de Energia Elétrica, são: a Usina Hidrelétrica de Canastra com 42.000 kW de potência, estando sua entrada em operação prevista para fins de 1955; a Usina de Salto Grande do Jacuí, já iniciada, com a potência final de 140.000 kW, sendo instaladas inicialmente duas unidades de 23.300 kW cada uma, num total de 46.600 kW, com entrada em operação prevista para o início de 1957, e, finalmente, a usina térmica de Candiota com a capacidade de 20.000 kW. O plano total de obras compreende a instalação de 139.800 kW no período 1953-1957.

*Companhia Hidro Elétrica do São Francisco* — A Companhia Hidro Elétrica do São Francisco, que está realizando o aproveitamento da energia hidráulica da cachoeira de Paulo Afonso, ultima a montagem dos dois primeiros grupos de 60.000 kW, cuja entrada em operação está prevista para o segundo semestre de 1954. Foi já iniciada a instalação da terceira unidade geradora, idêntica às duas primeiras, estando previsto o início de sua operação em fins de 1955.

A capacidade geradora total a ser instalada pela Companhia Hidro Elétrica do São Francisco será de 180.000 kW, no qüinqüênio 1953-1957.

* * *

Inúmeros outros programas de ampliação da potência de usinas geradoras de eletricidade estão em andamento. Seria por demais extenso mencioná-los um a um.

Para o conjunto brasileiro estima-se que, no período de 1953-1957, o acréscimo da capacidade geradora será de cêrca de 2.000.000 de kW, pràticamente dobrando o valor da existente em fins de 1953.

Será oportuno referir às importantes medidas que estão sendo adotadas pelo Govêrno da União, para promover os recursos necessários a um amplo programa de eletrificação, em complemento ao que está a cargo da iniciativa privada. Com essa finalidade encontram-se no Congresso Nacional, em final de tramitação, dois projetos de Lei, um instituindo o "Fundo Federal de Eletrificação" e criando o impôsto único sôbre energia elétrica, e o outro dispondo sôbre a distribuição e aplicação das quotas dêsse impôsto único, entre a União, Estados, Distrito Federal e Municípios.

As necessidades brasileiras em novas instalações geradoras de eletricidade, no qüinqüênio 1953-1957, foram estimadas, na Mensagem Presidencial que encaminhou aquêles projetos de Lei, da seguinte forma:

| | |
|---|---|
| Déficit atual ..................... | 1.000.000 kW |
| Crescimento em 5 anos ....... | 1.900.000 kW |
| Total ........................ | 2.900.000 kW |

Em dez anos, mantendo-se a taxa anual de crescimento de 10%, deverão ser providas novas instalações num total de 5.900.000 kW.

Os programas de ampliação, anteriormente referidos nesse capítulo, em sua maior parte em andamento, prevêm a instalação da capacidade adicional de cêrca de 2.000.000 kW, no qüinqüênio 1953-1957. Dessa forma, para ser alcançada a meta de 2.900.000 kW, estimada na Mensagem Presidencial, será necessário que, por conta dos recursos do "Fundo Federal de Eletrificação", sejam instalados ainda 900.000 kW até 1957, o que constituirá tarefa difícil, mas não impossível de ser cumprida, desde que as dotações iniciais daquele "Fundo" sejam aplicadas em projetos já elaborados.

Os recursos previstos em conseqüência do "Fundo Federal de Eletrificação", estimados em 30 bilhões de cruzeiros em 10 anos, proporcionarão à União cêrca de 20 bilhões de cruzeiros e aos Estados e Municípios cêrca de 10 bilhões de cruzeiros.

## Resumo

Em síntese, os autores da monografia — "Balanço dos Serviços de Eletricidade no Brasil" — expõem, da maneira mais condensada possível, a evolução dos serviços de eletricidade no País, examinam a situação dêsses serviços em anos recentes, analisam a utilização da energia elétrica pelas principais classes de consumidores, para concluirem o trabalho, apresentando os programas de ampliação da capacidade geradora das emprêsas de eletricidade no qüinqüênio 1953-1957.

É feito, inicialmente, o histórico suscinto da indústria de eletricidade no Brasil, desde junho de 1883 até 31 de dezembro de 1952. Digno de menção especial é que a razão de crescimento média cumulativa anual da capacidade instalada decresceu progressivamente de 29,5% no decênio 1900-1910, para 8,1% no decênio 1910-1920, 7,8% no decênio 1920-1930, 4,9% no decênio 1930-1940, 1,2% no decênio 1940-1950, caindo a 2,5% no biênio 1950-1952.

No segundo capítulo, são confrontadas, ano por ano, a potência instalada e a produção de energia elétrica das usinas geradoras, no período de 1940 a 1952. Enquanto a capacidade instalada aumentou de 58,8%, a produção de energia elétrica elevou-se de 192%, e o fator de utilização médio geral passou de cêrca de 29% em 1940 a 54% em 1952, o que põe bem à mostra o grau de esgotamento em que se encontram as usinas geradoras brasileiras.

O terceiro capítulo apresenta a potência instalada nas usinas geradoras das unidades da Federação, no ano de 1952, discriminadamente segundo a origem térmica e hidráulica. O total das primeiras era de 372.388 kW (19%) e das segundas de 1.602.627 kW (81%), perfazendo o total geral de 1.975.015 kW.

A seguir, no capítulo IV, são apresentadas as características principais dos serviços de energia elétrica no País, relativas a 1952, notando-se que o fator de carga médio anual no conjunto brasileiro alcançou 61%, o que confirma o alto grau de esgotamento das usinas geradoras.

No capítulo V, encontra-se o resumo da classificação do consumo de energia elétrica em todo o Brasil, no ano de 1952. Êsse consumo, que alcançou 7.903 milhões de kWh, se distribuiu percentualmente do seguinte modo: domiciliar 25%, industrial 49% e outros 26%.

O capítulo VI analisa o consumo domiciliar de energia elétrica em 1952. O número de consumidores domésticos, nesse ano, foi estimado em 2.940.000, enquanto em 1944, segundo a estimativa feita então pela Comissão da Indústria de Material Elétrico (CIME), era de cêrca de 2.000.000. Houve, pois, um aumento de 47% em 8 anos. A média de consumo por domicílio elevou-se de 405 kWh em 1944 para 683 kWh em 1952. O acréscimo foi, assim, de 44% nos mesmos 8 anos

O capítulo VII focaliza a utilização da energia elétrica pela indústria brasileira, apresentando diversos dados comparativos referentes aos anos de 1920, 1940 e 1950. A potência elétrica disponível por operário passou de 0,53 HP em 1920 para 1,87 HP em 1950, e a percentagem de eletrificação da indústria evoluiu de 17,5% em 1920 para 85% em 1950.

No capítulo VIII é apreciada a situação dos serviços tranviários urbanos, cuja tendência é para desaparecer progressivamente. Para substituí-los começam a surgir em várias cidades brasileiras os mais modernos serviços de troleibus, que constituem uma excelente solução para a maioria das grandes cidades brasileiras, especialmente quando a eletricidade utilizada é de origem hidráulica.

A Eletrificação Ferroviária é analisada no capítulo IX, após algumas considerações preliminares sôbre o consumo de combustível e energia elétrica pelos serviços de tração. É interessante assinalar que o consumo de lenha e de carvão de pedra importado decresceu nesses últimos anos, ao passo que o de combustíveis líquidos tem aumentado acentua-

ANEXO I

# BRASIL

## POTENCIA INSTALADA EM USINAS GERADORAS

## PERIODO 1883-1952

| ANOS | — kW — | | |
|---|---|---|---|
| | TERMICA | HIDRAULICA | TOTAL |
| 1883 | 52 | — | 52 |
| 1889 | 3.143 | 1.475 | 4.618 |
| 1900 | 6.585 | 5.500 | 12.085 |
| 1910 | 21.996 | 137.864 | 159.860 |
| 1920 | 77.825 | 279.378 | 357.203 |
| 1930 | 148.752 | 630.050 | 778.802 |
| 1940 | 234.531 | 1.009.346 | 1.243.877 |
| 1941 | 242.243 | 1.019.015 | 1.261.258 |
| 1942 | 247.022 | 1.060.646 | 1.307.668 |
| 1943 | 248.275 | 1.067.063 | 1.315.438 |
| 1944 | 257.239 | 1.076.969 | 1.334.208 |
| 1945 | 261.806 | 1.079.827 | 1.341.633 |
| 1946 | 280.738 | 1.134.245 | 1.414.983 |
| 1947 | 282.973 | 1.251.164 | 1.534.137 |
| 1948 | 291.789 | 1.333.546 | 1.625.335 |
| 1949 | 304.331 | 1.430.860 | 1.735.191 |
| 1950 | 346.830 | 1.536.177 | 1.883.007 |
| 1951 | 355.190 | 1.584.756 | 1.939.946 |
| 1952 | 372.388 | 1.602.627 | 1.975.015 |

FONTE: — Divisão de Aguas do Ministerio da Agricultura.

ANEXO 2

## BRASIL

# EMPRESAS DE ELETRICIDADE. USINAS GERADORAS. NÚMERO E POTÊNCIA POR UNIDADES DA FEDERAÇÃO

## ANOS DE 1930. 1940. 1950

| UNIDADES DA FEDERAÇÃO | ANOS | NÚMERO DE EMPRÊSAS | USINAS GERADORAS EM 31-XII |  |  |  |  |  | POTÊNCIA |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | FORNECEDORAS |  |  | PRIVATIVAS |  | TOTAL | ORIGEM TÉRMICA |  |
|  |  |  | Termo Elétricas | Hidro Elétricas | Mistas | Termo Elétricas | Hidro Elétricas |  | Usinas fornecedoras | Usinas privativas |
| GUAPORÉ | 1930 | 1 | 2 | — | — | — | — | 2 | 235 | — |
|  | 1940 | 2 | 4 | — | — | — | — | 4 | 817 | — |
|  | 1950 | 3 | 4 | — | — | — | — | 4 | 708 | — |
| ACRE | 1930 | 7 | 7 | — | — | — | — | 7 | 197 | — |
|  | 1940 | 9 | 9 | — | — | — | — | 9 | 283 | — |
|  | 1950 | 11 | 11 | — | — | — | — | 11 | 853 | — |
| AMAZONAS | 1930 | 8 | 8 | — | — | — | — | 8 | 2.589 | — |
|  | 1940 | 26 | 26 | — | — | — | — | 26 | 3.737 | — |
|  | 1950 | 31 | 31 | — | — | — | — | 31 | 3.786 | — |
| RIO BRANCO | 1930 | — | — | — | — | — | — | — | — | — |
|  | 1940 | 1 | 1 | — | — | — | — | 1 | 20 | — |
|  | 1950 | 1 | 1 | — | — | — | — | 1 | 20 | — |
| PARÁ | 1930 | 16 | 16 | — | — | — | — | 16 | 6.998 | — |
|  | 1940 | 47 | 50 | 1 | — | — | — | 51 | 10.863 | — |
|  | 1950 | 54 | 57 | 1 | — | — | — | 58 | 6.327 | — |
| AMAPÁ | 1930 | — | — | — | — | — | — | — | — | — |
|  | 1940 | 1 | 1 | — | — | — | — | 1 | 5 | — |
|  | 1950 | 5 | 6 | — | — | — | — | 6 | 252 | — |
| MARANHÃO | 1930 | 10 | 10 | — | — | — | — | 10 | 1.320 | — |
|  | 1940 | 14 | 13 | 1 | — | — | — | 14 | 2.451 | — |
|  | 1950 | 14 | 13 | 1 | — | — | — | 14 | 2.492 | — |
| PIAUÍ | 1930 | 7 | 7 | — | — | — | — | 7 | 993 | — |
|  | 1940 | 18 | 18 | — | — | — | — | 18 | 2.006 | — |
|  | 1950 | 17 | 18 | — | — | — | — | 18 | 8.523 | — |
| CEARÁ | 1930 | 35 | 32 | 2 | 1 | — | — | 35 | 6.552 | — |
|  | 1940 | 72 | 67 | 6 | — | — | — | 73 | 12.219 | — |
|  | 1950 | 73 | 69 | 5 | — | 2 | — | 76 | 12.437 | 1.075 |
| RIO GRANDE DO NORTE | 1930 | 20 | 20 | — | — | — | — | 20 | 1.812 | — |
|  | 1940 | 37 | 37 | — | — | — | — | 37 | 3.807 | — |
|  | 1950 | 41 | 44 | — | — | — | — | 44 | 5.210 | — |
| PARAÍBA | 1930 | 40 | 38 | 2 | — | — | — | 40 | 5.173 | — |
|  | 1940 | 72 | 80 | 3 | — | — | — | 83 | 9.079 | — |
|  | 1950 | 72 | 80 | 3 | — | — | — | 83 | 11.552 | — |
| PERNAMBUCO | 1930 | 91 | 83 | 8 | 1 | — | 7 | 99 | 27.843 | — |
|  | 1940 | 125 | 118 | 14 | 1 | 1 | 7 | 141 | 43.565 | 1.506 |
|  | 1950 | 138 | 125 | 22 | — | 3 | 8 | 158 | 46.609 | 3.550 |
| ALAGOAS | 1930 | 39 | 31 | 5 | 2 | — | — | 38 | 7.032 | — |
|  | 1940 | 58 | 49 | 5 | 4 | — | — | 58 | 10.150 | — |
|  | 1950 | 58 | 48 | 5 | 4 | — | — | 57 | 10.321 | — |
| FERNANDO NORONHA | 1950 | 1 | 1 | — | — | — | — | 1 | 350 | — |
| SERGIPE | 1930 | 18 | 19 | — | — | 1 | 1 | 21 | 2.271 | 800 |
|  | 1940 | 31 | 32 | — | — | 1 | 1 | 34 | 4.149 | 1.125 |
|  | 1950 | 31 | 32 | — | — | 1 | 1 | 34 | 5.323 | 1.125 |
| BAHIA | 1930 | 36 | 25 | 11 | — | — | — | 39 | 7.101 | — |
|  | 1940 | 70 | 54 | 18 | — | — | — | 72 | 9.339 | — |
|  | 1950 | 107 | 62 | 25 | — | — | — | 87 | 14.958 | — |
| MINAS GERAIS | 1930 | 252 | 12 | 292 | 2 | — | 13 | 319 | 3.852 | — |
|  | 1940 | 336 | 32 | 371 | 3 | — | 17 | 423 | 10.121 | — |
|  | 1950 | 364 | 33 | 393 | 3 | — | 25 | 454 | 12.378 | — |
| ESPÍRITO SANTO | 1930 | 31 | 6 | 26 | — | — | 1 | 33 | 944 | — |
|  | 1940 | 50 | 11 | 41 | — | — | 1 | 53 | 1.043 | — |
|  | 1950 | 53 | 12 | 44 | — | — | 1 | 57 | 1.981 | — |
| RIO DE JANEIRO | 1930 | 62 | 15 | 60 | — | — | 11 | 86 | 3.185 | — |
|  | 1940 | 77 | 26 | 71 | — | 1 | 14 | 112 | 4.901 | 7.500 |
|  | 1950 | 79 | 28 | 67 | 1 | 5 | 15 | 116 | 5.678 | 23.882 |
| DISTRITO FEDERAL | 1930 | 1 | 1 | — | — | — | 2 | 3 | 15.200 | — |
|  | 1940 | 2 | 2 | — | — | — | 2 | 4 | 15.320 | — |
|  | 1950 | 2 | 3 | — | — | — | 2 | 5 | 40.320 | — |
| SÃO PAULO | 1930 | 108 | 24 | 128 | 1 | — | 13 | 166 | 13.529 | — |
|  | 1940 | 133 | 45 | 129 | 2 | — | 20 | 196 | 16.573 | — |
|  | 1950 | 131 | 49 | 134 | 1 | 2 | 21 | 210 | 18.842 | 2.600 |
| PARANÁ | 1930 | 31 | 19 | 17 | — | — | 3 | 39 | 4.741 | — |
|  | 1940 | 38 | 22 | 21 | 1 | 1 | 3 | 48 | 2.527 | 589 |
|  | 1950 | 39 | 23 | 26 | 1 | 1 | 6 | 57 | 4.118 | 589 |
| SANTA CATARINA | 1930 | 29 | 8 | 20 | 1 | — | 1 | 30 | 1.315 | — |
|  | 1940 | 72 | 23 | 59 | 2 | — | 1 | 85 | 2.477 | — |
|  | 1950 | 77 | 23 | 66 | [illegible] | [illegible] | [illegible] | [illegible] | 14.472 | — |
| RIO GRANDE DO SUL | 1930 | 131 | 99 | 55 | 3 | 2 | — | 159 | 33.009 | 1.477 |
|  | 1940 | 273 | 170 | 137 | 4 | 2 | — | 313 | 53.502 | 2.127 |
|  | 1950 | 288 | 173 | 157 | 4 | 3 | — | 337 | 80.080 | 2.788 |
| [illegible] | 1930 | 10 | 6 | 4 |  |  |  |  |  |  |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ALAGOAS | 1930 | 39 | 31 | 5 | 2 | | | | | | |
| | 1940 | 58 | 19 | 5 | 1 | | | | 10.110 | | |
| | 1950 | 58 | 18 | 5 | 1 | | | | 10.121 | | |
| FERNANDO NORONHA | 1950 | 1 | | | | | | | 350 | | |
| SERGIPE | 1930 | 18 | 19 | - | - | 1 | 1 | 21 | 2.271 | 800 | - |
| | 1940 | 31 | 32 | | - | 1 | 2 | 31 | 1.149 | 1.125 | - |
| | 1950 | 31 | 32 | -- | | 1 | 2 | 31 | 5.525 | 1.125 | - |
| BAHIA | 1930 | 36 | 25 | 11 | -- | - | | 39 | 7.401 | - | 15 |
| | 1940 | 70 | 51 | 18 | -- | | - | 72 | 9.339 | - | 15 |
| | 1950 | 107 | 62 | 25 | -- | - | | 87 | 14.938 | -- | 18 |
| MINAS GERAIS | 1930 | 252 | 12 | 292 | 2 | - | 15 | 319 | 3.852 | -- | 85 |
| | 1945 | 336 | 32 | 371 | 3 | - | 17 | 423 | 10.121 | -- | 126 |
| | 1950 | 364 | 33 | 393 | 3 | -- | 25 | 451 | 12.378 | -- | 182 |
| ESPIRITO SANTO | 1930 | 31 | 6 | 26 | -- | -- | 1 | 33 | 944 | -- | 7 |
| | 1940 | 50 | 11 | 41 | -- | - | 1 | 53 | 1.045 | -- | 7 |
| | 1950 | 53 | 12 | 44 | - | -- | 1 | 57 | 1.981 | -- | 8 |
| RIO DE JANEIRO | 1930 | 62 | 15 | 60 | -- | | 11 | 86 | 3.185 | -- | 172 |
| | 1940 | 77 | 26 | 71 | -- | 1 | 14 | 112 | 4.901 | 7.500 | 247. |
| | 1950 | 79 | 28 | 67 | 1 | 5 | 15 | 116 | 5.678 | 23.882 | 388 |
| DISTRITO FEDERAL | 1930 | 1 | 1 | -- | -- | | 2 | 3 | 15.200 | -- | -- |
| | 1940 | 2 | 2 | -- | -- | -- | 2 | 1 | 15.320 | -- | -- |
| | 1950 | 2 | 3 | -- | -- | -- | 2 | 5 | 40.320 | -- | -- |
| SÃO PAULO | 1930 | 108 | 24 | 128 | 1 | - | 13 | 166 | 13.529 | -- | 311. |
| | 1940 | 133 | 15 | 129 | 2 | -- | 20 | 196 | 16.573 | -- | 539. |
| | 1950 | 131 | 19 | 134 | 1 | 2 | 24 | 210 | 18.842 | 2.600 | 815. |
| PARANÁ | 1930 | 31 | 19 | 17 | | -- | 3 | 39 | 1.741 | -- | 2. |
| | 1940 | 58 | 22 | 21 | 1 | 1 | 3 | 48 | 2.527 | 589 | 12 |
| | 1950 | 39 | 23 | 26 | 1 | 1 | 6 | 57 | 4.118 | 589 | 21. |
| SANTA CATARINA | 1930 | 29 | 8 | 20 | 1 | -- | 1 | 30 | 1.315 | -- | 7. |
| | 1940 | 72 | 23 | 59 | 2 | -- | 1 | 85 | 2.477 | -- | 14. |
| | 1950 | 77 | 23 | 66 | 2 | -- | 4 | 95 | 14.472 | -- | 22. |
| RIO GRANDE DO SUL | 1930 | 134 | 99 | 55 | 3 | 2 | -- | 159 | 33.009 | 1.477 | 5.0 |
| | 1940 | 273 | 170 | 137 | 1 | 2 | -- | 313 | 53.582 | 2.127 | 10.0 |
| | 1950 | 288 | 173 | 157 | 4 | 3 | -- | 337 | 80.080 | 2.788 | 13.0 |
| MATO GROSSO | 1930 | 10 | 6 | 4 | -- | -- | -- | 10 | 554 | -- | 1 |
| | 1940 | 17 | 13 | 6 | -- | -- | -- | 19 | 2.264 | -- | 2.0 |
| | 1950 | 26 | 17 | 12 | -- | -- | -- | 29 | 2.664 | -- | 2. |
| GOIAS | 1930 | 23 | 1 | 23 | -- | -- | -- | 24 | 30 | -- | 1.1 |
| | 1940 | 36 | 5 | 34 | -- | -- | -- | 39 | 182 | -- | 2.8 |
| | 1950 | 47 | 8 | 42 | - | -- | -- | 50 | 344 | -- | 4.5 |
| BRASIL | 1930 | 1.009 | 489 | 656 | 11 | 5 | 52 | 1.211 | 146.475 | 2.277 | 615.1 |
| | 1940 | 1.617 | 908 | 917 | 17 | 6 | 66 | 1.914 | 221.390 | 13.141 | 984.5 |
| | 1950 | 1.763 | 971 | 1.003 | 16 | 17 | 86 | 2.093 | 310.545 | 36.287 | 1.485.8 |

## BRASIL

# EMPRESAS DE ELETRICIDADE. USINAS GERADORAS. NÚMERO E POTÊNCIA POR UNIDADES DA FEDERAÇÃO

## ANOS DE 1930, 1940, 1950

| OS | NÚMERO DE EMPRESAS | USINAS GERADORAS EM 31-XII | | | | | | POTÊNCIA EM 31-XII — kW | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | FORNECEDORAS | | | PRIVATIVAS | | TOTAL | ORIGEM TÉRMICA | | ORIGEM HIDRAULICA | | TOTAL |
| | | Termo Elétricas | Hidro Elétricas | Mistas | Termo Elétricas | Hidro Elétricas | | Usinas fornecedoras | Usinas privativas | Usinas fornecedoras | Usinas privativas | |
| 30 | 1 | 2 | — | — | — | — | 2 | 235 | — | — | — | 235 |
| 40 | 2 | 4 | — | — | — | — | 4 | 817 | — | — | — | 817 |
| 50 | 3 | 4 | — | — | — | — | 4 | 703 | — | — | — | 703 |
| 30 | 7 | 7 | — | — | — | — | 7 | 197 | — | — | — | 197 |
| 40 | 9 | 9 | — | — | — | — | 9 | 283 | — | — | — | 283 |
| 50 | 11 | 11 | — | — | — | — | 11 | 853 | — | — | — | 853 |
| 30 | 8 | 8 | — | — | — | — | 8 | 2.589 | — | — | — | 2.589 |
| 40 | 26 | 26 | — | — | — | — | 26 | 3.737 | — | — | — | 3.737 |
| 50 | 31 | 31 | — | — | — | — | 31 | 3.786 | — | — | — | 3.786 |
| 30 | — | — | — | — | — | — | — | — | — | — | — | — |
| 40 | 1 | 1 | — | — | — | — | 1 | 20 | — | — | — | 20 |
| 50 | 1 | 1 | — | — | — | — | 1 | 20 | — | — | — | 20 |
| 30 | 16 | 16 | — | — | — | — | 16 | 6.998 | — | — | — | 6.998 |
| 40 | 47 | 50 | 1 | — | — | — | 51 | 10.863 | — | 15 | — | 10.878 |
| 50 | 54 | 57 | 1 | — | — | — | 58 | 6.327 | — | 15 | — | 6.342 |
| 30 | — | — | — | — | — | — | — | — | — | — | — | — |
| 40 | 1 | 1 | — | — | — | — | 1 | 5 | — | — | — | 5 |
| 50 | 5 | 6 | — | — | — | — | 6 | 252 | — | — | — | 252 |
| 30 | 10 | 10 | — | — | — | — | 10 | 1.320 | — | — | — | 1.320 |
| 40 | 14 | 13 | 1 | — | — | — | 14 | 2.451 | — | 99 | — | 2.550 |
| 50 | 14 | 13 | 1 | — | — | — | 14 | 2.492 | — | 99 | — | 2.591 |
| 30 | 7 | 7 | — | — | — | — | 7 | 993 | — | — | — | 993 |
| 40 | 18 | 18 | — | — | — | — | 18 | 2.006 | — | — | — | 2.006 |
| 50 | 17 | 18 | — | — | — | — | 18 | 8.523 | — | — | — | 8.523 |
| 30 | 35 | 32 | 2 | 1 | — | — | 35 | 6.552 | — | 99 | — | 6.651 |
| 40 | 72 | 67 | 6 | — | — | — | 73 | 12.219 | — | 310 | — | 12.529 |
| 50 | 73 | 69 | 5 | — | 2 | — | 76 | 12.437 | 1.673 | 387 | — | 14.497 |
| 30 | 20 | 20 | — | — | — | — | 20 | 1.812 | — | — | — | 1.812 |
| 40 | 37 | 37 | — | — | — | — | 37 | 3.807 | — | — | — | 3.807 |
| 50 | 41 | 41 | — | — | — | — | 41 | 5.210 | — | — | — | 5.210 |
| 30 | 40 | 38 | 2 | — | — | — | 40 | 5.173 | — | 105 | — | 5.278 |
| 40 | 72 | 80 | 3 | — | — | — | 83 | 9.079 | — | 252 | — | 9.331 |
| 50 | 72 | 80 | 3 | — | — | — | 85 | 11.522 | — | 252 | — | 11.774 |
| 30 | 91 | 83 | 8 | 1 | — | 7 | 99 | 27.843 | — | 1.999 | 941 | 30.783 |
| 40 | 125 | 118 | 14 | 1 | 1 | 7 | 141 | 43.565 | 1.500 | 2.738 | 878 | 48.681 |
| 50 | 138 | 125 | 22 | — | 3 | 8 | 158 | 46.609 | 3.330 | 4.827 | 1.397 | 56.163 |
| 30 | 39 | 31 | 5 | 2 | — | — | 38 | 7.032 | — | 2.831 | — | 9.863 |
| 40 | 58 | 49 | 5 | 4 | — | — | 58 | 10.140 | — | 2.842 | — | 12.982 |
| 50 | 58 | 48 | 5 | 4 | — | — | 57 | 10.321 | — | 2.842 | — | 13.163 |
| 50 | 1 | 1 | — | — | — | — | 1 | 350 | — | — | — | 350 |
| 30 | 18 | 19 | — | — | 1 | 1 | 21 | 2.271 | 800 | — | 405 | 3.476 |
| 40 | 31 | 32 | — | — | 1 | 1 | 34 | 4.149 | 1.425 | — | 405 | 5.974 |
| 50 | 31 | 32 | — | — | 1 | 1 | 34 | 5.323 | 1.425 | — | 405 | 7.153 |
| 30 | 36 | 25 | 14 | — | — | — | 39 | 7.101 | — | 15.563 | — | 22.664 |
| 40 | 70 | 54 | 18 | — | — | — | 72 | 9.339 | — | 15.698 | — | 25.037 |
| 50 | 107 | 62 | 25 | — | — | — | 87 | 14.938 | — | 18.074 | — | 33.012 |
| 30 | 252 | 12 | 292 | 2 | — | 13 | 319 | 3.852 | — | 85.416 | 1.482 | 90.750 |
| 40 | 336 | 32 | 371 | 3 | — | 17 | 423 | 10.121 | — | 126.929 | 7.597 | 144.647 |
| 50 | 364 | 33 | 393 | 3 | — | 25 | 454 | 12.378 | — | 182.067 | 16.778 | 211.223 |
| 30 | 31 | 6 | 26 | — | — | 1 | 33 | 944 | — | 7.282 | 75 | 8.301 |
| 40 | 50 | 11 | 41 | — | — | 1 | 53 | 1.043 | — | 7.912 | 75 | 9.030 |
| 50 | 53 | 12 | 44 | — | — | 1 | 57 | 1.981 | — | 8.267 | 75 | 10.323 |
| 30 | 62 | 15 | 60 | — | — | 11 | 86 | 3.185 | — | 172.600 | 2.303 | 178.088 |
| 40 | 77 | 26 | 71 | — | 1 | 11 | 112 | 4.901 | 7.500 | 247.127 | 4.084 | 263.612 |
| 50 | 79 | 28 | 67 | 1 | 5 | 15 | 116 | 5.678 | 23.882 | 388.477 | 5.070 | 423.107 |
| 30 | 1 | 1 | — | — | — | 2 | 3 | 15.200 | — | — | 376 | 15.576 |
| 40 | 2 | 2 | — | — | — | 2 | 4 | 15.320 | — | — | 376 | 15.696 |
| 50 | 2 | 3 | — | — | — | 2 | 5 | 40.320 | — | — | 376 | 40.696 |
| 30 | 108 | 24 | 128 | 1 | — | 13 | 166 | 13.529 | — | 311.037 | 6.598 | 331.164 |
| 40 | 133 | 45 | 129 | 2 | — | 20 | 196 | 16.573 | — | 539.403 | 8.678 | 564.654 |
| 50 | 131 | 49 | 131 | 1 | 2 | 24 | 210 | 18.842 | 2.600 | 815.517 | 10.456 | 847.415 |
| 30 | 31 | 19 | 17 | — | — | 3 | 39 | 4.741 | — | 2.673 | 2.642 | 10.056 |
| 40 | 38 | 22 | 21 | 1 | 1 | 3 | 48 | 2.527 | 589 | 12.061 | 2.642 | 17.819 |
| 50 | 39 | 23 | 26 | 1 | 1 | 6 | 57 | 4.118 | 589 | 21.459 | 13.807 | 39.973 |
| 30 | 29 | 8 | 20 | 1 | — | 1 | 30 | 1.315 | — | 7.905 | 50 | 9.270 |
| 40 | 72 | 23 | 59 | 2 | — | 1 | 85 | 2.477 | — | 14.178 | 50 | 16.705 |
| 50 | 77 | 23 | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | 39.012 |
| 30 | 134 | 99 | 55 | 3 | 2 | — | 159 | 33.009 | 1.477 | 5.668 | — | 40.154 |
| 40 | 273 | 170 | 137 | 4 | 2 | — | 313 | 53.502 | 2.127 | 10.047 | — | 65.676 |
| 50 | 288 | 173 | 157 | 4 | 3 | — | 337 | 80.080 | 2.788 | 13.635 | — | 96.503 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 940 | 1 | 1 | — | — | — | — | 1 | 20 | — | — | | 20 |
| 950 | 1 | 1 | — | — | — | — | 1 | 20 | — | — | | 20 |
| 930 | 16 | 16 | — | — | — | — | 16 | [illegible] | — | — | | 6.998 |
| 940 | 47 | 50 | — | — | — | — | 51 | 10.863 | — | 15 | | 10.878 |
| 950 | 54 | 57 | 1 | — | — | — | 58 | 6.327 | — | 15 | | 6.342 |
| 30 | — | — | — | — | — | — | — | — | — | — | — | — |
| 40 | 1 | 1 | — | — | — | — | 1 | 5 | — | — | — | 5 |
| 50 | 5 | 6 | — | — | — | — | 6 | 252 | — | — | — | 252 |
| 30 | 10 | 10 | — | — | — | — | 10 | 1.320 | — | — | — | 1.320 |
| 40 | 14 | 13 | 1 | — | — | — | 14 | 2.451 | — | 99 | — | 2.550 |
| 50 | 14 | 13 | 1 | — | — | — | 14 | 2.492 | — | 99 | — | 2.591 |
| 30 | 7 | 7 | — | — | — | — | 7 | 993 | — | — | — | 993 |
| 40 | 18 | 18 | — | — | — | — | 18 | 2.006 | — | — | — | 2.006 |
| 50 | 17 | 18 | — | — | — | — | 18 | 8.523 | — | — | — | 8.523 |
| 30 | 35 | 32 | 2 | 1 | — | — | 35 | 6.552 | — | 99 | — | 6.651 |
| 40 | 72 | 67 | 6 | — | — | — | 73 | 12.219 | — | 310 | — | 12.529 |
| 50 | 73 | 69 | 5 | — | 2 | — | 76 | 12.137 | 1.673 | 387 | — | 11.497 |
| 30 | 20 | 20 | — | — | — | — | 20 | 1.812 | — | — | — | 1.812 |
| 40 | 37 | 37 | — | — | — | — | 37 | 3.807 | — | — | — | 3.807 |
| 50 | 41 | 44 | — | — | — | — | 44 | 5.210 | — | — | — | 5.210 |
| 30 | 40 | 38 | 2 | — | — | — | 40 | 5.173 | — | 105 | — | 5.278 |
| 40 | 72 | 80 | 3 | — | — | — | 83 | 9.079 | — | 252 | — | 9.331 |
| 50 | 72 | 80 | 3 | — | — | — | 83 | 11.552 | — | 252 | — | 11.774 |
| 30 | 91 | 83 | 8 | 1 | — | 7 | 99 | 27.843 | — | 1.909 | 941 | 30.785 |
| 40 | 125 | 118 | 14 | 1 | 1 | 7 | 141 | 43.565 | 1.500 | 2.758 | 878 | 48.681 |
| 50 | 158 | 125 | 22 | — | 3 | 8 | 158 | 46.609 | 3.330 | 4.827 | 1.397 | 56.163 |
| 0 | 39 | 31 | 5 | 2 | — | — | 58 | 7.032 | — | 2.831 | — | 9.863 |
| 0 | 52 | 49 | 5 | 4 | — | — | 58 | 10.140 | — | 2.842 | — | 12.982 |
| 0 | 58 | 48 | 5 | 4 | — | — | 57 | 10.321 | — | 2.842 | — | 13.163 |
| 0 | 1 | 1 | — | — | — | — | 1 | 350 | — | | — | 350 |
| 0 | 18 | 19 | — | — | 1 | 1 | 21 | 2.271 | 800 | — | 405 | 3.476 |
| 0 | 31 | 32 | — | — | 1 | 1 | 34 | 4.149 | 1.425 | — | 405 | 5.974 |
| 0 | 31 | 32 | — | — | 1 | 1 | 34 | 5.323 | 1.425 | — | 405 | 7.153 |
| 0 | 36 | 25 | 14 | — | — | — | 39 | 7.101 | — | 15.563 | — | 22.664 |
| 0 | 70 | 54 | 18 | — | — | — | 72 | 9.339 | — | 15.698 | — | 25.037 |
| 0 | 107 | 62 | 25 | — | — | — | 87 | 14.938 | — | 18.074 | — | 33.012 |
| | 252 | 12 | 292 | 2 | — | 13 | 319 | 3.852 | — | 85.416 | 1.182 | 90.750 |
| | 336 | 32 | 371 | 3 | — | 17 | 423 | 10.121 | — | 126.922 | 7.597 | 144.647 |
| | 364 | 33 | 393 | 3 | — | 25 | 454 | 12.378 | — | 182.067 | 16.778 | 211.223 |
| | 31 | 6 | 26 | — | — | 1 | 33 | 944 | — | 7.282 | 75 | 8.301 |
| | 50 | 11 | 41 | — | — | 1 | 53 | 1.043 | — | 7.912 | 75 | 9.030 |
| | 53 | 12 | 44 | — | — | 1 | 57 | 1.981 | — | 8.267 | 75 | 10.323 |
| | 62 | 15 | 60 | — | — | 11 | 86 | 3.185 | — | 172.600 | 2.303 | 178.088 |
| | 77 | 26 | 71 | — | 1 | 11 | 112 | 4.901 | 7.500 | 247.127 | 4.084 | 263.612 |
| | 79 | 28 | 67 | 1 | 5 | 15 | 116 | 5.678 | 23.882 | 388.477 | 5.070 | 423.107 |
| | 1 | 1 | — | — | — | 2 | 3 | 15.200 | — | — | 376 | 15.576 |
| | 2 | 2 | — | — | — | 2 | 4 | 15.320 | — | — | 376 | 15.696 |
| | 2 | 3 | — | — | — | 2 | 5 | 40.320 | — | — | 376 | 40.696 |
| | 108 | 24 | 128 | 1 | — | 13 | 166 | 13.529 | — | 311.037 | 6.598 | 331.164 |
| | 133 | 45 | 129 | 2 | — | 20 | 196 | 16.573 | — | 539.403 | 8.678 | 564.654 |
| | 131 | 49 | 131 | 1 | 2 | 21 | 210 | 18.842 | 2.600 | 815.517 | 10.156 | 847.415 |
| | 31 | 19 | 17 | — | — | 3 | 39 | 4.741 | — | 2.673 | 2.642 | 10.056 |
| | 38 | 22 | 21 | 1 | 1 | 3 | 48 | 2.527 | 589 | 12.061 | 2.642 | 17.819 |
| | 39 | 23 | 26 | 1 | 1 | 6 | 57 | 4.118 | 589 | 21.459 | 13.807 | 39.973 |
| | 29 | 8 | 20 | 1 | — | 1 | 30 | 1.315 | — | 7.905 | 50 | 9.270 |
| | 72 | 23 | 59 | 2 | — | 1 | 85 | 2.477 | — | 14.178 | 50 | 16.705 |
| | 77 | 23 | 66 | 2 | — | 4 | 95 | 14.472 | — | 22.640 | 1.931 | 39.043 |
| | 134 | 99 | 55 | 3 | 2 | — | 159 | 33.009 | 1.177 | 5.668 | — | 40.154 |
| | 273 | 170 | 137 | 4 | 2 | — | 313 | 53.502 | 2.127 | 10.047 | — | 65.676 |
| | 288 | 173 | 157 | 4 | 3 | — | 337 | 80.080 | 2.788 | 13.655 | — | 96.502 |
| | 10 | 6 | 4 | — | — | — | 10 | 554 | — | 859 | — | 1.413 |
| | 17 | 13 | 6 | — | — | — | 19 | 2.264 | — | 2.097 | — | 4.361 |
| | 26 | 17 | 12 | — | — | — | 29 | 2.664 | — | 2.991 | — | 5.658 |
| | 23 | 1 | 23 | — | — | — | 24 | 30 | — | 1.141 | — | 1.171 |
| | 36 | 5 | 34 | — | — | — | 39 | 182 | — | 2.853 | — | 3.035 |
| | 47 | 8 | 42 | — | — | — | 50 | 344 | — | 4.330 | — | 4.671 |
| | 1.009 | 489 | 656 | 11 | 3 | 52 | 1.211 | 116.475 | 2.277 | 615.178 | 14.872 | 778.802 |
| | 1.617 | 908 | 917 | 17 | 6 | 66 | 1.914 | 221.390 | 13.141 | 984.561 | 24.785 | 1.243.877 |
| | 1.763 | 971 | 1.003 | 16 | 17 | 86 | 2.093 | 310.543 | 36.287 | 1.485.882 | 50.295 | 1.863.007 |

ANEXO 3

# ESTATÍSTICA DA ENERGIA ELÉTRICA NO BRASIL EM 1952

| | CAPACIDADE INSTALADA kW | CARGA MAXIMA HORARIA kWh/kW | PRODUÇAO kWh | FATOR DE CARGA % | RESIDENCIAL kWh | INDU |
|---|---|---|---|---|---|---|
| 1. Cia. de Carris Luz e Fôrça do Rio de Janeiro | 353.624 | 348.300 | 2.138.000.000 | 69,9 | 298.000.000 | 90 |
| 2. The São Paulo Tramway, Light and Power Co. | 604.449 | 572.525 | 3.600.000.000 | 71,6 | 710.000.000 | 1.811 |
| TOTAL DO GRUPO LIGHT | 958.073 | 920.825 | 5.738.000.000 | 71,1 | 1.008.000.000 | 2.714 |
| 3. Cia. Brasileira de Energia Elétrica | 40.775 | 38.460 | 191.600.000 | 56,9 | 35.700.000 | 79 |
| 4. Cia. Central Brasileira de Fôrça Elétrica | 7.912 | 6.970 | 35.600.000 | 58,0 | 7.300.000 | 9 |
| 5. Cia. Energia Elétrica da Bahia | 19.000 | 22.065 | 116.000.000 | 59,8 | 28.800.000 | 11 |
| 6. Cia. Energia Elétrica Riograndense | 24.600 | 32.400 | 155.900.000 | 54,7 | 31.100.000 | 29 |
| 7. Cia. Fôrça e Luz de Minas Gerais | 21.724 | 40.873 | 190.100.000 | 53,1 | 65.000.000 | 17 |
| 8. Cia. Fôrça e Luz do Paraná | 22.000 | 19.492 | 88.500.000 | 51,7 | 27.700.000 | 15 |
| 9. Cia. Fôrça e Luz Nordeste do Brasil | 7.980 | 5.568 | 23.100.000 | 47,1 | 1.900.000 | 2 |
| 10. Cia. Paulista de Fôrça e Luz | 92.616 | 101.569 | 578.000.000 | 61,8 | 120.200.000 | 154 |
| 11. The Pernambuco Tramway, Light and Power | 22.500 | 21.300 | 109.300.000 | 58,4 | 17.600.000 | 33 |
| 12. The Riograndense Light and Power Syndicate | 4.700 | 3.669 | 11.800.000 | 46,0 | 3.100.000 | 3 |
| TOTAL DO GRUPO E.E.B. | 266.837 | 292.357 | 1.503.500.000 | [illegible] | 341.100.000 | 356 |
| 13. Cia. Sul Americana de Serviços Públicos | 6.785 | 4.951 | 16.084.000 | 37,1 | 5.030.000 | 2. |
| 14. Cia. Sul Mineira de Eletricidade | 21.870 | 12.963 | 53.233.000 | 46,9 | 9.617.000 | 17. |
| TOTAL DO GRUPO C.S.M.E. | 28.653 | 17.914 | 69.317.000 | 46,7 | 14.647.000 | 19. |
| 15. Emprêsa de Fôrça e Luz Mogi-Mirim | 2.700 | 2.400 | 10.235.640 | 48,7 | 2.233.577 | 2. |
| 16. S. A. Central Elétrica Rio Claro | 14.000 | 10.552 | 52.030.120 | 56,3 | 14.765.954 | 22. |
| TOTAL DO GRUPO C.E.R.C. | 16.700 | 12.952 | 62.265.760 | 54,9 | 16.999.531 | 25. |
| 17. Comissão Estadual de Energia Elétrica, R. G. S. (1) | 19.785 | 13.393 | 53.542.000 | 45,6 | 22.648.000 | 15. |
| 18. Centrais Elétricas de Minas Gerais | 18.420 | 14.550 | 70.105.000 | 55,0 | — | |
| | 38.205 | 27.943 | 123.647.000 | 50,5 | 22.648.000 | 15. |
| 19. Ceará Tramway and Power Co. Ltd. | 7.750 | 5.567 | 22.604.730 | 46,3 | 9.574.307 | 3.0 |
| 20. Cia. de Eletricidade Nova Friburgo | 3.481 | 2.228 | 9.779.760 | 50,1 | 3.561.381 | 3.4 |
| 21. Cia. de Eletricidade Sul Paulista | 1.952 | 1.720 | 5.927.752 | 35,4 | 2.196.958 | 1.5 |
| 22. Cia. Docas de Santos (The City of Santos Imp. Co.) (2) | 15.298 | 11.000 | 73.381.275 | 59,8 | 55.659.245 | 66.3 |
| 23. Cia. Elétrica Caiuá | 5.360 | 5.360 | 22.152.293 | 47,8 | 10.700.000 | 5.1 |
| 24. Cia. Fôrça e Luz Cataguazes-Leopoldina | 8.600 | 4.117 | 38.799.000 | — | 11.128.000 | 17.6 |
| 25. Cia. Fôrça e Luz Norte Fluminense | 1.840 | 1.302 | 7.675.000 | 67,3 | 1.300.580 | 2.5 |
| 26. Cia. Fôrça e Luz Santa Cruz | 8.168 | 8.000 | 52.867.069 | 75,4 | 16.554.698 | 14.0 |
| 27. Cia. Luz e Fôrça Tatuí | 1.368 | 2.200 | 9.685.920 | 50,3 | 2.644.339 | 2.9 |
| 28. Cia. Geral de Eletricidade | 2.772 | 1.554 | 6.842.414 | 50,3 | 1.839.797 | 9 |
| 29. Cia. Mineira de Eletricidade | 17.289 | 7.455 | 50.345.423 | 86,3 | 21.952.700 | 20.9 |
| 30. Cia. Nacional de Energia Elétrica | 1.316 | 3.910 | 17.031.100 | 49,7 | 4.681.572 | 5.6 |
| 31. Cia. Paulista de Energia Elétrica | 4.164 | 2.438 | 11.660.000 | 68,6 | 3.165.000 | 1.7 |
| 32. Cia. Prada de Eletricidade | 17.204 | 10.935 | 52.118.478 | 94,8 | 19.813.856 | 17.7 |
| 33. Cia. Taubaté Industrial | 5.816 | 3.850 | 13.158.143 | 39,0 | 319.794 | 11.2 |
| 34. Emprêsa de Eletricidade Vale Paranapanema | 3.520 | 3.565 | 8.729.363 | 27,9 | 9.122.628 | 1.1 |
| 35. Emprêsa Fôrça e Luz Santa Catarina | 16.500 | 13.000 | 58.400.000 | 51,3 | 8.350.900 | 35.4 |
| 36. Emprêsa Luz e Fôrça Tietê S.A. | 2.240 | 1.200 | 4.883.160 | 46,5 | 829.319 | 1.3 |
| 37. Emprêsa Sul Brasileira de Eletricidade | 7.560 | 6.375 | 28.362.200 | 50,9 | 7.260.232 | 19.07 |
| 38. S. A. Emprêsa Fôrça e Luz Ibero-Americana | 2.063 | 1.752 | 6.755.000 | 44,0 | 1.495.487 | 2.2 |
| 39. Serviços de Fôrça e Luz de Aracaju | 2.800 | 1.760 | 9.200.000 | 59,7 | 2.920.000 | 58 |
| 40. Cia. Matogrossense de Eletricidade (3) | 3.990 | 3.060 | 6.740.000 | 25,2 | — | - |
| TOTAL DO GRUPO EMPRÊSAS INDEPENDENTES | 144.021 | 105.646 | 526.148.075 | 56,8 | 195.070.875 | 235.25 |
| TOTAL DOS 40 SISTEMAS (Informações diretas) | 1.452.489 | 1.377.637 | 8.022.877.835 | 66,5 | 1.598.765.404 | 3.366.9 |
| Outros sistemas (Estimativa) (4) | 522.526 | 365.504 | 1.284.117.888 | 40,0 | 410.917.725 | 515.0 |
| TOTAL DO BRASIL | 1.975.015 | 1.743.141 | 9.306.995.723 | 61,0 | 2.009.683.129 | 3.880 04 |

NOTAS — (1) Exclui os dados dos fornecimentos às cidades de Pôrto Alegre, Pelotas e Canoas, já incluídas nos respectivos sistemas do grupo das Emprêsas Elétricas B
é sòmente emprêsa fornecedora de energia elétrica e The City of Santos Improvments Co. consumidora, inclusive do Sistema Light. (3) — Não foram obtidos dados com re
incluído na estimativa dos sistemas restantes. (4) — A estimativa para outros sistemas foi feita da seguinte maneira: *Potência Instalada* — Do total de 1.975.015 kW do
Aguas do Ministério da Agricultura) foi deduzido o total da capacidade instalada nos 40 sistemas, cujos valores foram fornecidos diretamente. *Carga máxima horária*
*dução* — Carga máxima horária × n.º de horas anuais correspondente ao fator de carga de 40% — *Consumo* — adotando a perda de 20% e as mesmas porcentagens
outros para o total, verificado no grupo de emprêsas independentes.

## TÍSTICA DA ENERGIA ELÉTRICA NO BRASIL EM 1952

| | CAPACIDADE INSTALADA kW | CARGA MÁXIMA HORÁRIA kWh/kW | PRODUÇAO kWh | FATOR DE CARGA % | CONSUMO | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | RESIDENCIAL kWh | INDUSTRIAL kWh | OUTROS kWh | TOTAL kWh |
| | 353.624 | 348.300 | 2.138.000.000 | 69,9 | 298.000.000 | 903.000.000 | 631.000.000 | 1.832.000.000 |
| o. | 604.449 | 572.525 | 3.600.000.000 | 71,6 | 710.000.000 | 1.811.006.000 | 628.000.000 | 3.149.000.000 |
| | 958.073 | 920.825 | 5.738.000.000 | 71,1 | 1.008.000.000 | 2.714.000.000 | 1.259.000.000 | 4.981.000.000 |
| | 40.775 | 38.460 | 191.500.000 | 56,9 | 35.700.000 | 79.900.000 | 45.500.000 | 161.100.000 |
| | 7.912 | 6.970 | 35.600.000 | 58,0 | 7.300.000 | 9.500.000 | 9.600.000 | 26.400.000 |
| | 19.000 | 22.065 | 116.000.000 | 59,8 | 28.800.000 | 11.000.000 | 56.000.000 | 95.800.000 |
| | 24.600 | 32.400 | 155.900.000 | 54,7 | 31.100.000 | 29.400.000 | 71.600.000 | 132.100.000 |
| | 24.724 | 40.873 | 190.100.000 | 53,1 | 65.000.000 | 17.500.000 | 61.100.000 | 143.600.000 |
| | 22.000 | 19.492 | 88.500.000 | 51,7 | 27.700.000 | 15.300.000 | 31.100.000 | 74.100.000 |
| | 7.980 | 5.568 | 23.100.000 | 47,1 | 4.900.000 | 2.100.000 | 9.600.000 | 16.600.000 |
| | 92.646 | 101.569 | 578.000.000 | 61,8 | 120.200.000 | 154.200.000 | 180.800.000 | 455.200.000 |
| | 22.500 | 21.300 | 109.300.000 | 58,4 | 17.600.000 | 33.700.000 | 39.000.000 | 90.300.000 |
| | 4.700 | 3.660 | 11.800.000 | 46,0 | 3.100.000 | 3.400.000 | 5.000.000 | 11.500.000 |
| | 266.837 | 292.357 | 1.503.500.000 | 59,1 | 341.100.000 | 356.000.000 | 509.300.000 | 1.206.700.000 |
| | 6.783 | 4.951 | 16.081.000 | 37,1 | 5.030.000 | 2.076.000 | 5.693.000 | 12.799.000 |
| | 21.870 | 12.963 | 53.236.000 | 46,9 | 9.617.000 | 17.914.000 | 14.320.000 | 41.851.000 |
| | 28.653 | 17.914 | 69.317.000 | 46,7 | 14.647.000 | 19.990.000 | 20.013.000 | 54.650.000 |
| | 2.760 | 2.400 | 10.235.640 | 48,7 | 2.233.577 | 2.484.810 | 418.360 | 5.136.747 |
| | 14.000 | 10.552 | 52.030.120 | 56,3 | 14.765.954 | 22.931.989 | 2.278.830 | 39.976.773 |
| | 16.700 | 12.952 | 62.265.760 | 54,9 | 16.999.531 | 25.416.799 | 2.697.190 | 45.113.520 |
| (1) | 19.785 | 13.393 | 53.542.000 | 45,6 | 22.648.000 | 15.736.000 | 2.228.000 | 40.612.000 |
| | 18.420 | 14.550 | 70.105.000 | 55,0 | — | — | 61.078.000 | 61.078.000 |
| | 38.205 | 27.943 | 123.647.000 | 50,5 | 22.648.000 | 15.736.000 | 63.306.000 | 101.690.000 |
| | 7.750 | 5.567 | 22.601.730 | 46,3 | 9.574.307 | 3.033.367 | 4.734.687 | 17.342.361 |
| | 3.481 | 2.228 | 9.779.760 | 50,1 | 3.564.381 | 3.442.952 | 382.187 | 7.389.520 |
| | 1.952 | 1.720 | 5.327.752 | 35,1 | 2.196.958 | 1.599.919 | 323.400 | 4.120.277 |
| Co.) (2) | 15.298 | 14.060 | 73.381.275 | 59,8 | 58.659.245 | 66.305.808 | 1.223.582 | 126.188.635 |
| | 5.360 | 5.360 | 22.452.293 | 47,8 | 10.700.000 | 5.130.000 | 1.360.000 | 17.190.000 |
| | 8.600 | 4.417 | 38.799.000 | — | 11.128.000 | 17.634.000 | 1.902.000 | 30.664.000 |
| | 1.840 | 1.302 | 7.675.000 | 67,3 | 1.300.580 | 2.531.339 | 812.659 | 4.644.578 |
| | 8.168 | 8.000 | 52.867.069 | 75,4 | 16.554.698 | 14.620.801 | 2.727.678 | 33.903.177 |
| | 1.568 | 2.200 | 9.685.920 | 50,3 | 2.644.339 | 2.941.115 | 401.422 | 5.986.876 |
| | 2.772 | 1.554 | 6.842.414 | 50,3 | 1.839.797 | 949.775 | 866.775 | 3.656.347 |
| | 17.289 | 7.455 | 56.345.423 | 86,3 | 21.952.700 | 20.941.469 | 1.500.669 | 44.394.838 |
| | 4.316 | 3.910 | 17.031.100 | 49,7 | 4.681.572 | 5.617.033 | 1.276.167 | 11.574.772 |
| | 4.104 | 2.438 | 14.660.000 | 68,6 | 3.165.000 | 1.745.000 | 7.180.000 | 12.090.000 |
| | 17.204 | 10.935 | 52.148.473 | 94,8 | 19.813.836 | 17.785.177 | 8.369.745 | 45.968.758 |
| | 5.846 | 3.850 | 13.158.143 | 39,0 | 319.794 | 11.205.672 | 175.008 | 11.700.474 |
| | 3.520 | 3.565 | 8.729.363 | 27,9 | 9.122.628 | 1.175.564 | 1.076.155 | 11.374.347 |
| | 16.500 | 13.000 | 58.400.000 | 51,3 | 8.350.000 | 35.400.000 | 5.750.000 | 49.500.000 |
| | 2.240 | 1.200 | 4.883.160 | 46,5 | 829.319 | 1.302.228 | 1.568.712 | 3.700.259 |
| | 7.560 | 6.373 | 28.382.200 | 50,9 | 7.260.232 | 19.071.043 | 4.547.601 | 30.878.876 |
| | 2.063 | 1.752 | 6.755.000 | 44,0 | 1.493.487 | 2.240.337 | 619.698 | 4.353.522 |
| | 2.800 | 1.760 | 9.200.000 | 59,7 | 2.920.000 | 584.400 | 3.798.600 | 7.303.000 |
| | 3.990 | 3.060 | 6.740.000 | 25,2 | — | — | — | — |
| **INDEPENDENTES** ..... | 144.021 | 105.646 | 526.148.075 | 56,8 | 195.070.873 | 235.256.999 | 56.596.745 | 486.924.617 |
| rmações diretas) .......... | 1.452.489 | 1.377.637 | 8.022.877.835 | 66,5 | 1.598.765.404 | 3.366.399.798 | 1.910.912.935 | 6.876.078.137 |
| | 522.526 | 365.504 | 1.284.117.888 | 40,0 | 410.917.725 | 513.647.156 | 102.729.431 | 1.027.294.312 |
| | 1.975.015 | 1.743.141 | 9.306.995.723 | 61,0 | 2.009.683.129 | 3.880.046.954 | 2.013.642.366 | 7.903.372.449 |

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s cidades de Pôrto Alegre, Pelotas e Canoas, já incluídas nos respectivos sistemas do grupo das Emprêsas Elétricas Brasileiras. (2) — A Cia. Docas de Santos
The City of Santos Improvments Co. consumidora, inclusive do Sistema Light. (3) — Não foram obtidos dados com relação ao consumo, cujo valor encontra-se
A estimativa para outros sistemas foi feita da seguinte maneira: *Potência Instalada* — Do total de 1.975.015 kW do Brasil (dados fornecidos pela Divisão de
o total da capacidade instalada nos 40 sistemas, cujos valores foram fornecidos diretamente. *Carga máxima horária* — 70% da capacidade instalada. *Pro-*
uais correspondente ao fator de carga de 40% — *Consumo* — adotando a perda de 20% e as mesmas porcentagens dos consumos: residencial, industrial e
independentes.

ANEXO I

# CONSUMO DE ENERGIA ELÉTRICA NO BRASIL POR CATEGORIA DE SERVIÇO

## 1952

| EMPRÊSAS | Consumo Total 10⁶ × kWh | NÚMERO DE CONSUMIDORES | | | | CONSUMO POR CATEGORIA DE CONSUMIDOR | | | | Número de Lâmpadas Iluminação Pública | Consumo Por Residência kWh | Consumo Industrial Em Porcentagem Do Total % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Domésticos | Industriais | Outros | Total | Doméstico 10⁶ × kWh | Industrial 10⁶ × kWh | Tração Tranviária 10⁶ × kWh | Outros 10⁶ × kWh | | | |
| Cia. de Carris Luz e Fôrça do Rio de Janeiro | 1.832,0 | 393.993 | 25.790 | 49.875 | 469.658 | 298,0 | 903,0 | 119,0 | 512,0 | 55.874 | 756 | 49,3 |
| The São Paulo Tramway Light and Power Co. Ltd. | 3.149,0 | 509.401 | 26.654 | 6.454 | 542.509 | 710,0 | 1.811,0 | 90,0 | 538,0 | 54.406 | 1.394 | 57,5 |
| SUB-TOTAL | 4.981,0 | 903.394 | 52.444 | 56.329 | 1.012.167 | 1.008,0 | 2.714,0 | 209,0 | 1.050,0 | 110.280 | 1.116 | 54,5 |
| Cia. Brasileira de Energia Elétrica | 161,3 | 49.398 | 508 | 7.618 | 57.524 | 35,7 | 79,9 | — | 45,5 | 7.700 | 723 | 49,6 |
| Cia. Central Brasileira de Fôrça Elétrica | 26,4 | 12.966 | 330 | 3.166 | 16.462 | 7,3 | 9,5 | 1,8 | 7,8 | 2.967 | 563 | 36,0 |
| Cia. Energia Elétrica da Bahia | 95,8 | 40.594 | 128 | 10.721 | 51.443 | 28,8 | 11,0 | 17,4 | 38,6 | 10.202 | 709 | 11,5 |
| Cia. Energia Elétrica Riograndense | 132,1 | 65.855 | 1.034 | 12.547 | 79.436 | 31,1 | 29,4 | 6,9 | 64,7 | 8.196 | 472 | 22,3 |
| Cia. Fôrça e Luz de Minas Gerais | 143,6 | 50.361 | 169 | 8.909 | 59.439 | 65,0 | 17,5 | — | 61,1 | 9.671 | 1.291 | 12,2 |
| Cia. Fôrça e Luz do Paraná | 74,1 | 26.330 | 411 | 4.597 | 31.338 | 27,7 | 15,3 | — | 31,1 | 4.712 | 1.052 | 20,6 |
| Cia. Fôrça e Luz Nordeste do Brasil | 16,6 | 19.065 | 298 | 3.632 | 22.995 | 4,9 | 2,1 | 1,2 | 8,4 | 3.242 | 257 | 12,5 |
| Cia. Paulista de Fôrça e Luz | 455,2 | 162.192 | 8.948 | 38.704 | 209.844 | 120,2 | 154,2 | 4,1 | 176,7 | 61.163 | 741 | 33,9 |
| The Pernambuco Tramway, Light and Power | 90,3 | 49.820 | 485 | 7.583 | 57.888 | 17,6 | 33,7 | 3,0 | 36,0 | 10.334 | 353 | 37,3 |
| The Riograndense Light and Power Syndicate | 11,5 | 10.055 | 320 | 2.366 | 12.741 | 3,1 | 3,4 | 0,4 | 4,6 | 1.824 | 291 | 29,6 |
| SUB-TOTAL | 1.206,7 | 486.636 | 12.631 | 99.843 | 599.110 | 341,1 | 356,0 | 34,8 | 474,5 | 120.011 | 701 | 29,5 |
| Cia. Sul Americana de Serviços Públicos | 12,8 | 18.264 | 579 | 2.729 | 21.572 | 6,9 | 2,1 | — | 3,8 | 3.875 | 378 | 16,4 |
| Cia. Sul Mineira de Eletricidade | 41,8 | 39.656 | 1.777 | 827 | 42.260 | 15,4 | 17,9 | — | 8,5 | 17.070 | 388 | 42,8 |
| SUB-TOTAL | 54,6 | 57.920 | 2.356 | 3.556 | 63.832 | 22,3 | 20,0 | — | 12,3 | 20.945 | 385 | 36,6 |
| Comissão Estadual de Energia Elétrica (R.G.S.) | 40,6 | 45.569 | 3.033 | — | 48.602 | 22,6 | 15,7 | — | 2,3 | 7.768 | 496 | 37,7 |
| Cia. Fôrça e Luz Cataguazes-Leopoldina | 30,7 | 22.362 | 596 | 63 | 23.021 | 11,1 | 17,7 | — | 1,9 | 4.472 | 496 | 57,7 |
| Emprêsa Fôrça e Luz Santa Catarina | 49,5 | 16.223 | 2.314 | 1.492 | 20.029 | 8,3 | 35,4 | — | 5,8 | — | 512 | 71,5 |
| Emprêsa Sul Brasileira de Eletricidade | 30,9 | 14.870 | 1.388 | 13 | 16.271 | 7,3 | 19,1 | — | 4,5 | 4.840 | 491 | 61,8 |
| Serviços de Fôrça e Luz de Aracaju | 7,3 | 8.279 | 208 | 111 | 8.598 | 2,9 | 0,5 | 0,1 | 3,8 | — | 350 | 6,8 |
| SUB-TOTAL | 159,0 | 107.303 | 7.539 | 1.679 | 116.521 | 52,2 | 88,4 | 0,1 | 18,3 | 17.080 | 486 | 55,6 |
| Instalações restantes (estimativa) | 1.502,1 | 1.384.747 | — | — | — | 585,8 | 701,7 | — | 214,7 | — | 423 | 46,7 |
| GRANDE TOTAL (Estimativa) | 7.903,3 | 2.940.000 | — | — | — | 2.009,7 | 3.880,1 | 243,9 | 1.769,7 | — | 683 | 49,1 |

ANEXO 5

# CAPITAL, FÔRÇA MOTRIZ, OPERÁRIOS E VALOR DA PRODUÇÃO DOS ESTABELECIMENTOS, SEGUNDO RAMOS E CLASSES DE INDÚSTRIA

| RAMOS E CLASSES DE INDÚSTRIA | EM 1-1-1950 | | | ANO DE 1949 | | OBSERVAÇÕES |
|---|---|---|---|---|---|---|
| | Estabelecimentos | Capital Aplicado (Cr$ 1.000) | Fôrça Motriz (c. v.) (1) | Operários Ocupados (Média mensal) (2) | Valor da Produção (Cr$ 1.000) (3) | |
| **I – INDÚSTRIAS EXTRATIVAS** | | | | | | |
| 1. Indústrias extrativas de produtos minerais | 1.601 | 896.979 | 51.730 | 31.096 | 895.083 | (1) Exclusive a potência dos motores primários da indústria de produção de energia elétrica, no total de 2.070.621 c.v. |
| 2. Indústrias extrativas de produtos vegetais | 3.918 | 827.943 | 91.715 | 30.098 | 1.278.076 | |
| TOTAL DE INDÚSTRIAS EXTRATIVAS | 5.519 | 1.724.922 | 143.445 | 61.194 | 2.173.159 | |
| **II – INDÚSTRIAS DE TRANSFORMAÇÃO** | | | | | | (2) Calculada de acôrdo com a duração do trabalho efetivo do estabelecimento. |
| 1. Indústrias de transformação de miterai. não metálicos (exclusive combustíveis minerais) | 12.724 | 3.143.511 | 162.302 | 110.833 | 4.807.685 | (3) Inclusive receita proveniente de "serviços industriais prestados a terceiros". |
| 2. Indústrias metalúrgicas | 2.216 | 4.953.319 | 334.161 | 88.687 | 8.085.177 | |
| 3. Indústrias mecânicas (exclusive material elétrico e material de transporte) | | | | | | |
| 4. Indústrias do material elétrico e do material de comunicações | 753 | 760.684 | 44.858 | 21.350 | 1.651.580 | |
| 5. Indústrias da construção e montagem do material de transporte | 343 | 583.275 | 28.028 | 13.374 | 1.546.611 | |
| 6. Indústrias da madeira (exclusive artigos do mobiliário) | 529 | 1.029.417 | 38.906 | 14.156 | 2.315.449 | |
| 7. Indústrias do mobiliário (inclusive colchoaria) | 4.647 | 1.380.953 | 122.106 | 41.534 | 2.892.332 | |
| 8. Indústrias do papel e papelão | 2.894 | 539.740 | 38.921 | 32.015 | 1.811.936 | |
| 9. Indústrias da borracha | 436 | 1.702.091 | 153.205 | 22.267 | 2.143.812 | |
| 10. Indústrias de couros e peles e produtos similares (exclusive calçados e artigos do vestuário) | 93 | 388.924 | 22.801 | 7.833 | 1.659.206 | |
| 11. Indústrias químicas e farmacêuticas | 2.117 | 513.571 | 38.171 | 17.776 | 1.625.059 | |
| 12. Indústrias têxteis | 2.648 | 4.021.445 | 154.518 | 58.807 | 8.878.422 | |
| 13. Indústrias do vestuário, calçado e artefatos de tecidos (exclusive artigos manufaturados nas tecelagens) | 2.969 | 8.927.225 | 506.195 | 315.043 | 19.928.834 | |
| 14. Indústrias de produtos alimentares | 5.078 | 774.254 | 26.663 | 64.647 | 1.668.970 | |
| 15. Indústrias de bebidas | 32.247 | 8.927.992 | 621.769 | 208.755 | 33.578.326 | |
| 16. Indústrias do fumo | 4.174 | 1.896.594 | 65.530 | 31.366 | 3.262.397 | |
| 17. Indústrias editoriais e gráficas | 253 | 281.674 | 7.217 | 11.240 | 1.536.243 | |
| 18. Indústrias diversas | 2.731 | 1.731.177 | 29.739 | 34.776 | 2.963.413 | |
| | 1.582 | 646.825 | 28.534 | 22.183 | 1.459.591 | |
| TOTAL DE INDÚSTRIAS DE TRANSFORMAÇÃO | 78.434 | 42.202.671 | 2.423.624 | 1.119.642 | 104.815.043 | |
| **III – CONSTRUÇÃO CIVIL** | 2.992 | 1.081.401 | 61.249 | 98.401 | 6.931.545 | |
| **IV – SERVIÇOS INDUSTRIAIS DE UTILIDADE PÚBLICA** | | | | | | FONTE: – "Sinopse Preliminar do Censo Industrial" – Recenseamento Geral do Brasil – 1950 (I.B.G.E.) |
| 1. Produção de energia elétrica | 1.776 | 5.148.932 | — | 9.203 | 2.172.966 | |
| 2. Produção e distribuição de gás de iluminação | 7 | 720.194 | 9.961 | 2.205 | 340.601 | |
| 3. Abastecimento d'água | 257 | 170.402 | 15.366 | 1.453 | 51.842 | |
| 4. Abastecimento d'água e serviço de esgôto | 92 | 323.439 | 10.276 | 5.556 | 259.876 | |
| 5. Serviço de esgôto | 9 | 3.479 | 96 | 32 | 2.312 | |
| TOTAL DE SERVIÇOS INDUSTRIAIS DE UTILIDADE PÚBLICA | 2.141 | 6.665.546 | 35.699 | 18.449 | 2.827.517 | |
| TOTAL | 89.086 | 51.674.540 | 2.667.017 | 1.297.686 | 116.747.264 | |

ANEXO 6

# CAPITAL, FÔRÇA MOTRIZ, OPERÁRIOS, DESPESAS E VALOR DA PRODUÇÃO DOS ESTABELECIMENTOS, SEGUNDO AS UNIDADES DA FEDERAÇÃO

| UNIDADES DA FEDERAÇÃO | EM 1.º - I - 1950 | | | ANO DE 1949 | | | | |
|---|---|---|---|---|---|---|---|---|
| | ESTABELECIMENTOS | CAPITAL APLICADO (Cr$ 1.000) | FÔRÇA MOTRIZ (c.v.) (1) | OPERÁRIOS OCUPADOS (Média Mensal) (2) | SALÁRIOS E VENCIMENTOS PAGOS | | DESPESAS DE CONSUMO (3) | VALOR DA PRODUÇÃO (4) |
| | | | | | TOTAL | OPERÁRIOS | | |
| | | | | | CR$ 1.000 | | | |
| NORTE | | | | | | | | |
| Guaporé | 27 | 4.591 | 373 | 201 | 3.296 | 2.271 | 3.061 | 9.657 |
| Acre | 52 | 6.423 | 108 | 202 | 2.260 | 1.966 | 4.686 | 9.846 |
| Amazonas | 268 | 102.166 | 6.924 | 3.711 | 30.347 | 24.224 | 106.523 | 208.532 |
| Rio Branco | 8 | 3.377 | 120 | 220 | 1.996 | 1.685 | 1.243 | 5.981 |
| Pará | 938 | 349.867 | 23.042 | 10.540 | 67.796 | 55.321 | 263.780 | 524.289 |
| Amapá | 32 | 8.992 | 251 | 301 | 2.004 | 1.586 | 2.604 | 4.980 |
| NORDESTE | | | | | | | | |
| Maranhão | 1.003 | 112.825 | 12.971 | 8.600 | 40.862 | 34.164 | 147.682 | 291.127 |
| Piauí | 407 | 59.339 | 4.441 | 2.650 | 9.052 | 7.563 | 40.996 | 69.403 |
| Ceará | 2.652 | 480.382 | 32.216 | 27.987 | 91.513 | 73.447 | 580.231 | 922.450 |
| Rio Grande do Norte | 1.201 | 321.127 | 12.634 | 11.154 | 52.875 | 44.145 | 344.804 | 574.794 |
| Paraíba | 1.794 | 495.991 | 32.520 | 27.814 | 106.956 | 94.500 | 624.589 | 1.172.072 |
| Pernambuco | 3.633 | 2.077.572 | 121.420 | 77.570 | 584.921 | 454.814 | 2.365.847 | 4.583.205 |
| Alagoas | 1.203 | 568.426 | 35.460 | 21.662 | 117.561 | 102.637 | 433.983 | 886.984 |
| LESTE | | | | | | | | |
| Sergipe | 1.316 | 295.702 | 28.146 | 14.296 | 74.283 | 59.877 | 238.149 | 470.722 |
| Bahia | 4.007 | 763.143 | 38.108 | 35.622 | 232.398 | 202.320 | 785.595 | 1.563.782 |
| Minas Gerais | 11.346 | 4.072.632 | 220.756 | 119.870 | 981.966 | 804.029 | 4.602.642 | 8.387.343 |
| Espírito Santo | 1.870 | 243.268 | 21.012 | 7.988 | 49.954 | 42.144 | 528.093 | 800.377 |
| Rio de Janeiro | 3.856 | 5.912.918 | 291.236 | 78.306 | 985.504 | 771.495 | 3.424.900 | 7.320.673 |
| Distrito Federal | 5.681 | 5.596.011 | 278.488 | 164.907 | 2.727.715 | 2.168.697 | 8.986.486 | 17.497.670 |
| SUL | | | | | | | | |
| São Paulo | 24.519 | 22.734.433 | 1.063.232 | 487.352 | 7.333.437 | 5.783.950 | 28.321.486 | 54.624.024 |
| Paraná | 3.762 | 1.837.188 | 114.309 | 37.500 | 386.833 | 319.268 | 1.857.924 | 3.578.954 |
| Santa Catarina | 4.915 | 1.289.560 | 85.987 | 43.695 | 397.606 | 336.523 | 1.089.686 | 2.345.420 |
| Rio Grande do Sul | 13.361 | 4.066.961 | 252.493 | 108.394 | 1.162.035 | 969.514 | 5.868.432 | 10.101.425 |
| CENTRO-OESTE | | | | | | | | |
| Mato Grosso | 466 | 152.786 | 5.494 | 3.530 | 26.654 | 21.471 | 139.882 | 265.635 |
| Goiás | 674 | 114.977 | 4.853 | 3.797 | 28.898 | 23.997 | 327.090 | 307.852 |
| BRASIL | 89.086 | 51.674.540 | 2.667.017 | 1.297.686 | 15.499.152 | 12.401.958 | 61.102.996 | 116.747.264 |

OBSERVAÇÕES: — (1) Exclusive a potência dos motores primários da indústria de produção de energia elétrica.
(2) Calculada de acôrdo com a duração do trabalho efetivo do estabelecimento.
(3) Consumo de matérias-primas, material de embalagem, combustíveis, lubrificantes e energia elétrica adquirida.
(4) Inclusive receita de "serviços industriais prestados a terceiros".
Incluídos nos totais do BRASIL os dados correspondentes à região da Serra dos Aimorés, território em litígio entre os Estados de Minas Gerais e Espírito Santo.

FONTE: — "Sinopse Preliminar do Censo Industrial" — Recenseamento Geral do Brasil, 1950 (Publicação do IBGE).

ANEXO 7

# BRASIL

## PROGRAMA DE AMPLIAÇÃO DA CAPACIDADE GERADORA INSTALADA EM USINAS GERADORAS NO QÜINQÜÊNIO 1953 — 1957

| | Potência instalada kW | Estimativa do acréscimo anual da potência instalada — kW | | | | | Estimativa do total do aumento de capacidade no qüinqüênio | Estimativa da potência instalada em 1957 kW |
|---|---|---|---|---|---|---|---|---|
| | 1952 | 1953 | 1954 | 1955 | 1956 | 1957 | | |
| 1. Cia. de Carris, Luz e Fôrça do Rio de Janeiro | 353.624 | 70.000 | 260.000 | — | — | 150.000 | 480.000 | 833.624 |
| 2. The São Paulo Tramway, Light and Power | 604.419 | — | 160.000 | 147.000 | 147.000 | 147.000 | 601.000 | 1.205.419 |
| TOTAL DO GRUPO LIGHT | 958.073 | 70.000 | 420.000 | 147.000 | 147.000 | 297.000 | 1.081.000 | 2.039.073 |
| 3. Cia. Brasileira de Energia Elétrica | 40.775 | — | — | 10.000 | 10.000 | — | 20.000 | 60.775 |
| 4. Cia. Central Brasileira de Fôrça Elétrica | 7.912 | — | 1.000 | — | — | — | 1.000 | 8.912 |
| 5. Cia. Energia Elétrica da Bahia | 19.000 | — | — | — | — | — | — | 19.000 |
| 6. Cia. Energia Elétrica Riograndense | 24.600 | — | — | — | — | — | — | 24.600 |
| 7. Cia. Fôrça e Luz de Minas Gerais | 24.724 | — | 5.500 | — | — | — | 5.500 | 30.224 |
| 8. Cia. Fôrça e Luz do Paraná | 22.000 | — | 10.000 | — | 15.000 | — | 25.000 | 47.000 |
| 9. Cia. Fôrça e Luz Nordeste do Brasil | 7.980 | — | 3.000 | — | — | — | 3.000 | 10.980 |
| 10. Cia. Paulista de Fôrça e Luz | 92.646 | — | 15.000 | — | 80.000 | — | 125.000 | 217.646 |
| 11. The Pernambuco Tramway, Light and Power | 22.500 | — | — | — | — | — | — | 22.500 |
| 12. The Riograndense Light and Power Syndicate | 4.700 | — | — | — | — | — | — | 4.700 |
| TOTAL DO GRUPO E. E. B. | 266.837 | — | 61.500 | 10.000 | 105.000 | — | 179.500 | 446.337 |
| 13. Cia. Sul Americana de Serviços Públicos | 6.783 | 395 | — | — | — | — | 395 | 7.178 |
| 14. Cia. Sul Mineira de Eletricidade | 21.870 | — | — | — | 21.625 | — | 21.625 | 43.495 |
| TOTAL DO GRUPO C. S. M. E. | 28.653 | 395 | — | — | 21.625 | — | 22.020 | 50.673 |
| 15. Centrais Elétricas de Minas Gerais | 18.420 | 200 | 67.150 | — | 12.000 | 50.000 | 129.350 | 147.770 |
| 16. Comissão Estadual de Energia Elétrica RGS | 28.285 | 13.200 | 13.800 | 42.000 | 24.200 | 46.600 | 139.800 | 168.085 |
| 17. Cia. Hidro Elétrica do São Francisco | — | — | 120.000 | — | 60.000 | — | 180.000 | 180.000 |
| 18. Emprêsa Fôrça e Luz Santa Catarina | 13.000 | — | — | — | — | 11.000 | 11.000 | 24.000 |
| 19. Emprêsa Sul Brasileira de Eletricidade | 7.560 | — | — | — | — | — | — | 7.560 |
| 20. Ceará Tramway and Power Co. Ltd. | 7.750 | — | 10.000 | — | — | — | 10.000 | 17.750 |
| 21. Cia. de Eletricidade de Manaus | 2.000 | — | — | 10.000 | — | — | 10.000 | 12.000 |
| 22. Cia. Matogrossense de Eletricidade | 3.930 | 1.500 | — | — | 9.000 | — | 10.500 | 14.490 |
| 23. Cia. Eletricidade Paraense | 4.000 | — | — | 15.000 | — | — | 15.000 | 19.000 |
| 24. Cia. Fôrça e Luz Cataguazes-Leopoldina | 8.600 | — | — | — | 6.000 | — | 6.000 | 14.600 |
| 25. Govêrno do Estado de Santa Catarina | — | — | 9.200 | — | — | 8.950 | 18.150 | 18.150 |
| 26. Govêrno do Estado do Paraná | — | — | — | — | 10.000 | — | 10.000 | 10.000 |
| SUB-TOTAL PROGRAMADO | 1.347.168 | 85.295 | 704.650 | 224.000 | 394.825 | 413.550 | 1.822.320 | 3.169.488 |
| 27. Estimativa dos Sistemas Restantes | 627.847 | 20.000 | 30.000 | 40.000 | 50.000 | 60.000 | 200.000 | 827.847 |
| TOTAL DO BRASIL | 1.975.015 | 105.295 | 734.650 | 264.000 | 444.825 | 473.550 | 2.022.320 | 3.997.335 |

damente. O consumo de energia elétrica no serviço de tração ferroviária também apresenta aumento apreciável (38% de 1918 a 1952). Em dezembro de 1952 a extensão das linhas eletrificadas era de 1.349 km contra o total de 37.019 km da rêde ferroviária existente então no País, representando a primeira 3,6% dêsse último total. Em outubro de 1953, a potência total unihorária das locomotivas elétricas era de 538.639 HP e das locomotivas Diesel-elétricas de 438.081 HP, perfazendo o total próximo de um milhão de HP.

No capítulo final é apresentada a estimativa do crescimento da capacidade geradora no País, durante o qüinqüênio de 1953 a 1957, à vista de programas de ampliação já conhecidos. Em sua maioria, tais programas já estão em andamento, havendo grande probabilidade de poderem ser concluídos no decorrer do período considerado.

O ano de 1954 será particularmente expressivo para o País, porquanto deverão entrar em serviço cêrca de 735.000 kW de capacidade geradora adicional, representando aproximadamente 35% sôbre a capacidade total instalada em 1953.

Se os programas previstos puderem ser totalmente executados, o Brasil disporá, em fins de 1957, de cêrca de 4.000.000 kW de capacidade geradora instalada, que corresponde pràticamente ao dôbro da existente em dezembro de 1952.

Finalmente, é feita uma apreciação rápida sôbre as importantes medidas que estão sendo adotadas pelo Govêrno da União, que objetivam promover os recursos necessários a um amplo programa de eletrificação, complementando e entrosando-se intimamente com o que está a cargo das emprêsas privadas e das entidades públicas ou semi-públicas já existentes, a fim de conjurar a grave crise de energia elétrica existente no País, mediante a construção ou a ampliação de centrais geradoras e a instalação de grandes rêdes de transmissão para suprimento e interligação dos sistemas.

## Summary

The authors of the paper – "SURVEY OF THE ELECTRIC SERVICES IN BRAZIL" – present, in a most condensed form, the development of electric services in the country, examine the position of such services during recent years; analyse the use of electric power by principal classes of power customers; and conclude by describing the expansion program of the electric power generating industry during the five-year period 1953 to 1957.

Initially, the authors make a short revue of the development of the electric industry since June 1883 to December 31, 1952. It is of special interest to mention that the average annual cumulative rate of growth of installed capacity decreased progressively from an average of 29.5%

during the ten-year period 1900-1910 to 8.4% during the ten-year period 1910-1920. During the ten-year period 1920-1930, it decreased further to 7.8%; to 4.9% during the ten-year period 1930-1940; to 4.2% during the ten-year period 1940-1950; finally, falling to 2.5% during the two-year period 1950-1952.

In the second chapter a table presents, year by year, during the period 1940-1952, the installed capacity and the electric power production, as well as the annual percentage growth and the average capacity factor. It will be noted that while the installed capacity increased by 58.8% during the twelve-year period, power production grew by 192% and the average utilisation factor rose from 29% in 1940 to 54% in 1952. This indicates, in a very clear way, the state of saturation of the Brazilian electric power generating plants.

In the third chapter, a table sets forth the generating capacity, segregated by thermal and hydroelectric power plants, at the end of 1952, for the whole country. The installed capacity was then 372,388 kW (19%) in thermal power plants, and 1,602,627 kW (81%) in hydroelectric power plants, making together a total installed capacity of 1,975,015 kW.

In the fourth chapter, the highlights of the electric power industry in the country are reviewed for the year 1952. It will be noted that the average annual load factor for the whole industry, during that year, was 61%, which confirms the high degree of saturation of the power generating plants.

In the fifth chapter, a table indicates the electric power consumed by the major categories of electric power customers during 1952. The total electric power consumed was 7,903 million kWh in that year, distributed approximately as follows: domestic power uses 25%, industrial power 49% and other power 26%.

In the sixth chapter an analysis of the domestic electric power consumption is made for the year 1952. The number of domestic customers in that year was estimated at 2,940,000. In 1944, this figure was approximately 2,000,000, according to an estimate made at that time by the Commission for the Electrical Equipment Industry (CIME). Therefore, the increase was 47% in 8 years. The average annual consumption per home increased from 405 kWh in 1944 to 683 in 1952. This is the equivalent to an increase of 44% during the eight-year period.

The seventh chapter deals with the use of electric power by Brazilian industry. A condensed table is presented which compares the several data for the years 1920, 1940 and 1950. The electric power available for each industrial worker increased from 0.53 HP in 1920 to 1.87 HP in 1950. The electrification rate of Brazilian industry increased from 47.5% in 1920 to 85% in 1950.

The eigth chapter deals with the situation of street car services. The implication is that these services will disappear progressively. To replace them, modern trolley-bus services are being provided in several Brazilian cities.

The trolley-bus represents an excellent solution for the majority of the larger Brazilian cities, especially in those cases where electricity, produced in hydroelectric generating plants, is available.

Railroad electrification is studied in Chapter IX, following some preliminary remarks regarding the consumption of fuel and electricity by railroad traction services. It is of interest to mention that the consumption of firewood and imported coal has decreased in the last few years, but the importation of petroleum products has increased substantially. Electric power consumption by railroad traction has increased considerably (38% from 1948 to 1952). In December 1952, 1349 km of railroad tracks were electrified, or 3.6% of the total of 37,019 km of railroad tracks existing in Brazil at that time. In October 1953, the electric locomotives in service could develop an aggregate of 538,639 HP. In the same month, Diesel electric locomotives could develop an aggregate of 438.081 HP, making a total of close on one million HP.

In the last chapter, an estimate is made of the increase in installed generating capacity in the country, during the five-year period 1953 to 1957, by considering the development programs which are known. The majority of these programs are under construction, which makes it very probable that they will be completed during the period of time under consideration.

The year 1954 will be particularly important for the country, since it is expected that approximately 735,000 kW of additional generating capacity will go into service. This represents approximately 35% of the total installed capacity at the end of 1953.

If all the projected expansion programs are completed entirely by the end of 1957, Brazil will have an installed generating capacity of approximately 4,000,000 kW, which is in round figures double the installed generating capacity at the end of 1952.

The paper concludes with a brief report on the important steps which are being taken by the Federal Government to provide the necessary financial resources for an ample public electrification program, to complement the one for which private power companies and the already existing public or semi-public organizations are responsible. The purpose is to relieve the very serious power shortage which exists in the country, by promoting the construction of new generating plants or expanding the existing ones and to construct high voltage transmission lines for power supply or for interconnecting electric systems.

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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

Título 1
Assunto 1.1

OLIVEIRA (A. B. de)
Brasil

# CONSUMO DE ENERGIA NO BRASIL 1939-1952

Por AMERICO BARBOSA DE OLIVEIRA

Eng. Civil — Economista do Banco Nacional do Desenvolvimento Economico — Chefe do Dep. de Planejamento da Companhia Brasileira de Engenharia

COMITÊ NACIONAL BRASILEIRO

Ganha terreno entre nós a idéia de ser indispensável uma programação para que o desenvolvimento econômico se produza em ritmo mais acelerado. Tal aceleração pode ser obtida mediante uma política de inversões que considere os pontos de estrangulamento existentes, como o da capacidade para importar e o da escassez de capital.

Criou-se em anos recentes — mercê dos trabalhos da Comissão Econômica para a América Latina — uma técnica de projeções, através da qual se consegue formar uma idéia integrada do desenvolvimento provável dos setores agrícola, industrial, comercial, dos transportes e dos serviços, baseada na análise da produção e do suprimento no âmbito dos bens de consumo, dos bens de capital e dos serviços, abrangendo não só os produtos finais, mas também todos os bens intermédios.

Ora, entre êstes últimos figura a energia, cujo suprimento se obtém, em parte através da importação, e em parte pela produção nacional originada em vários setores de atividade econômica e que tanto se destina àqueles setores produtivos a fim de ser utilizada sob a forma de fôrça motriz, ou de calor ou luz, como se destina diretamente ao consumo doméstico ou ao transporte privado.

Para prever a demanda futura de energia e o abastecimento de qualquer país em recursos energéticos, impõe-se como medida preliminar o levantamento detalhado da utilização de energia no período passado, a fim de permitir análise das mudanças ocorridas quanto às fontes da energia e aos diferentes setores consumidores.

Esta Monografia limita-se à apresentação de um levantamento, do consumo de energia no Brasil, referente aos últimos 14 anos, e de alguns comentários sôbre os resultados apurados; não se vão incluir aqui dados sôbre os setores da economia a que se destina a energia, nem serão abordadas questões relativas à técnica para previsão da demanda de energia.

O levantamento abrange pràticamente tôdas as fontes de energia como convém, dada a intensa substituibilidade de uma por outra. Ficaram excluídas dêsse levantamento, apenas a energia animal, a humana e a hidráulica, quando não transformada em elétrica.

O ponto escolhido para a medida da energia foi o lado do consumidor. Por outras palavras, a quantidade de energia expressa em nossos quadros e gráficos é a que chega às mãos do consumidor para utilização. Caso a medida fôsse realizada do lado do produtor da energia, chegaríamos a valores mais elevados, pois estariam incluídas tôdas as perdas no processo de geração e nas operações até sua entrega ao consumidor.

Um balanço dêsse gênero apresenta vários pontos discutíveis dada a heterogeneidade das fontes e das formas de energia, bem como da utilização diversificada que se faz da mesma. A maneira escolhida para homogeneizar os diversos tipos de energia foi a sua redução a kWh.

Êsse critério, como qualquer outro, apresenta nítidas limitações e quando somamos kWh utilizados na indústria do alumínio com os kWh absorvidos pelo transporte ferroviário ou aéreo, com os kWh que poderiam gerar a lenha consumida nos fogões dos lares de milhões de pessoas, não o fazemos de consciência inteiramente tranqüila. Consola-nos, entretanto, o fato de que a adoção de coeficientes calóricos para a homogeneização nos conduziria a idênticas imperfeições. Por exemplo: a soma do total de "Btu" do óleo diesel com o do carvão no transporte ferroviário ignora que 1 "Btu" do primeiro equivale a 7 "Btu" do segundo.

Em balanço como êsse, há inevitáveis simplificações a introduzir. Para todos os combustíveis admitiu-se uma taxa de eficiência de 20%, ao reduzir o seu poder calorífico a kWh (1), salvo para a lenha onde se adotou 5% como rendimento médio. Na energia hidroelétrica as cifras representam os kWh vendidos aos consumidores.

O critério adotado visou reduzir a energia consumida a um equivalente de fôrça motriz, embora saibamos que parte dos combustíveis não se destina a utilização mecânica ou elétrica, pois é consumida sob a forma de calor, seja na indústria (siderurgia, por exemplo), seja nos lares. Essa parte utilizada como fonte de calor apresenta naturalmente um coeficiente de rendimento maior do que 20% (entre 50% e 70%); em compensação, outras utilizações como a em transportes oferecem rendimentos médios inferiores àquele limite: 5% para as locomotivas a carvão, 2% para as que queimam lenha, 18% para automóveis.

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(1) Critério adotado em "Energy Ressourcer of the World", Department of State, U. S. A. — Washington, 1949.

## QUADRO 1

### Brasil — Consumo de Energia — 1939 a 1952

(Em milhões de kWh)

| FONTES DA ENERGIA | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A - TÔDAS AS FONTES | 18 405 | 19 097 | 19 490 | 18 625 | 20 668 | 20 496 | 21 769 | 22 093 | 24 739 | 25 958 | 27 125 | 30 398 | 32 717 | 35 331 |
| B - COMBUSTÍVEIS LÍQUIDOS | 3 157 | 3 522 | 3 714 | 2 982 | 3 914 | 3 050 | 3 704 | 5 251 | 6 560 | 7 395 | 8 720 | 10 981 | 12 439 | 14 617 |
| Gasolina de Aviação | 27 | 30 | 41 | 106 | 189 | 91 | 120 | 164 | 246 | 283 | 314 | 359 | 406 | 407 |
| Gasolina Comum | 989 | 1 065 | 1 119 | 707 | 542 | 658 | 983 | 1 787 | 2 138 | 2 573 | 3 085 | 3 774 | 4 534 | 5 430 |
| Querosene | 283 | 283 | 330 | 197 | 170 | 187 | 225 | 333 | 372 | 423 | 822 | 838 | 715 | 859 |
| Óleo Diesel | 362 | 387 | 400 | 314 | 329 | 463 | 438 | 540 | 794 | 1 015 | 1 174 | 1 671 | 1 699 | 2 154 |
| Óleo Combustível | 1 449 | 1 717 | 1 721 | 1 567 | 2 606 | 1 561 | 1 893 | 2 377 | 2 943 | 3 008 | 3 537 | 4 507 | 5 052 | 5 704 |
| Outros (1) | 48 | 40 | 103 | 91 | 78 | 90 | 45 | 50 | 67 | 88 | 88 | 12 | 33 | 63 |
| C - COMBUSTÍVEIS SÓLIDOS | 12 984 | 13 019 | 12 996 | 12 620 | 13 526 | 13 899 | 14 350 | 12 740 | 13 681 | 13 553 | 12 861 | 13 587 | 13 974 | 14 055 |
| Carvão Mineral | 3 556 | 3 472 | 3 221 | 2 728 | 2 906 | 2 560 | 3 165 | 3 702 | 4 671 | 3 883 | 3 472 | 3 940 | 3 752 | 3 704 |
| Nacional | 985 | 1 221 | 1 252 | 1 581 | 1 813 | 1 645 | 1 833 | 1 710 | 1 746 | 1 869 | 1 957 | 1 791 | 1 761 | 1 928 |
| Importado | 2 571 | 2 251 | 1 969 | 1 147 | 1 093 | 915 | 1 332 | 1 992 | 2 925 | 2 014 | 1 515 | 2 149 | 1 991 | 1 776 |
| Lenha (2) | 7 171 | 7 123 | 7 345 | 7 585 | 7 947 | 8 615 | 8 333 | 6 775 | 6 470 | 6 770 | 6 598 | 6 732 | 6 778 | 6 362 |
| Bagaço de Cana | 1 004 | 1 166 | 1 142 | 1 120 | 1 103 | 1 164 | 1 150 | 1 343 | 1 508 | 1 803 | 1 740 | 1 675 | 1 938 | 2 211 |
| Carvão Vegetal | 1 253 | 1 258 | 1 288 | 1 187 | 1 570 | 1 560 | 1 702 | 920 | 1 032 | 1 097 | 1 051 | 1 240 | 1 506 | 1 778 |
| D - ENERGIA ELÉTRICA DE ORIGEM HIDRÁULICA | 2 264 | 2 556 | 2 780 | 3 023 | 3 228 | 3 547 | 3 715 | 4 102 | 4 498 | 5 010 | 5 544 | 5 850 | 6 304 | 6 659 |

FONTE : — Banco Nacional do Desenvolvimento Econômico — Grupo Misto BNDE-CEPAL

(1) — Inclui óleo para produzir gás, "signal-oil" e álcool adicionado à gasolina.
(2) — Não inclui lenha destinada à produção de carvão vegetal.

No quadro 1 figuram os resultados do nosso levantamento em milhões de kWh, para cada tipo de combustível e também para a energia hidroelétrica. No quadro 2 se apresentam os índices de variação de cada tipo de energia.

O consumo total evolui de 18 bilhões de kWh em 1939, para 35 bilhões em 1952, tendo permanecido pràticamente estacionário durante a guerra, quando o carvão nacional e a lenha foram chamados a substituir os combustíveis importados.

De fato, observa-se o consumo de lenha subir do índice 100 em 1939 a 120 em 1944, para então iniciar sua queda progressiva até o índice 89 em 1952; os combustíveis líquidos baixam a 94 em 1942, enquanto a gasolina comum baixa ao índice 55 em 1943, para alcançarem em 1952 a 463 e 549, respectivamente.

O gráfico I oferece-nos uma visão da composição percentual do nosso consumo de energia, pelo qual se percebe a expansão do setor combustíveis líquidos de 17% em 1939 para 41% em 1952 — em detrimento dos combustíveis sólidos, cuja participação caiu de 71% para 40% no mesmo período.

É interessante observar os efeitos da redução verificada no abastecimento de combustíveis líquidos durante a guerra; sua participação reduz-se a 15% em 1944 justamente quando a lenha atinge importância máxima: 42% do total da energia, iniciando então seu declínio até 18% em 1952.

Digno de nota é que o setor da energia hidroelétrica, depois de crescer continuamente, tenha registrado um máximo em 1949 com 20,5% do total, reduzindo sua participação para 19,3% e 18,8% em 1951 e 1952 respectivamente.

Não é de excluir-se, entretanto, a possibilidade de recuperação baseada em novos aproveitamentos hidráulicos a se inaugurarem nos anos seguintes.

Para a análise da evolução do consumo de energia no período em questão, impõe-se um confronto com as atividades produtoras do país já que grande parte da energia é utilizada em produzir e transformar mercadorias, bem como em transportar alimentos, matérias-primas, produtos acabados e também as crescentes massas demográficas absorvidas em atividades urbanas.

Uma solução simples — embora de valor limitado — é determinar o consumo de energia por unidade de produção real (1), tal como se procede na determinação de coeficientes físicos.

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(1) A produção real é expressa por um índice ponderado do volume físico da produção em cada setor da atividade econômica.

## QUADRO 2

### Brasil — Indices do Consumo de Energia — 1939 a 1952

(Base 1939=100)

| FONTES DE ENERGIA | 1939 | 1940 | 1941 | 1942 | 1943 | 1944 | 1945 | 1946 | 1947 | 1948 | 1949 | 1950 | 1951 | 1952 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A - TÔDAS AS FONTES | 100 | 104 | 106 | 101 | 112 | 111 | 118 | 120 | 134 | 141 | 147 | 165 | 178 | 192 |
| B - COMBUSTÍVEIS LÍQUIDOS | 100 | 112 | 118 | 94 | 124 | 97 | 117 | 166 | 208 | 234 | 276 | 347 | 394 | 463 |
| Gasolina de Aviação | 100 | 111 | 153 | 393 | 700 | 338 | 445 | 605 | 911 | 1048 | 1159 | 1329 | 1502 | 1505 |
| Gasolina Comum | 100 | 108 | 113 | 72 | 55 | 67 | 99 | 181 | 216 | 260 | 312 | 382 | 458 | 549 |
| Querosene | 100 | 100 | 117 | 70 | 60 | 66 | 79 | 118 | 132 | 151 | 185 | 226 | 253 | 304 |
| Óleo Diesel | 100 | 107 | 111 | 87 | 91 | 128 | 121 | 149 | 219 | 280 | 324 | 462 | 469 | 595 |
| Óleos Combustível | 100 | 119 | 119 | 108 | 180 | 108 | 131 | 164 | 203 | 208 | 244 | 311 | 349 | 394 |
| Outros (1) | 100 | 86 | 214 | 187 | 160 | 186 | 94 | 103 | 138 | 182 | 181 | 25 | 68 | 131 |
| C - COMBUSTÍVEIS SÓLIDOS | 100 | 100 | 100 | 97 | 104 | 107 | 111 | 98 | 105 | 104 | 99 | 105 | 108 | 108 |
| Carvão Mineral | 100 | 98 | 91 | 77 | 82 | 72 | 89 | 104 | 131 | 109 | 98 | 111 | 106 | 104 |
| Nacional | 100 | 124 | 127 | 161 | 184 | 167 | 185 | 174 | 177 | 190 | 199 | 182 | 179 | 196 |
| Importado | 100 | 68 | 77 | 45 | 42 | 36 | 52 | 77 | 114 | 78 | 59 | 84 | 77 | 69 |
| Lenha (2) | 100 | 93 | 102 | 106 | 111 | 120 | 116 | 94 | 90 | 94 | 92 | 94 | 95 | 89 |
| Bagaço de Cana | 100 | 116 | 114 | 112 | 110 | 115 | 113 | 134 | 150 | 180 | 173 | 167 | 193 | 220 |
| Carvão vegetal | 100 | 100 | 103 | 95 | 125 | 123 | 136 | 73 | 82 | 88 | 84 | 99 | 120 | 142 |
| D - ENERGIA ELÉTRICA DE ORIGEM HIDRÁULICA | 100 | 113 | 123 | 134 | 143 | 157 | 164 | 181 | 199 | 221 | 245 | 258 | 278 | 294 |

FONTE : — Banco Nacional do Desenvolvimento Econômico, Grupo Misto BNDE-CEPAL

(1) — Inclui óleo para produzir gás, "signal-oil" e álcool adicionado à gasolina.
(2) — Não inclui lenha destinada à produção de carvão vegetal.

Observa-se em países já desenvolvidos que o consumo de combustível por unidade de produto tende a baixar, dada a eficiência cada vez maior obtida da mesma unidade de energia (1).

Entre nós é compreensível que o fenômeno não se verifique na mesma extensão, porque a parte de energia que vai sendo liberada pela melhoria do rendimento, vai sendo absorvida nos setores novos em que o trabalho mecanizado vai penetrando tardiamente.

Nosso gráfico II apresenta os índices de consumo de energia, os índices da produção real (elaborado pelo Banco Nacional do Desenvolvimento Econômico) e os da variação do consumo de energia por unidade de produção real.

Observa-se que em todo o período anterior a 1949 o consumo por unidade de produção real manteve-se inferior ao nível de 1939. De 1949 para 1950 e 1951 ocorreu um aumento do índice de 100 para 103 e 105, respectivamente, o que pode ser explicado como conseqüência da intensificação do ritmo de equipamento do país no imediato após guerra e também causado pelo aumento do consumo de gasolina, decorrente da elevação dos gastos de consumo.

Com efeito, nossos gastos de consumo receberam sensível impulso imediatamente após o aumento dos preços de exportação dos produtos brasileiros iniciado em fins de 1949; e como justamente a gasolina — produto de largo consumo direto pela população — saltou do índice 312 em 1949 para o índice 549 em 1952, tem base a suposição de aumento considerável no consumo daquele carburante por parte dos automóveis particulares.

Se analisarmos a variação do consumo de energia por unidade de produção industrial, ao invés de, por unidade de produção global, encontraremos uma queda acentuada (índice 72 em 1952). É que ali o aumento de eficiência produtiva se processa com maior intensidade.

Se olharmos a variação do consumo de energia *per capita* verificaremos incremento de 42% sôbre o nível de 1939. Hoje estamos utilizando 648 kWh *per capita*, contra 457 em 1939 (2).

A rápida substituição dos combustíveis sólidos pelos líquidos e pela hidroeletricidade observada no período é explicável, tanto pelo maior rendimento físico, como pelo económico, de vez que o progresso tecnológico tem permitido, além de menores perdas na utilização, uma baixa dos

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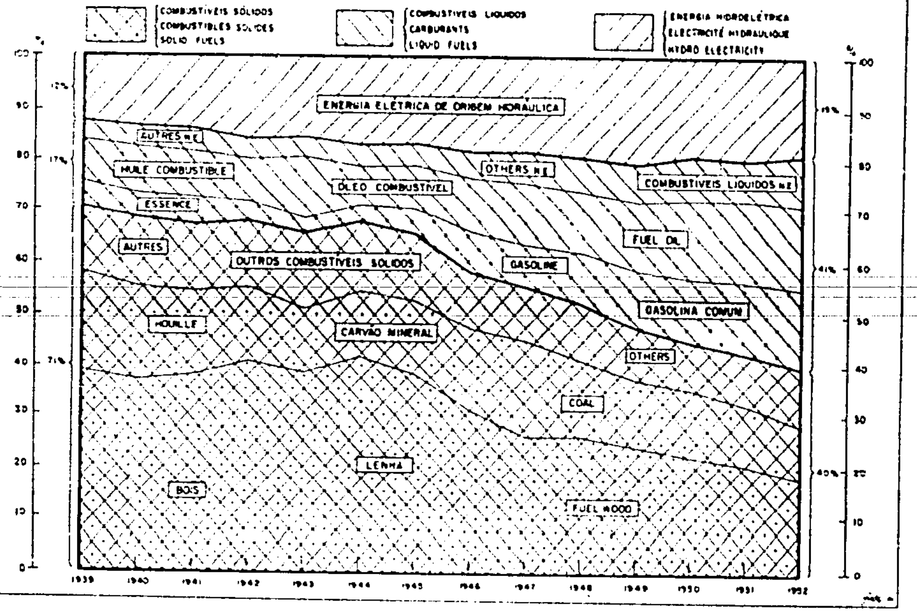
(1) Nos Estados Unidos, entre 1920 e 1940 o consumo de energia por unidade da produção nacional baixou de 100 para 71, como reflexo do aumento de rendimento em trabalho útil do equipamento. (Harold J. Barnett, "Energy Uses and Supplies", Bureau of Mines, U. S. Department of the Interior, 1950).

(2) Nos Estados Unidos, o consumo *per capita* de energia aumentou 56% entre 1939 e 1947.

## GRÁFICO I

**BRASIL** - CONSUMO ANUAL DE ENERGIA, DISTRIBUIÇÃO PERCENTUAL.

CONSOMMATION ANNUEL D'ÉNERGIE, DISTRIBUTION PERCENTUELLE     ANNUAL CONSUMPTION OF ENERGY, PERCENT DISTRIBUTION



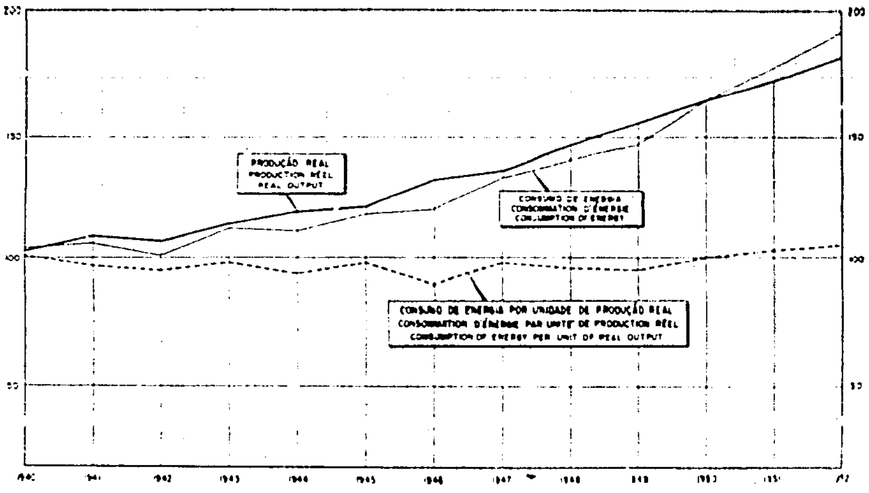
## GRÁFICO II

**BRASIL** - INDICES DO CONSUMO DE ENERGIA, DA PRODUÇÃO REAL E DO CONSUMO DE ENERGIA POR UNIDADE DE PRODUÇÃO 1940-1952

INDICES DE LA CONSOMMATION D'ENERGIE, DE LA PRODUCTION RÉEL ET DE LA CONSOMMATION D'ÉNERGIE PAR UNITÉ DE PRODUCTION

INDICES OF CONSUMPTION OF ENERGY, REAL OUTPUT AND CONSUMPTION OF ENERGY PER UNIT OF REAL OUTPUT

(BASE 1939 = 100)



preços relativos dos produtos petrolíferos e também da energia elétrica esta, aliás, recebe ainda outros favores, como tratamento preferencial quanto a câmbio para transferência de lucros e compra de equipamentos, além de favores de ordem administrativa e fiscal

Enquanto o preço do carvão nacional alcança em 1951 índice de 325 e o estrangeiro 306 (contra 100 em 1939), o preço do combustível líquido atinge apenas 164 e o da energia elétrica 172 (1). A lenha nos oferece a evolução mais desfavorável entre tôdas as fontes de energia. Sua produção, não se beneficiando com progressos técnicos e estando sujeita a transportes, cada vez mais longos, sofreu o maior impacto da alta geral do nível de preços. O índice de preço atinge 425 (em 1951) e a qualidade da lenha deverá ser seguramente pior agora do que em 1939.

Seria possível, e mesmo desejável, uma mudança nesse processo de eliminação da lenha dentre nossas fontes de energia. Um país com regimes pluviométricos altamente favoráveis às formações florestais e dotado de abundantes terras e condições de temperatura suscetíveis de criar rapidamente novas fontes de energia lenhosa ao pé de cada mercado consumidor, não tem por que desprezar êsse processo elementar de fixação de energia solar. O sucesso dessa política estaria na exploração com um nível tecnológico adequado da floresta artificial, em substituição à "mineração" dos cerrados e das capoeiras nativas cada vez mais pobres e distantes.

Os ligeiros comentários apresentados nos parágrafos acima permitem entrever a variedade de problemas que podem ser analisados com um levantamento do tipo que apresentamos.

Vê-se também que um levantamento dêste tipo é a primeira etapa para uma previsão da demanda global de energia.

## Resumo

É apresentado nesta Monografia um levantamento do consumo de energia de tôdas as formas e de tôdas as fontes. Todos os tipos de energia foram reduzidos a um equivalente em kWh, e o ponto de medida é junto ao consumidor, o que significa não estarem incluídas nas cifras apresentadas as perdas no processo de geração transmissão e distribuição. Trata-se pois de um agregado que corresponderia ao consumo final de energia ou melhor, à utilização da energia sob a forma elétrica e não ao consumo bruto inicial para produção da eletricidade.

O levantamento cobre o período de 1939 a 1952 que inclui os anos de guerra, com suas perturbações sôbre o abastecimento do país em combustíveis estrangeiros (quadros 1 e 2 e gráfico 1).

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(1) Esses índices referem-se aos preços médios pagos pelas 12 principais ferrovias do país.

Faz-se também um confronto do consumo de energia com a produção real do país, esta apresentada sob a forma de um índice ponderado do volume físico da produção em cada setor de atividade econômica (gráfico II).

Observa-se grande estabilidade do consumo de energia por unidade de produção real, embora o consumo *per capita* tenha crescido de 42% no período. Nota-se também intensa substituição dos combustíveis sólidos pelos líquidos e o crescimento moderado da energia elétrica de origem hidráulica. O maior rendimento físico e a evolução dos preços das diferentes fontes de energia explicam êsse fenômeno.

## RÉSUMÉ

On présente dans cette Monographie un bilan de la consommation d'energie en toutes ses formes et de toutes les sources. Tous les types ont été reduites a leur equivalent en kWh et le point de mesure est auprès du consommateur, c'est-à-dire, les chiffres indiqués ne computent pas les pertes subies dans le procés de génération transmission et distribution. Il s'agit donc d'un agrege qui corresponderait a une consommation finale d'énergie et non pas à une consommation brute initiel

La balance couvre la periode 1939-1952 où sont inclus les années de guerre, avec ses perturbations pour le ravitaillement du pays avec des combustibles étrangers (tableau I et 2 et graphique I).

On a fait aussi une confrontation de la consommation d'énergie avec la production reel du pays, celle-ci presentée sous la forme d'un index pondéré du volume physique de la production en chaque secteur d'activité économique (graphique II).

On observe une grande stabilité de la consommation d'energie par unité de la production reel malgré que la consommation par tête ait augmente de 42% dans cette periode. On observe aussi une intense substitution des combustibles solides par des combustibles liquides et l'augmentation moderée de la énergie electrique d'origine hydraulique. Le plus grand rendement physique et l'evolution des prix des differentes sources d'énergie expliquent le phénomène.

## SUMMARY

In this study a survey is presented of the consumption of energy in all shapes and from all sources. Every type of energy was reduced to an equivalent in kWh; the point of measurement is at the consumer stage, which means that the losses in the process of generation, transmission and distribution are not included in the figure[illegible]n. A total is dealt with, then, which would correspond to the final consumption of energy or, better, the utilization of energy in the shape of electricity and not with the initial gross input for the production of electricity.

The survey covers the period from 1939 to 1952 including the war years with their disturbances on the country's supplies of fuels from abroad (table 1 and 2 and diagram I).

A comparison is made as well between the consumption of energy and the actual production of the country and this is presented in the form of an index number weighted by the physical volume of production in each sector of economic activity (diagram II).

The consumption of energy per unit of real output is noticed to be very stable although the consumption per capita has grown by 42% during the period. In addition, an intense substitution of solid by liquid fuels and the moderate increase of hydro-electric energy is observed. The greater real income and the price movements of the different sources of energy explain this phenomenon.

### APÊNDICE

## ORIGEM DOS DADOS ESTATÍSTICOS E MÉTODOS ADOTADOS

### COMBUSTÍVEIS LÍQUIDOS

As séries do quadro A são do Conselho Nacional do Petróleo (CNP), compreendem os combustíveis importados e produzidos no País. Essa estatística, quanto à parte importada, é mais completa que os dados do comércio exterior divulgados pelo Serviço de Estatística Econômica e Financeira do Ministério da Fazenda (SEEF). A discrepância provém das bases de apuração; enquanto o SEEF utiliza apenas as faturas consulares, o CNP acrescenta o consumo de combustíveis líquidos importados sem exigência daquelas faturas (importações governamentais). Excluem-se do cálculo os itens de petróleo bruto, de gás de refinaria e gás natural, o que dada a sua insignificância — não afeta praticamente os resultados. A produção nacional de derivados de petróleo consta das séries de consumo apresentadas; vê-se portanto que a parcela do petróleo bruto utilizado pelas refinarias do País aparece nos cômputos dos destilados. (O emprêgo direto do petróleo em bruto como combustível é parcela insignificante).

### COMBUSTÍVEIS SÓLIDOS

*Carvão nacional:* Admitiu-se que o consumo é igual à produção. As séries básicas provêm do Serviço de Estatística de Produção (SEP), Ministério da Agricultura, do "Consórcio de Administração das Emprêsas de Mineração" (CADEM) e dos relatórios da "Companhia Siderúrgica Nacional". Computa-se como consumo apenas o "carvão vendável", isto é, produção bruta na bôca da mina, menos perdas durante o processo de beneficiamento. Os coeficientes de perda para o carvão

## CUADRO A

Brasil — Consumo de Energia - 1939 a 1957

| FONTES DE ENERGIA | UNIDADE | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A - COMBUSTÍVEIS LÍQUIDOS | | | | | | | | | | | | | | | |
| Gasolina de Aviação | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Gasolina Comum | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Querosene | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Óleo Diesel | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Óleo Combustível | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Outros | | | | | | | | | | | | | | | |
| Gases liquefeitos de petróleo | [illegible] | – | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | | – | | | | | | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | | [illegible] | |
| B - COMBUSTÍVEIS SÓLIDOS | | | | | | | | | | | | | | | |
| Carvão Mineral | | | | | | | | | | | | | | | |
| Nacional | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Importado | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Lenha (1) | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Bagaço de Cana | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| Carvão vegetal | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |
| C - ENERGIA ELÉTRICA DE ORIGEM HIDRÁULICA | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] | [illegible] |

FONTE : — Instituto Brasileiro de Geografia e Estatística, Conselho Nacional do Petróleo e Banco Nacional do Desenvolvimento Econômico, Grupo Misto BNDE-CEPAL.

(1) — Não inclui lenha destinada à produção de carvão vegetal

do Rio Grande do Sul eram conhecidos, através de informações do C.A. D.E.M. Para os demais Estados produtores de carvão arbitrou-se uma perda media de 30%. A conversão das séries de consumo de carvão, de toneladas para kWh teve em conta as diferenças de caloria do carvão de Santa Catarina (6.000 cal. t) e o do Rio Grande do Sul (5.000 cal. t), como se vê no quadro B.

### QUADRO B

Balanço Energetico do Brasil, Taxas de Conversão Utilizadas

| Discriminação | Unidade | Milhão de kcal por unidade | Mil kwh por unidade |
|---|---|---|---|
| A - COMBUSTIVEIS LIQUIDOS | | | |
| Gasolina de Aviação | Tonelada | 10,6 | 2,47 |
| | Mil litros | 7,5 | 1,74 |
| Gasolina Comum | Tonelada | 10,6 | 2,47 |
| | Mil litros | 7,8 | 1,82 |
| Querosene | Tonelada | 10,6 | 2,47 |
| | Mil litros | 8,5 | 1,99 |
| Óleo Diesel | Tonelada | 10,6 | 2,47 |
| | Mil litros | 9,0 | 2,10 |
| Óleo Combustivel | Tonelada | 10,6 | 2,47 |
| | Mil litros | 10,3 | 2,41 |
| Alcool adicionado a gasolina | Tonelada | 5,5 | 1,28 |
| | Mil litros | 4,4 | 1,02 |
| Outros oleos derivados do petroleo | Tonelada | 10,6 | 2,47 |
| | Mil litros | 8,7 | 2,03 |
| B - COMBUSTIVEIS SOLIDOS | | | |
| Carvão Mineral Nacional | | | |
| Rio Grande do Sul | Tonelada | 5,0 | 1,16 |
| Santa Catarina | Tonelada | 6,0 | 1,39 |
| Carvão Mineral Importado | Tonelada | 8,0 | 1,86 |
| Lenha | Tonelada | 4,0 | 0,23 |
| | m³ | 1,4 | 0,08 |
| Carvão Vegetal | Tonelada | 7,5 | 1,74 |
| Bagaço de Cana | Tonelada | 2,0 | 0,46 |
| C - ENERGIA ELETRICA | Mil kWh | | 1,00 |

NOTA — Parte dêsses coeficientes provem de "Energy Ressources of the World", Washington 1949. Foi admitido um coeficiente de eficiência de 5% para a utilização da lenha, de 100% para energia elétrica (dados de consumo) e 20% para os demais combustiveis sólidos e liquidos.

*Carvão importado*: Inclui o carvão, a pequena parcela de briquete e coque importado, conforme dados do SEEF.

*Lenha*: Admitiu-se que o consumo é igual à produção. Para 1941, 1946 a 1949 dispunha-se da estatística de produção nacional do SEP. Para os outros anos a produção foi estimada, tendo em conta a estatística da produção de Minas Gerais — o maior produtor de lenha no País. Dispunha-se de uma série para Minas de 1939 a 1950; os dois últimos anos foram estimados com base no consumo de lenha pelas ferrovias.

*Carvão vegetal*: As séries básicas disponíveis são idênticas às de lenha, inclusive o critério adotado para interpolar o consumo nos anos 1939, 1940 e de 1942 a 1945; para 1951 e 1952 a estimativa de consumo calculou-se nas variações observadas no consumo de carvão vegetal pela indústria siderúrgica.

*Bagaço de cana*: Dados do Instituto do Açúcar e do Alcool, compreende apenas o bagaço queimado nas usinas de açúcar, deixando de lado a parte dos engenhos. Arbitrado um coeficiente de 25% da tonelagem de cana de açúcar como bagaço e um poder calorífico de 2 000 kcal por tonelada.

## ENERGIA ELÉTRICA.

As séries de produção e consumo para as emprêsas principais, são extraídas da revista "Aguas e Energia Elétrica" do Conselho Nacional de Aguas e Energia Elétrica. Para as emprêsas do Grupo "Brazilian Traction" e "Bond & Share" são conhecidos dados de produção e consumo em todo o período 1939 - 1952. Para a discriminação da energia de origem hidráulica e térmica, e para o consumo de energia elétrica fornecido pelas emprêsas nacionais necessitou-se utilizar uma série de suposições a seguir enumeradas. O único levantamento completo da indústria de eletricidade data de 1941 (Boletim n.º 2, da Divisão de Aguas) e abrange 1598 emprêsas. Com base nesse levantamento foi possível conhecer o coeficiente de utilização da capacidade instalada. Assim, relacionando a energia entregue ao consumo com a capacidade de produção das usinas, encontramos os seguintes coeficientes: 24,88% para tôdas as 1598 emprêsas, 26,70% para as emprêsas do grupo "Brazilian Traction", 34,02% para as emprêsas da "Bond & Share" e finalmente 17,82% para as outras emprêsas. Aceitou-se 17,82% para representar em 1941 o grau de utilização das usinas pertencentes a emprêsas nacionais e ainda para tôdas as de origem térmica, em sua maioria unidades pequenas. Para os demais anos arbitrou-se uma variação crescente no grau de utilização à razão de 1% cada ano. Êste crescimento arbitrado é razoável, pois chega-se a 1951 e 1952 a um coeficiente de utilização de 28 e 29% respectivamente. Ora, as 28 maiores emprêsas nacionais representando 88% da potência instalada por nacionais, operaram com um coeficiente de utilização de 35% naqueles dois anos e é sabido que as demais emprêsas reúnem milhares de unidades de potência reduzidíssima, espalhadas pelo interior do País com fator de utilização mais baixo.

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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

Titulo 3
Assunto 3.1

BAUM (K.)
Alemanha

# AUTOGENOUS COKING

## A NEW METHOD FOR THE SIMULTANEOUS PRODUCTION OF LOW PRICED COKE AND THERMAL POWER

By KURT BAUM
Dr.-Ing., Consulting Engineer — Essen, Germany

NATIONAL COMMITTEE OF THE GERMANY FEDERAL REPUBLIC

The transformation of coal into coke so far has been generally achieved by dry destillation within externally heated retorts or chamber ovens out of contact with the atmosphere, the volatile matters (gas, tar, ammonia etc.) being collected as by-products in order to reduce the high cost of coke caused by the low rate of production (10-12 kg/m² of heated surface) and the correspondingly high capital investment. The equipment for such by-product recovery plants, however, is also quite elaborate, the market conditions not always favourable and prices in general do not follow in the same rate as the increased coal prices even in Europe, (see Table 1).

TABLE I

PRICE INCREASE FOR COKING COAL, COKE AND BY PRODUCTS IN GERMANY

1939 ./. 1953

(according to W. Reerink *)

| | |
|---|---|
| Coking coal | 1 : 3.5 |
| Blast furnace coke | 1 : 3.4 |
| Coke oven gas | 1 : 3.4 |
| Benzol | 1 : 1.7 |
| Ammonium sulphate | 1 : 2.3 |
| Tar pitch | 1 : 2.5 |
| Tar oils | 1 : 2.1 |
| Gasoline | 1 : 1.6 |
| Diesel oil | 1 : 1.5 |

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* "Glückauf" 1953, Page 909.

The needs for a cheaper method to convert coal into coke therefore have been steadily growing especially in such countries which have to take up the manufacture of coke for their industrial development program f.i. in connection with metallurgical and/or chemical industries and the huge capital required in general.

It is the aim of this paper to present a new and ingenious method how coal can be converted into coke in a very simple manner without such large capital investment for the coking ovens as such as well as for the equipment for the utilisation of the volatile matters driven out during destillation.

The roots of this process called "autogenous coking" are reaching back as far as to the old beehive oven more or less the eldest type of coking furnace ever applied in history. In 1938 Andersen and Renaud of Shawinigan Chemicals Limited, Montreal, took a patent describing the so-called "coking stoker" basing on the coking of a thin layer of coal on a standard travelling grate within a closed chamber i.e. representing more oder less a beehive oven with a "travelling bottom" in which the volatile matters are burned off in a continuous process.

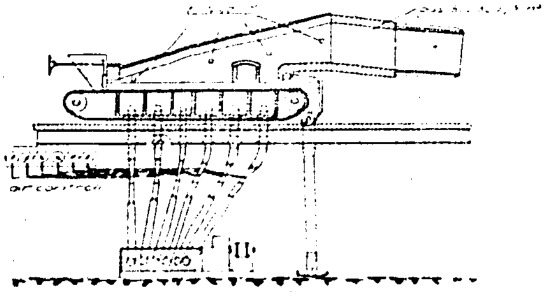

Fig 1 — Scheme of travelling grate coking stoker.

The first results were so encouraging that extensive development work by this company had been performed in an semi-industrial scale in the past and a new coking process had been finaliy developed as described in U.S. patent 2 380 930 of August 5th, 1945 (see Fig. 1, Scheme of travelling grate coking stoker). About 350 tons of coke/day are produced at present according to this method for use in calcium carbide production.

The principle as applied is basing on a very limited supply of air through the specially designed grate bars in the various separated zones of the grate to the coal bed during its travel through the coking chamber — not even enough to burn, but only to convert the gases escaping of the coal within or above the bed by partial combustion essentially into CO and $H_2$ the products of incomplete combustion instead into $CO_2$ and $H_2O$ the final combustion products. Under such "reducing" atmospheric conditions the fixed carbon represented by the remaining coke residue is not able to react with free oxygen respectively limited to a substantial minimum and is behaving during the meating similar to the conditions as existing in a closed retort. The coke obtained respectively drawn off from the grate at the end of his travel indeed does not show a more increased ash content as during dry destillation!

The remarkable progress achieved with such method was the high rate of coking.

It is generally know that coal might be completely burned in a layer of 60-100 mm with rates as far as 150-200 kg/m²/h and since within such complete combustion the coal itself is going through all the various stages of ignition, devolatilisation and coking until complete combustion of the coke it was clear that this coking stage is passed in much faster rates as during the dry destillation. Even in a mechanical gas producer where only half of the theoretical combustion air is admitted and correspondingly only one third of the exothermic reaction heats are developed, the remaining two thirds of the heating value being preserved in the gas as latent heat, 150-180 kg/m²/h can be easily gasified and the coal itself is also passing through the coking stage before its integral gasification.

The same coking speed therefore should be obtained when f.e. the coke would be extracted from a gas producer before the gasification of the fixed carbon i.e. of the coke residue is beginning.

In fact here is the key for the understanding of the so-called autogenous coking method which so far has been empirically developed successfully. In fact 180-200 kg/m²/h of coal are converted into coke in Shawinigan, representing an enormous progress as against 10-14 kg/m²/h in indirect heated ovens, resulting to a coking time of 12-20 minutes as against 16-20 hours.

The physical quality of the coke obtained, of course, is far inferior to ordinary lump size blast furnace coke but still attractive for quite a series of practical applications in the metallurgical or chemical field as will be described later on and sometimes even superior due to its special chemical reactivity

## THEORETICAL BASIS DATA FOR "AUTOGENOUS COKING"

In his paper "Integral Gasification of Finely Dispersed Carbonaceous Matter in Suspension" at the XII International Conference of Applied Chemistry, New York 1951 the writer has demonstrated how gasification — air and — gas produced differ against combustion products as well as the heat content respectively concentration in kcal/Nm$^3$ in the gases due to the different exothermic reactions involved. By the utilisation of an I, T diagram the theoretical reaction temperatures could be easily ascertained.

These reaction temperatures indeed are not much different when the partial combustion is limited to the volatiles as such and indeed sufficient to supply and transfer the necessary heat to carry out the coking process of the solid residue as will be shown lateron in relation to the volatile matter content of the various coals.

These somewhat complicated calculations were necessary in order to find the fundamental laws under which the "autogenous coking" can be performed with the various kinds of solid fuels, but represent the tools for the designing engineer which enable him to calculate rate of coking, capacity of the furnace, the theoretical and practical operation temperatures, gas composition to be expected etc. This was as more important since all data so far known in literature with regard to coking were exclusively valid for the indirect heating of a coal charge fundamentally covering the laws of heat transfer by convention and/or radiation respectively.

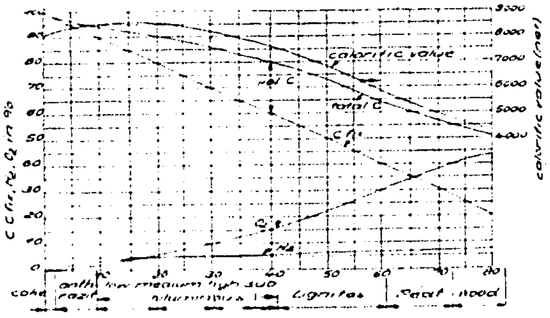

Fig. 2 — Ultimate analysis of solid fuels according to F.-Schulte. (water and ash free)

Basing on the general organic composition of the known solid fuels in relation to their volatile matter content (Fig. 2) the organic composition and heat content of the volatile matters had to be extracted first (see Fig. 3). Basing on these data which demonstrate an interesting relation between the volatile matter and their combustion heat for the various fuels, the relation with regard to the total heat content in the volatile proportion of solid fuels was discovered (Fig. 4).

With regard to their practical use the following curves are basing on 87% organic matter of the fuels as an average, the rest covering mineral matter (8%) and moistur (3%).

The next and important step was to calculate the reaction heats as well as the theoretical heat concentration in kcal/Nm³ gas resulting when

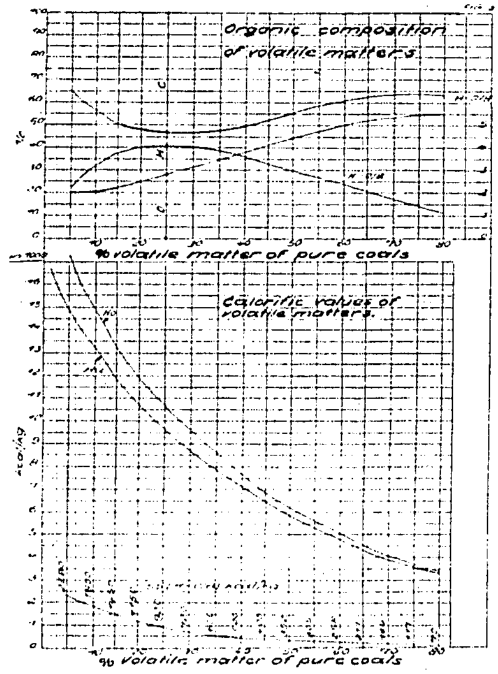

Fig. 5 — Reacting air and gas quantities heating value and theorical resulting volatile matter content.

such volatile matters are reacting with air by partial combustion as outlined.

These data are shown in Figure 5 Theoretical temperatures of 1250°C, necessary to supply and transfer sufficient heat for carbonisation (final coke temperature about 1000° C) can only be obtained within a certain range of fuels: between 15-45% volatile matter content, the effective reaction temperature moreover being lower due to heat losses by radiation.

Below and above this range of fuels reaction temperatures prevailing certainly do not allow continuous coking.

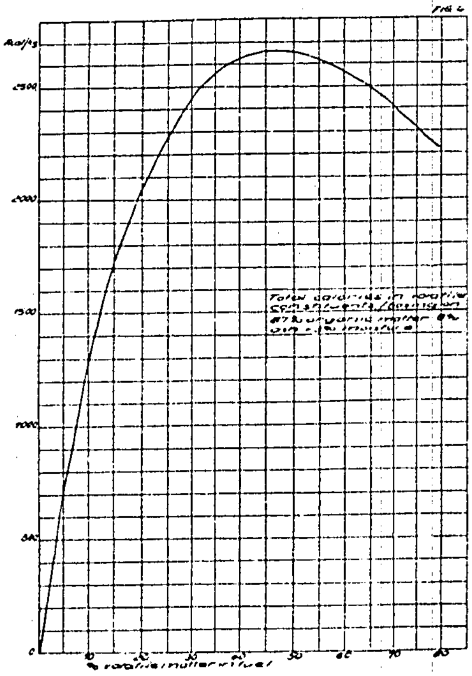

Fig. 4 — Total calories in volatile constituents, basing on 87% organic matter of fuels.

In Fig. 6 the same data are demonstrated when two factors are taken into account:

a) that 10% fixed carbon (the maximum admissable with regard to ash content) are gasified besides the conversion of the volatiles.

b) 260 kcal/kg of radiation losses are deducted as actually observed in large scale continuous coker stoker operation.

Besides larger air and resulting gas quantities no essential difference with regard to the range of fuels to be self-coking under such conditions can be observed.

In Figure 7 effective reaction temperatures are regulated to such degree-by more or less partial combustion (volatile matter and 10% fixed carbon) — that a temperature of about 1200° C is kept constant,

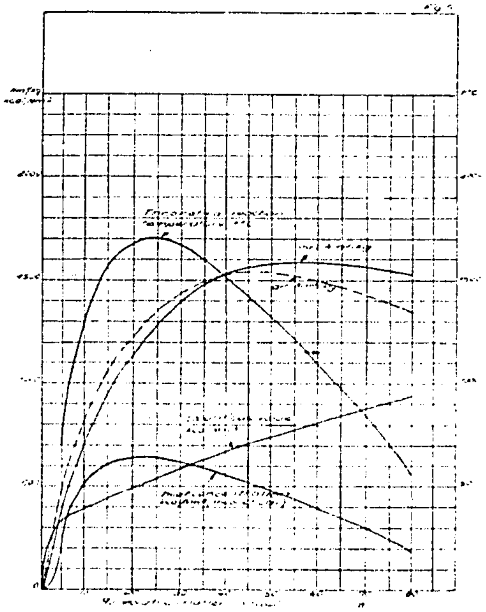

Fig. 5 — Reacting air and gas quantities heating value and theoretical resulting reaction temperatures.

as required for continuous coking. It is most interesting to state that almost any fuel may be converted into high temperature coke or char under such conditions! A free burning gas (650-850 kcal/Nm³ calorifique value of cold gas), however, can only be recovered within the small range of bituminous coals between minimum 15% and maximum 45% volatile matter content of the coal!

Thermal balance and heat distribution check calculations (see Fig. 8) are demonstrating that these complicated and integrated heat changes actually are in full coincidence with the total heat content of the fuel as applied. (Fig. 8 demonstrating the conditions prevailing under such "autogenous coking reactions" as outlined in Fig. 7).

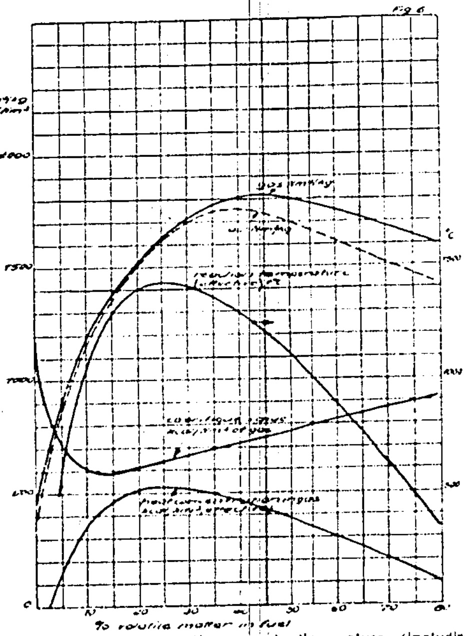

Fig. 6 — Reacting air and gas quantities, gas heating values (including 10% C fix gazification). Heat concentration in gas and effective reaction temperatures. (Radiation losses included).

## PRACTICAL APPLICATION AND ECONOMY

After the criterion by which the autogenous coking is governing had been discovered the following logical deductions were obtained:

1) Coking by means of autogenous reaction heat with air is possible for all kinds of solid fuels independent of their volatile matter content.

2) For low volatile anthracite, anthracite briquettes additional heating fuel may be required due to the fact that even complete combustion of the volatile matter does not supply the necessary heat required for coking.

3) The wide range of low — high volatile bituminous and subbituminous coals can be processed with the simultaneous production of a low grade free burning lean gas — equivalent about to blast furnace gas quality.

4) Lignite, peat or wood may be converted into char only when partial combustion is increased to more or less complete combustion of the volatile matter within respectively above the bed; any useful heating gas (except its sensible heat) cannot be recovered.

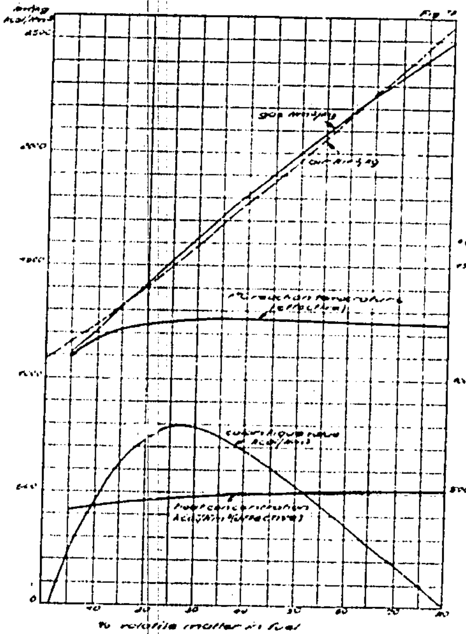

Fig. 7 — Reacting air and gas quantities, gas heating value (including 10% C fix gasification) and heat concentration in gas in case effective reaction temperatures are regulated to 1200°C.

5) Any carbonaceous matter to be processed should be applied air dry if any possible since additional vaporisation would decrease the operation temperature and/or gas quality immediately due to the high heat consumption involved. Elevated moisture content would not even allow to reach the minimum working temperature (about 1000° C), contrary to the countercurrent heat exchange between hot reaction gases and fuel in fixed bed gas producers.

6) The same rules are valid if f.i. mixed products (of minerals coal, pressed or extruded pieces) should be processed. The criterion is the total volatile matter content of the product (coal, binder applied etc.).

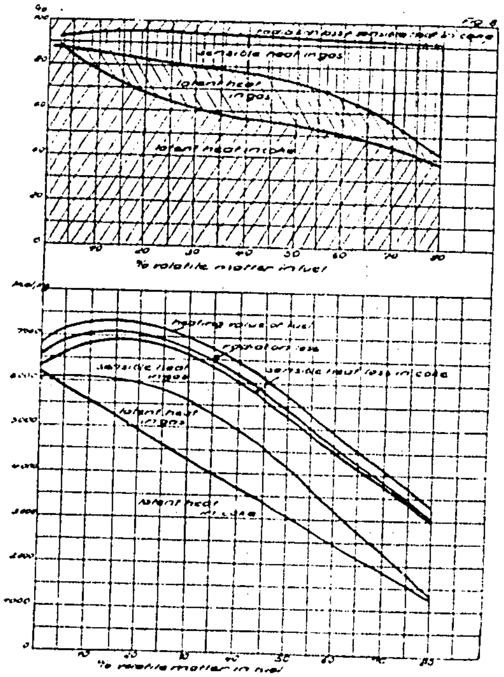

Fig. 8 — Thermal balance of autogenous coking reactions in relation to fuels with varying volatile matter content.

7) In order to keep a reducing atmosphere inside to the bed when partial combustion of the volatile matter alone cannot supply the necessary coking heat required, further combustion has to be achieved by secondary air *above* the bed in order to prevent contact and reaction of fixed carbon with surplus air respectively free oxygen.

Considering and following these fundamental laws, however, the door is open for a wide range of industrial application for autogenous coking with a large series of modifications; basing on the principle to split the ingoing fuel into two products only:

1) coke

2) gas and/or steam

1) *With regard to the coals and residual cokes to be obtained*:

a) Coke from a much wider range of bituminous coals; due to the fast heating effected, excellent coke may be obtained even from coals which do not cake under the slow heating rate prevailing in indirect heated ovens. This is especially valid with regard to mixed products (see to 6) where the coking power of coal is responsible for the production of hard and solid briquettes. Coke from bituminous coals, about 90% above 10 mm up to 30/40 mm, depending of local conditions may be used for all low shaft furnace operations, the production of water gas and/or chemical application as process coke.

b) Char, from high volatile non coking coals due to its high reactivity especially is adopted for all applications where carbon has to react with elements ($CaC_2$ phosphorus, SiC etc.) or where its reducing power is required for reduction and/or sintering of iron or metal ores, can be produced much cheaper than by any other method.

c) Solid mixed coke products can be produced under more or less instantaneous reduction of mineral fines under such reducing atmospheric conditions, preparing an intermediate product for final chemical reaction or reduction to metal.

2) *With regard to the utilisation of the heat content in the hot reaction gases* again a large variety is available:

a) Using such hot gases under any circumstances as boiler fuel, the most efficient method, since complete utilisation sensible and latent heat will bring the total process up to the most efficient method of coal conversion from a thermal point of view. (Low investment cost for gas heated boilers as compared to solid fuel combustion, Fig. 9).

The ratio coke: kW is varying between 355-950 kW produced per ton of coke.

b) Using the hot gases for industrial heating process (burning of lime, cement or calcining of minerals (Fig. 10).

c) Using the hot gases for direct drying or calcining of wet minerals or fuels like lignite, peat or wood with high moisture, (Fig. 11).

d) Using the hot gases f.e. for the heating of indirect heated ovens as f.e. coking ovens, Fig. 12. In such case all dry destillation gas will be available for better use (town gas, chemical application etc.) and the production of additional small size coke may bring additional benefit, if the market conditions are favourable (high coke — to coal-price ratio).

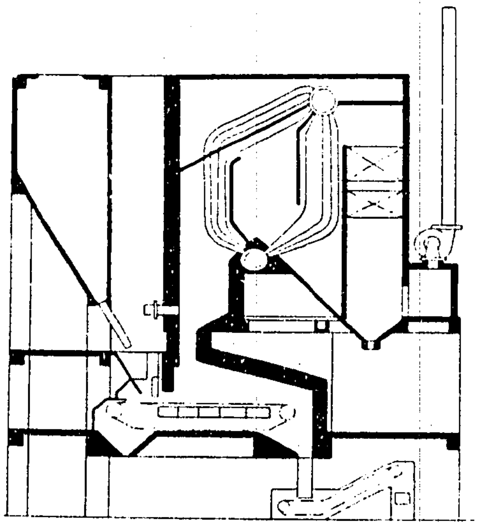

Fig. 9 — Coking stoker combined with boiler on thermal power station.

e) When using bituminous coals a valuable lean gas, similar to blast furnace gas can be obtained as a by-product after passing a waste heat boiler, gas scrubber and cooler to be used as heating — or power-gas or even base-gas for public utility use after carboretting and or admixture of high BTU[1] gases (see Fig. 13).

The investment costs for autogenous coking last not least will generally depend on local conditions, prices of construction materials and

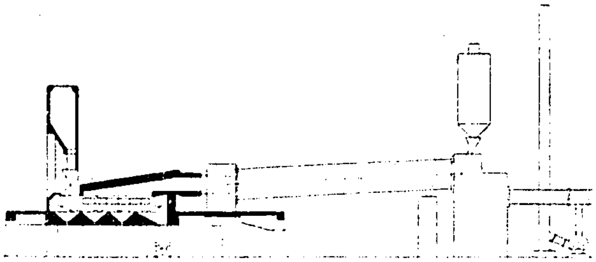

Fig. 10 — Coking stoker using hot gases for rotary Kiln operation.

labour. But just a few figures will be sufficiently characterize the enormous difference as compared to standard coking plants. Investment costs may vary between 1,5 and 2.5 $/t of coke production and year, depending mainly from the degree of gas utilisation equipment as against 25 — 28. — $/ton and year for standard by-product coking plants.

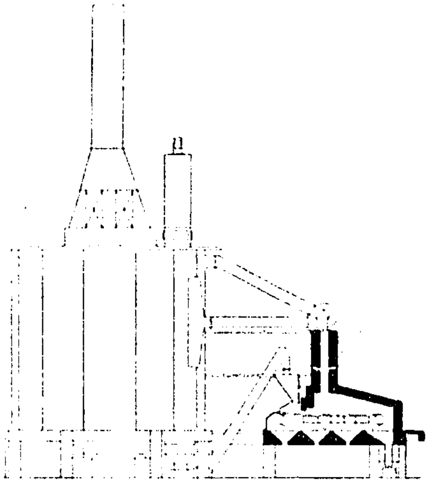

Fig. 11 — Coking stoker using hot gases for vertical dryer operation.

Deprecitiam and capital interest therefore are much lower items within the cost estimate of the coke price.

Labour, maintenance cost etc. do not amount to more than a fraction of the generally known figures due to the continuous and automatically controlled process as well as the limited amount of equipment to be maintained.

The coke price — and equal prices for first grade coking coals — therefore is 2. — to 3. — $/t less even considering the lack of revenue by the so-called by-products and a relatively high value of cokeoven gas under European conditions.

Industrial size units from association with ordinary travelling grate operation practise may be built for 1 - 10 t h or 20 - 250 tons per day for one single unit.

A distinct advantage is furthermore the ready availability and elasticity of such coking stokers. Starting up operation does not take more than about 4 hours. Production may be stopped at any time wanted according to market conditions or requirements.

Fig. 12 — Coking stoker supplying heat for indirect heated coke ovens.

As far as maintenance is concerned there are no temperatures involved which are not generally in application in all thermal processing (1250° C). Fire brick problems therefore do not exist. The only point where maintenance and replacement is required is concerning the grate bars carrying the bed through the coking chamber (about 1 grate bar per 5 tons of coke made). Even this work can be easily performed if necessary even during coking stoker operation.

The absence of high grade coking coals in this country, the so far known modest reserves of coals in general, will necessarily lead to a most careful study how to proceed and to economise the application of fuels and the investment for its use. Industrial planers therefore will have to consider essentially new methods of metallurgical and/or chemical processing differing from Standard practise, taking at the other hand the vast reserves of hydraulic energy in Brazil and their utilisation into account, which certainly require huge investment capital, but once overcome will supply cheap energy.

There are sufficient industrial processes available where low grade process coke, when available at sufficiently low price will allow economic operation especially considering the presence of such ample reserves of high grade ores and minerals, available moreover at comparatively low prices.

Electro-thermal processes as it is known do not require large amounts fuel — expect coke for reduction, a fact which is favourable in so far as quantity as well as quality of coke required is concerned. Brazilian coals are difficult to clean of its inherent ashes. Reducing the process coke applied therefore means reducing logically the ballast involved with the introduction of coke into the processing.

It is my sincere wish to have contributed at least to a certain extent to the important problems of industrial development in this country from the view point of the fuel technologist. Fuel and energy are the most important factors next to raw materials for the basic industries needed in any country and have to be studied most carefully before final decisions are made.

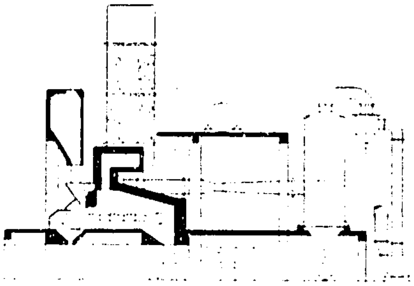

Fig. 13 — Coking stoker as coke and gas producer.

## SUMMARY

The conversion of coal into coke so far has been performed in closed retorts or chambers out of contact with the atmosphere. A new method is outlined by which a limited amount of air is admitted to a horizontal coal layer releasing sufficient exothermic reaction-heat, by which the necessary coking heat is covered. The process is performed on a travelling grate bottom and in continuous operation. The admission of air is limited to such extend that only a partial combustion of the volatile

matters of coal is performed, creating a strongly reducing gas atmosphere within the coking chamber, so that practically no combustion or gasification of fixed carbon can take place. The process is already in large scale in industrial operation and more over in a very special case: The manufacture of low-ash process as applied for the production of calcium-carbide.

The theoretical basis of the exothermic reactions prevailing under such conditions are outlined, and the application of this method for the conversion of various fuels from low and volatile conversion to high volatile bituminous coal and lignites into coke is illustrated.

The coke or char as produced has in principal a grain size of 10 - 30 mm and may be used for a wide range of chemical or metallurgical processing. This process is doubtless the cheapest method from the viewpoint of capital investment for the conversion of valid fuels into volatile free carbon.

Besides coke, hot reducing gases are produced in form of lean gas similar to blast furnace gas. Utilisation of thermal energy released in form of such gases, may be used for the heating of industrial furnaces in various ways and applications as illustrated. The most economic solution is the combined production of coke and power by which the total heat content of such gases, sensible and potential, is transformed into steam by secondary combustion.

The process should be of special interest for such countries in which the manufacture of coke so far is lacking, as more as in many cases a standard coking plant would need more capital investment than the industrial plants in which coke is needed as an auxiliary product.

## Résumé

La transformation de charbon en coke se faisait jusqu'ici dans des retortes ou chambres à destillation chauffées extérieurement et prévées d'air.

On note un nouveau moyen qui montre comment par le dégagement d'une réaction relativement forte exothermique, par une entrée d'air limité dans une couche de charbon horizontale d'une manière "autogène", les quantités de chaleur nécessaires peuvent être liberés pour carboniser les charbons.

Ce procédé se fait sur une fond d'une grille mouvable pour que la transformation de charbon en coke se fait d'une manière continuée.

La quantité d'air est alors établie de tel façon qu'elle ne suffit même pas pour la combustion complète des matières volatiles mais seulement pour une "gasification" des mêmes, c'est à dire une transformation en $CO + H_2$ au lieu de $CO_2 + H_2O$.

Ce procédé est déjà appliquée en grande escale et même un coke extrêmement pauvre en cendrés est fabriqué comme il est demandé pour la fabrication de carbure de calcium.

On explique clairement les bases théoriques pour les réactions qui se passent et l'application de ce procédé de carbonisation pour les différents charbons est expliqué.

Le coke même est produit en général en morceau de 10 à 30 mm, est applicable pour un grand nombre des procès chimiques et métallurgiques. La méthode represent sans doute une solution plus bon marché que la transformation standard de charbon en coke.

A côté du coke on produit des gazes de réaction sous forme d'un gaz pauvre de 800 Kcal/Nm$^3$ et d'une température de 1150°-1250° C. Ces gazes peuvent être utilisé direct avec leur chaleur sensible pour le chauffage des fours industriels variants, ou après récuperation de leur chaleur sensible dans toutes brûleurs industriels standard.

La meilleur solution au point de vue économique est la combination avec la production d'énergie où les gazes chauds en total sont directement utilisés dans un chaudière pour la fabrication du vapeur à haute pression.

Le procédé serait d'un intérêt spécial pour des pays nouveaux dans lesquels jusqu'ici on n'a pas de l'industrie du coke, depuis la cokerie jusqu'aujourd'hui avait besoin de grandes investions que souvent dépassent les capitaux, demandés pour cettes procédés métallurgiques ou chimiques, pour qui le coke n'est plus qu'une produit d'aide ou supplémentaire.

## RESUMO

A transformação de carvão em coque, até aqui, tem sido feita em retortas fechadas ou câmaras sem contacto com a atmosfera. Nota-se um novo meio pelo qual se admite uma limitada quantidade de ar para uma camada horizontal de carvão com suficiente libertação exotérmica de reação calorifica, pela qual se tem o calor necessário à coqueificação. Êsse processo é realizado no fundo de uma grelha móvel para que a coqueificação se faça de modo continuo. A admissão de ar se faz em quantidade tal que apenas realiza uma combustão parcial das matérias voláteis do carvão, reduzindo fortemente a criação de gás atmosférico dentro da câmara de coqueificação, de modo que, pràticamente, não pode se efetuar combustão ou gaseificação de carvão fixo. O processo já se encontra, em larga escala, no emprêgo industrial e, além disso, no caso muito especial do fabrico do coque com baixo teor de cinza, como se requer para a produção de carbureto de cálcio.

As bases teóricas das reações exotérmicas predominantes sob certas condições são descritas, e se ilustra a aplicação dêsse método para a transformação dos vários combustíveis de conversão baixa e volátil em carvão betuminoso altamente volátil, e de lignitas em coque.

O coque ou carvão animal assim produzido tem, em regra, um tamanho de grão de 10 a 30 mm e pode ser usado, com grande resultado e alcance, em processos químicos e metalúrgicos.

Êsse processo é, sem dúvida, o método mais barato sob o ponto de vista do capital investido na transformação de carvão em coque.

A par do coque produziram-se gases de reação sob forma de gás pobre semelhante ao gás de alto forno. O emprêgo da energia térmica realizada sob a forma de tais gases, pode ser efetivado para o aquecimento de fornos industriais de variados fins e demais aplicações conforme se ilustra. A solução mais econômica é a produção combinada de coque e energia pela qual o total de calor contido em tais gases, sensível ou potencialmente, se transforma em vapor dágua por combustão secundária.

O processo terá especial interêsse para os países que, até o momento, não possuem indústria de coque, tanto mais quando, em muitos casos, uma instalação padrão de coqueificação requererá um investimento de capital maior do que as instalações industriais nas quais o coque é apenas um produto auxiliar.

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Título 2
Assunto 2 2

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro – 1954

GASSER (O.)
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Alemanha

# CABLE PROBLEMS WITH EXTRA-HIGH-TENSION DC POWER TRANSMISSION

By O. GASSER
and Ch. HELD

NATIONAL COMMITTEE OF THE GERMANY NATIONAL REPUBLIC

## *Overhead Lines or Cables?*

Transmission of large amounts of electrical energy over great distances is carried out chiefly by means of overhead lines whose technical possibilities are already developed for voltage ratings up to 380 kV between conductors. The distance over which transmission can be economically effected with such overhead lines lies between 400 and 1000 km at frequencies from 40 to 60 c.p.s. In the future we shall find it necessary to open up new sources of energy still farther away from the load centers. Under these conditions the dificulties arising from the nature of alternating current and from the capacity of the lines are likely to become heavily accentuated and will require a large outlay on technical equipment. A disadvantage with overhead lines is their exposure to atmospheric disturbances and the fact that a relationship exists between the amount of energy which can be actually transmitted and the surge-impedance loading of the line.

Such difficulties as are encountered with the transmission of three-phase current will not be experienced when high- tension direct current is used. The inductive and capacitive properties of an overhead line will prove irrelevant when is is operated with d.c., and transmission of large amounts of energy is practically unlimited by distance. Transmission of smaller amounts of energy over very great distances, wehich with three-phase current meets with difficulties for stability reasons, likewise presents no problems with direct current.

Overhead lines having equal insulation, when operated with d.c. instead of three-phase a.c., are able to carry direct current at voltages equal to the permissible a.c. crest voltage.

The are no losses caused by charging current; the losses arising from power transmission and corona are smaller and the line instabilities encountered with three-phase operation are absent. However, an important disadvantage of d.c. operation with overhead lines lies in the fact that such lines under high d.c. potential are particularly subject to fouling by dust so that considerable sums have to be spent on their inspection, cleaning and maintenance. Other setbacks of overhead lines, which apply equally to a.c. and d.c. operation, are atmospheric surges, ice loads, and wind pressure. It would also be impossible to cross large stretches of deep water with overhead lines.

Obstacles of the terrain can much more easily be overcome by cables. In particular, crossing of arms or broad stretches of the sea presents no difficulties. Forest regions and pathless mountains can be easily crossed by cables where overhead lines could only be installed with great difficulties. Cables are not affected by atmospheric discharges and there are no corona losses, which with extra-high-tension three-phase overhead lines are to rise to a serious amount during rain.

### *Three-phase Cable*

Cables for three-phase transmission of electrical energy have likewise been developed for voltage ratings up to 380 kV and have proved satisfactory in actual service.

Theoretically the low dielectric long time strength of *ordinary solid type cables* would require a very thick insulation to be employed with extra-high operating voltages. This, however, is not feasible because with growing thickness of insulation the compound content of the cable is increased corresponding to the cross section of the insulation, i.e. in proportion to about the square of the cable diameter. The contraction of the compound when a solid type cable cools after loading (4% for every 50°C temperature difference) would thus cause excessive formation of voids. This excludes the increasing of the insulation thickness of a.c. — operated compound — filled cables beyond 16 mm.

The logical conclusion to be drawn from this is that solid type cables of ordinary design cannot be considered safe for three-phase voltages beyond 66 kV.

This explains why several methods of three-phase transmission have been tried in order to find a way that would permit higher operating voltages to be employed without the need for further increasing the insulating thickness of the cables. *Pressure cables of the gas-filled type* have gained a certain popularity in this respect. They use high gas pressure in the dielectric by which ionization effects in the voids are suppressed. With the so-called *compression cable* the formation of cavities is prevented by drawing the cores, which are covered with yielding sheaths, into a steel pipe. This pipe is then filled with gas under high pressure (200 psi). The sheaths, which are bulged out by the expansion of the compound when the cable heats up under load, will be reduced to their former shape again by the compressive force of the gas when the cable cools down. This method has allowed raising the transmission voltage for cables of this type to approx. 150 kV between conductors. But only *oil-filled cables* and *oilostatic cables*, which have much in common as they provide the possibility of oil expansion by special devices, are at present suitable for the transmission of extra-high voltages of 380 kV, the highest tension now employed for three-phase systems.

The possibilities of using cables for long-distance transmission of power in three-phase systems are very restricted. This must be attributed not only to the considerable price of the cables but also to their specific transmission characteristics.

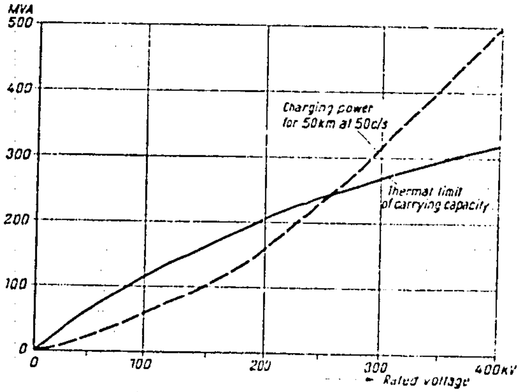

Fig. 1 — Three-phase carrying capacity of 3 oil-filled cables each of 50 $mm^2$ cross-sectional area.

*Fig. 1* shows for three single-core oil-filled cables of 500 sq.mm section each the thermal limiting load plotted over rated three-phase voltages when assuming a 50°C temperature rise of the conductors. Another curve shows the capacitive charging power for a 50 km cable line of the same three cables. Oil-filled cables have been selected for the example because this type is prefered for voltage ratings higher than 110 kV. The example shows that at a rated voltage of about 250 kV the capacitive power required for charging the cables already reaches the thermal limiting load. This is clear evidence that it will be practically impossible to employ three-phase a.c. transmission at extra-high voltages for distances considerably exceeding 50 km unless means for compensating the charging current are provided.

*Fig. 2* is particularly illustrative in this respect. For a polyphase system of three single-core oil-filled cables the line length has been plotted over the transmission voltage assuming the particular case that the charging power is equal to the overall thermal limiting load of the cable line. Apart from their high price, the large dielectric capacity therefore forms the chief obstacle to a wider use of cables for energy transmission with a.c..

## *The Dielectric of Cables under AC- and DC-Stresses*

A decisive technical and economical advantage of direct current is that the ordinary dielectric of cables — oil-impregnated or compound-impregnated paper insulation — sustains much higher stresses with d.c. than with a.c. of customary frequency. The ratios of these two values as given by different authors vary between 3:1 and 10:1. An explanation for this wide divergence is found by considering *fig. 3.* Here it is seen that with stresse of short duration the *dielectric strength* with d.c. is about three times higher than with a.c. But with operation over long periods, which alone corresponds to conditions of actual service, this ratio may rise to 10:1. Depending on the nature of the impregnating medium employed — whether thin oil as with oil-filled cables or a viscid compound of oil and resins as with solid type cables — the long time strength of the cable dielectric under a. c. stress is reduced to between 3/4 and 1/4 of the strength with stresses of only one minute duration.

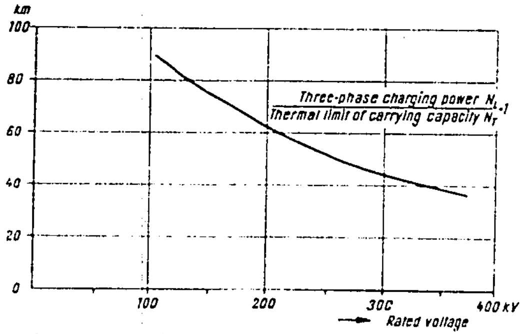

Fig. 2 — Longest cable distance at 50 c s Hollow conductor oil-filled cable.

The discrepancies found between the stated ratios, however, are not only explained by the fact that dielectric strength is compared for different durations of stressing, but in many cases the manner of impregnation and the temperature of the cable were different too. Sometimes the values obtained with d.c. referred to the r.m.s. values, at other times to the crest values of the alternating current. The a.c. values shown in our diagrams are r.m.s. values.

The average dielectric-strength values obtained from numerous tests are plotted in fig. 3 over a time scale $1:\sqrt[4]{t}$ as abscissa. As such long time strength tests cannot of course be continued indefinitely — although frequently they extend over several thousand hours — this form of graphical representation permits extrapolating the strength value for an ""infinite" time as shown by the ordinate at the right. The lower part of the diagram shows the well-known time function of the *dielectric strength of solid type and oil-filled cables under a.c. stress.* Whereas the dielectric strength of oil-filled cables, owing to the superior nature of their impregnating medium and the prevention of void formation, is impaired by only about 25% even under very heavy stress-load cycles, the long time

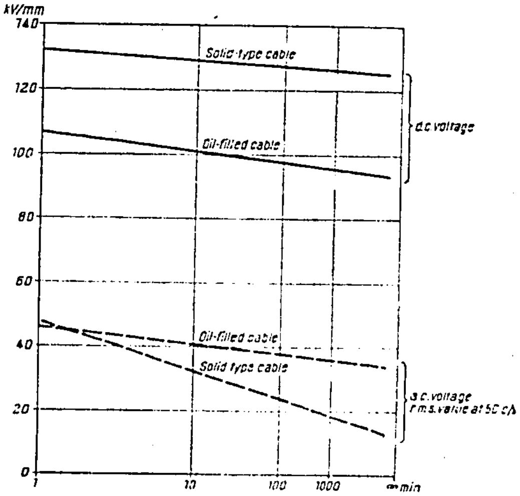

Fig. 3 — Time-voltage characteristics of h.v. cables.

strength of solid type cables drops to approx. 1/4 of the stress value obtained during one minute. When *stressing the cable dielectric by high-tension d.c.* the situation will be found much more promising than with a.c. as appears from the two upper curves in fig. 3. No ionization effects in the voids are experienced with d.c., so that corona losses, which are so detrimental with a.c., are absent. Furthermore the losses which arise from polarity reversal in the dielectric and manifest themselves with any a.c. cable by the dielectric power factor tan $\delta$, will not be found with d.c. operation. The only losses that remain are those caused by the leakage current which is determined by insulation resistance and will be extremely small with a well-dried paper insulation soaked with a high-grade impregnating medium. For cables of good quality the insulation resistance lies between $10^9$ and $10^{10}$ ohm per km, so that no heating of the dielectric will occur.

The above features explain why d. c. — operated cables show no decline of their dielectric properties worth mentioning even after long durations of service. This observation, of course, only holds good if — as is the case in actual service, — *the current load of the cable* is kept within the limits prescribed by economical considerations.

When transmitting large power over very great distances the maximum losses acceptable from the economic point of view determine the specific current load for the conductor. With the transmission distances and voltages hitherto contemplated, the designer is scarcely interested in loading the cables up to their thermal limiting capacity. Such considerations are of course to the advantage of the solid type cable. Whereas oil-filled cables can without difficulty be operated with conductor temperatures of 70° to 80°C, thermally high-stressed solid type cables would be liable to compound migration, especially if laid in mountainous regions. This hazard can be diminished only by keeping the specific current load low, so that the cable is only slightly heated; for at lower temperatures the viscosity of the impregnating medium remains high enough to check the tendency to migration.

Some authors compare the dielectric strength of solid type cables with that of oil-filled cables at the same very high current load. In such a comparison the oil-filled cable is bound to show up much better than the solid type cable because its impregnating medium is prevented from migrating as it flows over special recipients such as stop joints, into expansion tanks and the like, which serve for maintaining excellent filling of the cable at all times. But since in actual transmission over very great distances, as was pointed out above, high specific current loads are only rarely encountered, it seems justified to compare the dielectric strengths of cables at smaller loads — which from the economical aspect is more realistic — i. e. within a range of temperatures up to approx. 50°C which has proved most suitable for d. c. transmission also with solid type cables. On the other hand, the superiority of oil-filled cables over solid type cables as regards stability under thermal stresses can be made use of under special service conditions as are encountered in hot climate. In cases of this kind the use of solid type cables would require the conductors to be designed with larger cross-sections. Leaving aside such exceptional cases, however, the technically more straightforward solid type cable can be employed with adventage for d. c. transmission. A further point favouring the solid type of cable is that owing to the higher viscosity and higher insulation resistance of their impregnating compound the breakdown strength of compound-impregnated cables is appreciably higher than that of oil-filled cables, as will be seen from the two upper curves in Fig. 3.

The high dielectric-strength value in the diagram applies to a cable with compounded paper insulation of 12 mm thickness which had been built for the experimental 440-kV cable line Elbe-Berlin. The breakdown

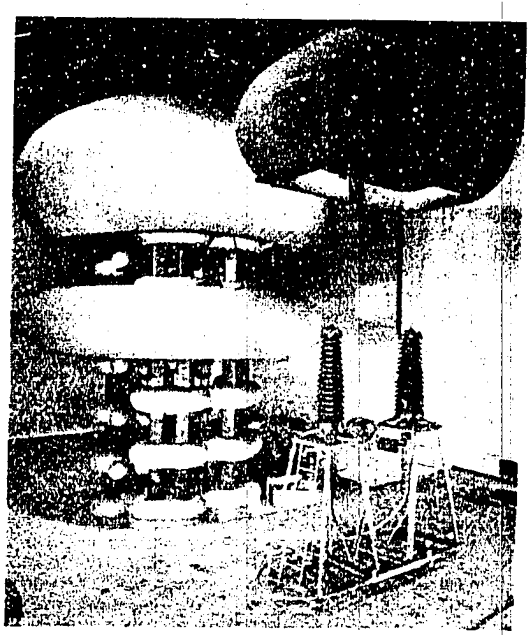

Fig. 4 — D.c. cable test set 1.8 MV and cable for transmission at 440 kV.

voltage measured on this cable with the help of the 1.8-million-volt test generator shown in Fig. 4 was 900 kV with negative potential and 1150 kV with positive potential. These values measured on heavily insulated cables can be used as a reliable basis for the design of new high-tension d. c. cable lines, although they may sometimes conflict with values published elsewhere that have been obtained mostly with weaker insulated cables. Our experience seems to indicate that cable lines for extra-high-voltage DC-transmission should be designed for a maximum *field gradient under service conditions* of approx. 40 kV/mm.

## *Cables for DC-Power Transmission*

This granted, computations will give *insulation-thickness values* as shown in Fig. 5 for a compound-impregnated cable of 500 sq. mm conductor area. It can be seen from the curve that for the transmission of d. c. power at 2 x 220 kV an insulation thickness as small as 7 mm would be adequate, although the cable completed in 1944 for the d. c. transmission line Elbe-Berlin still used a thickness of 12 mm over the conductor of 14 mm diameter. The generous dimensions in this case were explained by the fact that the designer had to allow for harmonics of considerable amplitude which were expected to be superimposed as ripple on the d. c. voltage, so that a voltage gradient of 32 kV/mm at the conductor surface was not to be exceeded. With the present state of development we can be safe in assuming that with large-scale transmission lines and distances of several hundred kilometers harmonics of an amplitude worth mentioning will not penetrate into the cables. By providing choke coils in series with the line and thanks to the naturally high dielectric capacity of the cables, it is possible to attenuate the amplitude of the harmonics to values low enough to leave them out of consideration when dimensioning the thickness of the insulation. The dielectric-strength values shown in Fig. 3 were measured with negative polarity and at ambient-air temperature. The tests furnished definite proof that the dielectric strength with positive polarity is approx. 20% higher. It suggests itself that economic savings on a transmission line operated with both polarities could therefore be achieved by a corresponding reduction in the insulation thickness of the positive cable. Savings of this kind, however, cannot be recommended; two cables of equal insulating strength will offer the possibility of using them with either polarity, and this is undoubtedly advantagious. In this connection it deserves mentioning that even when stressed by impulse voltage the breakdown of solid type cables will be found about 15% higher with positive than with negative polarity. *Loading and temperature rise of a cable* have a twofold effect on the break down strength of the dielectric. On the one hand, the dielectric strength in the hot state is less than in the cold state because the hot impregnating medium has lower viscosity and lower insulation resistance; on the other hand, with solid type cables which are heated beyond a certain temperature without giving the impregnating compound a possibility to escape and to return when the cable cools, voids are likely to be formed and these are very detrimental to the dielectric strength. Numerous tests on cables whose paper had not been impregnated with compound to saturation have shown that under unfavourable conditions the dielectric strength may drop to half the value measured on cables whose insulation had been impregnated thoroughly. This deterioration is chiefly explained by the fact that, especially at reduced pressure, the dielectric strength of air and gases is much less than that of paper or oil. Whereas the dielectric strength of a dielectric consisting of oil and paper under d. c. stress is from 3 to 10 times higher than under a. c. stress as can be seen from Fig. 3, this rule does not apply to air as dielectric. The breakdown strength of air is independent of the kind of current, and this is the reason why cables with gas in their insulation will be found less suitable for d. c. transmission than cables with fully-impregnated insulation.

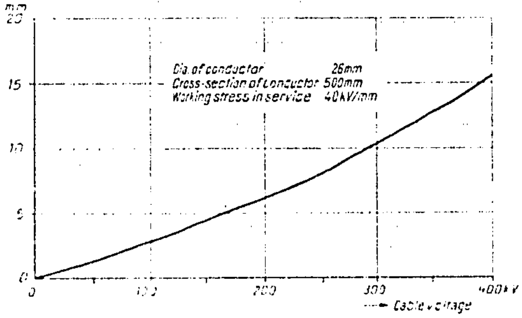

Fig. 5 — Thickness of di-electric for solid-type cables.

The load to which three-phase cables can be subjected will always depend on the cable construction. The same applies when operating the cable on d. c. With oil-filled cables, for example, conductor temperatures up to 80°C are permissible; with ordinary compound-impregnated, paper-insulated lead-sheathed cables, however, it is advisable to limit the highest operating temperature to 50°C, which corresponds to a *permissible temperature rise* of 30° — 40°C. Life-tests for dielectric strength on current-loaded oil-filled and solid type-cables have demonstrated that in this temperature range the dielectric strength is not much diminished. However, if solid type cables are subjected to the same high current loads as oil-filled cables and are thus heated to temperatures of 70°C and higher, the dielectric strength of solid type cables will be very much diminished in contrast to the smaller dielectric-strength reduction of oil-filled cables under the same load. It would however be a fallacy if the above test results were interpreted as meaning that for high-tension d. c. transmission oil-filled cables should be preferred to solid type cables. The use of oil-filled cables for very great distances involves an additional outlay on stop joints and other special cable accessories which seems unwarranted from an engineering as well as economical point of view. With long-distance transmission no profitable use can be made of the superior current-carrying capacity of oil-filled cables, at least not to the extent indicated by the ratio of respective permissible current loads of oil-filled and solid type cables. Transmission lines for long distances will in every event be dimensioned with regard to power loss, i. e. with regard to *voltage drop* in the case of d. c. transmission. It will thus be hardly ever possible to make full use of the thermal limiting load of a cable.

This can be clearly seen from *Fig.* 6. *The power that can be transmitted by a 1000 km long solid type cable line* with either copper or aluminium conductors when a voltage drop of 10% is assumed (power efficiency of the cable transmission $\eta = 90\%$) has been recorded in relation to the operating voltage. The thermal limiting loads are likewise indicated and it will be seen that with voltages between 2 x 100 kV and 2 x 200 kV the cables should be loaded with only about one third of their current rating. With all voltages lower than 2 x 360 kV when using copper conductors or lower than 2 x 460 kV with aluminium

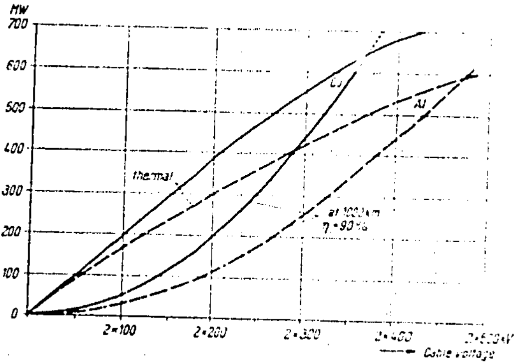

Fig. 6 — D.c. output of 2 solid-type cables, cross-section of conductors 500 mm2 each.

conductors, the power that can be economically transmitted over 1000 km ($\eta = 90\%$) will be below the thermal limiting load. With shorter distances the economically transmissible load will be higher, with greater distances it will of course be still smaller. The diagram refers to a 1000 km length of the line as this is the transmission distance of the majority of projects discussed during recent years.

The great advantage that can be derived from the higher electric strength of a cable under d. c. stress is seen in *Fig. 7*. Here, the three *single-core oil-filled cables of a 380-kV three-phase a.c. transmission line* are compared on the same scale with the *two single-core solid cables of a d. c.-transmission line designed for 2 x 220 kV* and equal current carrying capacity. With a cross-section of the conductor only 74% of the section of the three-phase cable the d. c. cable can carry 50% higher current because the insulation thickness of the d. c. cable is only 29% of that of the a. c. cable and no extra losses in the conductor, sheath and armour will occur as with a. c. When comparing the two transmission systems it should be kept in mind that 380 kV-three-phase cables in systems with directly-groundet neutral are stressed by an a. c. voltage of 220 kV r.m.s., i.e. by 310 kV crest voltage, whereas the d.c. cables have to withstand only 220 kV. The economic advantages to be gained from d.c. transmission can be clearly seen from a comparison of the cable weights. For each kilometer of line length three single-core a.c. cables will have a weight of 93 tons as compared to only 17 tons of the d.c. cables. Besides the savings that can be achieved in weight, transmission losses with d.c. will amount to less than half those with three-phase a.c.

| Three-phase current 380 kV | | direct current 2 × 220 kV |
|---|---|---|
| 470 A | | 705 A |
| $3 \times 500\ \mathrm{mm}^2$ | Conductor | $2 \times 370\ \mathrm{mm}^2$ |
| 26 mm | Insulation | 7,5 mm |
| 3,5 mm | lead-sheath | 1,6 mm |
| 109 mm | Cable diameter | 53 mm |
| 3 × 31 kg/m | Weight | 2 × 8,5 kg/m |
| 135 W/m | Total transmission loss | 53 W/m |

Fig. 7 — Cable for 310 MW Alternating current and direct current.

*Examples of cable lines*

The largest *d.c. transmission line* actually constructed, but not taken into operation because of dismantling in 1945, was intended to connect the "Elbe" power station with Berlin. The distance between the two terminal stations was 115 km. The cables for the planned two-wire line were built to uniform specifications by a group of three firms. These specifications provided for a conductor section of 150 sq. mm Al, an insulation thickness of 12 mm, and for 2 mm thickness of the lead sheath. As to the actual construction of the cable, the individual firms had full freedom of design. The Siemens-Schuckertwerke adopted the following construction for their cable: In order to prevent migration of the compound in longitudinal direction (a difference in elevation of more than 100 m had to be overcome between the terminal points of the line) the aluminium conductor built with a very high compactness factor consists of three stranded solid sector shaped wires surrounded by a layer of flat wires. The paper insulation spun on the conductor was impregnated by an oil-resin compound for which first-grade ingredients of highest purity were used. The core insulation was wrapped with a layer of metallized paper (Höchstädter foil). The lead sheath was covered with a highly effective corrosion-protective layer followed by an open, i.e. half-covering, layer of flat magnetic steel wires. The outer serving consisted of the customary layer of compound impregnated jute. The overall diameter of the cable was 55 mm, the unit weight 6.3 kg/m. The cable was laid in individual lengths of 800 to 1000 meters. With a service load on the cable of 275 amp d.c., equivalent to a transmitted power of 120 MW at 2 x 220 kV, the temperature rise of the conductor was 25°C. Thorough tests had shown that with this temperature rise the cable would have practically the same dielectric strength as in the cold state. As mentioned before the mean breakdown voltage of the cables furnished by the Siemens-Schuckertwerke was found at approx. 1000 kV by means of the 1.8 MV generator. Fig. 8 shows the design of the cable as actually built. Another cable will now be described which, in accordance with the above considerations, is suitable for the *transmission of large power* by positive and negative d.c. with a line potential to earth of 400 kV each. The design was based on a transmission distance of 1000 km, a voltage gradient at the conductor of 40 kV mm and an operating temperature of approx. 50°C. The thermal limiting load of a cable of this type, whose section is shown in *Fig.* 9 will be about 340 MW for a copper-conductor of 500 sq.mm. With a current of 850 amp and a resistance of the copper conductor of 0.04 ohm per km the ohmic voltage drop will be about 34 V per km, corresponding to 8.5% for the entire transmission distance. The design of this cable was governed by the following considerations. The conductor was to have the highest possible compactness factor, i.e. as few interstices as possible between the stranded wires as such hollows might cause migration of compound in mountainous regions. An appropriate material for the insulation, which is built up from layers of spun paper, is sodium cellulose paper of high-density. The dielectric field at the core surface will be screened by metallized Höchstädter foil. The present state of cable development permits the sheath to be produced either as seamless extruded lead tube or as aluminium sheath. The use of aluminium as sheathing material allows weight savings to be achieved which are particularly welcome from the cable-layer's point of view (see Fig. 9). A feature that is essential for the reliability of the cable in operation is

Fig. 3 — Cable of d.c. transmission Elbe-Berlin at 140 kV, 275 A.

the protection of the sheath against mechanical, electrolytical and chemical attack. In tropical climate extra protection against attack by insects has to be taken. The protection against corrosion should consist not only of the customary layers of compounded jute and paper, but also be additionally re-inforced by tapes of thermo-plastic or rubber or by sheaths of these materials applied over the cable by an extrusion process. The mechanical armour should afford protection to the cable not only against possible injury caused by digging operations, but should also facilitate the laying of the cable in difficult terrain. The need to save installation time makes it necessary to use the longest possible individual cable lengths. Laying of such great lengths of cable requires in some cases a closed armour of flat or round steel wires which is capable of taking up tensional stress. Under ordinary laying conditions an armour of two layers of steel tape spun one above the other as shown in the figure, the type generally employed nowadays, will be found sufficient. This armour is covered in the usual way by a jute spinning impregnated with bitumen. Ordinary steel can be used for the armour since, in contrast to single-core a.c. cables, there are no losses by magnetic hysteresis. A system of two such cables with copper-conductors allows transmitting a power of approx. 610 MW after deduction of losses over a distance of 1000 km. Where higher power is to be transmitted it will be convenient to lay several cables or several cable systems in parallel. If different routes are chosen for the parallel-connected cable lines, in the event of one line being disturbed by digging work, etc., the system can be kept in operation by means of the unaffected part of the line.

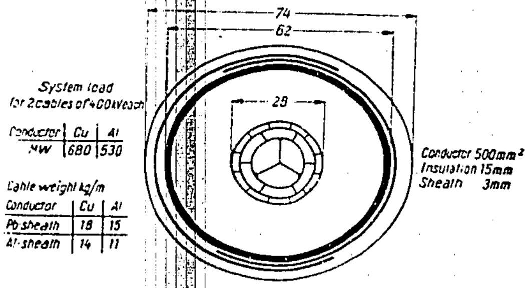

Fig. 9 — Solid-type cable for d.c. 2 · 400 kV.

As with three-phase transmission systems, dimensions and design of high-tension d.c. cables must be matched to prevailing local conditions.

With d.c. cables for such high tensions the joints and sealing ends require not only great care, but also a certain amount of experience; the latter thanks to actually built experimental installations, has now already been gained. In 1949 Mr. E. J. Errol and Lord Forrester pointed to some interesting projects which are awaiting realization. It would be a valuable contribution to technical progress and to the further development of energy transmission systems if one of these projects could be carried out in the near future.

In any event, cable engineering is today in a position to successfully solve any of the problems involved in long-distance power transmission.

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*Das Kabelproblem bei Gleichstrom-Höchstspannungs-Übertragungen*

*Cable Problems with Very-high D.C. Voltages*

*Le problème de câbles pour le transport d'énergie électrique sous très hautes tensions continues*

## SUMMARY

With alternating currents the transmission of electric power by cable is limited to short distances (below 100 km) due to the cable capacitance. With direct current, however, transmission over unlimited distances is possible. The advantages of cable as compared with overhead transmission lines are well-known — they are not subject to atmospheric disturbances, they can be used for submarine crossings, and power loss results only from the ohmic voltage drop.

With d.c. voltage stress the electrical strength of normal paper-insulated cable impregnated with compound or oil is many times greater than with a.c. voltage stress. Thus very high voltages can be applied

with small thicknesses of insulation. The d.c. strength is compared with the a.c. strength, taking into consideration the duration of stress, polarity and temperature.

An example shows the difference between 380-kV three-phase cable and 220-kV d.c. cable, both for the same transmitted power. The cables of the Elbe-Berlin Testing Station, 120 MW at 2 x 220 kV, are briefly described. A further example describes the design of cable for over 600 MW d.c. power at 2 x 400 kV.

*Das Kabelproblem bei Gleichstrom-Höchstspannungs-Übertragungen*

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*Le problème de câbles pour le transport d'énergie électrique sous très hautes tensions continues*

## RÉSUMÉ

Pour de grandes puissances d'énergie électrique en alternatif ou triphasé, on ne peut utiliser les câbles que pour des distances réduites (moins de 100 km) du fait de leur capacité. Pour courant continu, on peut se servir de câbles pour n'importe quelles distances. Comparés aux lignes aériennes les câbles présentent les avantages suivants:

aucun danger de perturbations atmosphériques;
possibilité d'utilisation sous-marine;
pertes réduites, provoquées pratiquement par la chute de tension ohmique seulement.

La rigidité diélectrique des câbles normaux isolés au papier et imprégnés d'huile ou de masse isolante, s'élève pour courant continu à un multiple de celle pour courant alternatif. On peut donc employer de très hautes tensions, même pour une épaisseur d'isolation réduite. On compare la rigidité en continu avec celle en alternatif, en tenant compte de la durée de charge, de la polarité et température.

A l'aide d'un exemple concret on indique la différence entre les câbles 380 kV triphasés et les câbles 220 kV pour courant continu. On donne une description sommaire des câbles 2 x 220 kV, 120 MW, de l'installation d'essai Elbe-Berlin. Par un autre exemple on indique la construction d'un câble 2 x 400 kV, pour une puissance dépassant 600 MW en courant continu.

## RESUMO

Com corrente alternada a transmissão de energia elétrica por meio de cabos é limitada a pequenas distâncias (abaixo de 100 km) em razão da capacitância dos cabos. Com corrente continua, contudo, a transmissão a distâncias ilimitadas se torna possivel. As vantagens dos cabos comparadas com as das linhas aéreas de transmissão são bem conhecidas: não estão sujeitos aos distúrbios atmosféricos, podem ser empregados para travessias submarinas, e perdas de energia resultam apenas da queda ôhmica de voltagem.

Com a tensão de corrente continua a resistência elétrica de cabos normais com isolamento de papel impregnado de óleo ou massa isolante é muito maior do que com a tensão de corrente alternada. Assim sendo, voltagens elevadas podem ser usadas com pequenas espessuras de matérias isolantes. A resistência elétrica da corrente continua é comparada com a da corrente alternada, levando-se em consideração a duração da tensão, polaridade e temperatura.

Um exemplo mostra a diferença entre o cabo 380 kV trifásico e o cabo 220 kV de corrente continua, ambos para a mesma energia transmitida. Os cabos 2 x 220 kV, 120 MW, da Elve-Berlin Testing Station são sumàriamente descritos. Um outro exemplo descreve o projeto de um cabo 2 x 400 kV, para potência acima de 600 MW em corrente continua.

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# LES USINES THERMIQUES ET LA COORDINATION ENTRE PRODUCTION HYDRAULIQUE ET THERMIQUE EN ITALIE

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COMITÉ NATIONAL ITALIEN

La situation de l'industrie électrique italienne à la fin de 1952 peut être représentée par les chiffres suivants:

- puissance effective des installations hydroélectriques: 7.200 MW
- productivité moyenne annuelle des installations hydroélectriques: 28.000 GWh
- capacité d'accumulation des réservoirs: 3.500 GWh
- puissance effective des usines thermiques: 1.700 MW
- production effective en 1952:

| | |
|---|---|
| des usines hydrauliques .... | 27.000 GWh |
| des usines thermiques ..... | 3.800 GWh |
| Total ............ | 30.800 GWh |

La situation actuelle est la suivante:

- puissance effective des usines hydrauliques: 7.500 MW
- productivité annuelle moyenne des usines hydrauliques: 29.000 GWh
- capacité d'accumulation des réservoirs: 3.750 GWh
- puissance effective des usines thermiques: 2.050 MW

La situation en 1955 sera à peu près la suivante:

- puissance effective des usines hydrauliques: 9.500 MW
- productivité annuelle moyenne des usines hydrauliques: 33.000 GWh

— capacité d'accumulation des réservoirs: 4.000 GWh
— puissance effective des usines thermiques: 2.500 MW

Les ressources hydrauliques italiennes réellement utilisables, qu'on évalue grosso modo à 50.000 GWh par an, sont déjà utilisées pour le 60% environ; c'est à dire qu'il reste à utiliser 20.000 GWh par an environ, correspondant aux augmentations probables des consommations d'énergie pour quelque chose comme dix années (augmentation de 6 ÷ 7% par an).

Cette exploitation de plus en plus poussée des ressources hydrauliques a donné lieu à une modification radicale de l'économie électrique de notre pays, dans le but de satisfaire aux augmentations de la consommation en partie avec de l'énergie hydraulique et en partie avec de l'énergie thermique.

Cette nouvelle tendance dans le plan de développement des installations a mis en évidence le problème d'une coordination dans la marche des usines hydrauliques et thermiques qui permette l'utilisation intégrale de nos ressources hydrauliques et le maximum d'économie dans la consommation des combustibles.

Pour atteindre une coordination rationnelle et économique de ces deux sources d'énergie il est nécessaire d'employer les usines hydrauliques à fil de l'eau et les usines thermiques pour le service de base à charge constante ou à charge programmée avec de lentes variations, et de confier le rôle d'usines de pointe pour le réglage de la fréquence, dont la charge peut changer rapidement, principalement aux usines hydrauliques alimentées par des réservoirs.

Dans la première période de développement des usines hydrauliques les usines thermiques italiennes jouaient principalement un rôle de réserve exceptionnelle en cas de dégâts aux lignes de transport; c'est pourquoi elles avaient été situées dans les centres principaux de consommation et proportionnées à la charge absorbée par ces centres. En vue de leur rôle d'usines d'émergence elle devaient être capables d'une marche indépendante, qui était nécessairement à charge variable.

Après l'étiage exceptionnel des années 1921-1922 les groupes électriques italiens les plus importants mirent en chantier un programme thermique rationnel qui confiait aux usines thermiques le rôle d'intégration des usines hydrauliques aux périodes d'étiage et seulement pour les manques d'énergie qui ne pouvaient pas être remplis par les installations pourvues d'un réservoir d'intégration saisonnière.

Les étiages exceptionnels des années 1947-48-49 et les graves conséquences qu'ils eurent sur les disponibilités d'énergie hydraulique (qui avaient été sensiblement amoindries par les ravages de la guerre, sans qu'il eût été possible de les rebâtir aussi vite qu'il était nécessaire, à cause de la difficulté dans l'approvisionnement des matériaux, conséquence elle aussi de la guerre) ont déterminé une autre innovation radicale en ce qui concerne la construction et l'exploitation des usines thermiques et des usines hydrauliques alimentées par des réservoirs.

Cette innovation consiste principalement:

- à augmenter dans la même proportion la production hydraulique et thermique;
- à donner le choix au cycle thermique et aux caractéristiques de la vapeur qui donnent le maximum de rendement par une charge constante;
- à bâtir les nouvelles usines hydroélectriques pour la production d'énergie de haute qualité, c'est à dire de façon à être capables de jouer un rôle d'usines de pointe pour le réglage de la fréquence;
- à ajouter aux installations hydrauliques existantes des réservoirs hebdomadaires et journaliers d'une capacité adéquate pour augmenter la valeur de l'énergie produite.

Un nouveau plan de développement des usines thermiques italiennes a été bâti sur ces prémisses, de façon à atteindre dans le 1955 une puissance totale de 2.500 MW environ; dans les aménagements hydrauliques on a donné le choix à ceux qui sont pourvus de réservoirs et même quelques unes des installations existantes seront modifiées de façon à servir comme usines de pointe.

Dans le projet des nouvelles usines thermiques l'on a cru bon de s'en tenir aux tendances des pays les plus avancés dans l'équipement thermique, en tenant compte de la nécessité de pouvoir employer une large gamme de combustibles, depuis les charbons à faible pouvoir calorifique et à forte teneur en cendres et en matieres volatiles jusqu'aux charbons anthraciteux à pouvoir calorifique élevé et à faible teneur en matières volatiles, depuis les naphtes denses jusqu'aux extradenses, depuis le méthane sec au méthane humide.

Quant à la situation des usines, le choix a été fait en tenant compte de la conformation des réseaux de transport des différents Groupes industriels et de la position du "centre de gravité des charges résidues", c'est à dire du besoin d'énergie des centres de consommation les plus éloignés des usines hydrauliques.

C'est seulement à titre d'information qu'on signale ici les idées fondamentales suivies dans le projet des nouvelles usines thermiques ou des extensions d'usines existantes.

Toutes les usines sont situées sur la mer ou bien aux bords de rivières ayant un débit tel à assurer — même en cas d'un étiage exceptionnel

— les fortes quantités d'eau demandées par la réfrigération des condenseurs, sans besoin d'avoir recours aux coûteux réfrigérants atmosphériques.

La situation des usines a été choisie d'ailleurs en proximité des centres de consommation les plus importants, dans des places d'approvisionnement facile des combustibles ou en proximité des sources de méthane.

Les puissances unitaires correspondent aux valeurs normalisées aux Etats-Unis et dans les pays européens, c'est à dire: 25/30; 50/60; 100/120 MW.

Les caractéristiques de la vapeur des groupes nouveaux ont été choisies en vue de la durée de marche des différentes usines et précisément:
- pour les usines à utilisation moyenne (2.000 à 3.000 heures par an) 60 kg/cm² et 482° C;
- pour les usines à utilisation élevée (plus de 3.000 heures par an) 105 ÷ 125 kg/cm² et 510 ÷ 538° C.

Le cycle de la vapeur est à régénération pour les usines à utilisation moyenne; à régénération et à résurchauffe pour les usines à utilisation élevée.

Les systèmes de brûlement ont été choisis en vue de la facilité de ravitaillement et de la convénience économique des différentes sortes de combustibles: charbon, naphte et méthane.

Pour le charbon on a adopté le système à "charbon pulvérisé à insufflation directe"; pour la naphte on emploie les brûleurs à atomisation par la vapeur ou bien ceux à poussée mécanique; pour le méthane les brûleurs simples.

Les chaudières sont toutes à circulation naturelle à irradiation avec de larges chambres de combustion entièrement tapissées d'écrans d'eau.

Toutes les chaudières sont pourvues de réchauffeur d'air (du ty Ljungström ou bien du type tubulaire), de souffleurs de suie à vapeur ou à air comprimé et de dépoussiéreurs à cyclones multiples ou bien électrostatiques.

Les turbo-alternateurs sont à 2 poles, correspondant à une vitesse de 3.000 t/min. pour 50 p/s, et la plupart des alternateurs sont refroidis à l'hydrogène.

Dans les nouvelles usines on a adopté le système "à commande centralisée" pour toutes les manoeuvres et les mesures, qui sont généralement coordonnées, concernant le réglage automatique du brûlage, de la température de la vapeur, de l'alimentation d'eau à la chaudière etc.

Dans le but d'aplatir autant que possible les diagrammes hebdomadaire et journalier des charges et d'accroitre en même temps la capacité des réservoirs de régularisation, on est en train de développer les stations de pompage, dont l'action est intermittente et complémentaire de celle des usines génératrices; c'est à dire que les stations de pompage sont destinées à marcher aux heures de faible charge pour aplatir le diagramme et pour augmenter, aux heures de pointe, le debit utile, régularisé par les réservoirs.

En ce qui concerne les caractéristiques des chambres d'equilibre, des conduites forcées et de l'équipement des usines destinées à marcher aux heures de pointe, c'est à dire des usines pourvues de réservoirs adéquats, les régles fondamentales suivantes ont été données:

1) proportionner les chambres d'équilibre d'une façon telle à permettre une marche régulière en face de changements brusques de la charge, en prévoyant aussi les cas de manoeuvres alternes de déclenchement et de reprise de la charge en phase de ressonance hydraulique;
2) proportionner les conduites forcées — c'est à dire le diametre optimum au point de vue économique — au débit de durée maximum, en admettant d'atteindre, pour le debit de pointe, les valeurs limites de la vitesse de l'eau, consenties par le type de conduite;
3) fixer la courbe caractéristique de rendement des turbines hydrauliques d'une façon telle à atteindre la valeur maximum du rendement moyen pondéré;
4) adopter des régulateurs de vitesse accélero-tachimétriques ou à statisme transitoire élevé et à amortissement rapide et des régulateurs de tension à action rapide;
5) établir pour les générateurs synchrones un rapport de court circuit et un moment d'inertie élevés;
6) prescrire pour les générateurs synchrones et pour les transformateurs élévateurs une surcharge de 20% pour la durée d'une heure, en admettant des hausses de température dans le fer et le cuivre qui, tout en étant au dehors des valeurs prévues par les règles du Comité Electrotechnique Italien, ne soient pas dangéreuses.

Là où il ne soit pas possible de bâtir des réservoirs adéquats de régularisation des charges hebdomadaires et journalières, il sera nécessaire d'avoir recours à des usines thermiques de pointe, c'est à dire adaptées à marcher à une charge variable et à supporter de brusques et fréquentes variations de puissance.

Ces usines là doivent être dotées de dispositifs d'alimentation du combustible à action rapide et automatique, de chaudières spéciales à circulation forcées ou contrôlée, de façon à consentir une marche intermittente à vaporisation rapidement variable, et de turbines à vapeur adaptées à supporter les fortes et dangereuses différences de température qu'on a dans le cas de brusques et fréquentes variations de la charge.

Les usines thermiques de pointe, non seulement sont continuellement tourmentées par des efforts thermiques et dynamiques dangereux, mais conduisent à un coût de l'énergie thermique sensiblement plus élevé que celui qu'on peut atteindre par des usines thermiques de base. Avant donc d'avoir recours à une telle solution, il sera bon d'évaluer l'avantage de confier à d'autres installations hydrauliques, pourvues de réservoirs, le rôle de régularisation des installations dans lesquelles la création de réservoirs ne parait pas possible.

Tout cela confirme la nécessité de bâtir de nouveaux aménagements hydrauliques de haute qualité, c'est à dire donnant le maximum de puissance aux heures de charge maximum, et d'ajouter aux installations existantes des réservoirs hebdomadaires et journaliers pour augmenter la valeur de l'énergie qui y est produite.

## RÉSUMÉ

Les données fondamentales de l'industrie electrique italienne sont signalées et les tendances suivies en Italie pour le développement des usines génératrices, pour la construction des nouvelles usines thermiques et pour une coordination rationnelle de la marche des usines thermiques et hydrauliques sont indiquées.

## SUMMARY

The fundamental data concerning the italian electrical industry are given and the lines followed in Italy for the development of generating plant, the construction of new steam electric stations and for a rational coordinated operation of hydro and steam electric stations are exposed.

## RESUMO

Os dados fundamentais da indústria elétrica italiana são assinalados e se expõem as diretrizes seguidas para o desenvolvimento das usinas geradoras de energia elétrica, para a construção das novas usinas centrais termoelétricas e para uma racional coordenação de funcionamento em relação com as centrais termoelétricas.

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HJORTH (S.)
(Dinamarca)

# HYDRO-ELECTRIC POWER STATIONS IN THE FAROY ISLANDS (DENMARK)

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## I. GROUND, CLIMATE, POPULATION AND TRADES

In a remote situation in the North Atlantic, some 185 miles north-west of the Shetlands and about 280 miles south-east of Iceland, the eighteen inhabited islands and numerous islets of the Faroes rise steeply out of the sea with their grass-grown rocks. The islands, whose total area is no more than 540 sq.miles, are of volcanic origin, consisting of basalt strata of lava alternating with thin tuff strata. In many ways, Nature is hard on these pompous ruins of a former volcanic landscape. A lowering of the ground, caused partially by the thrust of the ice in the glacial epoch, has allowed the sea to swallow up steep valleys, forming deep sounds and fjords. The turbulent sea has bombarded the rocky coasts, undermining them with caves and making exposed promontories collapse into the deeps. The island lie, as it were, crouching, arching their back to the west where the erosion of the sea has created vertical walls of rock up to 2450 ft. in height. And from inside, the rain, falling in such abundant quantities over those steep rocky islands in the middle of the route of the Gulf Stream, has contributed towards their destruction by seeping through cracks in the basalt and breaking it up when the frost sets in, and by forming gushing cataracts carrying earth, gravel and pebbles along on their short, but violent, flow to the sea. Also wind and weather attack the rocks; the loose tuff crumbles, drawing with it the hard basalt, the precipitations of which form inclines to the east with the stepped "hammers"*so characteristic of the Faroes.

This grand geological drama has created a small archipelago of great natural beauty but low yielding power, a group of long-drawn, steep isles, the highest peaks of which are barren, wind-blown plateaus of administration, might be resorted to for the rarer and more particular, imported necessities. Even if few of the islands were then self-sufficient in grain, the imports of food were small, corresponding to modest exports, chiefly of wool and knitted woolens. An essential proportion of the farm population had, however, to supplement its income from farming by "home fishing" from rowboats.

In the course of the nineteenth century, however, the Faroe Islands became subjetc to a development which shifted the point of gravity of the trades from farming to *fishing*. This has in many ways changed considerably the life conditions and outlook of the population. At the close of the nineteenth century, the Faroese started deep-sea fishing from cutters, especially around Iceland, and this fishery soon became the main trade of the islands and is still playing a considerable part beside the more industrialised fishing from trawlers of up to 650 tons registered gross tonnage and crews of up to 45 men which was begun after World War II. At the same time the Faroese are constantly seeking new fishing grounds — the sea around the Faroe Islands being utilised by British and other foreign fishermen – lately especially the sea off North Norway, Bear Island and Greenland. Also the industrial fishing of big whales from whale stations ashore has been systematised in the last decades.

The ever more intensive fishing has resulted in a drift of young labour away from agriculture, whose grain growing, etc., has therefore been decreasing continuously, and away from the small and most remotely situated farming settlements to Thorshavn (which has now between 5,000 and 6,000 inhabitants) and a few well situated small towns, which have developed into fishing and trading ports (each with a few thousand inhabitants), partially with a little industry, such as Klaksvig to the north, Tvaraa and Vaag to the south and Vestmanna to the west. The one-sided trade development has made the Faroe Islands dependent in an ever higher degree on exportation, particularly of salted fish and split cod. The produce economy has been replaced by a pecuniary economy, and that one in turn by a pronounced *credit economy*, by which crews, suppliers and savers — and in later years also, as before World War II, the Danish State — grant credits of an appreciable extent to shipowners and exporters.

This development has meant much progress to the Faroese, such as a higher standard of living, less strenuous and tedious work, more diversion and a better outlook. This progress is reflected in the increase in the total population from about 5,000 in 1801 to well over 30,000 in 1950. But at the same time this development involves certain risks.

The entire economy of this insular community has become fundamentally dependent on the *prices on the world market* of the few export articles: salted fish, split cod, fresh fish (to Great Britain) and whale products, and the Faroes have thus sailed into the tide of international market fluctuations. This tide carried the Faroes up to an economic crest during and right after World War II, but in later years the small community has found itself in an economic trough, shattered by heavy seas. Simultaneously, agriculture, which may form a natural trade reserve when times are bad for fishing, has been neglected and the small farming villages have been partially depopulated.

Thus, the Faroes are faced with a number of problems relating to population, trade policy and economy, and these problems call for a joint solution on the basis of considerations taking account of all these things:

How, for instance, would it be possible to avoid the one-sided dependence on the price fluctuations on the world market of a few export articles?

How would it be possible to create chances of occupation by further preparation or different preparation of the fish which today is being exported fresh, salted or as split cod?

How would it be possible to utilise the increasing shoals of herrings occurring around the Faroes in later years?

Could occupation be found ashore for the fishing crews in the slack periods of fishing?

Could industries be established in the Faroes to make up for the large amounts of foreign currency which Faroese fishing vessels have to pay to foreign shipyards?

Could other, new industries be established in the Faroes?

What steps could be taken to stop or check the depopulation of the farming villages?

These and similar problems cannot be solved by any one single measure but require a joint effort through many different channels.

Among such measures as may contribute permanently towards the solution of these problems, and at the same time bring about easements and advantages to the greater part of the Faroese population, are the plans of recent years, which have already been realised in part, for *electrification* of the Faroes on a grand scale through a combined utilisation of natural water power and diesel power.

These plans have made their greatest progress in respect of Thorshavn and Klaksvig. At the former place a new diesel electric power station of 1,200 HP was completed in 1951. At Klaksvig and old hydro-electric power station was extended substantially in the years around 1950 and combined with a diesel power plant. On Suderø, where an old and now absolutely inadequate hydro-electric power station at Vaag is being temporarily supplemented by a smaller diesel electric power station at Tværa, plans are afloat for the putting-up of a new hydro-electric power station which, in conjunction with a modernisation of the old station would make it possible to cover the island's requirements of electricity. Finally, the municipalities of the three large islands of Strømø, Osterø (Eastern Island) and Vaagø have formed an intermunicipal co-operative company, SEV (from the initials of the islands), which in a few months will have completed the first lap of the largest aggregate plant of the Faroes so far: a hydro-electric power station at Vestmanna on

Strφmφ. This plant is to supply electric power for all three islands via an extensive high-tension network (partially in co-operation with the diesel plant at Thorshavn).

Before the establishment of these new power stations the supply of electricity of the Faroes was very deficient. Only Thorshavn and the aforementtioned larger settlements were supplied with electricity from fairly up-to-date works, and even in these places the production of electricity was insufficient and too expensive. The rest of the population still has to rely on kerosene and carbide lamps or electric current provided by a few small and primitive works. The majority of the Faroese industrial concerns in the few settlements with fairly modern works either have to work without mechanical power or, in certain cases, instal their own small power plant for the purpose, possibly as a supplement.

When the development in the Faroes has got no further in this fields, this is due to geographical as well as financial conditions. The nature of the islands is magnificient. However, it is difficult to bring the barren soil under cultivation, and from the times when farming was the predominant trade, with a little fishing as an extra source of income, it has been necessary for the population to settle in a great number of small settlements, all situated on the coast and often having but a few hundred inhabitants. The great distances between these settlements, with narrow, breakneck mountain path as their only means of communication, apart from the sea, have tended to retard the progress of technology. Besides, the produce economy and the modest standard of living of the small settlements reduced the needs and the chances of establishing a more comprehensive, modern supply of electricity. It should also be borne in mind that the objective, difficult conditions of the ground as well as the subjective difficulties which so easily arise in isolated settlements with a strong individual self-assertion have presented serious obstacles to overcome in the attempts at finding a joint solution.

With the continuous disintegration of the produce economy and the great improvement in the standard of living in the years about World War II, the inhabitants of the settlements, however, became interested in the supply of electricity for the households. Whilst this elementary desire in the population for greater domestic convenience through electric lights in replacement of the kerosene and carbide lamps, electric power for radios and other installations and electric heating in replacement of the troublesome peat firing (the houses have to be heated all the year round) may primarily have been instrumental in creating the co-operation between the many small settlements which made possible the establishment of SEV, the importance of producing cheap power *for industry* has come ever more to the fore. It is costly to freight coal or oil to the Faroes and unload it there, and this fact reduces the chances of establishing competitive Faroese industries. Only with cheap electric power will the development of the Faroese industry have a chance. As already suggested, there is much to indicate that with the keen competition on the world market it may be decisive for the Faroes whether it will be possible there to expand the production of artificially dried split cod; take up other fish productions such as flash-frozen fillets, canned fish, and bait herrings; improve the storage facilities through electrically operated cold stores; and save considerable amounts of foreign currency by providing for repairs and classification in the Faroes of Faroese trawlers. By such means a well planned electrification would bring about an improved trade balance and a better chance of self-financing of the Faroes.

## II. THE HYDRO-ELECTRIC POWER STATION AT FOSSAA

*Hydro-electric plant.* For supplying the three principal islands of Strφmo, Østerφ and Vaagφ with hydro-electric power, there are several considerable waterfalls, the prospective annual capacity of which estimated at 30 to 40 mill. kWh.

After thourough investigations it has now been decided to build at Vestmanna, in the first instance, a hydro-electric power station designed for an annual capacity of about 8 mill. kWh. Fig. 1 (Fossaa). This plant will utilise the water from the Fossaa, two reservoirs being erected about 820 ft. above the sea, viz. the main reservoir at Vatnid, designed to hold 1484 mill. cu.ft. of water, and the take-in reservoir to the south of Vatnid, designed to hold 25 mill. cu.ft. of water. Both reservoirs take the water from a rainfall area of about 2,965 acres, within which an annual precipitation of 98" to 118" may be counted on.

From the take-in reservoir an about 4,000 ft. long tunnel of 6' 10 11/16" x 7' 6 9/16" cross section is led to two downpipes, one for each turbine. The tunnel is to be blasted through the mountain, and this work will call for the blasting of some 280,000 cu.ft. of solid rock. The downpipes are made of welded steel tubing, and they are run together from the equalising shaft at the end of the rock-blasted tunnel down to the power station. The diameters of the pipes are 2' 3 9/16" and 2' 11 7/16", respectively, corresponding to the turbine size.

The pipes are terminated at the power station in a heavy concrete structure and from there passed through a hydraulically operated stop valve into the power station proper, which is built in reinforced concrete and where, in the first instance, a 3,000 HP Pelton turbine is installed, provision being made for the future erection of a 5,000 HP turbine.

In the first instance a 3,000 HP Pelton turbine running at 600 RPM is installed. A 3,000 kVA flywheel generator, 3 x 6 kV, will be coupled to the turbine. With this turbine an annual output ex works of 8 million kWh is expected, corresponding to delivery to the consumers of 7 million kWh. By taking into use a larger rainfall area near Vatnid – Myrarna – and the erection of another turbine, of 5,000 HP, the capacity of the plant could be increased to about 15 million kWh per annum.

From the generator a 6-kV cable will be run to a main transformer station, 6/20 kV, from which bus-bars are run to the 20-kV switchgear.

The plant will be made as an open plant with standard oil switches for a short-circuiting effect of 125 MVA. It will be built in two stories with engine cubicles on the ground floor and cable cubicles on the first floor. From the station will be run three, later five, 20-kV distributor mains.

The control panel will be in ordinary steelplate design with flush-mounted instruments. The pilot current will be supplied by a special operating battery which is kept charged by a rectifier.

A machinist and a reliever will be able to take care of the daily running, the plant being equipped with alarm and control installations, so that it will be unnecessary for attendants to be present all the while, seeing that warning can be given to the attendant's house, which is situated close to the power station.

In the power station the water level in the lower reservoir is distant-measured, and the drain valve in the upper dam is designed for remote-operation from the power station.

The expenses for the construction of the plant described above will amount to about 8.5 million kroner.

## III. LINE SYSTEM AND TRANSFORMER STATIONS

The district to be served by the power station comprises, as already mentioned, the three largest islands of the group: Strφmφ, ∅sterφ and Vaagφ.

Some 12,000 persons live in this district, besides the about 6,000 inhabitants of Thorshavn. About 4,000 house-holds are figured on within the district to be supplied with electricity. The electricity is to be used for lighting power and heating. The heating purposes which may come into consideration are electric cooking and partial heating of dwelling houses. It is thus estimated that in a few years the total consumption will reach 2,500 to 3,000 kWh a year per household, or altogether 10 to 12 million kWh, to which will have to be added an industrial consumption estimated at 2 or 3 million kWh.

For the distribution of this energy a 20-kV high-tension system having an extent of about 210 miles, to which about 40 transformer sub-stations will be linked up, will be put up in the first instance. Later on a further, 112-mile, high-tension system with about 20 transformer sub-stations may be put up, and, finally, co-operation will be established with the diesel plant at Thorshavn (2 x 600 HP), which may later be extended by a 1,500 HP diesel engine.

The primary distribution voltage will be 20 kV and the secondary distribution voltage 3 x 380/220 volts.

The high-tension lines will be made of 3 x 25 sq.mm copper and run on wooden poles with triangular mountings and puncture-proof insulators for 125/95-kV flash-over voltage.

A deep fjord runs between Strφmφ and Vaagφ, and the connection between these two islands is made with an about 2.4 miles long overhead span suspended from the high walls of rock. As material for this line is used a coppercoated steel cable (Copperweld) having a breaking strength of about 12 tons.

The connection between Strømø and Østerø is likewise passed across one of the deep fjords by an about 820 ft. long span on about 66 ft. high poles; the ground conditions at this place cannot be utilised as in the case of the connection Strømø-Vaagø.

One or two transformer sub-stations are erected in each settlement and transformers of sizes 50-150 kVA are installed, as required. The sub-stations are made either as closed, galvanised steel towers or as pole stations, that is, stations in which the transformers, which are all supplied in outdoor design, are arranged about 16 ft. above ground level and there connected up to the 20-kV overhead lines through partitions and fuses which can be served from a platform, whereas attendance on the low-tension side takes place on the ground through the switches with fuses arranged at a suitable level.

The low-tension networks are carried on about 28 ft. wooden poles of ordinary design. The line system are dimensioned on the basis of an estimated connection, for which account is taken not only of the ordinary lighting consumption but also of the heating and cooking consumption, as well as special power consumption. Accordingly, the low-tension lines in the districts nearest the transformer are usually made as 25 and 35 sq.mm copper leads and in the extreme districts as 16 and 25 sq.mm copper leads. Normally, no consumer will be more than one mile away from the transformer sub-station from which he is to be served. To every house — except the smallest ones — two phases and neutral are run, on account of the cooking and heating; to greater consumers three phases and neutral are run.

In nearly all settlements, street lighting will be introduced. This is very important because in winter the daylight lasts only 5 or 6 hours. The street lighting is put on and off by a photoelectrically operated automatic device.

The first cost for high-tension networks transformer sub-stations, low-tensions networks and meters will amount to about 6.5 million kroner for the plant to be put up in the first instance.

## IV. ORGANISATION AND FINANCING

The SEV Company is an intermunicipal co-operative company, comprising 21 member municipalities which are served from the Company's power station (2,000 kW) and line system. Moreover, co-operation is established between the Company's power station and the previously mentioned electricity works at Thorshavn, where two diesel engines with a total output of 800 kW are installed.

The number of inhabitants in the district to which the Company is to supply electricity is about 18,000 (Thorshavn included), distributed on about 4,000 households.

The initial cost of the plant to be put up in the first instance is estimated at about 15 million kroner, viz. about 8.5 million kroner for hydraulic engineering plant and about 6.5 million kroner for high-tension network, transformer sub-stations, low-tension networks and meters.

The larger proportion of the first coast will be provided as follows:

| | | | |
|---|---|---|---|
| Loan from the Danish State ............... | 7 | mill. | kr. |
| " " local savings banks ............ | 2 | " | " |
| Cash deposits from the municipalities, about | 1 | " | " |
| Marshall aid .............................. | 1 | " | " |
| Bond loan ................................ | 3 | " | " |

Through negotiations with the State Authorities and the Lagting a financing scheme has been prepared which will make it possible to get through the first years where only 66% connection and a comparatively small annual consumption of about 1,000 kW per annum per household are counted on; with increasing consumption it is reckoned that at the end of the first five years the connection will be 80-85% and the annual consumption per household 2,500 kWh.

## V. ACCOUNTING

The electricity supplied to the consumers is proposed to be paid for on the basis of excessive consumption meters to be set at a certain subscribed effect corresponding to the size of the property. Besides the basis fee, it is suggested that an output fee of 100 kroner a year per subscribed kilowatt should be paid.

The energy of which delivery is taken is proposed to be paid for by 10 øre per kWh for energy taken below the subscribed effect and by 40 øre per KWh for energy taken above the subscribed effect.

If the Board of SEV adopt these proposals, a normal household having an annual consumption (lighting, partial house-heating, and cooking) of 1,200 kWh will have an annual expense for electricity amounting to about 360 kroner, or 30 øre per kWh. For the same household with an annual consumption of 2,500 kWh this annual expenditure will be about 500 kroner, equivalent to 20 øre per kWh.

According to information from the Faroes, the present annual expenditure is 500 to 600 kroner with the use of kerosene for the same purpose, and about 500 kroner with the use of oil gas.

For industries with larger consumptions, special tariffs will be worked out.

The work on the plants described here was begun in 1951 and is expected to be accomplished in time for the plants to be put into use at the end of 1953.

It may seem unreasonable to invest such large sums in a plant for serving a population of about 18,000 people only. However, when one has seen the many primitive plants, which even are expensive in operation, now serving the greater settlements and capable of supplying only poor electric lighting, while a public supply of electricity is wanting for industries such as canning factories, cold stores, fish-drying plant, wool spinning mills and many other concerns, one understands why the Faroese have now gathered all good forces to carry trough the Fossaa plant.

The Danish State has, as already mentioned, desired to encourage Faroese trade and industry by providing considerable financial support of the plant.

Finally, the financial aid granted for the plant through a Marshall loan of 3 million kroner, or about 20 per cent. of the total first cost, should be remembered and appreciated.

The abovementioned hydraulic engineering work has been planned and carried out by A/S Højgaard & Schultz, Copenhagen, in co-operation with Skanska Cementgjuteriet, of Malmö.

The electrical equipment has been designed by the engineering firm of P.A. Pedersen, Copenhagen, and carried out essentially by Danish firms and suppliers. The turbine was supplied by Maier, Brackwede in Germany in co-operation with A/S Siemens, Copenhagen.

## SUMMARY

The article describes the arrangement and design of an 8,000 HP hydro-electric power station for the Danish county of the Faroes, situated in the North Atlantic, giving an account of:

1. The climate and the population of the islands, as well as the trades: primarily deep-sea fishery.
2. The hydro-electric power plant which is in the course of construction near the settlement of Vestmanna on Strømø. In the first instance, it will comprise a 3,000 HP Pelton turbine designed for a height of the water-fall of 720 ft. Further, space is provided for a 5,000 HP turbine, after the installation of which the annual output of the plant will be 15 million kWh.
3. The line system and transformer equipment for the supply of electricity to about 3,000 households, industries, etc., and comprising about 85 miles of high-tension overhead line and 40 transformer sub-stations.
4. The organisation and financing. The Company is an inter-municipal co-operative society. The initial cost is calculated at 15 million kroner, of which Danish State investments will amount to 7 millions, while the Marshall Aid will contribute 3 million kroner as a gift. The balance, 5 million kroner, will be contributed by local authorities and savings banks.

5. Squaring of consumers' accounts, which is done partly by the payment of fixed dues to cover the capital outlay and partly by the payment of 10 øre per kWh consumed. An ordinary household will then have an annual expenditure of about 500 kroner with an annual consumption of 2,500 kWh for lighting and cooking. The plant will be put in service towards the end of 1953.

### Résumé

L'article donnant une description de la disposition et de la construction d'une centrale hydro-électrique de 8000 CV pour le département danois des îles Féroé situées dans le Nord de l'Atlantique, contient un compte-rendu des points suivants:

1. Le climat des îles, la population et ses professions, pricipalement la pêche maritime.
2. L'installation hydro-électrique en construction près de l'agglomération de Vestmanna sur l'île de Strømø. La première installation comprend une turbine Pelton de 3000 CV prévue pour une chute d'eau de 220 m, avec la place disponible pour une turbine de 5000 CV; après l'installation de celle-ci, la capacité totale annuelle de la centrale sera de 15 millions de kWh.
3. Les installations de câbles et de transformateurs pour l'approvisionnement d'environ 3000 ménages, de l'industrie, ect., comprenant environ 130 km de câble aérien de haute tension et 40 postes de transformateurs.
4. L'organisation et le financement. La société est une société coopérative intermunicipale. Les frais d'installation ont été calculés à 15 millions de couronnes, dont l'État danois apporte 7 millions de couronnes, l'Aide Marshall 3 millions de couronnes à titre de don, tandis que le solde, soit 5 millions de couronnes, est apporté par les communes et les caisses d'épargne.
5. Le règlement des paiements des consommateurs, qui se fait soit par le paiement de droits fixes pour le service des capitaux investis, soit par le paiement de 10 øre par kWh consommé. Un ménage normal aura alors à payer un montant annuel d'environ 500 couronnes pour une consommation annuelle de 2500 kWh pour l'éclairage et la cuisine. — L'installation sera mise en service vers la fin de 1953.

[redacted]

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Titulo 4
Assunto 4.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

HUTTER (U.)
Alemanha

# THE USE OF WIND ENERGY FOR GENERATING ELECTRIC CURRENT IN WESTERN GERMANY

By U. HUTTER

NATIONAL COMMITTEE OF THE GERMANY FEDERAL REPUBLIC

The invention of the internal combustion engine and the increase in public power lines caused, within less than 20 years, the abandonment of almost 27 000 large windmills which at the turn of the century had still been grinding almost the entire grain harvested in Holland, Denmark, and the low countries of Northern Germany.

Although between 1900 and 1930, 8 to 10 small and medium sized manufacturers /1/, primarily in Saxony and Sleswig-Holstein, had built around 3 600 steel wind turbines for driving generators and water pumps according to the American type, the decline in the use of windmills continued, since after a short ascent the production figures decreased after 1912 so considerably that almost all manufacturers in Germany were forced to discontinue the production of such machines.

The multiblade sheet metal turbines shown for the first time at the World's Fair in Philadelphia in 1876 with the relatively small circular sweep of their turbine wheels of 6 to 30 m² constituted a technical retrogression as compared with the windmills with their four-blade propellers of 18 to 24 m diameter, which were running faster and had a circular sweep of 250 to 450 m², and which had been developed by centuries of practical experience.

In spite of this they later attained world-wide use especially for pumping water for farms, which shows that under certain circumstances wind motors can be used to advantage for certain limited purposes in place of other driving systems, even though 75 years of technical progress had passed by them almost without notice.

As an example of their wide spread use, it may be mentioned that, according to the statements of the Agricultural College at Glenn near Bloemfontain, 77 000 small wind pumps were counted merely on farms of the South-African Union alone. Many of these farms have several such wind motors to pump as much ground water as possible to the surface.

High speed turbines in which the ratio of the top speed of the blades to the speed of the undisturbed wind current (maximum speed $\lambda = \frac{u}{v}$) is 6 to 8, have so far been built only of relatively small dimensions (circular sweep of 7 to 18 $m^2$) for driving low tension generators and were made primarily in the United States from where they were exported all over the world.

These so-called wind chargers were developed in the 'Twenties for charging batteries of radios, and today several hundreds of thousands of them are in use the world over. The owners of these small machines often used the batteries charged by them for illuminating their homes and driving small household apparatus. However, unless the existing wind conditions are unusually favorable — which is rarely found —, the full amount of current required by medium sized farms can hardly ever be furnished by machines of this size.

If machines are to be built of larger size, the respective forces, the masses to be moved, and the varying action of the wind as it affects the machine, also increase considerably, necessitating such high demands on the controlling accuracy, multiple control mechanisms, quietness of operation, etc., that only an entirely new kind of machine of a more differential type and resulting from a thorough systematic research can satisfy all the necessary requirements.

In Germany, it had been recognized at an early date that wind energy could furnish a worth-while part of the world energy only if the units to be built were of at least the same dimensions as those of the old windmills.

Immediately after the First World War, K. Bilau applied the latest knowledge of aerodynamics of airplane wings to windmills which had not yet been destroyed or which had been rebuilt for motor operation. By streamlining the windmill blades with sheet metal coverings, he succeeded in improving the efficiency of old mill wheels by more than 60% and in reising the maximum speed from 1.7 to 3.5, that is by 106% /2/. Then, however, he had to face the problem of finding a much faster acting control than was used on the old windmills. After experimenting unsuccessfully with large wheels which were stopped by pivotable tangential interference surfaces, he finally found the solution in a turning stern (Fig. 1) which was pivotable about an axis parallel to the longitudinal axis of the blade. This solution turned out well and saved many beautiful old windmills from being dismantled. Bilau also erected experimental wind power plants on a farm in East Prussia and later in

Southern England, and there he carried out tests of new types of wind motors with tubular steel towers and propellers with a maximum speed of 3 and 4.5.

Bilau's power plants possessed all the more up-to-date features of the machines which had been recently developed. A streamlined nacelle containing the gear transmission and the generator for producing the electric current was rotatably mounted on a tower of tubular steel braced by cables. Unfortunately, Bilau's experiments did not lead to an actual production of his electric plants of 8 to 12 m diameter (Fig. 2), probably because he had not as yet mastered the difficulty of building the fast running blades of the required solidity and also those encountered by the electrical equipment of the plants.

Fig. 1 — Dutch wind mill two blades of which are equipped with "Bilau-Venti" edges and "Drehhecks" (rotatable trailing edges).

Major Bilau was employed in 1939 as an advisor of the newly founded Ventimotor Company in Weimar. Tthis company planned to develop wind power plants for generating electric current and for pumping water. Its founders, W. Schieber and A. Fleischmann, hoped by combining experiences gained with existing wind power plants with the most recent knowledge of aerodynamics and electrical and constructional engineering to arrive at a quick and practical solution. Work was begun with the creation of a large and well equipped testing ground for the power plants, where well tried models of customary construction, particulary those of Stahlwind of Dresden und Köster of Heide in Molstein were erected, and where small wind chargers of American and Dutch manufacture were also tested. The equipment of the testing ground permitted the energy produced by the plants to be used either for generating direct or alternating current, or for operating water pumps of a circulatory system.

Just one year after the company was founded, it was able to try out propellers of its own design on the existing towers and to test them in various wind tunnels. Propellers of new shape and

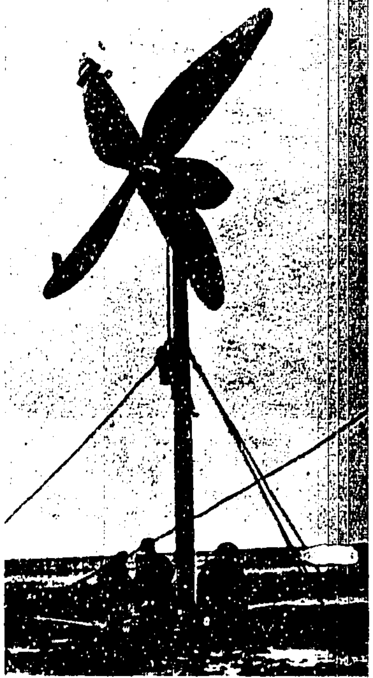

Fig. 2 — Test plant of 9 m diameter by K. Bilau 1924.

profile produced coefficients, that is, degrees of efficiency, which were better than any of the values which had been obtained up to that time.

A plant with a propeller diameter of 10 m was provided with a purely electrical control /3/, and a plant of 7 m propeller diameter was connected in parallel with the public power lines of the city of Weimar and thus operated for an entire year. At the end of the war in 1945, six wind power plants (Fig. 3) were running on the test ground, the largest having a diameter of 18 m, a maximum speed $\lambda = 6$, a tower height of 30 m, and an installed power of 50 kW /4/.

Fig. 3 — Test field of Ventimotor G.m.b.H. Weimar 1943. From rigth to left: 10 kW D.C. plant of 10 m diameter with fully electric control, 50 kW plant of 18 m diameter with mechanical control, "Stahlwind" plant of 7.2 m diameter for parallel operation tests, "Koster" wind-driven pump of 7 m diameter.

Also in preparation was the project of a plant with a 40 m propeller diameter and an installed power output of 500 kW which was to be erected on the Inselsberg in the Thuringian Forest. The engines, the tower, and the propellers had already been ordered when operations had to be discontinued due to the outcome of the war.

However, after the war, engineers of the former Ventimotor Company continued their research and the development of wind power plants at the Allgaier Company at Uhingen in Wuerttemberg, and the Pleuger Company at Hamburg.

In 1940, the Porsche Company at Stuttgart-Zuffenhausen also engaged in the development of wind power plants.

After only short preliminary tests, a two-bladed test propeller of 3.4 m diameter was tried out. After completing a series of experiments in the wind tunnels of the research institute for automobile engines and vehicles at Stuttgart to determine the most suitable shape of the blades and the storm safety appliances, a plant with a four-blade propeller of 7.2 m diameter was tested on the grounds of the Agricultural College at Stuttgart-Hohenheim. This plant was equipped with a hydraulic mechanism for controlling the pitch of the blades and has in four years of operation withstood wind velocities of up to 44 m/sec. without damage.

On the basis of the experience gained with this plant, a machine was built for production in smal lots, with an installed power output of 10 kW, a tower height of 19.6 m, a diameter of the three-bladed propeller of 9.2 m, and a maximum speed of $\lambda = 7$ (Fig. 4). The plant was equipped with a two-step spur gear transmission and a differentially compounded direct current engine for a rated output of 110 V. Its total weight was 2 000 kg.

The Porsche plant had been the first to try, especially by an improved blade design, to develop a machine which was suitable for production in greater numbers. The blades were made of simple curved shells of sheet metal which were secured to each other by a special sport welding process.

Unfortunately, after the end of the war, this research work of the Porsche Company was likewise discontinued.

At about the same time, the Reichsarbeitsgemeinscharft Windkraft (RAW) (German Wind Power Research Society) was founded which by recording and evaluating prior experiences on wind power plants intended to establish a basis for future developments of its own. Aside from theoretical works of Kleinheinz concerning the most suitable design of large wind power plants with towers of 250 m height, propeller diameters of 130 m, and an installed power output of 20 000 kW, which was to be obtained at a wind velocity of 17 m/sec. /5/ but which for obvious reasons never led to the actual construction of any plant, the RAW primarily supported the practical research carried out by König and Teubert.

G. König, working for Hein, Lehmann & Comp. at Berlin, developed wind power plants with propeller diameters of 10 m and an installed power output of 5 kW, which were exposed to the wind on braced lattice towers of 10 to 30 m height (Fig. 5) /6/. König who, aside from constructing this plant, delved deeply into the problems of the efficiency of wind energy on a large scale basis also developed a control method in which, by means of a centrifugal governor of ample size which was rotating at the speed of the generator, the wing blades were directly adjusted about their longitudinal axes by a rod mechanism. By adjusting the pitch of the blades, König was able to restrict the variation of the speed of his plant to ± 3% even at strongly gusty winds, provided the wind velocity was sufficient to obtain the rated speed at the respective load.

In 1932, a book by H. Honnef was published which dealt with the possibilities of utilizing the powerful air currents at 200 to 400 m above the earth's surface /7/. Honnef, a designer of steel towers, in building the radio towers at Berlin and Königswusterhausen, for static reasons, had to deal with the distribution of the wind velocities at such heights. From extensive meteorological data collected at this occasion, as well as from his own observations, he

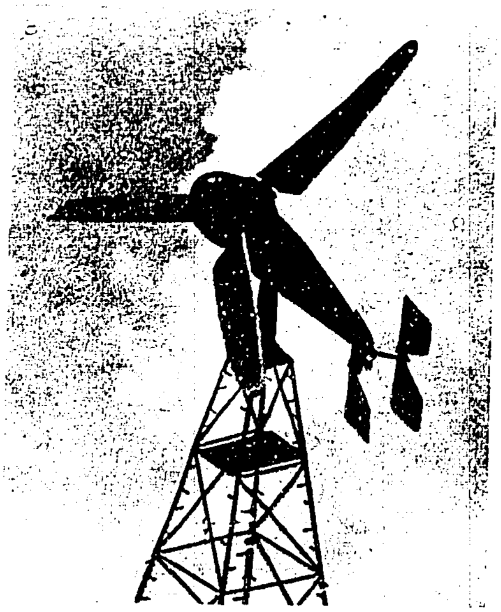

Fig. 4 — Porsche 10 kW wind power plant of 9.2 m diameter, 1944.

reached the conclusion that wind power plants could be used on a large scale for the production of energy if they were built of sufficiently large dimensions and at a sufficient height above the ground. This book, although only intended as a theoretical work, found wide-spread attention and did a good deal to popularize again the idea of utilizing the energy of the wind.

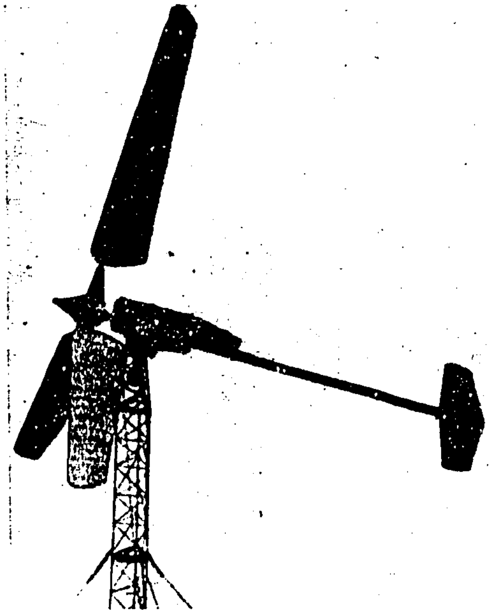

Fig. 5 — "Konig/Ringer" 5 kW plant of 10 m diameter at Bornim near Potsdam, 1943.

In 1940, with the support of the German government, he built at Bötzow, north-west of Berlin, an experimental station for testing large scale models of his high altitude power plants. Several plants with a tower height of up to 37 m, a propeller diameter of 9 m, and an installed power output of up 20 kW with the characteristic ring generators proposed by Honnef were tested (Fig. 6). In the turnmoil at the end of the war, parts of a larger test plant which had been under construction, were destroyed.

F. Teubert, an associate of H. Honnef before the Second World War, also developed at the Gute Hoffnungshütte high speed electric plants with adjustable pitch propellers /8/. His first plant at Rhene in the Northern Harz Mountains had a four-bladed propeller of 8 m diameter at a maximum speed of $\lambda = 6$ on a 33 m lattice tower. The installed power output was 8 kW. Later, at the test grounds of the GHH at Fernwald near Sterkrade, a plant was built with a three-bladed propeller of 15 m diameter, a maximum speed

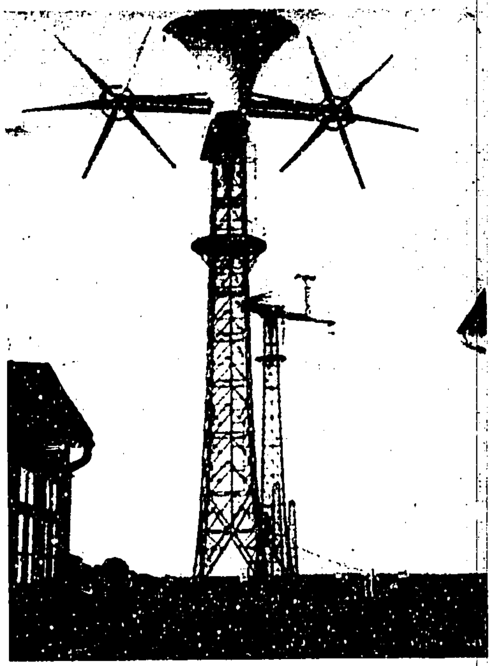

Fig. 6 — Test field Honnef at Dotzow near Berlin.

of $\lambda = 8$ on a lattice tower of 15 m height, and an installed power output of 10 kW (Fig. 7).

After the war, further research and development work on these interesting plants was likewise not continued.

In 1945, D. Stein, scientific associate of the RAW, together with North-German industrialists, founded the Nordwind Company at Porta Westfalica. There, together with H. Evers he designed and

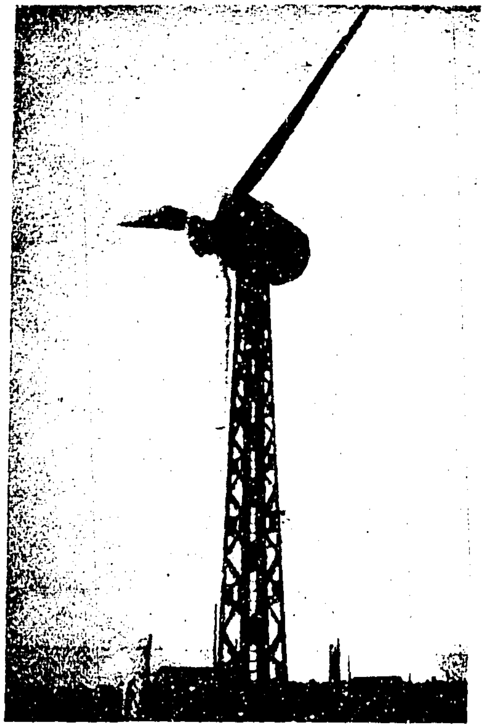

Fig. 7 — "Teubert" 10 kW plant of 15 m diameter at Farnwald near Sterkrade.

built a wind power plant with a three-bladed propeller of 15 m diameter and a maximum speed of $\lambda = 6$ on a 20 m high lattice tower. By the manner of its control and the transmission of energy this plant was in many respects similar to large modern Russian plants. For controlling the operation when the rated speed is exceeded by the effect of their own centrifugal force, the outer blades pivot 28% of their radius. Such pivoting of the blade tips, however, only serves to regulate the speed, whereas by means of a mechanism controlled at a considerable delay by the directional steering device of the tower head gear, the entire tower head may be gradually turned out of the wind if the average wind velocity becomes too high. The rotatable tower head contains a bevel gear transmission for driving a vertical shaft which transmits the energy from the tower head to the ground, where it may be used in any way desired either for driving generators or water pumps, or for any other purpose.

Fig. 8 — "Nordwind" universal wind driven pumping plant of 15 m diameter with vertical shaft for energy transmission, at Klostergut Marienmünster near Steinheim Westphalia.

Plants of this type have been in actual use for years and have proved very successful (Fig. 8). Thus, for example, the North Sea island of Neuwerk in front of the mouth of the Elbe river, including its lighthouse, is supplied with electric current exclusively by such a plant /9/. During the four years since this plant was built. about 180 000 kilowatt hours of eletric energy were supplied for the needs of this island.

Another plants is being used as a water elevating pump for the irrigation of the Sahara oasis Adrar and, when put into operation, had a maximum pumping capacity of 100 000 liters per hour at a total lift of over 40 m. This amount is sufficient to provide an ample supply of water for the entire oasis with its large fruit and palm

Fig. 9 — Monoblade plant by R. Bauer, diameter : 9.6 m; rated power : 3 kW.

orchards. At present, additional plants of this type are being readied for shipment and installation in Northern Africa and other Sahara oases.

R. Bauer had an opportunity to make experiments on a four-bladed 10 kW test plant with a propeller of 12 m and a maximum speed of $\lambda = 8$, which was built and erected in 1924 by the firm Grohmann & Paulsen at Ratzeburg utilizing the knowledge of aerodynamics of that time. These experiments caused him to take up the development of wind motors again in 1945.

Correctly recognizing the fact that the efficiency and usefulness of wind power plants depend entirely upon the total expenditure for their erection, as well as upon their total weight, Bauer designed a rotor with only one blade, the maximum speed of which of 12.6 to 16, depending upon the diameter of the rotor, exceeded those of the large three-bladed Danish plants of F. L. Schmidth with a maximum speed of $\lambda = 12$. In order to overcome the difficulties of the unsymmetrical arrangement and a possible distortion of the blade, he permitted it to rotate together with its counter-weight about a free axis. For this purpose, the shaft of the propeller was made elastic so that the rotor can freely adjust itself, similar to that of the Laval turbine. The blade rotates on the long wheel shaft, designed as an elastic cantilever, at such a large distance from the vertical axis of the tower that the rotor is able to adjust itself automatically about such axis and vertically to the direction of the wind without any supplementary equipment, such as a vane or the like (Fig. 9).

For controlling purposes, Bauer used a small, narrow front or preliminary blade which in operative position was set so as to provide the blade profile with the best possible qualities insofar as the gliding angle and the maximum lift was concerned. When the control mechanism was operating, the front blade turned so as to destroy the lift of the blade profile and thus the effective action of the blade. For stopping the plant, the cantilever shaft was turned vertically upward so that the rotor stopped and adjusted itself in the direction of the wind like a vane.

This peculiar design, which was in many ways revolutionary, was at first tried in smaller sizes with a rotor diameter of 3 m. In its final development, it has been built and sold since 1952 by the Winkelsträtter Company at Wuppertal in sizes similar to the American wind chargers.

Then, after the small machine had proved very successful, a larger experimental plant was built which was put in operation in 1949 (Fig. 9). This plant was designed for 3 kW with a rotor diameter of 8.6 m and a maximum speed of $\lambda = 16$. At the present time, this firm is building a plant with a rotor diameter of 10 to 12 m, while another with a diameter of 38 m and an installed power of 100 kW is being designed.

The author, who during his employment as a designer and consultant engineer with the Ventimotor Company at Weimar, built primarily the wind power plant with high coefficients /10/, continued in 1946 the development of wind power plants by designing a one-bladed rotor for the Schempp-Hirth Company at Kirchheim/Teck in Wuerttemberg. Similar to the French Andreau plant /11/, the pressure drop and the curents, which arise in this plant with an open blade tip at the inside of the rotating blade from the root to the tip thereof, were utilized for driving an air turbine mounted within the hub of the rotor which, through a short shaft, directly

Fig. 10 — "Hütter" monoblade plant with air turbine installed in blade root and 600 watt generator as counterweight Kirchheim/Teck 1946.

drove the generator which was acting as a counterweight of the one-blade rotor (Fig. 10). The rotor diameter was 6 m, the installed power only 600 watts. The adjustment of the wind wheel disc into the wind was caused by free forces of the rotor rotating behind the tower. Unfortunately, this interesting development worked on during the deepest depression following the war, which, as shown by the 100 kW Andreau plant /12/ presently being installed in England, had a good chance of success, had to be abandoned because of financial difficulties.

In 1948, E. Allgaier took a serious interest in the work of the author and enabled him to continue his research in his firm, the Allgaier Werkzeugbau Company, at Uhingen in Wuerttemberg with

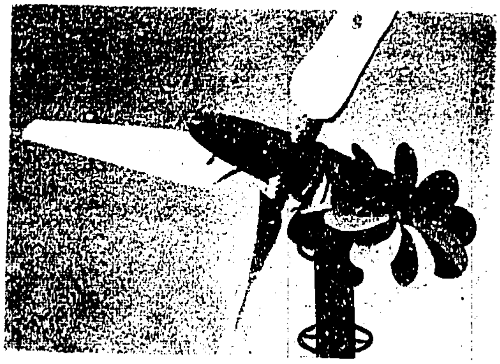

Fig. 11 — Head of 1.3 kW Allgaier test plant of 8 m diameter, Ohmden, 1948.

the aim of creating a standard machine which was suitable to be manufactured in greater numbers and could be built to satisfy the real need of the world market for such plants, a fact fully realized by him. In the summer of the same year, a three-bladed experimental plant was built with a propeller diameter of 8 m an intended maximum speed of $\lambda = 8$ and an installed power of only 1.3 kW, mounted on a tubular steel tripod which was erected for a long range test on a chicken farm near Ohmden in Wuerttemberg (Fig. 10). In 1949, a test station was built at Uhingen for carrying out systematic tests and acurate measurements. In the same year, models of a plant of this type were demonstrated at exhibitions at Hannover, Munich, and Lyon, France.

An analysis of the market in South Africa made early in 1950 resulted in starting the production of a first series of 25 plants in which the propeller diameter was increased to 10 m and the installed power to 7.2 kW, while the intended maximum speed remained at $\lambda = 2$. In the course of 1951, the largest part of these plants were installed in South-West Africa, Abessinia, Argentina and Germany.

During the following years, the development was systematically continued. In place of the blades which originally had been built of wood bonded together thermoplastically, they were then made of steel plate and, in order to obtain the shape with the best possible aerodynamic features, shells of steel plate shaped by large specially built tools constituted the structural elements of the blades which were then put together by spot and acetylene welding. (Fig. 12).

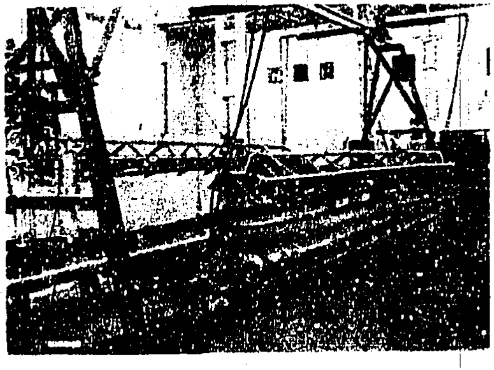

Fig. 12 — Cooled welding outfit for torsionfree welding sheet steel blades for Allgaier plant of 10 m diameter.

The control mechanism of these plants which originally was intended to be similar to those of König and Teubert, that is, entirely by a directly acting high speed centrifugal governor, was considerably improved in the course of the construction. For limiting the speed of rotation mechanically, an automatic hydraulic mechanism was added for adjusting the blades to such a position at which the maximum value of the starting momentum could be obtained. Such mechanism is brought into action when at long lulls of the wind the plant stops, and it is thereby made extremely sensitive so that the plant may start already at such wind velocities which do not yet permit any worth-while power output, so that, as soon as the wind increases in strength, it is able to take up and transmit even the smallest amount of energy from weak gusts.

A further improvement consisted in the hurricane stop mechanism which was likewise operated hydraulically. The static evaluation of meteorological data concerning the time distribution of the wind velocity of heavy storms showed that the peak velocities which had been observed, the action of which may be devastating, only occur at a small percentage of the total length of the storms. Dangerous gusty storms usually start extremely quickly and may be destructive to trees, roofs, and high biuldings. For the utilization of energy, however, these peak velocities and their extremely high power are of on practical value and are therefore of no special interest.

The hydraulically operating hurricane stop developed for the Allgaier plant considerably reduces the rotary speed of the plant within a fraction of a second when strong gusts of wind occur, while after 1 to 2 seconds it attains about one third of the rated speed, and it thereby reduces all the forces of the mass and air approximately to 12 to 15% of the values occurring during the normal operation. After the gusts subside, however, the speed and output of the plant again rise within a few seconds to those of the normal operation.

The hydraulic control mechanism also permits the rotary speed and output of the plant to be acted upon by devices of other types. After early failures with electrically controlled generators for producing a constant voltage, this possibility was utilized for maintaining the voltage and limiting the charging of batteries. In the newest types of plants, an effective and sensitive control of the rotary speed is obtained by a magnetic valve which is controlled by a voltage measuring bridge, and any desired voltage limit may be set by the simple twist of a knob on a centrally located control apparatus.

The adjustable limitation of the voltage permits a simple and reliable control of the battery charging process. It is a well-known fact that the counter-voltage of battery cells increases in accordance with the charging conditions and the current used. If at a certain charging condition, a certain charging current can no longer be exceeded, the charging voltage must be held below certain limits. When further charging the battery at a limited voltage, the charging current then gradually decreases more and more until finally, when the battery is fully charged, it reaches such small values that even at very small currents a state of balance is reached between the charge and the withdrawal.

The control of the machine unit of the plant and thus of the circular described by the propeller blades to a position relative to the wind in which the maximum output of energy is obtained, is produced in the Allgaier plant by a small auxiliary wind weel which is mounted on the side of the machine unit and is rotatable about an axis vertical to the axis of the main propeller, and which operates in the same menner as those used for 200 years in the Dutch windmills.

In the machine unit itself, the generator, the gear transmission, and the head bearing were combined into a compact closed set. The generator is mounted on the gear housing without a forward end plate. No additional casing is required.

For a tower, a braced tubular tower similar to the kind as firts shown by Bilau (Fig. 13) has been used since 1951. The stepped

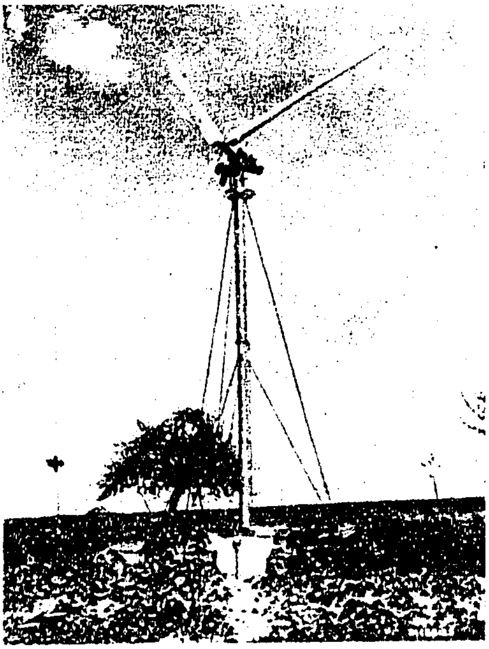

Fig. 13 — 6 kW Allgaier D.C standard plant of 10 m diameter.

diameters of the individual sections of the tube permit telescoping them into each other for easier shipment, the bracing rods etc. then being placed at the inside of the innermost tube.

Until the middle of 1953, altogether about 60 plants of this standard type have been delivered. They provide electric current to sheep farms, pastures, farms, housing developments, light houses, mountain inns, and relay stations for ultra-short wave chains in South-West Africa, Argentina, Abessinia, North Africa, Saudi-Arabia, Burma, Peru, Belgium, Spain, Italy, Holland and Western Germany. They have proved a complete success under all possible climatic conditions — in dust storms, under the effects of a moist sea climate, at high heat, in high snow drifts, and when iced up. The total annual production of the plants presently operating in Germany alone amounts to 250 000 to 300 000 kWh.

In the fall of 1949, the Studiengesellschaft Windkraft (Research Society Windkraft) was founded in Stuttgart which is intended to form a neutral mother organization to combine all the various research groups in Western Germany dealing with the utilization of wind energy. This society succeeded in soliciting the interest of the government, public utility companies, and industry and commerce for the utilization of wind energy. Aside from an extensive evaluation of existing wind measuring values in cooperation with the German Weather Service at Frankfurt on the Main, and a neutral advisory service, the society primarily initiated the parallel operation of wind power plants with public light circuits over a long period of time, and plans were made for building a plant with an installed output of 100 kW for feeding into the public circuits. At the present time, the research society is studying four projects of medium sized plants to render an opinion thereon, and it is expected that construction of the first larger unit will be started during 1954.

In the summer of 1952, a three-phase current was fed from a 10 m standard plant equipped with an 8,8 kW asynchronous generator of the testing ground of the Allgaier Company into the nearly 10 kV line of the Neckarwerke. The course of the wind and the electric energy were registered continuously by Ferrari fixed range integrating instruments of the AEG (German General Electric Company), so that at the end of this test definite results of the action of the wind power plant when operating in parallel connection with a public power circuit could be obtained /13/. These results were so promising that further tests of unlimited duration will be carried out in an area where the winds are more favorable, that is, at Büsum on the German coast of the North Sea. After one year of operation, the test results obtained during that time will again be evaluated and published.

Similar tests have been carried out at the beginning of the 1930s with a three-bladed 100 kW plant at Balaklawa on the Krim peninsula /14/, in 1940 to 1943, as previously mentioned, by the Ventimotor Company at Weimar, between 1940 and 1943 with a 1 000 kW unit at Grandpa's Knob in Vermont/USA /15/, and from June 1950 to August 1951 by the engineer Juul at Egersborg in Denmark with a plant of 12 m diameter /16/.

It is worth nothing that all these tests showed excellent results, even though — because of the unevenness of the winds — the prognosis of outside experts regarding the possibilities of carrying out a parallel operation successfully had not been favourable at all. On the other hand, M. Kloos /17/ already proved in 1942 that even with synchronous generators the parallel operation with large timing networks would be possible and could be made very stable. The author also proved in his treatise published in 1947 /18/ that, despite the strongly varying wind velocities, when considering the distribution of the frequency of the winds, the total resulting energy of a wind power plant operating in parallel with a public circuit would amount up to 96% of the theoretical optimum. These prognoses have proved to be correct by the test.

It is also possible to drive a wind power plant at a constant speed despite the strongly varying wind velocities, provided the ratio of the rotation to the constant load or of the frequency to the constant load of the machine driven by the propeller will permit this under partial loads, that is, provided the driven machine no longer takes up any load when the frequency decreases below a certain value which is determined by the generator slip, as this is the case when operating in parallel with public power lines.

The propeller freely running in the air current reaches its highest possible output at the maximum speed which is determined by calculation. At maximum speeds above such value, the dimensionless power factor — the power coefficient — decreases gradually, while at an increasing maximum speed it decreases very rapidly so that at a certain value of the maximum speed it will arrive at the value zero (Fig. 14).

The highest obtainable value of the maximum speed possible in the operation of turbines amounts approximately to twice the calculated maximum speed. At maximum speeds which lie below the calculated value, the power coefficient likewise decreases gradually in the beginning, while later, when the current flows past the blade, it decreases rapidly. A certain residual torque, which causes the standing propeller to start provided the moments of the air forces exceed those of the friction, remains even at the smallest maximum speeds, since the twist of the blade prevents the current from flowing off along its entire length.

The actual operation at the proper relative proportions of the wind wheel, the gear transmission, and the driven machine is carried out under conditions which lie very close to the optimum value of the power coefficient. Because of the "flat" optimum, very considerable deviations from the calculated maximum speed are possible both upwardly and downwardly without any appreciable losses.

If the rotary speed is maintained, a decrease of the wind velocity means an increase of the maximum speed, or vice versa. If the plant is properly tuned to the frequency of occurrance of the individual

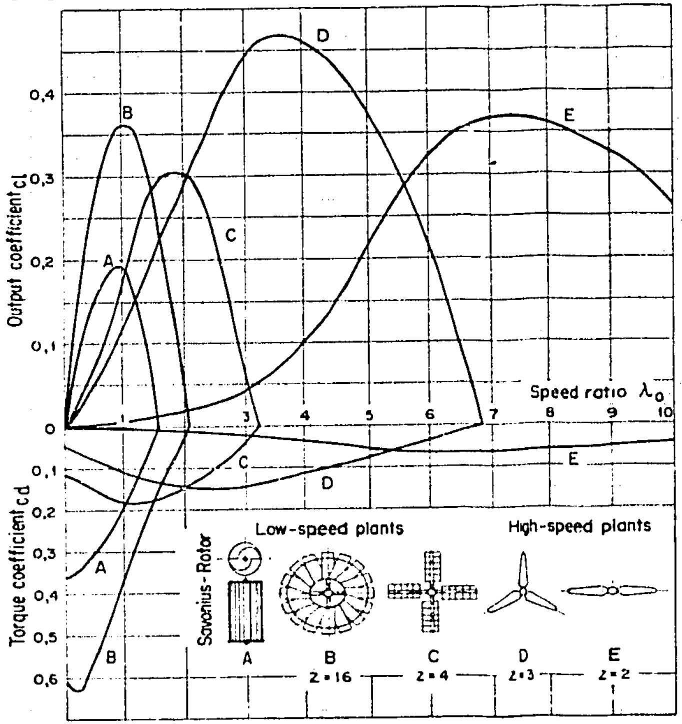

Fig. 14 — Relation between output coefficient and speed ratio of wind turbines of various designs according to Fateew.

inherent in the shape of the blades, but by the difficulty of controlling the propeller blades statically and dynamically, which, as the maximum speeds are greatly increased, must be made extremely narrow. If the width of the blades is expressed in percentages of the radius thereof, the following ratio of the width to the radius for different maximum speeds is obtained :

| $\lambda$ | 1 | 2 | 3 | 6 | 8 | 12 |
|---|---|---|---|---|---|---|
| r/R % | 120 | 40 | 11 | 6 | 3 | 1.3 |

The required width of the blade at the maximum speed of $\lambda = 12$ is therfore almost 1/100 of the value which it must have at the maximum speed of $\lambda = 1$.

The results obtained from practical test extended over long periods of time, however, show that any increase of the maximum speed of propellers, even though only by apparently small amounts, caused more and more difficulties and setbacks until the problems necessarily arising from the higher peripheral speeds were solved by entirely new methods of designing the control and the mounting of the blades. This phase in the development of wind power plants is peculiarly similar to the difficulties encountered in the development of water turbines and thermoelectric engines.

However, the possibility of controlling maximum speeds between 8 and 12 may be regarded as the maximum achievement of today. The propeller dimensions developed for use at these speeds have great similarity to the dimensions which are characteristic of the propellers of modern heliocopters. A greater increase of the max. speed may be attained only by further research. Thus, wind power plants of larger dimensions than previously known appear clearly indicated, and it is expected that within a few years such plants will be installed as a supplementary source of energy both for individual users as well as for feeding into public circuits.

In examining the question of the efficiency of such plants, the two before mentioned possibilities of applying them should be considered entirely apart from each other :

a) plants for supplying remotely located users who are not reached by public power lines; and
b) plants for feeding into existing power lines.

The best size of the units to be used for supplying remotely located individual users will probably range between 40 and 200 $m^2$ propeller area, as already mentioned. The installed output resulting therefrom would then have a value ranging from 3 to 30 kW. As far as their efficiency is concerned, only power plants driven by Diesel oil are able to compete with wind power plants of this type.

However, the efficiency of Diesel engine units decreases rapidly when only a small amount of current is required. Both wind power plants as well as Diesel engine units require a mechanism for energy compensation, unless — which is rarely the case the current needed is uniform and continuous.

Even in Germany, where the public power lines are close together and extensive, there are many people who are interested in producing their own power. It has been found that even though Diesel engine units are already available, there is considerable interest in acquiring wind power plants in order to save the high costs of a continuous Diesel operation. A very simple calculation already shows that a wind power plant with a life expectancy of at least 5 to 8 years, such plant will be more profitable than a Diesel unit of similar efficiency, especially since so far only a very small number of wind power plants have been built, whereas Diesel units are being built in mass production. There is not the least doubt that if similar production facilities are provided and certain difficulties resulting from the novelty of the plants are overcome, that is, if, on the one hand, a certain minimum life of the plants can be guaranteed and, on the other hand, a service organization of sufficient size can be provided to keep the plants in proper condition, wind power plants will be considerably more profitable than small thermoelectric units, in areas which are favorably supplied with wind.

When feeding into public power lines, there is no longer any necessity for directly compensating the energy. The units which are to be used for this purpose must — and will — be considerably larger than those designed for individual users. Therefore, for regulating and controlling purposes, larger amounts should be expended so that a fully automatic operation which requires hardly any service may assuredly be expected and guaranteed.

The research carried out by the British Electrical Research Association in London and the Electrical Supply Board in Dublin along the British and Irish Northern, North-Western, and South-Western coast has shown that at a suitable location of the place of erection on freely exposed hills in the vicinity of the coast an annual average of the wind velocity of 9 to 11m/sec can be expected. With such high averages, the usefulness even of small plants, which are designed for the use of the individual customer and built in very small quantities, is obvious. Even plants of less than 100 m² propeller area produce in these places annually 480 to 520 kWh per square meter of propeller area, which means that a plant of 500 m² propeller area, that is, with the dimensions of a larger Dutch windmill, would be able to feed approximately 250 000 kWh per year into a public power line.

In considering whether wind power plants could be used for supplementing the power produced by water or thermoelectric power plants, the question appears as to whether the total energy availables is sufficient. It can be estimated from the density of energy of solar radiation. The total output of energy radiated from the sun to the earth amounts to:

1.694 x $10^{14}$ kW or
1.452 x $10^{18}$ kWh per year.

Renowned meteorologists, among them Süring /19/, estimate the amount of energy which is continuously converted into moving energy of the air currents to be 2 to 2.5 % of the total energy.

The results of innumerable measurements have been published which show the distribution of the velocity of the air currents at various altitudes above the earth surface up to and into the stratosphere (Fig. 15). These values not only permit an estimate of the kinetic energy of the entire air ocean to be

2.5 x $10^{14}$ kWh,

but also of that output which maintains the equilibrium between the friction on the ground and the internal friction of the aerial bodies moved past each other at different velocities. From the forms of movement of the low pressure and high pressure areas the order of magnitude of the Reynolds values of aerial bodies moving over the earth surface may be estimated. The velocities upon which the calculation is to be based correspond to the value which is measured at an altitude of about 200 to 300 m above the ground.

This kind of calculation shows the entire output required for overcoming the friction of the air on the ground and its internal friction to be approximately

$10^{12}$ kW,

that is, within the order of magnitude of the portion of the total output of radiation which was mentioned by Süring.

The largest part of these energies, however, is contained within the high altitude current on 8 000 to 14 000 m height above the ground which, with 18 to 26 m/sec, is extremely fast as compared with the conditions on the surface of the earth, and, at least for the time being, is beyond our reach for practical use. However, from the distribution of velocities over the different altitudes conclusions may be drawn as to that portion of the total current energy which can be utilized. Naturally, this portion is the larger, the more densely the earth surface is provided with larger units of wind

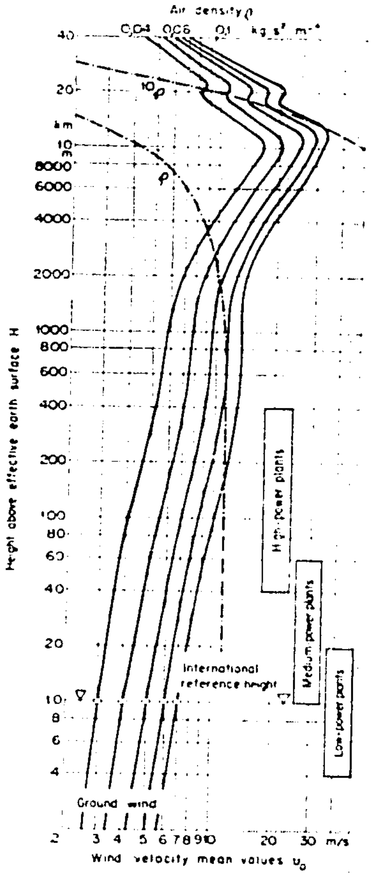

Fig. 15 — Wind speed vs. height above ground with reference to rounded off mean values at a height of 10 m.

power plants because, if the velocity of the lower atmospheric strata should thus be considerably retarded, additional energy will be supplied there to from the higher strata through a process of intermixing which from the science of aerodynamics is known as turbulence. Thus, the large energies of the air currents of medium altitudes are within our reach without requiring any of the so-called high altitude wind power plants, simply by providing a network of ground power stations of sufficient density.

The design and type of the plants to be used is already apparent from the research which has been carried on for years in the USA, Russia, Denmark, France, and Germany. It is safe to assume that if this research is systematically continued, similar as was done in more recent years with the heliocopter, the utilization of the wind energy will suddenly leave utopic spheres and enter the sphere of practical use on a very large scale.

## SUMMARY

With the gradual disappearance of the old windmills from the countryside of North-Western Europe there began in Germany the era of the development of plants for generating electric energy from the wind.

The Vereinigte Windturbinenwerke Meissen, Herkules Windmotoren, Stahlwind & Reinach, Dresden, as well as Köster at Heide in Holstein and, later, K. Bilau in East Prussia and Oxford, the Porsche K.G. in Stuttgart together with J. Mickl, the Ventimotor G.m.b.H. in Weimar with A. Fleischmann and the author, further the Reichsarbeitsgemeinschaft Windkraft at Berlin with K. König and F. Kleinheinz, the Gute Hoffnungshütte at Oberhausen with F. Teubert, H. Honnef at Bötzow near Berlin, the Nordwind G.m.b.H. at Porta Westfalica with D. Stein and H. Evers, R. Bauer at Ratzeburg and Augsburg, and, finally, the Allgaier Werkzeugbau G.m.b.H. at Uhingen have built wind power plants in Germany, tested them in experimental operation, and used them under any climatic conditions and any conditions of operation which could possibly occur. The most characteristic feature of all the plants built is the fact that all of their propellers describe an area of 50 to 250 m$^2$ at an installed power output of 3 to 50 kW.

The developments in this art over the last 30 years, as described, clearly demonstrate the existing tendency to increase the maximum speed, first from 2 to 4, then to 8, and now to 16. As the result of this research and development, the world market which so far has hardly been touched, is able to avail itself of a continued supply of well--designed and thoroughly tested plants of a rated power of 3 kW, 6 kW, and 22 kW.

Successful Danish, American, Russian, French, and German tests over long periods of time have definitely shown that the parallel operation of wind power plants with public power lines is possible without any difficulties. Thus, it is an accomplished fact that for supplying the continuously increasing demand for power the world over, wind energy is also available, the inexhaustible supply of which is demonstrated by the above rough estimate of the volume of the total energy of the air ocean.

## Résumé

Petit à petit les vieux *moulins à vent* disparaissent complètement du paysage du nord-ouest de l'Europe, et l'on commence maintenant aussi en Allemagne à développer des installations qui permettent de produire *l'energie électrique à l'aide du vent.*

En Allemagne de telles installations ont été construites et soumises à l'examen en service d'essai dans différentes conditions climatiques et techniques par les entreprises que voici: Vereinigte Windturbinenwerke Meissen, Herkules Windmotoren, Stahlwind et Reinsch Dresden, ainsi que Koster, Heide/Holstein et plus tard K. Bilau en Prusse-Orientale et à Oxford, Porsche K. G. à Stuttgart avec J. Mickl, Ventimotor GmbH à Weimar avec A. Fleischmann et l'auteur, en outre la Reichsarbeitsgemeinschaft Windkraft à Berlin avec G. Konig et F. Kleinhenz, Gute Hoffnungshutte à Oberhausen avec F. Teubert, H. Honnef à Botzow près Berlin, Nordwind GmbH à Porta Westfalica avec D. Stein et H. Evers, R. Bauer à Ratzeburg et Augsburg et enfin la maison Allgaier, Werkzeugbau GmbH à Uhingen. Ces installations ont en commun ce trait marquant qu'elles appartiennent toutes à la classe de grandeur de 50 à 250 m² de surface balayée par les ailes à des puissances nominales de 3 à 50 kW.

Le développement exposé ci-devant révèle nettement la tendance d'augmenter à une hauteur de 8 à 16 le coefficient de vitesse qui, au début, était de 2 à 4. Comme résultat du développemert, des installations à puissance nominale de 3 kW, 6 kW et 22 kW, parfaitement mises au point et éprouvées, sont, constamment fabriquées et disponibles. Le marché n'est d'ailleurs encore que peu ouvert à l'heure actuelle.

Des épreuves d'endurance ont été effectuées avec succès par des Danois, des Américains, des Russes, des Français et des Allemands. Ces épreuves ont apporté la preuve qu'un service parallèle de ces installations avec les réseaux d'énergie public est sans difficultés possible. L'énergie du vent est donc aujourd'hui également à notre disposition pour couvir les besoins en électricité toujours accroissants, et il ne faut qu'une simple approximation de la quantité d'énergie contenue dans l'atmosphère pour se rendre compte que cette [illegible] de vent est vraiment inépuisable.

## Resumo

Pouco a pouco, os velhos moinhos de vento vão desaparecendo, completamente, da paisagem do noroeste da Europa, e se começa agora também na Alemanha a aproveitar instalações que permitem produzir energia elétrica por meio do vento

Na Alemanha, tais instalações foram construidas e submetidas a "tests" em operações experimentais, sob diferentes condições climáticas, pelas seguintes emprêsas: Vereinigte Windturbinenwerke Meissen, Herkules Windmotoren, Stahlwind & Reinach, Dresden, assim como Koster, Heide/Holstein, e mais tarde K. Bilau na Prússia Oriental e em Oxford, Porsche K. G. em Stuttgart, juntamente com J. Mickl, Ventimotor GmbH em Weimar com A. Fleischmann e o autor, além de Reichsarbeitsgemeinschaft Windkraft em Berlim com K. Kenig e F. Kleinheinz, Gute Hoffnungshutte em Oberhausen com F. Teubert, H. Honnef em Bötzow perto de Berlim, Nordwind GmbH em Porta Westfalica com D. Stein e H. Evers, R. Bauer em Ratzeburg e Augsburg, e, finalmente, Allgaier Werkzeugbau GmbH em Uhingen. O traço mais característico de tôdas as instalações construidas é o fato de que tôdas as suas hélices propulsoras descrevem uma área de 50 a 250 m² numa instalação com potência útil de energia de 3 a 50 kW.

Os progressos nesta arte nos últimos 30 anos, tal como se descreve, demonstra, claramente, a tendência existente em desenvolver a máxima velocidade, que tendo sido de 2 a 4 no início, passou depois a 8 e agora a 16. Como resultado de tais estudos e desenvolvimentos, o mercado mundial, até então dificilmente alcançado, está apto a avaliar, por si mesmo, um contínuo suprimento de instalações, bem projetadas e inteiramente testadas, com uma potência nominal de 3 kW, 6 kW, e 22 kW.

Bem sucedidos e prolongados "tests" dinamarquêses, norte-americanos, franceses e alemães mostraram, definitivamente, que a operação paralela das instalações de energia elétrica por meio do vento com as linhas públicas de energia é possivel sem qualquer dificuldade. Assim sendo, é um fato consumado que, para suprir a continua e crescente solicitação de energia no mundo, a energia elétrica por meio do vento é também útil, sendo o exaustivo suprimento da mesma demonstrado pelo cálculo estimado acima do volume da energia total do ar atmosférico, verdadeiramente inesgotável.

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CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Titulo I
Assunto 1.2

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro – 1954

STRANDBERG (G.R.)
CHAPMAN (J.R.)
Estados Unidos

# THERMAL POWER AS A COMPLEMENT TO HYDROELECTRIC POWER IN REGIONS OF LARGE HYDRAULIC POTENTIAL

## BASED ON CONDITIONS IN BRAZIL

By GEORGE R. STRANDBERG,
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UNITED STATES NATIONAL COMMITTEE

Electric power is playing an ever greater part in raising the standard of living of men, nations and the world. Few countries with any industrial activity have not felt the pressing demand for more power, in fact some have had their requirements doubled in the last few years. Much of the unrest in troubled sections of the world has been due to man's awakening to the unlimited possibilities of relief from harship and toil which the intelligent utilization of the latent forces of nature makes available to those who use them.

It is, therefore, incumbent upon nations, groups and individuals to employ their highest engineering capabilities toward the efficient development of their power resources. These resources may be available in the form of gaseous, liquid or solid fuels and, more recently, minerals which may soon be responsible for a share of electric power generation, or as water power potential. Fuel sources of power, however economic they may be at present, are expended with use and are not recoverable. The use of minerals for power generation is such a new field that their potentialities are, at present, difficult to appraise. Hydroelectric power, by comparison is practicable and relatively inexhaustible. In order that communities served by hydroelectric power sources obtain the maximum derived benefits, the economic application of water flows for the generation of usable power must be fully explored.

The early development of hydroelectric power usually consists of the utilization of the best sources nearest the load centers. These centers may be communities which are gradually becoming industrialized. Unfortunately, most communities are located on geographical considerations rather than regard for the availability of economic power. As sites requiring the lowest investment for storage, generating equipment and transmission are utilized, continued community and industry expansion forces the consideration of sources which, due to higher costs of construction and transmission were, initially, less desirable. As the limit to the practicable development of hydroelectric power is reached, it becomes necessary to consider every possible means for increasing the power which can be economically generated from sources already developed.

The installed capacity of a hydroelectric system is usually based on a compromise between the requirements of the load and the availability of water power within the range of economic development. A mixed community and industrial type load is usually one which has some seasonal variation but which demands a basic daily peak of firm power. This daily peak requirement dictates the minimum continously available generating capacity of a hydroelectric system if power shortages are to be avoided. The type of hydroelectric generating equipment and the amount of storage depend on the physical characteristics of the site. Probably the most critical factor is that of river flow. In the establishment of the proper size plant to be installed, run-off records covering a long period are ideal, although many plants are designed with only short time records available.

Records of this type based on as reliable data as are available permit the establishment of dry, average and wet year flows. Water supplies are rare, which are not subject to considerable fluctuation seasonally and from year to year. It is desirable to smooth out such variations as much as practical by the provision of storage capacity. Often sufficient capacity can be provided to absorb seasonal variations. It is not, as a rule, however, practical or economical to carry sufficient storage to smooth out flows many years. If this were feasible, facilities could be installed to permit the maximum generation of electric power from the average flow over many years' period and the total flow of water during that period could be used without waste. With such a system, installed capacity would be utilized to the fullest extent and every cubic meter of water flowing into the reservoirs would be latent electrical energy.

It is more common, due to economic and topographical considerations to carry storage which will impound the excess flow for only a limited period of more than average flow, thereby limiting the reserve available to carry the system over dry periods of long duration. Depleted storage caused by successive dry years results in the curtailment of generation with its consequent deleterious effects on industry. Occasionally where river flow characteristics permit and where adequate storage for long term regulation is not available, generating capacity greater than normal is installed and low cost power offered when available to industries which can interrupt their operations during periods when power is not available. The prolonged power shortage resulting from continued dry years, however, generally results in curtailments of magnitude and duration intolerable to even such type of industry.

It is seldom practicable in a purely hydroelectric system to base plant size on wet year or even average year flows and some lower figure must be adopted which will reconcile development costs with the type of load. Where seasonal variations in load coincide with seasonal variations in stream flow, the development of power sites to use much larger than average flows is justified even without large reservoir storage capacity. However, for the usual system without adequate storage capacity, power developments on streams with wide fluctuations in flow are generally limited to the prime capacity of the stream applied to the peak or lowest load factor portion of the system load. During higher flow periods such a plant may operate on the base or continuous load.

Brazilian Traction, Light & Power Company, Limited, through its two principal operating companies, supplies power to the area in southeastern Brazil including the important seaports of Rio de Janeiro and Santos, and the rapidly growing City of São Paulo located about 720 meters above sea level. In this area is concentrated nearly 80 per cent of Brazil's industry. The Rio de Janeiro Tramway, Light and Power Company, Limited supplies 50 cycle electric power to the Federal District of Rio de Janeiro and the State of Rio de Janeiro. The São Paulo Light and Power Company, Limited supplies 60 cycle electric power to the Cities of São Paulo and Santos and the surrounding area. Power from these companies also serves the expanding railroad electrification program which, due to the high cost of imported fuels, is taking advantage of lower cost hydroelectric power. The Rio system supplies a large amount of power to the Volta Redonda steel mill which is vigorously expanding its facilities and hence its power requirements.

The hydroelectric power systems supplying São Paulo and Rio de Janeiro are typical examples of systems which, in the past, have depended almost entirely on hydroelectric power which has been relatively cheap and close at hand. The coastal topography of this part of Brazil consists of a steep escarpment which rises out of the ocean southwest of Rio de Janeiro and which is about 350 meters high were the city's main power stations at Lages are located and which is about 730 meters high south of São Paulo where that city's main power stations at Cubatão are located. Back of the edge of the escarpment, the general slope is parallel to and slightly inland from the ocean and the main rivers empty into the ocean northeast of Rio de Janeiro and southwest of São Paulo. Large reservoirs have been constructed at each of these sites and by building low dams on the main drainage rivers in the area and installing low lift pumps, waters are diverted to these storage reservoirs and dropped down over the escarpment through high head power stations. The pumping stations have equipment installed to divert flows well above the low flows and the reservoir capacities are sufficient to utilize average year flows on the system load.

Dry periods on record show that two or more years of less than average flow may succeed each other and if the reservoir capacity is drawn down by using average year flows to schedule power generation during the first dry year, the reservoirs would not refill in the second year, and the system would be short possibly 25 per cent in output before an average or better than average flow year should occur.

For additional hydroelectric power to meet the growing demands of the São Paulo area, it would be necessary either to divert and pump additional water from streams and drainage areas further away from the main storage reservoirs or to make comparatively lower head developments on these streams with longer transmission lines to the areas requiring power. Both of these alternatives mean higher cost power. At this point, the merits of thermal electric generating capacity as a complement to hydroelectric power were thoroughly explored. If thermal electric power is considered only on the basis of fixed and operating costs in competition with hydroelectric energy, the following comparisons are generally apparent:

*Pro*

A thermal plant can be erected at less capital cost.
The plant may be located near the load center.
Construction time is less.
Land purchase is minimized.

*Con*

A thermal plant requires fuel and in high fuel cost areas this becomes a large proportion of the cost of the power.
A larger operating staff is required.
Maintenance is higher.

Aside from the importance of the amount of firm generating capacity, which is added to a system by the installation of a thermal electric plant, of equal or perhaps greater importance is the considerable amount by which thermal plants in a large hydroelectric system permit the higher utilization of water flows to deliver energy, which can be considered as firm supply when supplemented by thermal generating capacity.

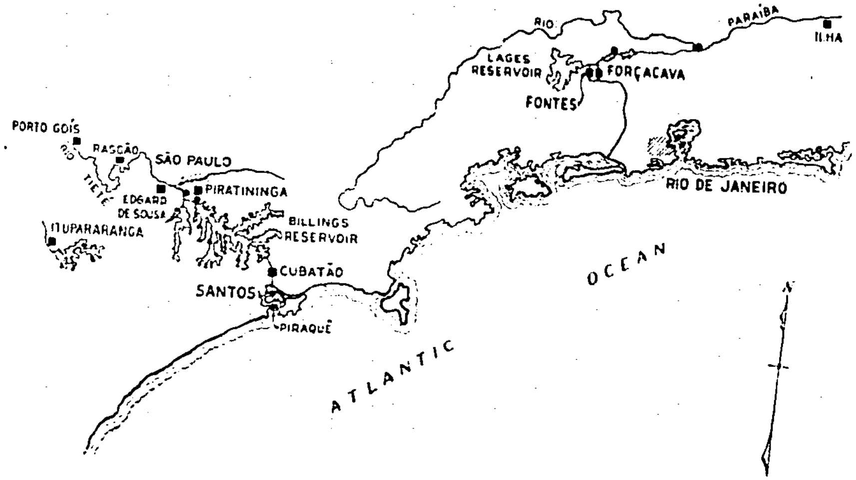
The São Paulo company is a good example of a large system to which has been added thermal electric capacity. The general scope of the São Paulo and Rio systems is illustrated in Figure 1.

The São Paulo system estimated unrestricted 1953 peak load was about 800,000 kw. The major part of this load is presently supplied by the Cubatão Power Plant, located about 40 km south of the city. This station has been the topic of many papers, due to its unusual supply of large quantities of water at a head of about 726 m. Its storage capacity in Billings reservoir is about 1,900 million kwhr. In addition, there are

FIG. 1

SÃO PAULO LIGHT AND POWER COMPANY. LIMITED
AND
THE RIO DE JANEIRO TRAMWAY, LIGHT AND POWER COMPANY. LIMITED

▨ LOAD CENTERS ■ GENERATING STATIONS ● PUMPING STATIONS



several smaller plants located to the south and west of the city. The São Paulo system is interconnected with the Rio system over a 230 kv transmission line, which has a frequency changer located at its center to permit the supply of some 50 cycle power from the Rio system to the 60 cycle São Paulo system. In addition to new hydroelectric generating capacity now under or scheduled for construction, the Piratininga Plant, now nearing completion on the outskirts of São Paulo, will initially contain two thermal turbine generator units each rated at 80,000 kw.

About 70 per cent of the total load in the São Paulo system is in and around the City of São Paulo. The estimated rate of load growth of the system is about 12 per cent per year.

The Rio de Janeiro system estimated unrestricted 1953 peak load was about 460,000 kw. The major part of this load is now supplied by the Fontes Power Plant located about 60 km west of the city. Its storage capacity in Lages reservoir is about 790 million kwhr. The new underground power plant named Forçacava located near Fontes will take water from Lages reservoir as well as from the Paraíba-Piraí diversion and is scheduled ultimately to constitute the largest source of power for the Rio system. The Ilha plant, located about 150 km northeast of the city, is a run-of-the-river installation with very little storage, and the available capacity of this plant is dependent upon river flow. The amount of energy available at the Fontes and Forçacava plants has recently been substantially increased by the Paraiba-Piraí diversion. Other minor sources are scheduled for development.

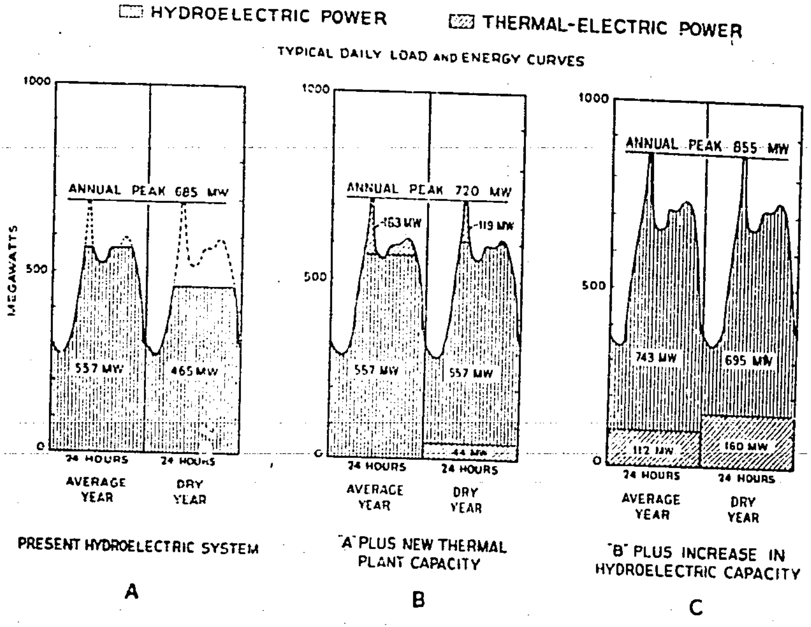
By operating a thermal plant in conjunction with the hydroelectric plants, the overall economy of a power system may be significantly improved. Figure 2 illustrates the energy and capacity which can be added to the São Paulo system due to the installation of thermal electric capacity. Figure 2a is comprised of two identical curves each constructed to indicate the average daily load variation in the present, essentially all-hydroelectric, system. Installed capacity and available energy are marked on the curves, one of which indicates conditions in a year of average water flow and the other for a dry year. The peak load of 685,000 kw is above the available capacity of the system although in an average year the present system of water diversion into Billings reservoir furnishes sufficient energy. During a dry year, depleted storage capacity results in the system being deficient in energy as well as capacity.

Figure 2 b illustrates the same system to which has been added 160,000 kw of thermal electric generating capacity. There is now installed capacity to carry peak loads of 720,000 kw. In average years, the thermal plant supplying only peak loads would be operated at an annual capacity factor of 14 per cent. In dry years, due to the reduction of hydroelectric energy, the thermal plant would carry part of the base load as well as the peaks at an annual capacity factor of 44 per cent.

Figure 2c emphasizes the way in which thermal capacity in a large hydroelectric system permits the higher utilization of water flows to

FIG. 2

## SÃO PAULO SYSTEM



PRESENT HYDROELECTRIC SYSTEM
A

"A" PLUS NEW THERMAL PLANT CAPACITY
B

"B" PLUS INCREASE IN HYDROELECTRIC CAPACITY
C

increase the available capacity and energy of the system and supply higher load peaks without the threat of power shortages. In an average year, the annual capacity factor of the thermal plant would be 70 per cent. In a dry year, the thermal plant would be base loaded to its maximum capacity. In a period of better than average flow, the additional hydroelectric energy available would permit the operation of the thermal units at a lower capacity factor to the extent that they might ultimately be used only for peak capacity. Since the increase in hydro capacity would require no additional pumping capacity nor storage reservoirs, the added hydro capacity would be obtained relatively cheaply both in regard to capital investment and operating cost.

An important factor which should not be overlooked in the addition of hydroelectric capacity made possible by thermal plants is that the new hydroelectric units can be designed with higher operating efficiencies than many of the already installed older units. With the new, high efficiency units to carry the base load, the older less efficient units can be used for peaking service. The thermal capacity also permits considerable flexibility in system loading and relieves the need for the continuous operation of installed hydro units in excess of their ratings. Maintenance is thereby reduced and forced outages minimized.

In an overall comparison of steam plants and hydroelectric plants, the annual costs for the steam-electric plants should be credited with a proportion of the savings made possible by the larger installations at the hydro plants, based on the utilization of average steam flow, instead of being based on dry period limitations. Over a period of years, it is possible that circumstances might arise which would make it advantageous to defer for one or two years a large scale step [illegible] hydroelectric development by the addition of a steam turbine generator unit in an available steam plant, at relatively moderate capital investment, accepting for a time the higher operating cost of the steam units.

The thermal plant, located near the center of load also aids in stabilizing the system voltage, and when the thermal units are operating at less than full kilowatt load, the surplus available kilovars can be used to assist the transmission system and hydroelectric generators in supplying the wattless load requirements.

Thermal electric generating plants have often been used to supplement hydroelectric systems where abundant low cost fuel is available. In high cost fuel areas, however, it is sometimes considered that the high operating costs will not justify the operation of thermal plants even as reserve or peak load units.

An analysis of possible sites led to the selection of the present location on the outskirts of São Paulo. The principal advantages of this site are the proximity of the load center, existence of transmission facilities, available land, accessibility of construction labor and operating personnel, favorable climate, an adequate condensing water supply and the close proximity of a pipe line for conveying fuel oil from seaport to plant site.

The size of turbine generator units was determined by economic and practical considerations. The ultimate capacity of thermal electric power required in the area can be most economically provided by the fewest number of largest size units. Due, however, to the problems in transporting the heavy and bulky pieces of equipment from the factory to the site the size of the units was limited to 80,000 kw rated capacity. Due to inadequate domestic fuel supplies, it was decided to design the Piratininga Plant to burn Bunker "C" oil as the basic fuel.

Since fuel cost will be high and annual capacity factors are expected to be low throughout the life of the plant except for prolonged dry periods, it was considered wise to place special emphasis on low capital investment. Steam conditions of 850 psi, 925 F were selected as the design pressure and temperature at the turbines. The steam conditions are well within conservative limits and no special metallurgical problems are involved. Considerably higher steam pressures are common in other areas and many plants now operate at higher temperatures with some as high as 1,050 F. In the United States of America, the gross annual return in the form of reduced operating expense, on the additional investment necessary for a station designed for steam conditions of 1,250 psi, 950 F over the investment required by the selected conditions of 850 psi, 925 F would be a little more than five per cent at an assumed annual capacity factor of 30 per cent and a fuel price of $10 per metric ton of oil. For plants built and operated in Brazil, the gross reduction in operating expense attributable to the additional investment necessary for the higher steam conditions would be somewhat less assuming the same price for fuel. For an estimated fuel price of $22.50 per metric ton, the gain would be approximately seven per cent, which was not considered attractive.

Although design requirements to enhance fuel economy have been successfully undertaken in some systems which are predominantly thermal electric, less operating risks will be incurred in the new plant by the use of a design which, although not the most advanced, has an efficiency consistent with the operating experience available.

The principal features of the Piratininga Plant consist of two 80,000 kw, 1,800 rpm condensing type turbine generators, each supplied with steam from an 850,000 lb per hr, two drum radiant type boiler with tubular type air heater. Boiler supply is employing three closed type tubular heaters and two direct contact or tray type heaters, one of which will be deaerating type. The water, which will be heated to a maximum of about 405 F before injection into the boiler drums is provided by evaporators which will distill coagulated and filtered water from Billings reservoir.

Each turbine is connected to a generator rated at 100,000 kva, 0.80 pf, 3 phase, 60 cycles, 13,800 v. Each generator is hydrogen cooled with direct connected air cooled main and pilot exciters. Each turbine will exhaust steam at 1 1/2 in. of water, absolute pressure into a 78,500 sq ft tubular condenser supplied with 70,000 gpm of cooling water taken from the Pinheiros Canal, adjacent to the station. Three 40,000 kva, 13.8 to 88 kv, single phase transformers are connected directly to each generator to step the voltage up to that of the subtransmission ring surrounding the City of São Paulo.

In addition to being designed for maximum operating economy consistent with low investment cost, the thermal units are designed for minimum operation overnight or between peaks not far enough apart to justify complete shutdow, thereby reducing fuel requirements while the system load is being supplied by lower cost hydroelectric power.

This installation of thermal capacity in a system that has been essentially hydroelectric will give the São Paulo operating company experience in joint operation of the two sources of power from which economies will be developed. It will make possible the increased installation of hydroelectric capacity on the basis of presently developed water resources.

## SUMMARY

Thermal power as a complement to hydroelectric power in regions of large hydraulic potential (based on conditions in Brazil) by G. R. Strandberg (1) and J. R. Chapman (2) is the title of a paper in which the authors describe sources of hydraulic potential as so valuable in today's economy that they should be utilized to the greatest practical extent. Where stream flow and load variations are such that dependable capacity of hydroelectric supply without other sources to fall back on would be limited to dry year flows, the installation of thermal electric generating capacity will complement the hydroelectric capacity in two ways. In addition to adding generating capacity to the system to meet load peaks it provides a back-up of firm capacity that justifies the installation of additional low cost hydroelectric units to utilize average or better than average water flows. During periods of less than average flows, the capacity of the system is supported by operation of the thermal plant at a high capacity factor. This complementary feature makes possible a total system capacity increase in excess of that provided by the thermal plant alone.

A description of the dual role of thermal electric capacity in a predominantly hydroelectric system is given in the paper.

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## SOMMAIRE

La Puissance Thermique comme un Complément à la Puissance Hydroélectrique dans les Régions du Grand Potentiel Hydraulique (Basé sur les Conditions au Brésil) par G. R. Strandberg (1) et J. R. Chapman (2) est le titre d'article dans lequel les auteurs décrivent les sources du potentiel hydraulique si précieuses dans l'économie d'aujourd'hui qu'elles devraient être utilisées jusqu'à plus grande étendue possible. Où le débit de la rivière et les variations de charge sont tels que la capacité de production hydro-électrique sur laquelle on peut dépendre sans autres sources de support serait limitée par le débit des années sèches l'instalation d'une capacité de production thermoélectrique suppléera la capacité hydro-électrique de deux manières. En plus d'ajouter au système la capacité supplémentaire pour les pointes elle fournira capacité disponible en réserve qui justifiera l'installation des unités hydro-électriques peu coûteuses pour utiliser les débits moyens ou les débits au dessus des moyens de la rivière. Pendant les débits au dessous des moyens la capacité du système est soutenue par l'operation à capacité maxima de l'usine thermique. Cette caractéristique complémentaire permet d'augmenter la capacité du système en excès de celle de l'usine thermique seule. Une description du rôle double de la capacité thermoélectrique dans un système de capacité hydro-électrique prédominante est donnée dans cet article.

## RESUMO

Energia Térmica como Complemento à Energia Hidro-Elétrica em regiões de grande potencial hidráulico (baseado em condições existentes no Brasil), por R. G. Strandberg (1) e J. R. Chapman (2), é o título de um relatório no qual os autores descrevem fontes de potencial hidráulico como de tal maneira valiosas na economia de hoje, que elas devem ser utilizadas na maior extensão prática possívei. Onde débito da corrente e variações de carga são tais que a capacidade segura de suprimento hidro-elétrico sem outras fontes complementares estaria limitada a débitos de anos secos, a instalação de capacidade geradora termo-elétrica complementaria a capacidade hidro-elétrica de duas maneiras. Além de aumentar a capacidade geradora do sistema para fazer face às cargas máximas, ela garantiria uma reserva de capacidade disponível que justifica a instalação de unidades hidro-elétricas adicionais de baixo custo para o aproveitamento de débitos de água médios ou superiores aos médios. Durante os

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(1) Ingénieur en Chef de l'Hydraulique
(2) Ingénieur Mécanicien.

(1) Engenheiro Chefe Hidráulico
(2) Engenheiro mecânico.

períodos de débitos inferiores aos médios, a capacidade do sistema fica apoiada na operação da usina térmica de alto fator de capacidade. Esse auxílio complementar torna possível um aumento da capacidade total do sistema superior ao que seria fornecido pela usina térmica apenas.

O relatório oferece uma descrição do duplo papel que pode desempenhar a capacidade termo-elétrica num sistema predominantemente hidro-elétrico.

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Título 1
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REUNIÃO PARCIAL
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Rio de Janeiro – 1954

PETRI (F.)
LINGSTRAND (L.)
Suécia

# STEAM POWER AS A SUPPLEMENT TO WATER POWER IN SWEDEN

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SWEDEN NATIONAL COMMITTEE

## GEOGRAPHY AND CLIMATE

Lying between north latitudes 55° and 69° and between 11° and 24° east of Greenwich, Sweden is one of the most northerly countries in the world and on the same parallels as southern Greenland, Alaska and a number of other polar countries. Due to the proximity of the Atlantic, however, the average temperature is about 10° C higer than is normal at these latitudes and no part of the country has an arctic climate. The length of the country from north to south is about 1,000 miles and the total area about 173,700 square miles. About one-seventh of the country is north of the Artic circle. The country is bounded on the western, or Norwegian side, by the Scandinavian mountain range and, from a height of about 3,000 feet, slopes eastwards to the shores of the Gulf of Bothnia and the Baltic. The largest rivers in Sweden, which run from east to west, drain the mountainous region of the country. During the Ice Age many of these rivers were dammed by alluvial deposits which resulted in the formation of many of the lakes which today cover about 9% of the land area.

The climate is mainly maritime and is influenced by the Gulf Stream. The Swedish winter, defined as the time when the average daily temperature is below 0° C, lasts for about 7 months in the northern parts of the country and for about 2 1/2 to 3 months in the southern. Summer, that is when the average daily temperature exceeds 10° C, lasts for about 2 months in the north and 4 1/2 months in the south. The average annual rainfall is about 25 inches and the evaporation about 10 inches. The greatest rainfall, up to and exceeding 80 inches, has been recorded in the north-west mountain district.

The country has hardly any mineral fuel although there are small coal deposits in the most southerly regions. The deposits of economically workable coal are estimated at about 100,000,000 tons. There are no deposits of oil as such, but shale oil to an estimated total of 350,000,000 tons can be extracted from known deposits. The country has rich peat deposits, estimated to be equal to about 4,000,000,000 tons of coal, but no really satisfactory method of using this fuel has been devised.

## POWER SUPPLY IN SWEDEN

In 1952 Sweden's output of electrical energy amounted to 20,600 million kWh, or about 2,900 kWh per capita. This figure is about the same as in the USA and Switzerland but less than that for Norway and Canada. The consumption has risen steadily and relatively rapidy. To date the annual increase in consumption averages about 6.5% which represents a doubling in 11 yars. The power consumption for various purposes is devided approximately as follows:

| | % of total consumption |
|---|---|
| Heavy industry | 65 |
| Railways | 10 |
| Towns and municipalities | 20 |
| Rural districts | 5 |

Industry is the chief consumer and the largest users are the electrochemical industry, the steel mills and the pulp and paper industry. The greatest increase in recent years has been in the pulp and paper industry, although the use of electric furnaces in metal production and working has increased considerably. Electricity is being used on an increasing scale in towns and municipalities. In the domestic sphere electric cooking and water heating is on the increase and in the light industries more electricity is being used for heating and motive power. The water power is not sufficient for the large scale heating of dwellings. In the rural dictricts more than 95% of the homes have been electrified. This figure has been attained mainly as the result of more than ten years of substantial aid from the State to the electrification scheme. Power consumption in the rural districts is currently about 1,000 kWh per household which works out to about 260 kWh per acre of cultivated land per year.

Power production in Sweden is controlled by the State, who are responsible for about 40% of the total production, and by the municipalities and private companies who account for about 5% and 55% respectively. Of this 55% about 20% is produced by the industrial concerns for their own use and the balance is produced by power companies. The supply of power to the consumer is mainly through the medium of municipal electricity works or collective distributing companies.

The production of power is based almost entirely on water power, which, at the normal rate of flow, meets with about 95% of the total requirements. The theoretical amount of energy that Sweden can pro-

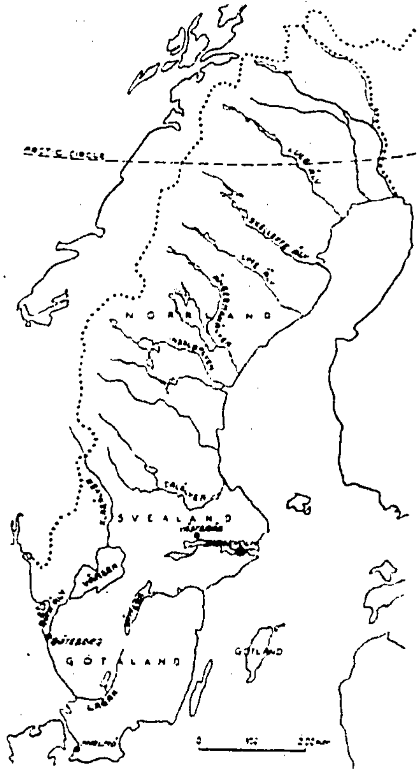

Fig. 1 — Map of Sweden

duce from water power is about 150,000 million kWh. Of this amount at least 60,000 milion kWh can be exploited economically, and about one-third of this amount, 22,000 million kWh, is harnessed and affords a capacity of 4,000 MW. The ratio of the amount of power that could be economically harnessed and that actually preduced differs in varying parts of the country. In the more densely populated southern region practically all the available water power is harnessed. The large remaining water power resources are in the sparsely populated northern regions.

In the south of Sweden the water flow is fairly evenly distributed over the winter and summer. In the north, however, there are strongly marked variations due to the accumlation of winter snows and the summer thaw and the result is water shortage in the winter and an abundance in the summer. The land is, however, covered with lakes and this allows regulation of the seasonal flow. The numerous regulating stations allow adjusting the flow not only to the amount of power required over the year, but to weekly and daily requirements. The existing reservoirs make possible the production of an annual quantity of 6,000 million kWh, that is, about 27% of the country's total power production.

Approximately 5% of the total power production is thermal power and of this amount 3% is obtained from industrial back pressure installations and the rest from the condensing power plants of power supply undertakings. Many of the large industrial firms have installed back pressure installations, in particular the pulp and paper industry. The largest back pressure plants are each about 10,000 kW and the total power derived by this means is estimated at about 150,000 kW. The total capacity of the condensing power plants is about 750,000 kW of which more than one half comes from the four largest stations and the rest from a number of smaller stations.

Nowadays nearly all the power stations are coupled on to a nationwide grid system which enables maximum advantage to be taken of water power and reduces the need for steam power.

Occasional and constant surpluses of water power in certain regions can be used to make up the deficit in other areas where it would otherwise be necessary to use steam power. The need for emergency or reserve plant in the form of condensing plants is reduced and the chances of a power failure lessened.

The grid system, which makes this joint operation possible, stretches from the Harsprånget power station north of the Arctic circle to the most southerly regions of the country, a total distance of about 812 miles as the crow flies. The voltage varies from 380 kV to 50 kV. In south

Sweden the system is connected by cable under Öresund to the Danish steam power stations. In the extreme north there is a connection with Norway.

## STEAM POWER TODAY

In a country such as Sweden where the electric power supply is based almost entirely on water power, steam power does not, on the whole, play a very important part but it is, nevertheless, a necessary complement if the water power is to be harnessed to the best economical advantage.

The main advantage of steam power plants over water power stations is that they can be located near to the load centres. This reduces the cost of transmitting power which, in a country with the length of Sweden, forms an appreciable proportion of the cost of delivering the power to the consumer. The need for a suitable water supply for the boilers and cooling system and also the need of a good port so as to minimise fuel transport costs somewhat reduces the possibilities for erecting steam power stations just where they would be most useful. However, as the large consumers of electric power are very often ports, the desired conditions are met as a rule thus the defficulties of locating steam power stations are relatively sligth. A further advantage of a steam power station is its independence of hydrological conditions, regulation restrictions and the like.

The main disadvantage of steam power stations in Sweden is that the necessary coal or fuel oil has to be imported, which means the risk of a fuel crisis in the event of international disturbances or transport or dock strikes. For a long time now efforts have been made to utilise the peat deposits, but so far this fuel has been used only as an emergency measure, to a certain extent for heating purposes, and hardly ever for steam power production.

From the operational point of view there is the disadvantage that steam power cannot be turned on immediately but, in this respect, Swedish technicians have been able to reduce the starting time to a degree that was believed impossible in other countries.

A further disadvantage is that there are considerably more sources of possible trouble with a steam engine on intermittent duty than with water power.

An analysis of the use of steam power in Sweden today shows that it is required mainly to fill the following functions:

1. During the years when the water supply is adequate steam power can be used for peak load generation when the output from the water power stations is insufficient. Fig. 2 shows how the varying daily requirements are covered by water and steam power. Even if the volume of water is sufficient to meet the power requirements the capacity is not always enough to cover the peak loading, especially during the winter peaks. These are, however, comparatively short. Even if it were possible to raise the output of the water power stations so that they could cover the peak load periods this would not be economical. Further details of this aspect of the question are given in the ensuing chapter "Optimum supplementary steam power".

2. Perhaps the most important function of steam power is as basic power when there is a shortage of energy. The most economical way of applying this is to run the steam plants under as even a daily load as possible and to cover the peak periods with water power, as is shown in fig. 3. It would not be feasible to harness so much water power so that one could dispence with steam power during the more marked water shortages. The variations in the water flow are too great to make this economically possible. In the more extreme dry periods water power can fall to about 80% — 85% of normal and in some years to 65% — 70%. Variations in individual rivers are even greater and it is only due

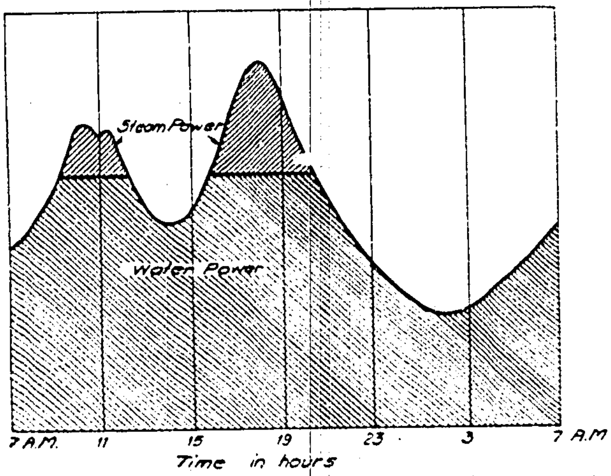

Fig. 2 — The combination of water power and steam power with adequate water level

to the linking between various rivers that the figures are held to the limits mentioned. The average annual flow in the rivers in south and central Sweden can drop to 40% — 50% of normal and in the north to 70% — 80%.

3. Steam power stations are important as a reserve in case of breakdown. As steam power stations are generally situated near the more important load centres they serve as a reserve for both the water power stations and the transmission installations. In this connection it is assumed that the steam power station can be quickly brought into action. This means that the construction of the boilers and the turbines must allow for such exigencies and that, to a greater or lesser extent, a head of steam must be maintained sufficient to meet the breakdown risk and the operating conditions.

4. A fourth function is the use of steam power as a reserve in the event that the development programme lags behind the increase in load. This can arise when the load imposed turns out to be greater than had been estimated or when construction falls behind schedule. As there are quite large differences in the amounts of power generated by water power stations the flexibility afforded by a steam power station is a valuable complement.

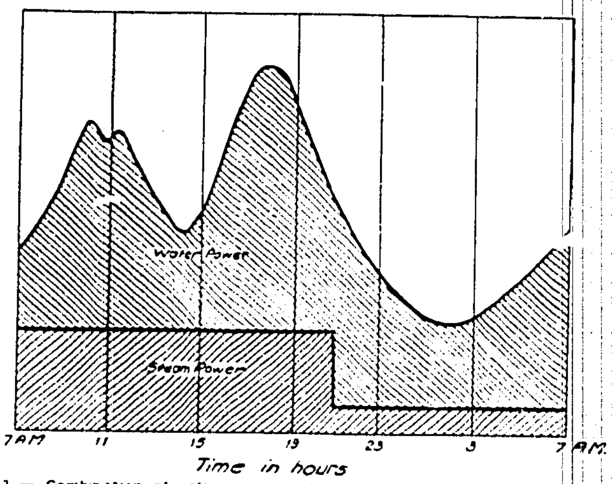

Fig 3 — Combination of water power and steam power at time of water shortage

5. Steam power station can be used for voltage regulation and increasing the stability of the long distance power supply systems. The fact that they are located near the load centres is advantageous for phase compensation.

## HARNESSED STEAM POWER STATIONS

As has been previously mentioned the harnessed steam power capacity in Sweden amounts to 900 MW and that from water power to 4,000 MW. This means that steam power capacity is about 20% of the total, but the actual amount of power generated is appreciably smaller. The highest power production from steam condensing plants was during the exceptionally dry period in 1947/48 when it reached not less than 1.140 million kWh. or about 9% of the country's total production of water and steam power. In addition there was the not inconsiderable production of 660 million kWh from industrial back pressure installations. The combined thermal power generation that year was about 14% of the total production.

The four largest steam power stations are:

The Västeras plant, which is the State's steam power station. The capacity is 220,000 kW from seven turbo-generators, the two largest of which each produce 65,000 kW. The additional boiler plant consists of six old-type conventional boilers for a pressure of 20 atmospheres, four tower boilers fired with pulverised coal and oil, two of which work at 24 atmospheres, and two newly built ones working at 35 atmospheres. The reason for the relatively low pressures is partly that the plant is designed to operate as a peak load and reserve station and consequently has to be of the quick-starting type. Under normal conditions the plant can start from cold boilers in 60 minutes or, with forced draught firing, in 30 minutes. The steam temperatures for the older installations are 350° C and 435° C respectively and 480° C for the recently installed ones. With the exception of one, the turbines are Ljungström double rotation type (Stal). These are characterised by their high thermo-dynamic efficiency and small dimensions. As a result of the symmetrical construction of the turbine system the temperature increases are uniform and the turbines can therefore be started quickly and take rapid load changes. The largest of the existing turbines, generating about 65 MW, can thus reach full load from a cold start in 15 minutes. The load can be varied from zero to maximum almost instantly.

The Värtan plant in Stockholm, belonging to the Stockholm Electricity Works, is one of the older type with a capacity of 100,000 kW. The steam pressures are 14 and 24 atmospheres.

The Malmö plant, belonging to the South Swedish Power Company, has three turbo-generators giving a total output of 70,000 kW. The steam pressures are 31 and 50 atmospheres.

The Öresund plant, also in Malmö and belonging to the South Swedish Power company, is the most modern installation and the first section, generating 65,000 kW, was started in 1953. The turbine is the same as that at Västeras and has two coal and oil fired radiation boilers for 80 atmospheres and 500° C. The boiler capacity has been divided to increase the efficiency at part load and to lessen the damage in the event of a boiler breakdown.

## OPTIMUM SUPPLEMENTARY STEAM POWER

As far as the relative costs of steam and water power are concerned it can be said, very generally, that the installation costs per kWh for a steam power station are less than those for a water power station when allowing for transmission costs. On the other hand the annual running costs for a steam power station are much higher. This is due mainly to the fact that fuel costs are high but also to the higher operating and maintenance costs. On the basis of energy produced the steam power station gives a low cost per kW but a high cost per kW. For water power station the opposite is the case. Long term energy requirements are produced more cheaply with water power but otherwise steam power is advantageous. By combining steam and water power it is possible, therefore, to calculate the most economical application of steam power. The present cost of erecting a steam power station works out to approximately 500 Swedish kronor (100 Swedish kronor = £ 7 or $ 20) per kW or something over that for the largest installations and up to 700 — 1,000 kronor for smaller plants. The corresponding costs for water power stations are only occasionally as low as 500 kronor per kW and are more often between 700 and 1,000 plus transmission costs averaging 300 — 400 per kW, bringing the total to about 1,000 — 1,400 per kW.

These total costs are generally applicable for power stations in southern Sweden where the transmission costs are certainly lower but the cost of harnessing the power is generally higher.

In order to make a comparison between the relative costs of producing energy by water power and steam power the percentage cost per annum and the utilisation time must be allowed for. The annual percentage cost at the present interest rate in Sweden (about 4%) is about 8% for water power station and about 10% for steam power stations, excluding fuel costs. The utilisation time, calculated on the installed capacity, works out to about 5,000 hours a year in modern water power stations. Applying the current relationship between water and steam power the utilisation time in a steam power station can be expected to average about 1,000 hours. Based on these figures the output cost for water power is calculated at 0.016 — 0.022 Swedish kronor per kWh. The cost of steam power, allowing for the operating costs, is 0.04 Swedish kronor, which, corresponding to the price of 80 Swedish kronor per ton for coal and allowing for a consumption of 0.5 kg. per kWh, is 0.09 Swedish kronor per kWh for large installations and up to 0.14 for small. The difference in output cost is, therefore, considerable. The price of fuel makes little difference. If for example, the price of coal was altered by 10 Swedish kronor per ton the cost of steam power would only differ by 0.005 Swedish kronor per kWh. On the other hand the costs are greatly affected by the utilisation time.

Figure 4 shows how, in principle, steam power, surplus power and overflows, calculated on an annual basis, differ with the available water power. With steam power, only power from condensing plants is considered, and with surplus power, only deliveries to industrial electrical steam boilers. These are of great importance in a country such as Sweden which has widely varyng water power resources. Overflow is the amount of power that could have been produced if the need had demanded it. The percentage of available water power allows for the load including power transmission losses but excludes power deliveries to electric steam boilers. The curves are based on statistical material and the figures for a particular year could, of course, vary appreciably from those shown. For instance, if the water power resources fall below a certain point the steam power supplement rises rapidly. During an exceptionally dry year the need for steam power is appreciably higher than in normal years and as a rule this determines the steam power capacity that must be harnessed to ensure that power supply is maintained during such years. With greater water power resources, on the other hand, the water power surplus rises and a greater or lesser quantity can be used in electrical steam boilers and the rest stored in reservoirs until the following year, the so-called annual regulation, or run to waste. If there were no limit on the degrees of regulation and the water power stations had a sufficient capacity margin there would be no surplus power or overflow during the years when the water level was less than 100% and no need to use supplementary steam power when the level was over 100%. However, as the water power capacity is now insufficient and the facilities for regulation are limited, the water level cannot be adjusted to the net load throughout the year and in consequence there is a surplus of power and overflow at the same time as supplementary steam power is needed.

By marking fig. 4 with a permanent curve representing annual water power resources over a longer period, calculated at the same stage of development, and relating the costs of water and steam power.

the most economical average water power resources can be determined. Experiments carried out have shown that the economical optimum for the degree of development, which means the average or normal water power resources in relation to the load, calculated as mentioned above and related to present costs, is about 110%. At this degree of development the average supplement from condesing plants is about 1 — 2%.

Calculations carried out prior to the second world war showed that a normal steam power supplement of 10% gave an economical optimum if the following factors were allowed for: relatively speaking, lower steam power costs, and a considerably smaller power joint operation with larger variations in the water power resources from year to year as a result. During and after the war the cost of steam power has risen in proportion to that of water power, mainly because of the heavy increase in the cost of fuel, and this has resulted in the reduction of the economical influence of steam power, at current prices, to the 1 — 2% mentioned above.

The amount of energy produced by steam power as related to the total produced has, during the post war years, been greater than the optimum given above. The reason for this is that the post war load rose so quickly that there has not been time to erect water power stations to the extent that was necessary to maintain the desired water power reserve.

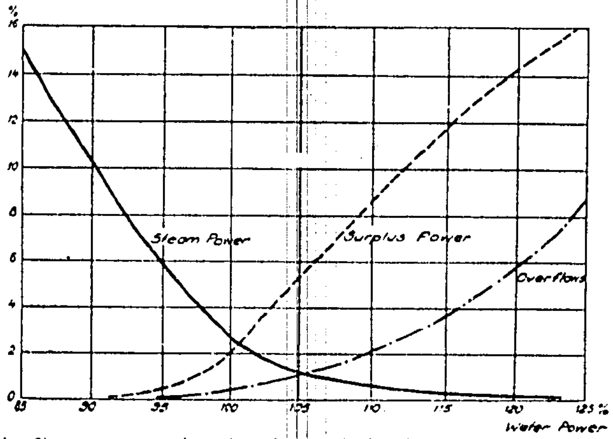

Fig. 4 — Steam power, surplus and overflow as the functions of water power resources

## THE FUTURE OF STEAM POWER STATIONS.

The water power available is limited and, on the basis of the load increase of 6.5% that has been experienced during recent years, will be fully utilised by 1970. Before that time, when all the power is harnessed, one can either harness enough water power so that both sufficient capacity and energy can be obtained from water power, even during a dry year, or supplement a more normally developed water power with adequate thermal power. As has been shown earlier, maintaining the economical optimum at current prices, the exploited water power resources during a normal year exceed the net load by about 10%.

Current plans for developing water power are being directed so as to achieve the surplus mentioned. This means, on the average, an annual addition of 1,600 — 1,700 million kWh, corresponding to an annual capacity increase of about 300 MW. It is not certain that development on such a scale can be maintained in the future, owing to labour difficulties and financing. The latter factor becomes more important when the smaller and more expensive falls are to be exploited. One should, therefore, reckon with a certain reduction in the future development of water power. As a result of the large scale exploitation of water power during the coming few years the need for power from condensing plants will decrease, but this can be expected to increase later.

The deciding factor in constructing steam power stations is not how much thermal power is needed in a normal year but how much is needed in a dry year. The steam power capacity required is determined by this and by the maximum utilisation time for steam power plants. The factors that limit the utilisation time are firstly, allocation difficulties owing to the limited possibilities for regulation in the water power stations and secondly, shut downs in the steam power plants. One of the main reasons for producing steam power is that the water power resources do not accommodate the net load. With a very low load, such as is encountered during public holidays and during the industrial vacation period, and when the river is high, for example during the spring floods when the snows have begun to melt, the uncontrollable water power resources are, as a rule, so large in relation to the load that steam power cannot be used. At certain times of the year short-time regulation of the water flow is forbidden in a number of power stations. Similarly the amount of water drawn off must not be varied at the beginning or end of the winter season when the ice begins to form and thaw. This is to protect the inhabitant's right to winter paths over the rivers and so as to prevent the formation of ice dams. It is also, as a rule, forbidden to vary the flow appreciably when timber is being floated down the river. These regulations result in so much water being drawn off during the night and during holiday periods that steam power cannot be allowed during these periods. Allowing for the necessary shutting down of the boilers and turbines for maintenance and repair, the maximum utilisation time for steam power plants is about 3,000 hours, which is little more than half of the load utilisation time. With a load increase of 1,500 million kWh per annum and a maximum utilisation time of 3,000 hours the annual addition in power required from condensing plants is about 50 MW.

When the time arrives that all the water power begins to be utilised and the cost of harnessing water power increases rapidly, the need for steam power will increase. It will soon be necessary to utilise steam power stations for basic power and steam power will have a considerably longer utilisation time. This means that greater consideration must be given to the efficiency of the installation and the need for quick-starting boilers and turbines is thus reduced. In order to attain the highest possible efficiency in condensing power plants, load variations will be avoided and they will only be used for seasonal, weekly and, possibly, daily regulation. The water power stations, on the other hand, will take care of the shorter capacity variations. Of course, any development in this direction depends largely on the planning of future water power stations. Probably developments will be such that water power stations that afford good facilities for short time regulation should be intensively developed. It is necessary therefore, to bear this in mind now when planning the water power stations that will come into use during the next ten years. The new stations now being built are, in general, designed so that one or more sections can be added in the future. It is evident that the harnessing of water power becomes unreasonable if the production of steam power plants in the future is mainly to provide basic power evenly distributed over the year. It is quite posible that, as the result of the increase in steam power, one must also build steam power stations for a shorter utilisation time than has at present been envisaged. This will, of course, be decided by how the power can be most cheaply produced, either by harnessing increased quantities of water from the rivers or the development of steam power stations.

## PLANNED STEAM POWER STATIONS.

Development plans for condensing steam power plants in Sweden during the next few years include three large stations in the vicinity of the three largest towns in the country. The old Värtan plant in Stockholm will be augmented by a 60 MW station and, in Malmö, the Öresund plant mentioned earlier is being developed, the planned total capacity being 350 MW. The first section has already been set in operation and another one is expected to be ready next year. The State Power Board plans to erect a steam power station generating 400 MW near Gothenburg and to have the first section in operation by 1960. The conditions under which this plant will operate have been examined, and as they are expected to be representative of requirements during the 1960's it may be of interest to mention some of the results of the investigation.

The utilisation time for steam power during the 1960's has been calculated, on the average, as being 1.350 hours at 105 % development and 750 hours at 110% degree of water power development. On the average steam power will be used every fifth year to provide long term production (utilisation time 3,000 hours) whilst in the other years the plant will be used for peak load generation. In order to decide which is the most important, high efficiency with steady operation or low starting costs for peak load operation, the annual cost of basic plant and stand-by plant can be calculated for various utilisation periods. Fig. 5 shows the curves for the annual costs as the function of the utilisation time for an assumed output of 300 MW. The capacity has been calculated on an instalation cost of kronor 500/kW and a fixed annual cost of 10%. For the basic plant a 10% increase in efficiency, a 100% increase in starting costs and a 4% increase in installation costs have been assumed. The crossing point of the lines is at about 1,500 hours, that is at a somewhat higher utilisation time than has been calculated for steam power stations during 1960. On the basis of the calculated utilisation time a stand-by plant is preferable.

On the basis of the above results it has been decided to build the projected plant as a stand-by station with facilities for quick starting and rapid variations in load. With a 100 MW turbine the normal starting time is computed at about 15 minutes. The boilers are designed as radiation steam boilers and will take 1 - 2 hours to heat up. On the days when — according to a pre-arranged plan — peak capacity is required, the boilers will be brought up to full pressure early in the morning and then the fires will be put out. When the peak load is approaching the turbines are started and the boilers re-fired. The turbines begin to generate power in about 15 minutes. If quicker starting is called for the turbines are held in phase with the net and are allowed to idle while the boilers kept warm so that there is no drop in pressure. In this case the starting time is reduced to about a minute. During winter peak periods, when there are two or more peaks, the above operational method involves starting up the turbines and re-firing the boilers several times a day. This method of starting is already being used in existing plants with good results.

## THE DEVELOPMENT OF BACK PRESSURE INSTALLATIONS.

The previous remarks on steam power are applicable to condensing plants, but it can be of interest to examine the position concerning the development of back pressure installations. Production by this method has, in recent years, reached about 500 - 600 million kWh per annum. By the development of existing plants and the erection of new industrial and heat and power plants this production will rise to between 1,500 and 2,000 million kWh per annum by 1970. The combination of heat distribution and power production is of special interest as it can result in a saving of fuel. This is of special importance in Sweden where the lack of fuel is so marked. Research shows that we can expect the Swedish towns with over 20.000 inhabitants to produce 700 MW or 1,600 million kWh per annum together in such installations. As a result of the higher efficiency in relation to other types of heating, the annual coal saving should amount to about 150,000 tons. Electric power from heat and power plants will, in the main, be used only during the winter months when the need for electric power is greatest. This should prove a valuable addition and should reduce the need for

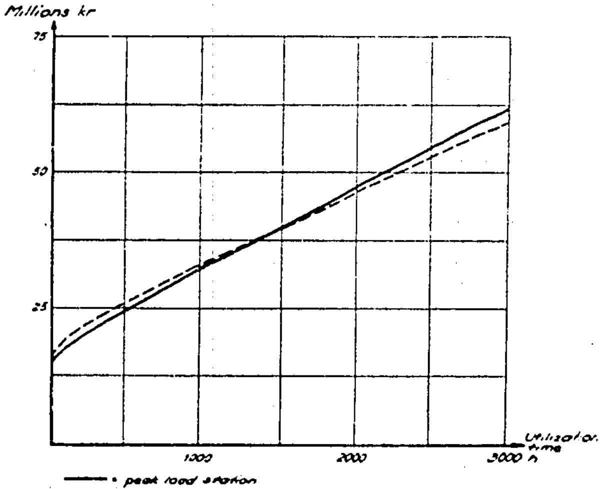

Fig. 5 — Annual cost of stand-by plant and basic plant as functions of the utilisation time

condensing power installations, which use much more coal per kWh. A recent survey shows, however, that as long as cheap, untapped water power is available and there is a surplus of water power during the greater part of the year, the advantage to be gained from heat economy and electric power production is comparatively unimportant. The interest in heat and power stations is great, however, and research as to how remote thermal power can be incorporated in the power supply system continues. The two technical highschools in Sweden take a share in the efforts for development of this branch. Thus rather big plants have been built at the Royal Institutes of Technology in Stockholm as well as in oGothenburg.

## SUMMARY

In a country such as Sweden, where the power supply is based almost entirely on water power, steam power does not, on the whole, play a very important part but, it is nevertheless, a necessary complement if the water power is to be harnessed to the best economic advantage.

Steam power stations serve as stand-by stations when there is a capacity shortage, and as basic stations when tnere is a shortage of energy. They can be used as reserve stations in the event of a breakdown and can be incorporated in the development schemes for water power stations when the power output, additions to which are made in fairly large increments, cannot be adequately adjusted to the continuously increasing load. They are also used for voltage regulation and for improving the stability of the distribution service system.

Steam power gives a low cost per kW but a high cost per kWh, whereas with water power the opposite is the case. With reference to the relationship between water power and steam power an economical optimum is reached when the average water power resources amount to 110% of the load. This results in an average supplement of 1 - 2% from condensing installations. The maximum utilisation time for steam power stations is 3,000 hours. An annual addition of about 50 MW in condensing plant power is required when water power is — as at present — extended by 300 MW per annum.

The country's water power resources are limited and can be expected to be fully utilised by about 1975. From then on load increases must be covered by thermal power and it will be necessary to make a continuous use of steam for basic power, while the water power stations handle the peak loads. Greater consideration must be given to the efficiency of steam power stations.

The combination of heat distribution and power generation in heat and power stations can be an important factor.

## Resumen

En suecia, cuya aprovisionamiento de energía eléctrica se basa casi exclusivamente en la fuerza hidráulica, la fuerza de vapor desempeña un papel poco importante. Sin embargo representa un complemento necesario a la fuerza hidráulica a fin de que se pueda aprovechar esta última de una manera económica.

Las centrales térmicas sirven de centrales de sobrecarga, es decir, para la producción de energía durante las horas de mayor consumo, y también hacen las veces de centrales de reserva durante épocas de escasez de energía. También se usan como centrales de reserva en caso de interrupciones de marcha y se recurre a estas centrales en los casos en que el programa de expansión de las centrales de fuerza hidráulica, con su continua construcción de nuevas centrales, no se puede ajustar por entero al consumo que aumenta constantemente. También se usan para la regulación del voltaje y para el aumento de la estabilidad del sistema de transmisión de corriente.

La energía térmica supone un bajo precio por kW pero un alto precio por kWh, mientras que para la fuerza hidráulica, si se incluye el coste de la transmisión de la energía, se obtiene el resultado contrario. Considerando la relación entre los costos de la fuerza hidráulica y de la fuerza térmica, se obtiene un óptimo económico cuando el suministro promedio de fuerza hidráulica sube a un 110% de la carga, dando una adición promedia de fuerza de condensación de 1 a 2%.

El tiempo máximo de aprovechamiento de las centrales térmicas es de 3.000 horas. Una adición anual de fuerza de condensación de aproximadamente 50 MW es necesaria cuando la fuerza hidráulica se completa, como actualmente, con 300 MW/año.

Los recursos hidráulicos del país son limitados y se calcula que estarán completamente explotados hacia el año 1975. El aumento del consumo de energía a partir de esa fecha tendrá que cubrirse con fuerza térmica y habrá necesidad de aprovechar normalmente las centrales térmicas para el suministro del consumo corriente, mientras que habrá que recurrir a la fuerza hidráulica para atender a las horas de máximo consumo. Entonces hay que obtener el máximo rendimiento de las centrales térmicas.

La combinación de distribución de calor y la producción de energía en las centrales de fuerza y de calor puede ser de importancia.

## Résumé

En Suède, où l'alimentation en énergie électrique est pratiquement fondée uniquement sur la force hydraulique, l'énergie thermique joue un

très petit rôle. Les centrales à vapeur constituent seulement un complément nécessaire aux centrales hydrauliques afin qu'on puisse les exploiter de la manière la plus économique possible.

Les centrales à vapeur servent comme centrales de pointe en cas de manque de puissance et comme centrales de base en cas de manque d'énergie. On les utilise comme réserve en cas de perturbations d'exploitation et l'on peut y avoir recours quand le programme d'extension des centrales hydrauliques, qui fournit de gros appoints d'énergie, ne peut par suivre tout à fait l'accroissement continu de la charge. On les utilise aussi pour le réglage de la tension et pour améliorer la stabilité dans les réseaux de transport de force.

Les centrales à vapeur exigent un faible prix par kW installé mais un prix élevé par kWh produit alors que c'est le contraire avec les centrales hydrauliques, si l'on compte les frais de transport. En considérant les frais relatifs entre les centrales hydrauliques et les centrales à vapeur, on obtient le résultat économique optimum quand la puissance hydraulique moyenne dont on dispose s'élève à 110% de la charge, ce qui donne un appoint moyen de puissance thermique à condensation de 1 à 2%.

Le temps d'utilisation maximum des centrales à vapeur s'élève à 3.000 heures. Un appoint annuel de puissance thermique à condensation d'environ 50 MW est nécessaire, quand le développement de la puissance hydraulique atteint comme maintenant 300 MW/an.

La puissance hydraulique dont dispose le pays est limitée et l'on peut compter qu'elle sera toute utilisée environ 1975. L'accroissement de la consommation devra être couvert à partir de ce moment par de l'énergie thermique et l'on sera obligé d'employer les centrales à vapeur pour la production de l'énergie de base, tandis que les centrales hydrauliques assureront la consommation de pointe. Il y aura lieu d'apporter une attention particulière au rendement des centrales à vapeur.

La combinaison de la distribution de chaleur avec la production de force motrice pourra avoir de l'importance.

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# PLANNING OF NEW POWER PLANTS INTO A COOPERATIVE POWER PLANT SYSTEM WITH PARTICULAR REGARD TO RUN-OF-STREAM PLANTS

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## 1. *Introduction — Objectives*

Whenever a new power plant is to be set up one of the most important tasks confronting the planners *is to examine how economical the new establishment is*. In order to define briefly the object of this examination, may it suffice to say that the new power plant should be designed, built and operated in such a way as to ensure that the forms of energy supplied therefrom should be charged with the smallest possible total cost from the point of view of national economy relative to the place of consumption, and the same time the security of the energy supply should be the greatest in so far as is warranted by considerations falling into the sphere of national economy.

The respective examination assumes different forms if the new power plant supplies an isolated district of consumers, as for instance in the case of heat energy supply — the steam supplying power plants are generally of this kind — and if the new power plant feeds a cooperating network.

The examination of the reciprocal and mutual effects of a new generating plant and the existing power plant system are manifold and complicated as compared with calculations concerning the economy of an isolated power plant, yet this examination is of fundamental importance as the new power plants — except in some exceptional cases — are no longer operating separately, but in cooperation with a power plant system interconnected by a high capacity transmission system.

It is advisable to examine the economy of a new cooperating power plant in order to be able to select the most suitable type in the case of a conventional condensating power plant, but it is inevitable when we erect a special power plant. This is the case of hydraulic power plants are to be introduced into a system consisting mainly of steam power plants, or vice versa; the same also refers to cases, when a heating power plant, a steam or hydraulic peak power plant or any new power plant is being built which has to supply a given section of the load curve of consumers. In such a case, in order to find the most favourable solution from an economic point of view, we must examine also the case when the system being supplemented with instead of a new special power plant is supplemented with such as e.g. a customary type of a condensating power plant, the production capacity of which is, from the consumers' point of view, "worth" as much as the power plant in question.

The present paper gives, by utilising the previous results of technical literature, a new method for the examination of the economy of a new power plant inserted into a cooperating system, taking into consideration the effect of the new power plant on the system. It is generally known that the examinations concerning economy take into account *the fluctuation of the yearly overall costs* and are thus extended to the change in both the investment and operation costs. The capacity of power plants of different types evaluated from the stand point of the admissible increase of consumers' peak demand deduced and established by probability calculation — and which determines the fixed costs, and furthermore the direct examination of the change of the current costs of the whole system, are together the factors that make possible the estimation of the economy of a new power plant.

## 2. *Preliminary estimates relating to load fluctuations of the network*

When making calculations concerning economy of power plants one must be aware of the load fluctuations in function of time. In the case of a power plant system this requires knowledge concerning the resulting load curves. As we try to make examinations concerning the economy for a possibly maximum time period it is necessary to know the load curves of the system in the late future.

Methods are known according to which the probable load — and duration curves may be drawn knowing the characteristics of consumers. Calculations concerning economy have so far been derived essentially from the yearly load and duration curves pre-estimated in this manner.

The yearly load and duration curves are, however, only suited for a description of phenomenae of power plant system in a rough, approximate way, notably on account of the fact that, although giving information concerning the frequency of a certain given load, no conclusions whatsover can be drawn relating to the temporary course of load fluctuations. In the interest of the perspicuity of the relations of the power plant system our examinations must be worked out for a shorter period, practically for days and from the result we can conclude to the whole year.

It is to mention that the pre-estimated daily load curves, of course, signify only probable values, and in practice deviations may be expected. Despite this we shall, forthwith, handle the pre-estimated load values as actual facts. Results attained this way will, however, have to be corrected by introducing the *probability of consumption*, instead of consumption taken as actual fact.

### 3. *Share of yearly current costs of a new thermal power plant introduced into a power plant system.*

In thermal power plants the decisive part of the yearly current costs is in proportion with the amount of generated electric power; a smaller part of it depends on the investiment costs of the plant.

As we know it is a plain task to determine the current costs of an isolated condensating power plant. The case is different in connection with a power plant operating in a power plant system, in which case the share of the new power plant in the costs proportional to generated electric power is the resultant of its own cost and of the modification of costs of the whole system.

The yearly current costs of the new power plant depend thus on the load of the power plant and on the load changes of the existing power plants, thus on *the distribution* of the total consumer load between the existing power plant system and the new power plant.

The distribution of loads must take place on the basis of principles of economy, the method of which, i.e. *the economic load distribution* is duly known from practice as well as from literature /1, 2/. As well-known load distribution is economical if the total consumer load is distributed between the existing power plant system and the new power plant in a way that the cost of 1 kw added to the load of the existing power plant system should be equivalent with the cost of 1 kw added to the load of the new power plant. *The equality of increment costs* is a condition of economical distribution of load.

The overwhelming part of costs proportional to the amount of generated electric power derives from the coal cost of the power plant, which is again proportional with the heat consumption of the power plant. In general, we do not commit a noteworthy fault when determining the load distribution — instead of on the basis of the equality of the increment costs of the power plants — on the basis of the *equality of increment-heat-consumption*, wherefore we shall forthwith follow this method, mentioning that eventually some correction is required.

Thus the somewhat simplified task is to calculate the heat consumption allotted to the new power plant on some average day by paying attention, apart from the power plant's own heat consumption, to the change in heat consumption of the existing power plant system, as compared to conditions preceding the insertion of the new power plant. A calculation method must be applied according to which *the change in heat consumption of the existing power plant system may be calculated directly*. For this end the existing increment heat consumption characteristics may be used which are anyhow required for the calculation of an economical load distribution. We introduce the calculation method for the case when the power plant system is supplemented with a plant having any value of efficiency. (Fig. 1.)

The daily load curve of the existing power plant system, prior to the load increase, is shown by curve *a* of figure 1, and that after the load increase by curve *b*. From the presumably known heat consumption conditions of the existing power plant system the increment heat consumption curve, marked by curve *c*, may be drawn.

In order to cover the $N_p$ peak demand surplus, we install a new thermal power plant of $N_p$ generating capacity, by neglecting self-consumption and reserves. Presuming to know the specific heat consumption curve of the new power plant we make a calculation concerning its increment heat consumption curve marked by lines *d* in figura 1. The distribution between the existing power plant system and the new power plant is economical if the existing power plant system and the new power plant are operating at identical increment heat consumption points. The resultant increment-heat-consumption curve of the supplemented system is shown by curve e.

The economical distribution of the output $N''$ increased in any $t$ time is shown by points 1 and 2 of figure 1. The new thermal power plant carries a load ($\Delta N$) according to point 2, and the existing power plant system a load $N'$ according to point 1. In this way we can fix the load shared by the new thermal power plant in any time of the examined day (curve *f*) and, on the other hand, whether the existing power plant system will, as compared to its previous state, carry more or less load (curve *g*).

The daily heat consumption of the new power plant may be calculated from its determined daily load curve (*f*) and of the values of its heat consumption known in function of load. The decrease or increase of the daily heat consumption of the existing power plant system may be drawn on the basis of the increment-heat-consumption curves of the system (figure 1, curve *c*). In the examined time $t$ the load change ($N' - N$) of the existing power plant system is known on the basis of the load distribution between the existing power plant system and the new power plant, the corresponding heat consumption change of which (in the present case a surplus) is the striped area on figure 1. After counting the values of the whole day we get, on the one hand, the heat consumption of the new power plant on the examined day and, on the other hand, the change in daily heat consumption of the existing power plant system. The summing up of the two values renders the daily total heat consumption used for generating the electric power surplus.

The determination of the daily heat consumption allotted to the new power plant has been, with the help of the increment-heat-consumption curves suited for revealing the essentials of the method to be followed. When making a calculation concerning economy we are, however, ultimately not seeking the value of heat-consumption allotted to the new power plant but *the yearly overall current cost allotted to the new power plant.* In the same manner as the daily heat-consumption allotted to the new power plant could be calculated with the help of the increment heat-consumption curves, we may also calculate the daily current cost allotted to the new power plant with the help of the increment cost curves and thus obtain the yearly current costs.

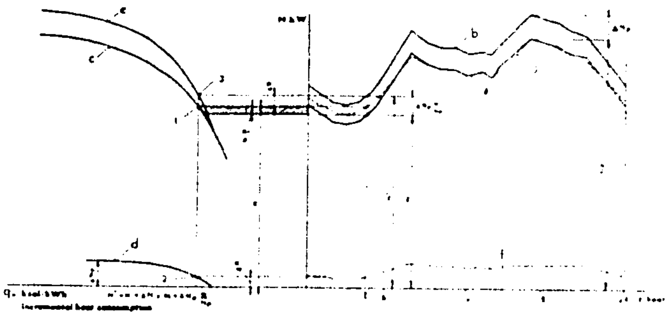

Fig. 3

## 4. *Valuable Capacity*

Apart from the current costs the economy of power plants is chiefly influenced by the investment costs and the fixed costs respectively, proportional to the former. The investment cost is definitely determined by the equipment and inner layout of the power plant. The generating capacity obtained by the power plant is, however, not so exact.

Concerning the generating capacity of power plant sharp difference must be made between the so-called *installed generating capacity* of the power plant, which generally means the total installed generating capacity of generators and the capacity by which the power plant stands at the disposal of the network of consumers and which changes in the course of time. This generating capacity is always samller than the installed one, partly on account of the missing generating capacity of idle machines, owing to maintenance according to the operating schedule, partly on account of the loss of generating capacity due to unexpected breakdowns and partly on account of other, periodically changing causes. Causes of this kind may be: the fluctuation of the stream flow of hydro power plants, the variation of heat demands in case of power plants supplying steam for heating and industrial purposes, or in principle the seasonal fluctuation of the temperature of cooling water in condensating power plants etc.

In full knowledge of the inner structure and the operation schedule of the power plant further of the required reserve capacity the size of the power plant may be chosen for the safe power supply to given consumers or vice-versa, it may be stated what generating capacity is represented by a power plant erected with a fixed investment expenditure, from the stand-point of safe power supply to a given system. The output permitting an increase of the demand of consumption by establishing the new power plant will be called *valuable capacity.*

In order to fix the valuation of different types of new power plants on a common basis and thus to get commensurable values from the standpoint of investment costs we introduce the conception of the *equivalency factor*, which reveals how much installed capacity covering a similar consumer's peak demand corresponds with the capacity of any kind of power plant to be established.

As long as the decisive majority of power plants of the system consists of power plants of similar types e. g. condensating power plants in our country, the introduction of the new conception of valuable capacity has not been inevitable since practical figures could be determined which revealed how much peak demand increase $N_p$ is permitted in the system by the introduction of a certain condensating power plant of $N_i$ installed generating capacity. According to the wellknown calculation

$$N_p = \frac{N_i}{r \cdot (1 + \varepsilon)}$$

where $r$ is the overall reserve factor determined from practical datas and $\varepsilon$ is the factor of self consumption.

In the course of the extension of a power plant system it became soon evident that the estimated reserve factors do not form a suitable basis for planning the power plant system and that the establishment of the reserve requirement of the power plant system demands a detailed examination. *An examination relating to reserve relations is of particular importance if power plants of the system are of different types.* On the other hand this case is more and more frequent because in compliance with up to date power economy an increasing number of hydro plants is set up and the number and generating capacity of heat-supplying power plants is on the increase too. In addition special peak power plant for supplying peaks may be set up too as for instance the pumped storage plants, or thermal peak power plants etc.

In this case we must determine the reserve requirements of both power plants, as well as the further reason of the difference between the generating capacity actually at the disposal of the network and the installed generating capacity, furthermore the amount of the difference. So we must establish the valuable capacity of both power plants. *In the course of our comparison, from the view-point of capacity, we may only consider the power plants of similar valuable capacity as equal.*

Forthwith we shall report on a *well defined method* with the help of which the generating capacity of power plants or of a power plant system respectively, can be established, for the safe electric supply to a consumption system with a given peak-load demand. With the same method we can establish the increment-peak demand admissible after the enlargement of the existing system with a new power plant, and which we call valuable capacity of the new power plant.

It must be noted that the *valuable capacity* i.e. the admissible peak demand increase resulting from the introduction of the new power plant *depends, apart from the characteristics of the power plants, also on the power plant system cooperating with the new power plant.*

## 4-1 *Definition of the conception of valuable capacity and equivalent generating capacity*

In order to fix the relations let us primarily examine the valuable capacity in the case of enlarging *the system with a new condensating power plant of $N_{i\,cond}$ generating capacity.*

The operating reserve to be kept in the system for the sake of the unexpected shortages in the generating capacity of power plants and the unexpected demand increase of consumers increases because, as a result of the new machines breakdowns in the system are more frequent. We mark the increase of operating reserve with $\Delta N_{op\,cond}$.

The capacity-time area occupied for maintenance in the system increases in a similar manner; the maintenance reserve surplus is $N_{M\,cond}$.

*The generating capacity valuable from the stand-point of the network* $N_{v\,cond}$ with regard to the extent of the self-consumption $N_{e\,cond}$ of the power plant is.

$$N_{v\,cond} = N_{i\,cond} - \Delta N_{M\,cond} - \Delta N_{op\,cond} - N_{e\,cond}\ \mathrm{MW}$$

With non-condensating steam power plants and hydro plants the factors diminishing the valuable capacity against installed capacity are generally different from those with condensating power plants. The maintenance reserve requirement $N_{M\,pl}$ develops differently, so does the self consumption of the new power plant $N_{e}\,pl$ and the development of the oparting reserve requirement of the system $\Delta N_{op\,pl}$ will be particularly different. In the case of a condensating power plant apart from the effect of self-consumption maintenance and unexpected outages the valuable capacity may be shortened only by the seasonal change of the cooling water temperature which has been disregarded before. In the case of a hydro plant as well as of a heat-supplying power plant the generating capacity is, however, in a similar manner influenced essentially by other uncertainties too. Such circumstances are the unforeseen change in the water run-of or heat consumption as well as the fluctuation of out-of-door temperature. It is also on account of these uncertainties that operating reserves must be kept in the system and that a surplus value of operating reserves kept owing to the new power plant may change considerably according to the type of the new power plant. The valuable capacity of any type of power plant, by applying the above drawn conceptions:

$$N_{val} = N_{\text{[illegible]}} - \Delta N_{\text{[illegible]}} - \Delta N_{\text{[illegible]}} - N_{\text{[illegible]}}\ \mathrm{MW}$$

*The equivalency factor* e according to the definition given in the preamble is the ratio of the installed capacity of the new power plant introduced into the system and of the installed capacity of a condensating power plant, the valuable capacities of which are equal $N_{\text{[illegible]}} = N_{\text{[illegible]}}$.

$$e = \frac{N_{i.pl}}{N_{i.cond}} = \frac{N_{\text{[illegible]}} + \Delta N_{\text{[illegible]}} + \Delta N_{\text{[illegible]}} + N_{\text{[illegible]}}}{N_{\text{[illegible]}} + \Delta N_{\text{[illegible]}} + \Delta N_{\text{[illegible]}} + N_{\text{[illegible]}}}$$

When examining equivalence we do not take into consideration the network losses due to the dislocation of various power plants, usually differing from each other and therefore of different size although calculations may easily be supplemented with them.

### 4-2. *Factors influencing the valuable capacity.*

### 4-2.A *The effect of generating capacity chaning in a determined way. Maintenance reserves.*

A characteristical case of the provided capacity changes is due to the maintenance.

If maintenance is carried out on the whole year as all maintenance operations cannot be accomplished during the periods of the low consumptions peak demand i.e. in summer the utilisation of the provided generating capacity of the new power plant with an average value will be possible essentially by way of the adequate devising of the maintenance schedule of the whole power plant system. If this conditions did not exist the valuable part of the provided generating capacity of the new power plant would, in an extreme case, be determined by the generating capacity at our disposal in peak periods, i.e. in winter. In the meantime the valuable capacity would fall between the generating capacity at our disposal in winter and the average generating capacity.

In most cases — for instance in our country — we therefore may consider that the valuable capacity of the new power plant is the average of the provided capacity if we have not to reckon with non preliminaried outages. Thus the maintenance reserve surplus in the system $\Delta N_M'$ is, e.g. the average of the maintained generating capacity of the new power plant.

### 4-2.B. *The effect of breakdowns and of consumers demand increases. Operating reserves.*

Apart from the provided temporary generating capacity shortages of power plants we must also reckon with unexpected outages: causes may be breakdowns of certain equipments, the change of out-of-door temperature, in the case of hydro plants fluctuation in the run of water etc. To the above we must add the unexpected increase of the consumers' demands in view of the fact that its effect is of similar significance.

In order to outweigh the unexpected capacity shortages we must augment the operating reserves of the power plant system this operating reserve increase reduces the valuable capacity of the power plant, according to previous markings by $\Delta N$...

For the determination of the reserve surplus to be kept due to the new power plant, we seek a well defined method to calculate the operating reserves of the whole existing power plant system and subsequently we examine how the value of the operating reserves changes due to the introduction of the new power plant. This well defined method is *the calculation of the economical operating reserve*. We shall first explain the calculation applied to the analysis concerning *the effect of breakdowns*.

Should we introduce only as much generating capacity into the co-operating power plant system as required for complying with the highest load and just suited, in addition, for taking scheduled maintenance into account, every unexpected capacity shortage would appear in the form of a power restriction, provided the shortage occured in the peak hour of daily load. This restriction means a financial loss for consumers resulting from the shortage in production. The extent of restrictions decreases if we keep reserves in the power plant system. By increasing reserves this decrease will, at the beginning, by very rapid and later gradually slower. *An increase of reserves means an increase of investment costs of the power plant*, yearly costs deriving from installing the reserves increase in fair proportion with the extent of reserves. *The condition of the economical choice of operating reserves is to ensure that the sum of the twofold cost be as small as possible*. Reserves fixed in this manner are economical operating reserves.

The applications of a *probability calculation* is an obvious means for examining losses deriving from breakdowns. In the case of a power plant consisting of a comparatively small number of machine units we may apply *Bernoulli's probability distribution* for the definition of shortages.

while, in the case of a greater number of machines the application of a *normal distribution* may cause only a negligible deviation 3,4 5. With regard to the fact that the application of a normal distribution is incomparably easier from the technical stand-point, we propose the application of the method of normal distribution in the case of a power plant system consisting of 50-100 or more machines.

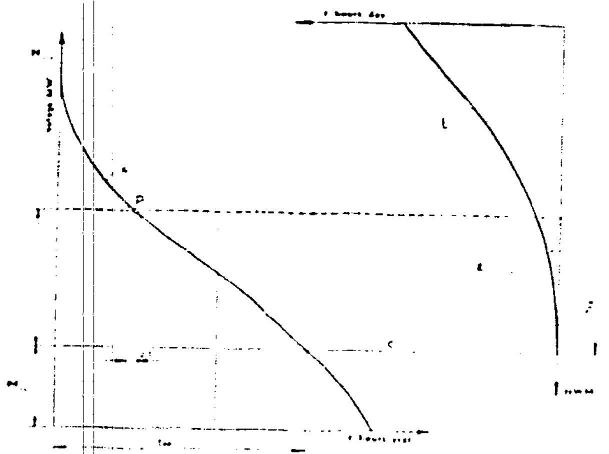
DETERMINATION OF THE INDUSTRIAL RESTRICTIONS DUE TO BREAKDOWNS WITH DIFFERENT RESERVE CAPACITIES

FIG. 2

If the unexpected shortage is greater than the difference between the generating capacity at our disposal and the existing load, consumers' restriction follows. The time of the restriction is at first the peak-load period and the extent of it is determined by the form of peak-load-time diagram.

Generally the course of the load diagram's peak does not differ essentially in the various seasons of the year and therefore in order to simplify calculations we may reckon with an average peak course curve *b*, figure 2.

*Consequently the calculation of consumer restrictions is shown in figure 2.*

Let us presume operating reserve value $N_{op}$ and examine the extent of consumer restriction in connection with this reserve. For this end we draw the duration diagram of peak load — turned upside down — in a way that the peak of the diagram should be on line c fixed by reserve $N_{op}$ curve b . Forthwith let us choose a time-band $\Delta t$ hours/ year belonging to a point *P* of the shortage duration diagram. Let us presume that within this time-band the amount of shortage is a permanent value $N_{hi} - N_{op}$ in which $N_{hi}$ means the shortage and $N_{op}$ the reserve. Should this loss last throughout a day t 24 hours we shall at one occasion cut the load peak in compliance with value $N_{hi} - N_{op}$. The striped area on the figure shows the lost power E [illegible]. If restriction $N_{hi}-N_{op}$ does not last for a day but for $\Delta t$ hours the extent of restrictions is

$$\frac{\Delta t}{24} \cdot E_{\ldots} \quad \text{MWh year}$$

Applying the same method on a $\Delta t$ band chosen anywhere else, and summing up restrictions belonging to every band, we shall get, in case of the supposed $N_{op}$ reserve: the value of restrictions to be expected per year. Performing the same calculation referring to different $N_{op}$ reserves we shall get the value restrictions in the function of reserve.

If we know the average loss caused to consumers by 1 kWh interruption we may with a simple calculation obtain the annual financial value caused by consumer restriction in the function of the operating reserve. curve *K*, figure 3. K' is the differential quotient curve .

The yearly loss resulting from restrictions may obviously be reduced by increasing reserves in the system. The annual cost caused by the installing of reserves may be calculated easily from the fixed costs of the investment, and from the change in the current cost of the cooperating power plant system due to the installed reserve chapter 3 . Its value is indicated by line *a* on figure 3. a' is the differential quotient .

The amount of the economical operating reserve may be found where the loss caused by consumers restriction curve *K*, figure 3 and the cost of the installed reserve curve *a* gives a minimum, thus when the differential quotients of the two curves are equal, but of different signs. $N_{op.optim}$ figure 3.

In the course of the examination we have, so far, considered the pre-estimated *value of network load* not as a probable, but as an actual value. If we take into account, in compliance with facts, also the uncertainty of pre-estimates the value of $N_{op.optim}$ will increase.

### 4-2.C. *Determination of the additional operating reserve.*

In the course of the above statements we have succeeded in plotting the duration curve curve *a*, figure 2 of the generating capacity shortages of the system; at present we seek the duration curve of shortages concerning the power plant system supplemented by the new power plant. If the shortages of the new power plant are of normal distribution the surplus of shortage may be calculated equally mathematically, thus directly. In the majority of cases, however, the shortages of the new power plant cannot be calculated on the basis of a normal distribution, as the number of its machine units is small In this case the unexpected shortage resulting from machine breakdowns in the new power plant may be calculated on the basis of Bernoulli's probability distribution.

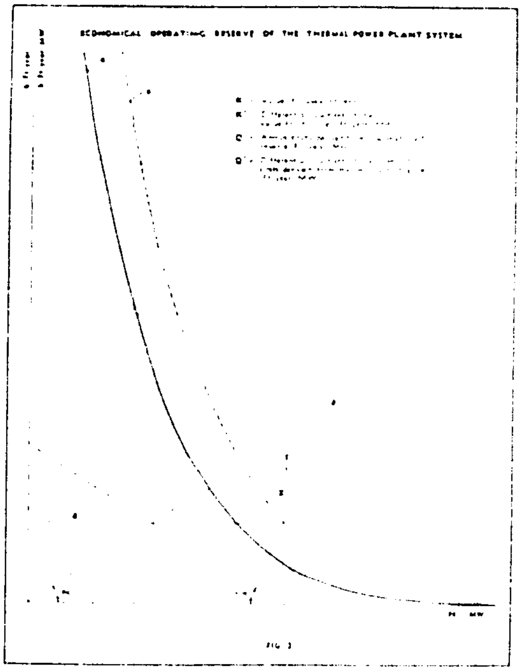

FIG. 3

As an example we introduce a new condensating power plant, consisting of two boilers and two machines into the system. Calculated on the basis of Bernoulli's probability distribution the shortage duration diagramm of the new power plant is shown on figure 4. One con see that the probable, simultaneous breakdowns of both machines of a condensating power plant consisting of two units is 10 hours per year. the breakdown of one machine will amount to 562 hours per year and in the remaining time of the year, thus during 8188 hours, no machine will be out of operation.

Curve a of figure 5. shows the shortage duration diagram of the existing power plant system worked out previously. As there is equal probability any time for breakdowns of the new power plant and the existing power plant system to coincide, any breakdown value of the existing power plant system may occur in the course of the 8188 hours without breakdowns of the new power plant which we can, when plotting the resultant shortage curve take into account by shrinking the shortage curve containing 8760 hours /curve a, figure 5./ of the power plant system in proportion 8188/8760 hours /curve 1, figure 6./. On the basis of the same principle we shrink the curve a of figure 5. in proportion 562/8760 concerning the loss caused by one machine during 562 hours in a year of the new power plant and sum up the shortages with those of the new power plant referred to one machine /curve 2, figure 6./. We plot the shortage caused by two machines of the new power plant with those of the existing power plant system on the basis of a similar principle. /curve 3, figure 6./.

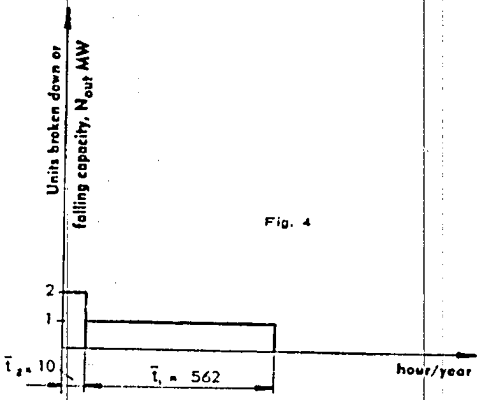

Fig. 4

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As revealed on figure 6. the length of time belonging to any shortage of $N$ generating capacity

$$t = t_1 + t_2 + t_3 \text{ hour/year}$$
$$t_1 = t'_1 \;.\; 8188/8760$$
$$t_2 = t'_2 \;.\; 562/8760$$
$$t_3 = t'_3 \;.\; 10/8760$$

the periods $t'_1$, $t'_2$, $t'_3$ may be read on the shortage duration diagram /curve *a* of figure 5./ of the existing system. The difference between the resultant new shortage duration curve and the duration curve of the existing system is

$$\Delta t = t - t'_1 \text{ hours/year}$$

By determining the amount $\Delta t$ for every shortage $N_{out}$ we obtain the new, resultant duration curve /curve b. figure 5./.

Our task is now to make a calculation concerning the power supply restrictions belonging to the additional shortage periods and concerning consumer losses respectively. Essentially the calculation may be done in the manner shown figure 2, with the difference that, instead of the shortage duration diagram of the system, we make a use of the duration curve of the additional shortages caused by the new power plant /$\Delta t = f/N_{out}/$. This is how we can calculate in the case of different $N_{out}$ operating

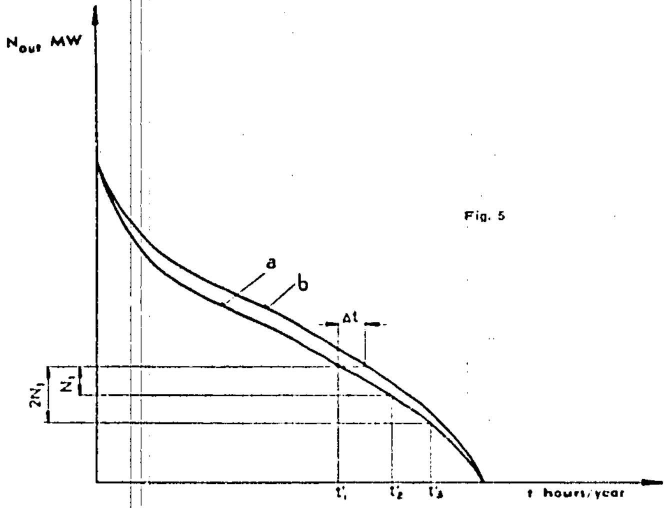

Fig. 5

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reserve the loss surplus of consumers due to the additional shortage and from this the value of the economical operating reserve surplus.

4-3. *The valuable capacity of a new condensating power plant.*

The valuable capacity of a new condensating power plant may be established on the basis of the above statements.

The detailed elaboration of all these calculations for the case of the enlargement of a power plant system of our country with a condensating power plant consisting of 4 × 50 MW turbine generators, has given the following results:

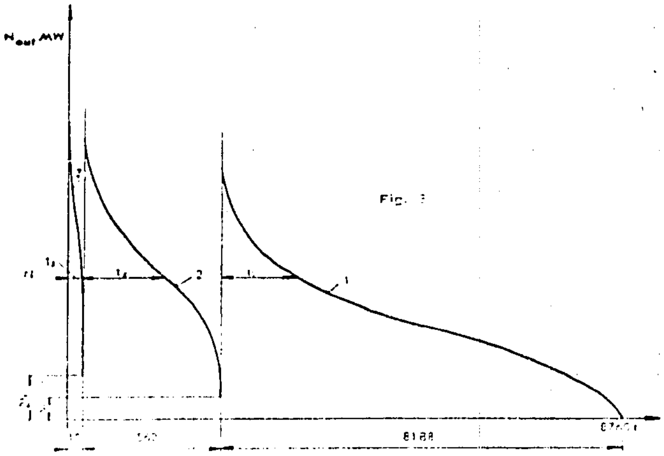

Fig. 3

(the scale of the sketch is not right)

| | | | |
|---|---|---|---|
| The installed capacity of the new power plant | $N_{I,cond}$ | = | 200 MW |
| Additional maintenance reserve | $N_{M,cond}$ | = | 17.4 " |
| Additional operating reserve | $N_{op,cond}$ | = | 12.9 " |
| Average generating capacity decrease due to the change in the temperature of cooling water | $N_{ctr}$ | = | 1.0 " |
| Self consumption | $N_{t,cond}$ | = | 17.1 " |
| valuable capacity | $N_{v,cond}$ | = | 151.6 MW |

thus 75.8% of the installed generating capacity.

### 4-4. *The valuable capacity of the new power plants chaning their capacity according to seasons.*

Additional operating reserve due to a new power plant of non-condensating type, must not only be kept on account of breakdowns of the new power plant, but also owing to other reasons. This is characteristic of a run-of-stream plant in the case of which the capacity of the hydro plant varies depending on the run of water. The situation is similar in connection with heating power plants where the capacity depends on the momentary heat demand determined by the out-of-door temperature.

Knowing the *statistical data* relating to the run of water or to the out-of-door temperature for a longer period of time, we may establish the effect of these weather factors on the generating capacity of the power plant, or, we may also state, *the probable value of the generating capacity decrease of power plants resulting from the run of water, the weather or other external causes.* The shortage duration curve of a new power plant under examination, obtained in this manner, may essentially be handled in a similar way as the duration curve of breakdowns (for instance figure 2.) and similarly to the case of breakdowns we shall obtain another operating reserve requirement which, as compared to the installed generating capacity of the new power plant will further reduce the valuable capacity of the new power plant.

The extension of the idea and calculation concerning the valuable capacity is extremely useful, as it offers an opportunity to valuate the generating capacity of hydro plants, the capacity of which varies extremely whereby so far only estimates were possible and thus contradictory and considerably fluctuating opinions have developed. In the same manner we have an opportunity to valuate the generating capacity of heating power plants as a result of which we obtain important help for the economical election of their type.

### 4-4.A. *The valuable capacity of new run-of-stream power plant.*

Hitherto the discharge of the turbines of a run-of-stream plant was chosen sparily, that means the power plant was erected for a high utilisation referred to the discharge. This tendency cannot, however, be considered correct from the view-point of power economy, as in consequence of it, during a considerable part of the year, a more or less large quantity of water flow will be unused. According to the new trend the discharge is more and more determined in the direction of lower durations. As result of this general, and from the stand-point of coal economy very correct, development the run-of-stream plants stand, in a considerable part of the year with a smaller, often a perceptibly smaller generating capacity at the disposal of the network than their installed generating capacity. We reveal calculations concerning the valuation of the generating capacity of a planned run-of-stream plant of our country, without a reservoir, i.e. without a possibility of daily regulations. Our first task is to establish what generating capacity variation we may expect from the run-of-stream plant.

The generating capacity values, resulting from different waterflows and in connection with different grades of development of the run-of-stream plant, are shown on figure 7 and determined by the well-known calculations methods. It becomes apparent that the limits of variation in generating capacity increase with the increase of the extent of development of the plant. We may first estimate the development of the examined run-of-stream plant on 2500 $m^3$/sec water flow which corresponds with 38.5% duration. On this basis figure 7. reveals now the generating capacity of the plant in connection with every water flow.

We may with the help of statistical data referring to the water flow of many years determine how much the generating capacity of the run-of-stream plant, built according to the assumed basic data, would have varied in the function of time. Comparing the generating capacity-time curve of different years it was ascertainable, that the generating capacity of the run-of-stream plant varies unsystematically and especially floods may cause great and suddon generating capacity shortages. The average generating capacity duration diagram may be plotted on the basis of data relating to the generating capacity-time diagrams /figure 8./.

If the run-of, or the generating capacity forecast connected with it respectively could be carried out for an adequately long period of time, the maintenance time of thermal power plants could be disposed of in a way to ensure that in times, when the generating capacity of the run-of-stream plant is missed, proportionately less steam power plant should be under maintenance, and thus the varying generating capacity could be utilised by the system with an average value as a provided generating capacity /point 421/. It must be noted that this possibility exists only as long as the joint generating capacity of the run-of-stream plants is small as compared to the power plant system, the decisive majority of which consists of condensating power plants. Detailed examinations have, however, revealed that in given cases variations in the water flow cannot be estimated for more than 3-4 days in advance, which is too short a time as to be adapted to the maintenance schedule of steam power plants. Let us therefore carry out examinations primarily on the basis of the supposition that the generating capacity of the run-of-stream plant can by no means be indicated in advance, a fact which slightly reduces the valuability and so the expected real value will be greater.

The plotted generating capacity duration curve /figure 8./ may also be considered as the curve of unexpected capacity shortages, occuring in comparison to the installed generating capacity of the run-of-stream plant, the time of the outages of which is equally probable at any time of the examined period!. Reserves must be kept for eliminating to an economic extent the unexpected generating capacity shortages of the run-of-stream plant, in other words the generating capacity must be devaluated. Even so far as a reserve, the economical operating reserve existed in the cooperating power plant system to render breakdowns ineffective to an economical extent. We would, obviously, falsify the run-of-stream plant's valuation, were we to use the same reserve for rendering ineffective the shortages of the run-of-stream plant system. It may occur, on the other hand that, despite this the operating reserve of the power system is for the time being unused, and may therefore be used for invalidating the generating capacity shortage — due to the water flow — of the run-of-stream plant, without affecting the security of the steam power plants. The reserve kept for the run-of-stream power plant may, in the same manner, from time to time, come to the help of the steam power plants. We are finally seeking the operating reserve which invalitades to an economic extent the generating capacity shortages — due to the water flow — of the run-of-stream plant and which does not affect the reserve conditions of the existing system. This may be attained by making a calculation concerning the economical operating reserve of the power plant system supplemented by the run-of-stream plant with the help of the above, well defined method.

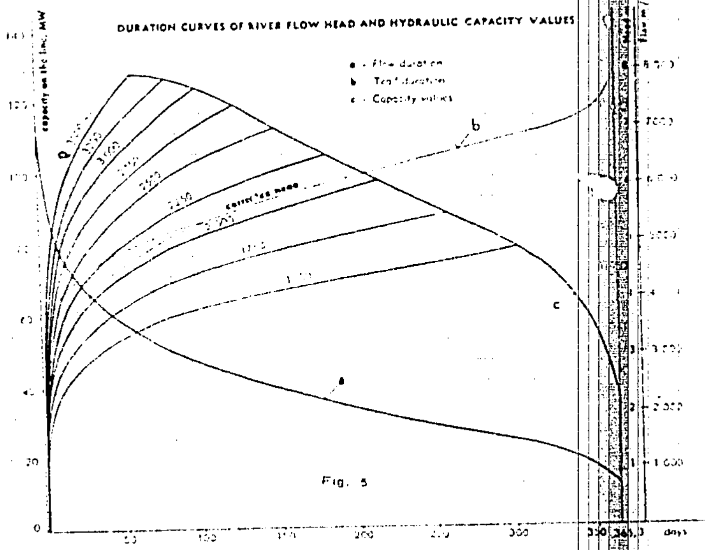
DURATION CURVES OF RIVER FLOW HEAD AND HYDRAULIC CAPACITY VALUES

Fig. 5

Our first task is *to examine the coinciding probability of shortages that occur in the stream power plants and in the new run-of-stream plant,* i.e. to combine the plotting of the shortage duration curves of the steam power plant system and the run-of-stream plant. While plotting we must take into account that, according to our supposition, no time has been indicated as to the occurrence of shortages neither in the power plant system nor in the run-of-stream plant as they may happen in both cases in any time. Consequently the plotting must be performed by dividing both shortage duration curves to equal time-bands and by determining all possible combinations — supposing permanent shortages during these time-bands, furthermore arranging these according to their amount *we shall obtain the joint shortage duration curves of the steam power plants and the run-of-stream plant* (figure 9.).

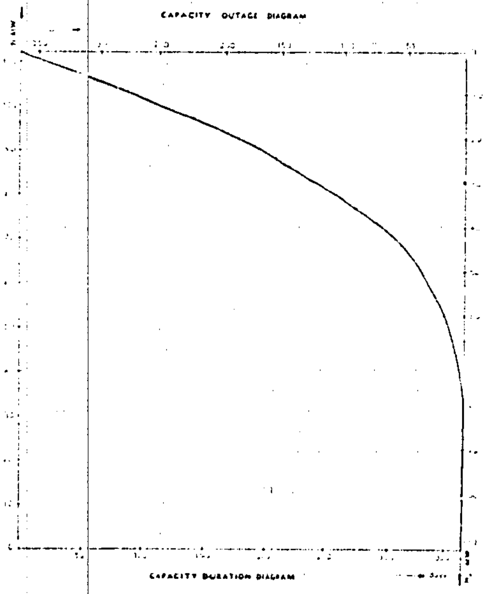

FIG. 8

We shall than, as done by establishing the operating reserve of the cooperating steam power plant system, determine the consumer restriction, as depicted by the graph shown on figure 2, the people's economy loss occuring as a consequence of the restriction and the differential curve of the loss curve. With the graph shown on figure 3, we shall herefrom obtain the operating reserve /$N'_{op.econ}$/ of the system supplemented with the run-of-stream plant. In the knowledge of the economical operating reserve in the system before the introduction of the run-of-stream plant /$N_{op.econ}$/ the additional operating reserve is

$$\Delta N_{op.w} = N'_{op.econ} - N_{op.econ} \quad \text{MW}$$

This is the economical operating reserve which must be kept as a surplus in the system after the introduction of the run-of-stream plant if we valuated the capacity of the run-of-stream plant with its installed generating capacity. We may also express our result by stating that the generating capacity of the run-of-stream plant to be provided economically, is smaller than its installed capacity with regard to the run-of by the economical operating reserve surplus.

Now we can make a calculation concerning the valuable capacity of the run-of-stream plant:

$$N_{v.w} = N_{i.w} - \Delta N_{m.w} - \Delta N_{op.w} - N_{e.w} \quad \text{MW}$$

In principle the maintenance reserve $\Delta N_{m.w}$ would be calculated in a similar manner as in the case of a condensating power plant. Its value is, however, zero as the maintenance of a run-of-stream plant may be carried out during the season of low waters. It must be noted that by this conception we deviate slightly, although correctly, from the, as compared to reality, too severe supposition that we are quite unable to estimate the run-of in advance.

We have, in the course of the above dealt in details with the operating reserve demand $\Delta N_{op.w}$ for the elimination of capacity shortages, due to the run-of to an economic extent. Operating reserves are, however, also needed in excess of this — as well as in the case of condensating steam power plants — for the economical elimination of shortages due to machine breakdowns and to unexpected consumption increases. It is not entirely correct to count and sum up separately the operating reserve surplus needed for two reasons. Instead we should make a joint calculus. The fault committed is, however unimportant.

In the course of previous calculations relating to the valuable capacity of the run-of-stream plant and the operating reserve to be kept due to run-of respectively, we have supposed that the possibility of generating capacity shortages occuring in consequence of the run-of, is independent from seasons and cannot be estimated in advance. We shall obtain a result approaching truth even better if we take into consideration that the generating capacity variation of the run-of-stream plant, although it cannot be estimated for a lengthy period of time in advance, is however, of different nature in different seasons.

We have therefore, despite the impossibility of estimating the run-of exactly in advance, a certain knowledge concerning the probable values of the run-of. The utilisation of these data reduces the operating reserve required, owing to variation in the run-of, and respectively, increases the valuable capacity of the run-of-stream plant. When making calculations concerning the operating reserve demands we can take into account data relating to the probabilitiy of the run-of, by plotting from the generating capacity-time-diagram, a generating capacity duration diagram divided into seasons or months and carry out our previously revealed calculation concerning the economical operating reserve surplus separately, relating to these seasons or months. By this we shall obtain different reserve surpluses concerning the run-of-stream plant for seasons or months and thus we get the capacity to be provided economically. The value of yearly resultant generating capacity, to be provided economically, is gained with the help of taking the mean value of the basis of the same conception which we have followed inconnection with the valuation of the capacity varying according to schedule /point 421./. We shall obviously reach an equal result if we establish the

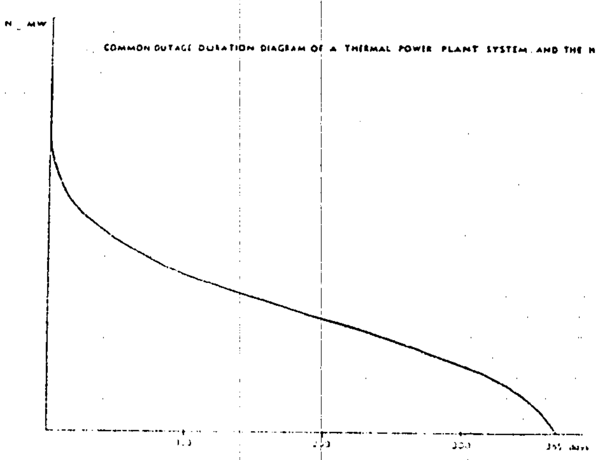

FIG. 9

mean value of generating capacity values to be provided per seasons. per months, or by determining the mean value of the economical operating reserve surplus.

The effect of the run-of-stream plant's self-consumption /$N_{ö}$/ on the decrease of the valuable capacity may, in principle, be calculated in a similar manner as in the case of a condensating heat power plant /point 43./ The numerical value is naturally influenced fundamentally by the fact that while in the case of an up-to-date condensating power plant self-consumption is at full load about 8-9%, the same does not even attain 1.5% in the case of a run-of-stream plant.

In the course of the detailed elaboration of all these calculations performed in connection with the planning of the run-of-stream plant referred to of our country obtained the following results:

| | |
|---|---|
| The installed generating capacity of the run-of-stream plant $N_{i}$ . . . . . . . . . . . . . . . . . . . . . . . | 112 MW |
| Operating reserve required owing to the variation of run-of in yearly average . . . . . . . . . . . . | 25.7 MW |
| Yearly average operating reserve required due to breakdowns and unforeseen increase of consumption . . . . . . . . . . . . . . . . . . . . . . . . . . . . | 3.2 " |
| Self-consumption $N_{ö}$ . . . . . . . . . . . . . . . . . . . . . . . | 1.3 " |
| Valuable capacity $N_{é}$ . . . . . . . . . . . . . . . . . . . . . | 81.8 MW |

thus 73% of the installed generating capacity. The equality factor correlated with the condensating power plant:

$$e_{é} = \frac{73}{75.8} = 0.963$$

Thus we obtain the astonishing result that the examined run-of-stream plant is practically of the same value as a new condensating heat power plant.

4.4.B. *The valuable capacity of a heat supplying power plant.*

The valuable capacity of any type of power plant — industrial heat supplying power plant, heating power plant, storage power plant — may be established in a similar way than the valuable capacity of a condensating power plant and a run-of-stream plant. On account of the importance of gained results we also reveal the result of an examination carried out in connection with a heating power plant.

Figure 10 shows the schematic heat balance diagram of the heating power plant. The characteristic feature of the plant is the fact that the boiler capacity just unused for heating is being used for generating power with condensation. The boiler capacity of the power plant is determined in any way that in the extreme cold weather all steam is used for heating and the condensating part of the extraction turbines get only the, from the technological view-point, smallest possible amount of steam. It must be noted that a heating power plant equipped with extraction turbines may be established on the basis of several other heat balances too. The valuation is, however, not affected decisively by the heat balance, but by the energetical structure /the type of back pressure or extraction turbine/.

The installed generating capacity of the heating power plant equals to that of a condensating power plant of similar boiler capacity, since the power plant operates as a pure condensating power plant when heating stops. As compared to the installed generating capacity the valuable capacity is reduced by self-consumption /point 43/ by maintenance reserve /point 421/, by operating reserve to be kept owing to machine breakdowns /point 422/ and finally by the operating reserve to be kept on account of the generating capacity varying in the function of the out-of-door temperature /point 44/. When heat de-

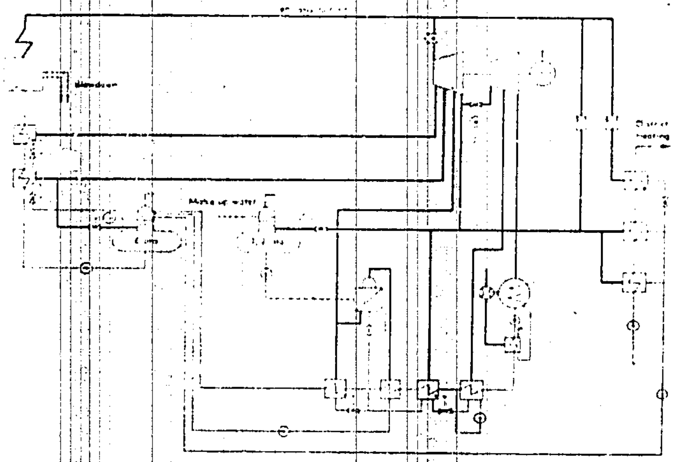

FIG. 10

mands are greater, i.e. when it is colder, the generating capacity of the heating power plant is obviously smaller as it can expand less and less steam to condensation. By this the generating capacity varies in an unexpected manner on account of the out-of-door temperature unknown in advance. It decreases as compared to the installed capacity and thus we face a similar effect as in the case of the run-of-stream plant in connection with the effect of the variation of the run-of- which could not be estimated in advance.

Counting all devaluating effects in connection with the heating power plant in the given case we have stated that the valuable capacity amounts to 65,1% of the installed generating capacity and thus its equality factor concerning a condensating power plant is:

$$c_{heat} = \frac{65,1}{75,8} = 0,858$$

## 5. SUMMARY

The displayed calculation methods are further facilities for the economical planning and running of power plant systems. From the results of actually performed calculations we may draw the following important conclusions:

a. A run-of-stream plant without storage, for instance the economical hydro plant to be developed on a Hungarian river, despite the fact that its generating capacity is subject to substancial fluctuations owing to variation in the run-of is however, from the view-point of valuable capacity nearly equal to a thermal plant having the same installed capacity as the run-of-stream plant. This result supports and strengthens even more than before the well-known tendency according to which hydro plants are developed in increasing number and for increasing discharges.

b. Town-heating power plants the heating turbines of which are suited for producing condensation power too, or which possess, apart from heating turbines condensating turbines too, are hardly worth less than some pure condensating power plants of nominally the same size and will therefore play a particularly important role concurrently with the development of town-heating systems in supplying towns and even consumer districts with electric power.

The application of calculation methods in connections with different power plant systems will presumably raise problems which will lead to a further development of the conceptions we have dealt with.

Thus a particularly careful further examination is required by a further analysis concerning the consumer loss resulting from the compulsory interruption of the electric power supply and it must be noted that an interruption of supply to consumers in not only an economical question but also a social and cultural one. A correct statement concerning the consumer loss influences the comparable capacity of different power plant types to a smaller extent while it influences the absolute value of reserves considerably. A further detailed analysis is also required in connection with a statement concerning the probability of the coincidence of the industrial steam supply and the electric load of the network which will lead to the valuation of the capacity of industrial power plants.

[redacted]

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Titulo 3
Assunto 3.1

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro — 1954

SCHLATTNER (J.)
Hungria

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# COAL DISTILLATION IN CONNECTION WITH POWER STATIONS

By JENŐ SCHLATTNER

HUNGARIAN NATIONAL COMMITTEE

50% of the coal reserve of Hungary consists of brown coal, 38% of lignite. Our more recent and older brown coals, ranging from Pontian lignite to brown coals deriving from the oligocene and eocene periods account for a total of 88% of our total coal reserve. The low-temperature distillation of brown coal, as well as its practical use in connection with high-temperature distillation has a past of 25 years in our country.

In power generation the main purpose in view has generally been the firing of our coals of lower quality. As however the development in the production of coke, semi-coke and brigetted coke has been slow, means had to be sought to enable the production of tar, as an important basic material of the organic chemical industry, to be ensured in other ways also. What appears the most natural method, is cooperation with power production and with industrial furnaces, particularly as the quantity of coal burnt on chain and travelling grates in Hungary is quite considerable and burning of its tar content greatly affects the chemical industry by the loss of the cresol, xylenol and impregnating oil otherwise obtainable from it. There is a possibility already to recover with a yield of 50 to 60% this quantity of tar that is burned on stokers mentioned above.

About 25% of this quantity of coal have a tar content exceeding 10%, and accordingly its treatment is undoubtedly lucrative. The quantity of tar recoverable from this quantity of fuel is considerable and therefore a device suitable for the recovery of the tar contained in non-caking coals burnt in industrial furnaces equipped with chain and travelling grates may expect to meet great interest in our country.

Efforts have been made for a long time to find means for carrying out the distillation, in some way, of coals possessing a high content of tar before its combustion, and for obtaining the tar so recovered as a basic material for the chemical industry. This purpose may be achieved in various ways. One way consists in constructing a distilling plant, of the products of which the semi-coke is, after suitable cooling, treatment and storage, handed over to the stokers. Another way is to employ total gasification and after recovering the tar, hand over the gas for firing purposes. A third method is to build the distilling apparatus immediately in front of the furnace, and to transfer the incandescent semi-coke to the grate. The most perfect recovery of the products is ensured by the first-named, the best utilisation of heat by the last-named method. As to total gasification, it will, in the present case, owing to the fact that in order to recover the tar the whole quantity of gas would have to be cooled down, remain behind in thermal efficiency when compared to the efficiency of up-to-date travelling-grates. Another drawback of gas producers consists in that the majority of equipments are only suitable for treating coal consisting of lumps of substantial size, and containing only a small proportion of coal dust. On the other hand, to equip a plant specially for treating small coal (Winkler) is only rational on a very large scala.

The distillating chamber built in front of the grates (Pontsch) is a device, which will already take us one step further, because although the coal placed into it in great chickness and the uniform flow of the heating gases can only be ensured in the case of coal of uniform grain size and devoid of any content of coal dust, it will nevertheless ensure that in consequence of partial distillation a smaller quantity of gas has to be cooled for the sake of recovering the tar, whilst, on the other hand, the coke, or semi-coke will, in incandescent condition, be passed immediately to the grate for the purpose of being burnt and therefore the heat it carries along with itself will be usefully applied.

By means of the apparatus to be described in what follows, the problem has been solved in such a manner, that the non-caking small coal (0 to 15 mm) to be burnt on up-to-date travelling grates flows through the carbonizing chamber in relatively thin layers, the uniform passage of the hot flue gases through it is ensured in such a manner, that in those places, where owing to a lower content of fines, the resistance to transflow is smaller, resistances are inserted into the path of flow of the gases, thus ensuring that the flow will pass through the parts possessing a higher content of fines also and accordingly presenting a greater resistance to the flow. Another characteristic feature of the arrangement consists in that a part of the heat is imparted to the coal by means of radiation, thereby making-up for that quantity of heat which, owing to less perfect heat transfer, cannot be transmitted by means of the scavenging gas flowing through a relatively thin layer of coal. For this purpose, the apparatus is built on the firing chamber /see figure/ in such a manner that the coal is conveyed towards the grate in a relatively thin layer between the wall equipped with louvres forming one boundary wall of the furnace and a similar wall arranged opposite to the former on the outside, during which passage it will be heated to the temperature of distillation /500°C/ and finally is burnt on the grate.

The direct incandescent flue gases of the furnace can also be utilised for heating the equipment. The flue gases of the boiler furnace have a substantial content /7 to 8%/ of oxygen, accordingly it has been found preferable, in the interests of preserving the products of distillation, to protect them against combustion by means of a screen, immediately in front of the distillating chamber, formed by the gas burnt with a nearly theoretical quantity of air. This flame screen, will at the same time, transmit a part of the heat directly to the coal by the radiation of the gas. By this the quantity of scavenging gas — employed for conveying heat — can be decreased and so the dilution of the distillation gases will be less.

The distilling equipment actually constructed, as shown on the accompanying illustration, was built in front of the chain-grate of old type having a grate surface of 5 m² of a steam boiler of 146,76 m² heating surface. The boiler had a superheater with a surface of 36,00 m². Neither pre-heating of feedwater or of air nor forced draft is employed.

The data of the test made with the equipment are the following:

Duration of test 7 hours 30 minutes

| | | |
|---|---|---|
| Steam pressure | 5,3 atm gauge pressure | |
| Superheat temperature | 360°C | |
| Feedwater " | 23 " | |
| Flue gas " | 320 " | |
| Composition of flue gases | $CO_2$ | 10,6% |
| | $O_2$ | 6,4% |
| | CO | 0,4% |
| Total feedwater | 24.000 kg | |
| " coal consumption | 6.570 "/8-20 mm/ | |
| " residue /ashes and clinker, dry/ | 1.020 " | |
| " riddlings, dry | 156 " | |

Ultimate analysis of coal:

| | |
|---|---|
| Moisture | 15,63% |
| Ash | 15,46% |
| C | 48,25% |
| H | 4,13% |
| O | 11,99% |
| N | 1,00% |
| S | 4,14% |
| Calorific value, gross | 5090 cal. |
| " " , net | 4774 " |

Fischer analysis of coal:

| | |
|---|---|
| Semi-coke | 62,95% |
| Tar | 10,40% |
| Moisture + liquor | 19,00% |
| Gas + loss | 7,65% |
| Combustible part in residue | 18,7 % |
| " " " riddlings | 55,2 % |
| Coal consumption par hour | 875 kg |
| Steam production par hour | 3220 " |
| Boiler duty | 22 kg/m2/h |
| Rough evaporation | 3,68% |
| Heat transmitted to 1 kg of steam | 740 cal. |

Tar recovery equipment:

| | |
|---|---|
| Temperature entering tar recovery app. | 192°C |
| " " surface cooler | 118°C |
| " leaving " " | 57°C |
| Pressure entering tar recovery app. | -25 mm w.g. |
| " leaving surface cooler | -80 " |
| " " fan | + 35 " |

| | | |
|---|---|---|
| Composition of gas: | $CO_2 + H_2S$ | 10,2% |
| | $C_nH_m$ | 0,4% |
| | $O_2$ | 4,2% |
| | $CO$ | 4,5% |
| | $H_2$ | 2,4% |
| | $CH_4$ | 3,0% |
| | $C_2H_6$ | 1,0% |
| | $N_2$ | 74,3% |

| | |
|---|---|
| Calorific value of gas | 746 cal/n.m.3 |
| Weight per unit volume | 1.293 kg/ |
| Content of vapour of gas drawn off | 0,342 " " |
| " " returned gas | 0,167 " " |
| Quantity of dry gas per hour | 940 " |
| " gas and water vapour drawn off/h | 1335 " |
| Mean specific heat of gas and water vapour drawn off | 0,3418 |
| Quantity of returned gas and water vapour/h | 1133 " |
| Mean specific heat of returned gas and water vapour | 0,3346 |
| Total quantity of anhydrous tar produced | 450 kg |
| Quantity of tar per hour | 60 " |
| " " as a percentage of coal | 6,90% |
| " " as percentage of theoretical quantity of tar | 66% |
| " " returned with gas per hour | 0,4 kg |

| | |
|---|---|
| Coal dust drawn off with gas per hour | 5,3 kg |
| Water vapour condensed | 164,0 " |

Heat balance of equipment:

| | | |
|---|---|---|
| Heat transmitted to steam | 2720 cal. | 57,0% |
| Cal. value of tar | 620 " | 13,0% |
| Heat lost in cooling equipment | 110 " | 2,3% |
| Stack loss | 740 " | 15,5% |
| Unburnt flue gas | 90 " | 1,9% |
| " parts in residue | 230 " | 4,8% |
| " " " riddlings | 90 " | 1,9% |
| " " " coal-dust drawn off with gases | 30 " | 0,6% |
| Other losses | 144 " | 3,0% |
| Calorific value of coal, net | 4774 cal/kg | 100,0% |

$$\text{Boiler efficiency} = \frac{2720}{4774-620} = 65.7\%$$

The expression figuring in the denominator is the calorific value of the coal less the calorific value of the tar extracted.

A boiler and grate of exactly similar design, but without distilling equipment worked with the same efficiency whilst producing 2300 kg of steam per hour. If the tar cooler is used for pre-heating the air of combustion, the efficiency can be improved still further.

The equipment described has also proved suitable for burning by its aid combustible slates possessing high content of ash, which was not possible to burn in boilers not fitted with such an equipment because within two hours the fire went out on the grate. With the equipment described it was possible to obtain with this kind of coal a boiler duty of 2100 kg of steam per hour, which approximates the duty obtained on the boiler not fitted with the equipment when burning coal of good quality having a calorific value of 5000 cal/kg.

In our coals possessing a high content of sulphur, a substantial part of the sulphur can be recovered from the gases, a fact which is not negligible from the point of view of preserving the un-impaired condition of the boiler body, and the purity of the ambient air.

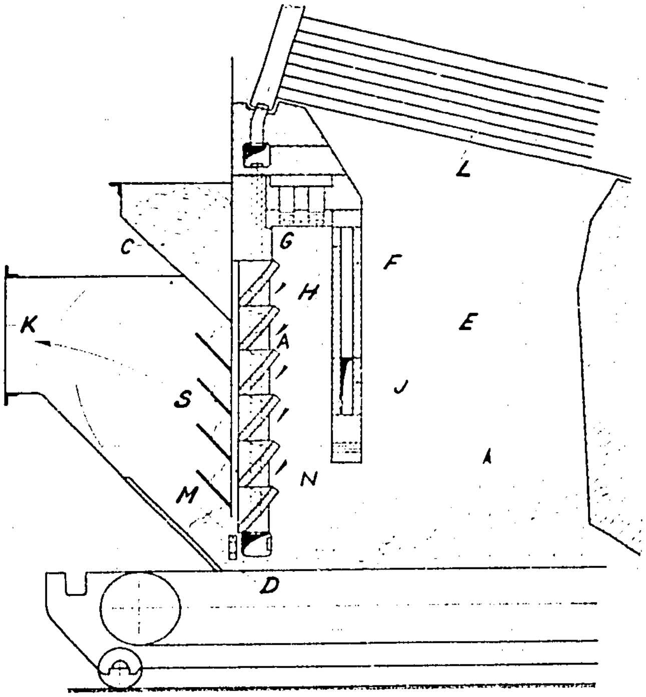

Fig. 1

The coal is conveyed from the hopper "C" towards the travelling-grate "D" between the refractory wall "A" fitted with louvres and the wall "S" equipped with adjustable members. For heating the distilling chamber, it is also possible to employ the hot combustion gases of the combustion chamber "E", but in order to protect the products of distillation, it is preferable to make use for this purpose of the heat of the flame curtain "H" formed by the gas the combustion of wich, with a scarcity of air, is effected by means of the burner "G" in the space closed-off by the wall "F". The duct "I" serves for the admission of the air required for the combustion of the gas. The volatile products of distillation mixed with the heating gases are removed through the funnel "K" into the tar recovery apparatus. The solid product burnt on the grate is used for heating the boiler body "L". The water-cooled gate "M" serves for adjusting the thickness of fire. The system of tubes "N" connected into the boiler circulation serve for supporting the refractory wall "A".

## SUMMARY

The author describes one of the constructional forms of an equipment suitable for realising mutual cooperation between power generation and the chemical industry. This equipment makes possible the distillation of coals of high tar content immediately before burning them. The equipment is also suitable for the efficient combustion of fuels with high moisture or ash content, which otherwise would take fire on travelling grates with great difficulty only, or not at all.

## RÉSUMÉ

L'auteur décrit l'une des formes constructionnelles d'un équipement capable de réaliser une coopération mutuelle entre la génération d'énergie et l'industrie chimique. Cet équipement rend possible la distillation de charbons de haute teneur en goudron, immédiatement avant leur combustion. Il convient également pour la bonne combustion de combustibles d'une haute teneur en humidité et en cendre qui, autrement, ne prendraient feu sur des grilles mobiles qu'avec grande difficulté ou ne prendraient même pas feu.

## RESUMO

O autor descreve as formas relativas à construção de um equipamento apropriado para realizar uma cooperação mútua entre a geração de energia e a indústria química. Tal equipamento torna possivel a destilação de carvão de alto conteúdo de alcatrão imediatamente antes da sua combustão. O equipamento é, também, apropriado à eficiente combustão de combustiveis com alta humidade ou conteúdo de cinza, que de outro modo se incendiariam com dificuldade sôbre grelhas móveis, ou mesmo não pegariam fogo de modo algum.

CONFERÊNCIA MUNDIAL DA ENERGIA
WORLD POWER CONFERENCE

Título 2
Assunto 2.1.1.

REUNIÃO PARCIAL
SECTIONAL MEETING
Rio de Janeiro – 1954

SEDIJATMO (R.M.)
Indonésia

# THE DESIGN AND CONSTRUCTION OF CAST-IN-PLACE CONCRETE PIPE LINES FOR HIGH PRESSURES, SUITABLE FOR THE TRANSPORT OF WATER OIL OR GAS

By R. M. SEDIJATMO
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## INTRODUCTION

The great advantages of concrete pipes, in general, over steel pipes are, as is well known, the [illegible] durability and in particular the much lower costs of maintenar[illegible]

Hydraulically both k[illegible] pipes have about the same smoothness of surface so that for both [illegible] loss of [illegible] due to frictio[illegible] will be practically the same.

As regards the costs of [illegible]nstruction, these depend to a great extent on local conditions and o[illegible] ratio between the cost of material and the cost of transport.

In Indonesia the situation is such that for heads up to about 70 meters (230 ft) concrete pipes, according to the classic methods, can be constructed at lower costs than steel pipes, though for both kinds of pipes the amounts of steel needed, expressed in tons, are about the same.

This is because the cost of one ton of welded steel pipes mounted into its place is about three times the corresponding cost of reinforcement steel. This again is caused by circumstances which affect the cost of steel pipes unfavourably, namely the much higher cost of transportation of steel pipes reckoned from the factory to the site, and further the higher cost of manipulation and erection.

It is a fact, that for the construction of all-steel pipes we need operators with better skill than for the construction of concrete pipes.

For countries like Indonesia and other technically less developed countries this fact is of great significance. Not less important is the fact, that the lack of good supply-roads to remote or isolated sites is a great handicap for steel pipes and, in general, for pipes consisting of prefabricated pipe sections which are not only heavy but also demand a lot of space during transportation.

Besides all the above factors which make the cost of construction of all-steel pipes high there is in Indonesia with her unfavourable economic condition still another fact, viz. that concrete pipes use more local building materials like gravel, sand and timber for centering, by which a great deal of the erection costs remain in the country, which again means a saving in foreign bills.

Therefore the construction of conduits consisting of pipe sections imported from abroad, is here out of consideration, the more so because the transport over sea of such space-devouring articles means only unnecessary expenditure of foreign bills.

From the foregoing it is obvious that for a country as Indonesia the construction of reinforced concrete pipes for penstocks is very attractive, and indeed it is becoming more and more practice; that is, within the bounds of what is technically allowable.

Finally it should be noted that under the relations and circumstances prevailing in Indonesia it is found in practice that the construction time for cast-in-place reinforced concrete pipes is usually shorter than, and certainly not longer than the corresponding time for all-steel pipes.

Against all the above advantages of reinforced concrete pipes there is the great disadvantage, that reinforced concrete conduits, built according to the classical methods, are only applicable to limited heads (for Indonesia only up to a maximum of 70 m (230 ft) which itself is already beyond the usual practice in America and Europe, where the maximum allowable head is not more than 50 m (164 ft).

## ON THE EXISTING SYSTEMS FOR REINFORCED CONCRETE PIPES

### A. GENERAL REMARKS

With the development of reinforced concrete engineering, especially during the last 30 years, in Europe as well as in America, we have seen a trend towards the production of pipes of reinforced concrete, which besides the cast iron or steel pipes can be used for transport conduit for water.

In the beginning this has been urged primarily by financial and economical considerations; only later on it came out that from the point of view of corrosion the application of reinforced concrete is greatly more preferable over steel, in particular for under-ground sewerage and for drinking water pipes.

In reinforced pipes in general we encounter the difficulty, that the concrete has only a very limited capability of taking up tensile stresses.

When a pipe is under an internal pressure, e.g. water pressure, the pipe walls undergo, as we know, tangential tensile stresses.

Hence from the point of view of statics steel is the most appropriate material for pipes, and it is not rational (again speaking in terms of statics) to use concrete or even reinforced concrete for conduits undergoing fluid pressure. It is indeed a remarkable irony of engineering that a material is used for purposes for which it is pronounced inappropriate.

As is well known, in the calculations for re-inforced concrete structures we start in general from the assumption that concrete is incapable of taking up tensile stresses. We therefore assume that in the tension zone only the steel reinforcement and in the compression zone only the concrete, strengthened or not by the reinforcement present, which take up the stresses which occur in those regions. This allocation of stresses is just what we don't find in reinforced concrete pipes, in particular in penstocks, where due to the internal pressure there occur in the pipe-walls mainly tensile stresses.

This in my opinion is the reason why uptil now reinforced concrete with or without pre-stressing of the concrete, in spite of the fact that in many ways it has superior qualities over steel, cannot compete with that classical material in the application to penstocks for heads beyond 100 m (328 ft).

## B. THE NORMAL TYPE REINFORCED CONCRETE PIPES

As stated before the internal fluid pressure is taken up by the cylinder wall which consists of concrete provided with circumferential reinforcement.

The calculation of the tangential tensile stresses in cylinder walls makes use of the fundamental formula for pipes with internal pressure, viz. the fundamental hoop-tension formula.

Hereby we proceed in two steps.

In the first step we consider the circumferential stresses to be taken up by the concrete together with the circumferential reinforcement, and treating the whole as if it were all concrete. For this purpose the cross-sectional area to be taken into account is the area of the concrete proper increased with n-times the cross-sectional area of steel reinforcement. In Continental practice n is usually taken to be 15.

The tensile stress obtained in this way must be less than the tensile strength of concrete proper.

In central European countries they generally take for this design a safety factor of 2, that means that the calculated tensile stress may be at most one half of the tensile strength of concrete after 28 days' ageing (generally they take an allowable tensile stress of about 10 kg/cm² (137 lbs/in²).

In France and probably also in Anglo-American countries generally they permit a greater allowable stress, somewhere near the breaking tensile strength (about 20 kg/cm² ≈ 274 lbs/in²).

The second step of calculation determines the amount of steel necessary for the reinforcement.

This quantity is calculated under the assumption that the circumferential reinforcement alone (in case the concrete might be cracked due to internal pressure) is able without any help from the concrete to withstand the whole internal pressure. This boils down to the fact, that the amount of steel in the reinforcement is equal to the quantity of steel which would be required for an all-steel pipe.

In some American handbooks certain empirical formula's are applied for finding the required thickness of reinforced concrete pipes.

The wall thickness in inches must, for instance, be equal to the diameter in feet, with a definite minimum thickness.

As a good mixture for concrete is prescribed 1 : 2 : 4 or richer.

The above mentioned concrete pipes are cast-in-place and are preferably provided with contraction-joints at distances of about 40 m (130 ft). Such joints generally tend to tighten under use owing to the action of sediment in the water.

As a matter of fact several concrete penstocks have been built with no contraction-joints, which have cracked more or less but have tightened under use.

Besides circumferential reinforcement we also have longitudinal reinforcement (longitudinal bars). These longitudinal bars, to take care of temperature and shrinkage stresses, should be from 1/4% to 1/2% of the cross-sectional area of the concrete.

From the foregoing we can draw the following important conclusions with regard to normal type reinforced concrete pressure pipes:

a) The concrete cylinder wall of the pipe forms the wall to convey the water. Hence it must be designed to withstand, together with the circumferential reinforcement, the internal water pressure.

b) The wall thickness which is calculated with the hoop-tension formula for internal pressure, is therefore determined by the magnitude of that pressure and hence it is directly depending on it; that means the greater the diameter of the pipe and the greater the internal pressure, the greater the tangential circumferential stresses, and the thicker the concrete-pipe walls must be.

c) Besides the requirements of strength the pipe walls have to satisfy the requirements of water-tightness.

d) The amount of steel for the circular reinforcement equals, roughly, that needed for a normal all-steel penstock with the same diameter and water-pressure (i.e. with the same allowable stresses for the materials).

The extra steel for the longitudinal bars in reinforced concrete pipes is counterbalanced by the extra steel added as rust-allowance in all-steel pipes.

e) For cast-in-place pipes there are no such difficulties as the transportation of space-wasting prefabricated pipe-sections.

## C. PRE-STRESSED CONCRETE PIPES

Here, pre-stressing the concrete has the purpose of reducing the amount of concrete as far as possible.

This pre-stressing is obtained during construction by creating initial compressive stresses in the pipe walls while empty, by winding the pipe with a spiral steel reinforcement under tension. These initial stresses under empty conditions must be of such magnitude (from about 100 to 150 kg/cm²) that they reduce to from 0 to 10 kg/cm² (still compressive!) under running-full conditions.

It is then clear that in this way the concrete is only subjected to stresses for which it is appropriate. In the case of pre-stressed concrete pipes we have the concrete walls mainly subjected to tangential compressive stresses, when empty as well as when running full.

Viewed from the standpoint of statics the working of a pre-stressed concrete penstock is exactly the same as that of a wood-stave pipe, which is often used in the western part of the U.S.A. and Canada for moderate heads. The wood-staves in the wooden pipes have the same role as concrete in the pre-stressed concrete pipes. A modern factory-made pre-stressed concrete pipe therefore can, viewed from statics, be completely looked upon as a wood-stave pipe, wire-wound in factory. Just as it is the ring formed by the wood staves which forms the conveying walls for the water in the wood-stave pipe, it is the wire wound concrete pipe wall which forms the conveying wall in the pre-stressed concrete pipe.

The consequence of this is that here, too, the concrete has to satisfy two different requirements, viz. it must have great strength and it must also be water-tight.

In the older types of pre-stressed concrete pipes water-tightness of the concrete for great water-pressures is ensured by a thin metal "core-tube" in the concrete pipe walls. As the name suggests this core-tube is wholly embedded in the concrete walls and therefore it is not the metal tube that performs the function of conveying the water. Its only task is to ensure water-tightness for high pressures and it is generally not even calculated to help withstand the internal water pressure, though in fact it does help.

In the newer types the above mentioned steel core-tube is completely dispensed with. The water tightness is hereby achieved by using only superior quality concrete. Furthermore the concrete pipe wall is prestressed in cross as well as in longitudinal direction with steel wires of high quality.

As a further step to ensure water-tightness it is prescribed in the design that at running full condition at maximum head the stress in the concrete wall must be still compressive and of a magnitude of at least 8 to 10 kg/cm².

Finally from the foregoing we can also draw the following important conclusions with respect to pre-stressed concrete pipes:

a) The concrete cylinder wall of the pipe forms the conveying wall for the water, with the consequences connected with it.

b) The wall thickness is, just like in the ordinary reinforced concrete pipes, wholly determined by the magnitude of the internal pressure and by the diameter of the pipe.

c) Besides the requirements of strength the wall must furthermore satisfy the requirements of water-tightness.

d) The amount of steel for the circumferential reinforcement is approximately equal to that necessary for an ordinary all-steel pipe of the same diameter and the same internal pressure, i.e. if the allowable steel stresses are also the same for both types of pipes.

e) The pre-stressing of the concrete wall results in an important reduction in concrete, since with empty as well as with running full conditions there occur only compressive stresses in the pipe walls.

f) But the great saving in the use of steel is due only to the use of steel of very high quality, with a breaking stress of 1500 kg/cm² or more, while the cost of it is only about 3-times that of the normal steel-37. That means, that with the use of normal steel-37 no steel saving could be obtained with respect to normal reinforced concrete pipes, neither with respect to the all-steel pipes.

In conjunction with the use of high valence steel we also apply to the pre-stressed concrete pipes superior quality concrete with a compressive strength of 800 kg/cm², by which a further reduction in concrete is obtained.

All the above measures are necessary to keep the weight of factory-made pipe-sections as small as possible, such being in connection with transport.

## D. THE NEW TYPE PENSTOCK AS PROPOSED BY AUTHOR

Though in appearance not much differing from the previous two types, in statical aspects the proposed type of penstock is quite different.

The prime objective of the new type is simply to combine the advantages of concrete pipes with those of steel pipes, thereby excluding as far as possible their disadvantages.

In other words, the new type pipe has to satisfy the following requirements which have, in particular, bearing on technically less developed countries like Indonesia:

1st. the pipe must combine great durability with minimum maintenance.
2nd. it must be able to withstand very high internal pressures and furthermore proof against positive as well negative waterhammer.
3rd. it must be simple and cheap in construction; this goes also for transport of materials.
4th. in the construction local building materials have to be utilised as far as possible, by which the greatest possible savings is effected in foreign bills.
5th. the pipe has further to be watertight; and for the transport of gas it has to be airtight.

As will appear hereafter the proposed type of pipe satisfies these 5 requirements. It is readily seen that the normal or classic type of reinforced pipes does not satisfy the second and fifth requirements. The prestressed concrete pipe in a country as Indonesia does not satisfy the requirement as mentioned in sub 3 and is further more hard to get water and airtight because of the many junctions between the pipe sections.

As is well known the fabrication of pre-stressed concrete pipes demands very great and specialised skill. Even more, it is such that a pre-stressed concrete pipe generally consists of pre-fabricated pipe sections.

As far as I know the only exception to this is the prestressed concrete penstock which conveys water from the Rhue-river to the Bort-reservoir (in the Dordogne-river in Central France). This penstock namely is wholly cast-in-place and thereafter pre-stressed (also on the site) with the aid of a helical wire of very hard steel. The static head is here 83.5 m (255 ft.).

Furthermore, in pre-stressed concrete pipes the concrete requires ballast (like sand and gravel) of very high quality which in Indonesia, with her young soil formations, is not or only in small quantities available.

From the above it is understandable why pre-stressed concrete constructions are quite unknown there.

Finally, the all-steel pipes are not very resistant to negative water-hammer and besides that they are for Indonesia expensive in construction as well as in transport. It is less durable than a concrete pipe and it requires more maintenance.

After this brief introduction we can now discuss the construction, the calculation and the execution.

## CONSTRUCTION AND CALCULATION

The pipe consists of a thin internal steel cylinder with a thickness of from 2 to maximum 4 mm, depending on the pipe diameter, made of stainless steel which is very highly air-corrosion-proof. (e.g. "COR-TEN steel, which is 4 to 6 times as air-corrosion-proof as ordinary steel).

This thin steel internal cylinder then forms the wall proper for the conveyance of the water or other liquid. It is durable, has a smooth surface, is moreover absolutely water and air-tight and is in addition designed to take up a small portion of the internal pressure.

In order to take care of the remainder of the internal pressure separate steel rings are installed, made of ordinary reinforcement steel or thin steel bars. These rings are laid concentric around the internal cylinder at a definite distance, in one row which extends over the whole length of the pipe.

The space between the steel rings and the internal cylinder and between the steel rings themselves, which space for practical reasons must be at least 5 cm (2 inches), is cast full with concrete which must have sufficient strength to transmit and distribute the internal pressure from the internal cylinder to the steel rings or hoops. The above mentioned space of 5 cm is only determined by the practical consideration that this space must be capable of being easily filled with concrete without voids.

This concrete layer is by way of speaking the foundation bed for the steel rings and at the same time the supporting layer for the thin steel cylinder.

Further, in order to protect the steel rings against rust or mechanical damage another protecting concrete layer is laid on top of the steel rings and hence also on top of the afore mentioned foundation layer. This protecting layer must have a thickness of at least 3 cm.

If the necessary steel ring rod-diameter is, for example, 3 cm the overall thickness of the concrete cylinder becomes:

5 cm (foundation layer thickness)
3 cm (rod diameter for ring)
3 cm (protecting layer)
----
11 cm

The idea of the new pipe system is therefore not based on the principle of the ordinary all-steel pipe as is the case in the normal or classic reinforced concrete pipe, nor on the idea of the so called "wood-stave pipe" as in the pre-stressed concrete pipe, but, completely departing from those two, on the principle of the so-called hooped steel pipes, which is applied only to very high internal pressures.

The calculation of the proposed pipe for internal pressures follows therefore the same procedure as the hooped steel penstocks.

With the new system this calculation is even simpler because the investigation of bending moments in the thin steel internal cylinder is wholly dispensed with. This is due to the presence of the concrete layer which serves not only as a foundation bed for the steel rings or hoops, but also as a supporting layer for the thin steel cylinder and which immediately transmits the internal pressure from the thin steel cylinder on to the steel rings.

Further, with the hooped steel pipes there is the great difficulty of getting the rings exactly concentric and of fitting the hoops tighly closed and unmovable around the pipe wall for the prevention of undesirable and dangerous stress rise in this relatively thin pipe wall.

This difficulty now is completely eliminated from the new pipe system where the steel rings are firmly anchored in the concrete. In this way the concrete performs structurally (not statically!) a very important function.

*Emphatically I want to point out here that the concrete cylinder should by no means be considered as an outer pipe wall which would have to withstand, together with the internal wall, the internal pressure.*

*In fact, the concrete is used here as a stuffing mass only. Therefore it may even crack without impairing in the least the water and air-tightness or the strength of the pipe.*

It should further be clear that in this pipe system, also, the total amount of steel needed is practically equal to that in the all-steel pipe. As we saw earlier this is also the case with the previous two types of pipes (see under B and C).

Summarising we can bring forward the following essential features with respect to construction and calculation:

a. The thin cylinder of corrosion resisting steel forms the proper and only pipe wall which conveys the water or the liquid (or gas). Being such it is subjected to the internal fluid (gas) pressure. However due to its small thickness it can take up only a small portion of this internal pressure. The great bulk of it is transmitted through the concrete to the steel rings or hoops.

b. However, for economical reasons the thickness of the steel internal cylinder can be taken only as small as is feasable with regard to workability and transportability. In this system the steel internal cylinder serves only to ensure water- and air-tightness of the pipe. The internal fluid pressure is considered to be taken up wholly by steel rings or hoops.

c. The external concrete cylinder does not at all take part in taking up the internal pressure. The thickness thereof is only determined by practical considerations. The use of higher quality concrete which is customary with the ordinary reinforced concrete structures is therefore superfluous.

d. The amount of steel is here also, for the same allowable stresses, almost the same as with the all-steel pipes of the same diameter and for the same pressure.

e. The steel internal cylinder which, with the aid of electrical welding, extends over the whole length of the pipe, also serves to take up eventual axial tensile stresses due to shrinking of the concrete. Furthermore it serves during construction as centering for the casting of the concrete cylinder, which makes the construction considerably simpler and cheaper. In this way the steel concrete pipe can be cast-in-place in a simple way for large as well as for small diameters, against slight as well as against steep grades, and furthermore without expansion joints.

f. Besides efficacious protection of the steel cylinder and steel rings against rust and other damage, the concrete cylinder of sufficient thickness gives the pipe also the feature of being proof against negative water-hammer, or even against vacuum. Due to the presence of the steel internal cylinder and the steel rings this pipe is as proof against positive waterhammer as the all-steel pipe.

Therefore the concrete cylinder may crack without impairing the quality of the pipe.

With the disappearance of the pressure surge the cracks will tighten due to the tightening force of the steel rings. *A few remarks concerning the construction.*

As stated earlier the main objective of the new system is to make a durable, little maintenance requiring reinforced concrete pipe, suitable for the transport of water, oil or gas under high pressure.

Further the construction has to avoid as far as possible the need of transportation of heavy, long and space-wasting pipe-sections to the site.

The result of all this is that the pipe has to be cast-in-place in the form of a long continuous water- and air-tight pipe without sleeves or expansion joints.

Only the thin internal cylinder, made of stainless (corrosion resisting) steel, has to be transported from a central workshop where it is prefabricated in the form of from 2 to 4 m long pipe sections, i.e. if, for technical or economic considerations, these pipe sections can not be fabricated on the site itself.

In order to keep those short pipe sections in shape during transportation and also to enhance adhesion of the internal cylinder to the concrete external cylinder, round concentrical stiffening rings of small angle- or channel-iron are welded to the pipe sections at distances of from 1 to 1.25 m.

These stiffened pipe sections are electrically welded together to form a continuous pipe without sleeves, *and this internal pipe forms a welcome and reliable centering for the concrete cylinder.*

Thereafter the reinforcement steel rings or hoops are laid concentric around the internal cylinder at a distance of 5 cm, which during the erection are held in place with the aid of longitudinal bars. (see accompanying figure).

Then the concrete supporting-slab between rings and steel cylinder and the protecting layer are cast simultaneously on to a form, already laid in the ground, made of weak concrete or masonry.

On regular distances, fixed by the daily concrete-casting capacity, construction joints are left open, which are filled with concrete only later in order to prevent shrinking cracks in the concrete during ageing.

This is possible without any difficulty due just to the presence of the steel internal pipe.

In the ordinary reinforced concrete pipes this is not readily possible and it is even undesirable, because the presence of too many expansion joints enlarge the possibilities of leakage. In that case special expansion or contraction joints are made at larger distances of about 10 m or more, which later on are cast full with the aid of special constructions.

Thereafter, when all the concrete is well aged, the pipe is covered with soil over the whole length to restrict temperature influences.

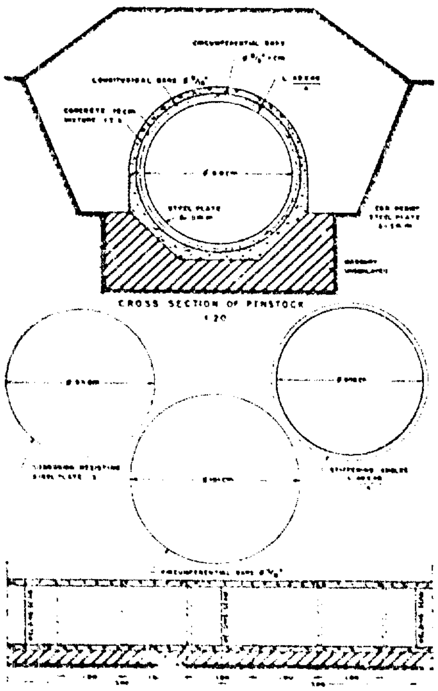
## FINAL REMARKS

Since the cost of reinforcement steel per unit weight is far below that of finished and mounted steel plate, and since the casting of a concrete pipe is much simpler and cheaper than the erection of an all-steel pipe, the construction of the new pipe system is, at least for Indonesia, about 35% lower in cost than that of an all-steel pipe.

Moreover due to the stainless steel internal tube and due to the concrete external cylinder the new pipe system requires practically no maintenance at all, and its durability is also much greater.

If necessary the concrete cylinder can, after testing the complete pipe at working pressure, be coated with bitumen or asphalt in order to fill cracks that may have developed eventually.

HYDRO-POWER PLANT GOLANG



CROSS SECTION OF PENSTOCK
1:20

LONGITUDINAL SECTION 1:50