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USSR Report

ENERGY

(FOUO 22/80)

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USSR REPORT

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CONTENTS

ELECTRIC POWER

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PROSPECTS FOR THE DEVELOPMENT OF RURAL ELECTRIC POWER

Moscow ELEKTRICHESKIYE STANTSII in Russian No 7, Jul 80 pp 2-6

[Article by I. A. Budzko, academician of the all-Union Academy of Agricultural Sciences, P. A. Katkov, engineer, A. Ye. Muradyan, candidate of technical sciences]

[Text] The modern level on which electric power is supplied to agriculture in the USSR is characterized by significant development of the centralized system for the production, transmission and distribution of electric power encompassing in practice 100% of the users in the populous zone.

Agricultural electric power supply, as a rule, is based on the three-stage voltage system 110/35/10/0.38 kv, and only in a small fraction of the electric networks for agricultural purposes is two-stage transformation 110/10/0.38, 110/20/0.38, 110/35/0.38 kv used in the individual regions or instead of 10 kv, 6 kv is used in the three-stage system. The majority of electric power is transmitted by overhead lines.

The continuously developing agriculture is imposing new increased requirements on the quality of the electric power supply, and the achievements in areas of the electrical industry, electric power engineering and other branches of the national economy are opening up additional possibilities for further progress in the rural electric power supply.

The technical-economic indexes of the electric networks for agricultural purposes are determined to a significant degree by the peculiarities of the rural electric power users. This is primarily the high degree of their concentration with comparatively low electric power and also unceasing, rapid growth of electric loads in time. The necessity for considering these peculiarities complicates the technical-economic substantiation of the parameters of the rural electric networks.

In agriculture, along with the traditional users of electric power which still are in the majority, users of a new type have appeared -- the large agricultural complexes with concentrated and quite stable loads over prolonged periods of time.

At the present time a large number of such complexes, poultry farms, industrially based hothouse combines have been built, the primary processing of plant-growing products is being converted to industrial means; mechanization and automation are being widely used here.

The modern agricultural production complexes approach the middle industrial enterprises with respect to number of motors and other electric power users and also with respect to intake power. They have greater sensitivity by comparison with the traditional electric power users to interruptions of the electric power supply and worsening of the quality of electric power; therefore the electric power supply quality indexes of the large agricultural complexes must be higher than for the traditional rural and even industrial users.

The Central Committee of the CPSU and the USSR Council of Ministers, by resolution of 13 June 1973, have categorized the large animal husbandry farms and complexes producing on an industrial basis as primary category users with respect to electric power supply reliability. Increased requirements are also being imposed on the quality of the electric power fed to the terminals of the electric users of the complexes; it is regulated more rigidly than required by the "Instructions for Application of Revision No 1 to Item 2.3 of All-Union State Standard 13109-67." The "temporary instructions with respect to planning and design of the electric power supply of the complexes" confirmed in 1976 by the USSR Ministry of Power Engineering and the USSR Ministry of Agriculture provide for maintenance of the voltage on the terminals of the electric users of the complexes within the limits of ±5% of the rated value instead of ±7.5% used in agriculture. These increased requirements on the electric power supply reliability and quality of electric power for the complexes influence the technical-economic indexes of the electric power supply system and complicate the problem of creating efficient electric power supply systems for agriculture and their development.

The problem of efficient construction of the electric networks for agricultural purposes must be considered as a complex problem considering the interests of agriculture and the possibility of the electric power supplying organizations. The electric power supply system must provide for transmission and distribution of electric power to all of the electric users in its zone of operations with the network parameters permitting satisfaction of the rural users with the required power, including during peak load hours and under emergency conditions.

The basic requirements primarily determining the parameters of the electric networks for agricultural purposes are requirements including the normalized values of the voltage deviations, normalized or optimal (if the latter can be determined) with respect to duration and date of disconnection of the rural electric power users and, finally, the rules for selecting the configuration of the overhead lines.

Considering the primary role of the agricultural requirements on the indexes for development of electric power supply systems, let us discuss the procedural principles of the formation of these requirements in more detail.

In order to determine the requirements, on the one hand, it is necessary to consider the losses which can be imposed on agriculture on deviation of the electric power supply system parameters from the indexes corresponding to the most favorable, ideal conditions, that is, absence of disconnection of the electric power supply, maintenance of rated voltages on the electric user terminals, routing of the overhead lines which does not interfere with the farm lands. On the other hand, it is necessary to consider the expenditures on electric power supply. It is obvious that the greater the expenditures (under the condition of efficient use of them), the closer the investigated parameters to ideal from the point of view of the interests of agriculture.

The intensification of agricultural production, the growth of the cultural and domestic standard of living of the farm population require further approximation to the ideal conditions of the functioning of the electric power supply systems. The determination of a substantiated degree of approximation to these conditions will be one of the areas of scientific research in the field of electric power supply of agriculture, and it is connected with the necessity for calculating the losses caused by deviations of the parameters and operating conditions of the electric power supply units from the ideal case.

It is known that the electric networks for agricultural purposes have all the primary signs of complex developing systems, and in their development they interact with the farm electric power users. The latter, if they are considered from the point of view of the relations to the electric power supply system can be represented by a set of transducers which convert electric power to other forms of power required for the functioning of the agricultural users (mechanical, thermal, light, and so on).

The agricultural users function in a unified management and process complex which, just as the rural electric networks, have all of the primary signs of a complex developing system further complicated by such specific elements as agricultural objects -- animals, plants, and so on.

When investigating the peculiarities of the interaction of these systems as defined it is necessary to consider the system of electric power users. The parameters and characteristics of the electric power supply system basically depend on its parameters and characteristics. For determination of the nature of the interaction it is expedient to use the sum of the corresponding efficiency criteria: reduced expenditures on the electric power supply system and losses in the users connected with the peculiarities of the organization and functioning of the rural electric networks.

The efficiency criterion is a function of many independent variables determining the required capital investments, operating expenditures and possible losses. However, for a study of the interaction of the investigated systems when calculating the efficiency criteria it is superfluous to involve all the factors in influencing their formation. Consideration of only the factors common to both systems affecting the efficiency criteria to one degree or another is sufficient.

Beginning with what has been investigated, it is necessary to consider the following to be the most important factors:

The quality of electric power on the terminals of the transducers;

The number and duration of interruptions of the electric power supply or its reliability;

Configuration of the networks by which the electric power supply is realized.

It is obvious that each of the calculated efficiency criteria does not reach the extremal value for the same value of the common factors; therefore the optimal conditions of joint functioning of the investigated pair of systems can be achieved on the basis of the compromise solution which corresponds to the minimum sum of the efficiency criteria.

The determination of the compromise values of the voltage on the transducers, the reliability of the electric power supply and the network configuration indexes corresponding to the minimum sum of two efficiency criteria

$$E_1 + E_2 = \sum_{i=1}^{M} Z_i + \sum_{J+L}^{N} Y_j \rightarrow \min,$$

where M is the number of elements of the electric power supply system; Z_i is the reduced expenditures per element i; N is the number of factors which can cause losses on the part of the users and simultaneously influence the value of the reduced expenditures on the network; Y_j is the loss connected with the factor j which is a highly complex problem and requires, on the one hand, the solution of a series of optimization problems of electric power supply, and on the other hand, finding of estimates of the efficiency criterion in the users for values of the influencing factors differing from ideal.

These compromise values are in the strict sense of the word requirements of agriculture on electric power supply.

With respect to nature they are a dynamic category which depends on the level of development of the various branches: agriculture, electric power engineering, the electrical industry, and so on. However, as a result of significant inertia, the transition from certain quantitative indexes characterizing the requirements to others is made quite rarely.

The solution of the problem of optimizing the electric networks for agricultural purposes is connected with significant difficulties characteristic of the developing systems. The most effective approach in analogous cases is the application of the methods of mathematical programming and, as a consequence, the use of computers.

In order to determine the losses, on the one hand, it is necessary to gather a large number of statistical data on the reliability of the electric power supply, the quality of electric power, the configuration of the network routings, and on the other hand, calculation of the values of the losses by the investigated set of specific objects.

The relations obtained as a result of this processing Z=f(H, V, K) and Y=f(H, V, K), where H, V, K are the generalized indexes of electric power supply reliability, quality of electric power and configuration of the routings, can be used as the basis for determining the requirements which are calculated as the roots of the system of equations:

$$\frac{\partial(Z+Y)}{\partial H}=0;\ \frac{\partial(Z+Y)}{\partial V}=0;\ \frac{\partial(Z+Y)}{\partial K}=0.$$

However, a number of peculiarities characteristic of the electric power supply systems such as discreteness of the variables, a large number of restrictions, dynamic nature of the problem, and so on, as a rule, do not permit us to in all cases use only the presented system of equations and leads to the necessity for the application of various procedures and methods which the modern theory of operations research has at its disposal.

At the same time this system of equations defines the theoretical path of the solution of the problem with respect to substantiation of the requirements on the electric power supply.

The indicated approach was, for example, used when introducing revision No 1 to All-Union State Standard 16309-67 and also when substantiating the normalized values of the deviation of the voltages of ±5% for the transducers of the animal husbandry complexes.

Analogously, when determining the optimal degree of reliability of the electric power supply of the agricultural objects, the expenditures on the networks and losses from interruptions in the electric power supply were compared. At the present time these calculations are being performed to determine the optimal configurations of the routings of the rural distribution networks.

In the resolution of the Central Committee of the CPSU and the USSR Council of Ministers "On Measures for Further Development of Electrification of Agriculture," adopted 31 January 1979, the agencies responsible for electrification of agriculture were faced with the following basic problems: bringing the electric power consumption in agriculture to 170-190 billion kilowatt-hours in 1985; an increase in the power available per worker in agricultural production by 1.6 to 1.8 times and the electric power consumption for communal-domestic needs per farm resident by 1.8-2 times in 1981-1985; gradual transition from automation of individual production processes and operations to full automation of the shops and agricultural enterprises.

The successful fulfillment of these goals will be promoted to a high degree by the further development of the farm electric power supply systems provided for in the resolution of 31 January 1979.

The basic areas with respect to improvement of the electric networks for agricultural purposes include primarily measures to increase the reliability of electric power and quality of electric power considering the increasing requirements of the farm users and also the necessity for leading development of the electric power engineering base of agriculture, one of the components of which is the electric power supply system.

It is recognized that the development of the farm networks, an increase in their carrying capacity are most expediently realized by building additional 35 and 110 kv subdividing substations, which leads to reduction of the range of the 10 kv networks which will in the future basically perform the functions of distribution networks inside populated areas. The technical condition of the networks will be improved as a result of the application of more advanced and more reliable structural designs for the wood and reinforced concrete supports, insulators, fiberglass cross members, wires, replacement of wires and individual sections of the networks with wires with higher conductivity. The operating qualities and structural designs of the 10/0.4 kv KTP transformer substations.

The operating reliability of the rural electric power supply systems is increasing as a result of the introduction of network reserving with respect to the 35 and 10 kv lines and automation media of the networks.

At the present time a significant number of rural distribution networks have been built and are being operated, and now the operations with respect to their reconstruction and with respect to the construction of new networks to replace those that are becoming unsuitable are advancing to first place. The reconstruction of the networks, as one of the theoretically important measures with respect to improving their condition, has found reflection in the resolution of the Central Committee of the CPSU and the USSR Council of Ministers "On Measures for Further Development of the Electrification of Agriculture." At the present time the problem is arising of the development of optimal methods and times of reconstruction, determination of the normatives with respect to performance of operations in this area.

It is necessary to organize the operations with respect to the replacement of the overloaded transformers at the substations as one of the simple means of improving the quality of electric power supply.

As the electrical loads and electric power consumption increase, the approach of the higher voltage of 10-35-110 kv to the farm users must be provided for. This goal is served primarily by the subdivision of the 35-100/10 kv transformer substations and conversion of the 35 and 110 kv lines to distribution lines; secondly, the application of deep inputs with direct transformation of 110/10/0.38 kv and 110/35/0.38 kv voltage and, finally, the application of built-in and built-on substations for the production facilities and conversion of the 0.38 kv distribution networks to the intrashop networks.

The transition from the four-step to the three-step voltage system with exclusion of 10 kv or 35 kv voltages has special significance for improving the efficiency of rural electric power supply, improving the voltage quality of the users and lowering the electric power losses. This transition has already started, but the development and mass production of the lighter equipment for 35 kv voltage and the 35/0.4 kv transformers are required for it to become widespread.

Special attention has been given to improvement of the use of the reserve carrying capacity of the electric networks. For this purpose it is necessary to provide organization of the operation of the process units at the farm sites which will insure (of course, without losses to the processes) multiplexing and equalizing of the electric load charts and improvement of the use coefficient of the installed power of the power transformers. Here it is very important to increase the accuracy of determining the maximum calculated and also prospective electric loads and the demand for electric power.

Significant effect will be obtained from the introduction of the full set of known methods, means and measures for improving the level of reliability to the optimal or normalized amounts into the rural networks [1]. The basic element of this complex is the automation devices, including multiple automatic reclosures (APV), sectioning using breakers, dividers and separators, automatic input of reserve power, improved forms of relay protection. The complex will also include remote control and signal units [2]. It is necessary to make broader use of two-way feed of the main sections of the lines by connecting them to different power supplies by a jumper with sectioning breaker.

One of the conditions of broad introduction of automation and control of the electric networks is the development of methods of estimating the cost benefit of the application of automation and remote control means in the rural electric power supply systems -- an important problem the solution of which needs the help of the scientific research and planning and design organizations.

Among the developed measures for improving the reliability of electric power supply is repair of the 10-35 kv overhead electric power lines under voltage permitting significant reduction of the planned disconnections of farm users. The measures to melt ice off the lines and equipment are included in the same group of means of improving reliability.

In the last decade, underground cable lines have replaced overhead lines in world practice to improve the electric power supply system for rural and suburban users. The primary causes of the conversion to cables are increased requirements on the power supply reliability, saving valuable fertile farm lands, the necessity for introducing advanced methods of growing farm crops, widespread communication and aviation in agriculture, esthetic compatibility between the transmission and distribution of electric power with the environment and, finally, improvement of electric safety [3, 4].

In addition, the application of cables has been promoted by intensive development of the production of insulation materials based on synthetic polymers, the creation of new types and lighter structural designs for cables at reduced cost based on plastic insulations, high degree of mechanization and specialization of the construction and maintenance of cable networks.

It is expedient to isolate the areas of primary conversion to cable networks with specially responsible users, with new farm sites and also with serious meteorological conditions and valuable land as an experiment in the forthcoming five-year plan.

The improvement of the quality of electric power is at the present time being given a great deal of attention; in the rural electric networks this problem is especially acute, for, as a rule, the means of regulating the voltage are unavailable, and the voltage deviations frequently go beyond the normalized values.

In order to improve the quality of electric power fed to the farm transducers, it is necessary to make broad application of the voltage regulators and devices to compensate reactive load with optimal combination of 110-35 kv transformers with regulation under load and booster regulation under load for the operating transformers insuring counter voltage regulation which are installed at the feed centers; adjustable capacitors with transverse compensation for the reactive loads, the 10/0.4 kv user transformers with regulation under load based on semiconductor engineering, 0.38 kv voltage stabilizers with the corresponding technical-economic base.

In the rural networks it is very important to decrease the voltage asymmetry, both nonrandom caused by nonuniform distribution by phases of the single-phase loads and probability asymmetry which is the consequence of nonuniform inclusion of the single-phase transducers. For radical solution of this problem it is necessary to make use of the user transformers up to 250-400 kv-amps with connection of the windings in a star-zigzag circuit with null in place of the star-star circuit with null used at the present time. In the networks where transformers using the latter circuitry have already been installed, and there are more than 700,000 of them, it is necessary to use static symmetrizers, for example, those developed by the Institute of Electric Dynamics of the Ukrainian SSR Academy of Sciences.

In order to decrease the power losses in the rural networks it is necessary to develop and introduce a set of measures including the replacement of the lightly loaded transformers, ringing of the networks with optimalization of the break points, symmetrizing of the signal-phase loads, regulation of the voltage under load, use of capacitors to compensate for reactive power, 10/0.4 kv transformers with star-zigzag-null circuitry, and a decrease in the number of transformation stages in the electric power supply systems. Among the measures aimed at decreasing the energy losses in the networks and requiring additional investigation it is necessary to note the necessity for studying the problem of a special series of transformers for agricultural purposes with increased ratio of losses in copper to losses in steel by comparison with ordinary transformers. From the point of view of decreasing the energy losses it is also of interest to use the 660 volt voltage in the large complexes.

Further specialization and concentration of agricultural production, the development of large complexes require intensified attention to the development of optimal circuits for electric power supply of them. Considering the serious consequences for the large animal husbandry and poultry complexes from prolonged interruptions in the electric power which can occur during system emergencies and elemental disasters, it is necessary to install reserve diesel electric power plants (DES) at them. The power of the DES must be selected optimal considering the losses or by the process reserve-quota load. As the latter it is necessary to use the load of the devices, the operation of which creates minimum comfort conditions preventing disease of the animals [5].

When selecting the optimal power of the reserve electric power plant it is also necessary to consider the peculiarities of the centralized electric power system. For example, if a 600-head dairy complex is fed from a two-transformer 10/0.4 kv substation connected by two 10 kv overhead lines to different sections of 10 kv buses of a two-transformer 110-35/10 kv substation, then an electric power plant with two 2x24 kilowatt units will be selected as optimal. For the same complex, but with electric power supply from one 10/0.4 kv transformer substation connected to a two-transformer 110-35/10 kv substation, a two-unit 2x72 kilowatt-power plant will be optimal.

It is necessary to develop and introduce economical and reliable electric power distribution systems in the territories and in the facilities of the farm enterprises with optimal configuration of the routings of the distribution networks and the number and placement of the 10/0.4 kv transformer substations.

In the future the social function of the electrification of agriculture directed at eliminating the difference between city and country, mental and physical labor, will be intensified to a still greater degree.

A significant effect on the optimization of the parameters of the rural electric power supply systems and their operating conditions is felt from the application of computers when designing and operating the rural electric networks. In the future, as the introduction of computers into design and operating practice expands this influence will become stronger [6].

The use of computers when planning rural electric power supply or automation of design has received special development. First, a computer permits the productivity of labor in the design organizations to be improved, and, secondly, it makes possible a significant approach to optimal design solutions.

The following steps have been gone through in a comparatively short operating period with respect to automation of design:

The development of individual programs designed for mechanization of routine work of the designer, the facilitation and improvement of the productivity of his labor; the programs almost completely repeat the course of action of manual design;

The creation of algorithms contain elements of the creative approach, for example, optimization of the rural electric power supply parameters; the rich possibilities of the computer are more completely used here; significant changes are being introduced into "manual" methods of accounting;

Transition from individual programs to the complexes of programs with respect to autonomous steps of the design process, which are the terminal automated design subsystems.

At the present time a transition is being made to the integration of the developments with respect to the entire cycle of algorithms and programs for automatic design, the creation of automatic design systems (SAPR) for rural electric power supply.

The application of the methods of designing the rural electric power supply based on the use of computers has made it possible to resort to the solution of a number of design problems which up to now were solved only on the basis of the experience and intuition of the designer, which frequently has led to a reduction in quality of design, worsening of its economic indexes.

An important step ahead in the automation of the design of the rural electric power supply system must be considered to be the introduction of interactive methods which in the future must play the leading role in the

SAPR and which will permit combination of strict methods of solving design problems with intuition and experience of the engineer. In particular, the solution of the complex problems of determining the optimal configuration of the rural network will be facilitated significantly considering the losses imposed on the farm lands, the selection of the optimal combination of means providing for normalized limits of voltage variation in the transducers with minimum expenditures and also optimal combination of the means of insuring optimal reliability.

An important problem requiring solution is the optimization of the design system considering the introduction of SAPR on the level of the design organization. This optimization includes the selection of computers, determination of an efficient ratio of volumes of design work performed by machine and man, determination of the requirements on the automated work place (ARM) of the designer, and so on. The equipment of an automated work place is theoretically important from the point of view of accelerating the introduction of interactive methods into design practice and acceleration of the conversion to SAPR.

At the present time the computer is used by the designers as auxiliary equipment. In the future the central, primary role in design must go to man. However, the role of machining will increase significantly, and in the design organization man must service it and make decisions on the basis of the results of the operation of the computer. Thus, the great possibilities of the computer will be used more completely.

An automated design system is being created and functions in the design organization as an independent system. However, in the rural electric power supply other automated systems are developing in parallel. In particular, operations have started with respect to the application of computers in the operation of the rural electric networks. The region of their application is highly significant. Thus, they are used for calculations of the optimal repair times, determination of the losses of electric power in the networks, and the performance of calculations with the subscribers. Considering that a number of the initial information files can be used both for design purposes and for operation and maintenance, in the future the SAPR and automated system for operation and maintenance of the networks can function as interrelated on the level of hardware and data banks.

For further technical progress in the rural electric power supply the use of advanced foreign experience has great significance.

This pertains primarily to the underground low and medium voltage cables which have become widespread in the rural networks not only of small countries (Belgium, The Netherlands), but also in the United States where 10 to 15,000 km of such lines are being built annually.

The equipment for the rural electric networks, light reliable and with small dimensions, in particular for 35 kv voltage is of significant interest. In particular, this includes vacuum breakers which have become widespread.

In many countries wide use is being made of small KRU* This is making it possible to convert to the kiosk type transformer substations which are significantly more reliable and convenient for operation (Norway, Belgium, and so on).

The experience in the application of computers in operation of rural networks (Belgium, the Federal Republic of Germany) deserves to be studied. Not only are the previously presented problems solved by computers, but problems are also solved in the dispatch control of the areas with a very large number of transformer substations and highly branched network.

The studies of the voltage systems used in various countries in order to establish a voltage system in the rural networks of the Soviet Union for the distant future are of interest.

The technical designs adopted in the future must insure minimum national economic expenditures considering the specific requirements of the rural users and the electric power supply conditions and also the forecasting data and scientific and technical progress in farm production and the standard of living of the farm population, electric power engineering and the electrotechnical industry.

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PERFORMANCE OF STARTUP, ADJUSTMENT OPERATIONS AT KOLA NUCLEAR POWER PLANT

Moscow ELEKTRICHESKIYE STANTSII in Russian No 7, 1980 pp 7-10

[Article by L. M. Voronin, candidate of technical sciences, A. P. Volkov, B. A. Trofimov, engineers]

[Text] The first phase of the Kola Nuclear Power Plant consists of two series power units with VVER-440 water-cooled, water-moderated reactors.

In January 1973, complex startup and adjustment operations began on unit I, and in August 1974, on unit II. Here power unit I was started up in June 1973, and II in December 1974.

When preparing for the performance of the startup and adjustment operations on units I and II of the Kola Nuclear Power Plant, the experience of the Novovoronezh Nuclear Power Plant was considered, and a procedure was defined for successive performance of the startup and adjustment operations and their volume. Schedules and programs were compiled.

In order to reduce the time required for the startup and adjustment operations, the decision was made to do away with the time charts and, accordingly, to put the following units and systems into operation first:

The chemical water purifiers -- to provide desalinated water for flushing and purging the process systems and equipment;

The 110/6 kv reserve transformer for inhouse needs -- to feed the inhouse electrical system from the power system;

Storage battery -- to provide direct current to the signal and protection systems;

Electrical distribution stations for inhouse needs on 6 and 0.4 kv -- to provide electric power to the inhouse machinery;

An electrolyzer to provide the turbogenerators with hydrogen when testing at idle and under load;

An oil system to provide oil to the turbogenerators and transformers;

A technical water supply system to provide water to the chemical water purifiers and for flushing the system and equipment;

Nitrogen-oxygen station to provide all of the systems of the nuclear power plant with nitrogen.

It is especially necessary to note the decision for advanced testing and adjustment of the turbo units from an outside steam supply.

The boiler cars of a power train were used as the outside source of steam on unit I. Steam was fed from unit I to adjust the turbogenerator of unit II.

Testing the turbo units from an outside source of steam permitted not only more uniform distribution of the efforts of the personnel, but also significantly reduced the time for power startup and bringing the unit up to power.

Thus, the startup and adjustment operations on units I and II of the Kola Nuclear Power Plant were divided into several steps.

1. Adjustment and introduction into operation of the auxiliary system and objects providing for starting up the basic equipment.

2. Adjustment and testing at idle and under load of the basic and auxiliary equipment of the turbine shop and the electrical equipment of the main system.

3. Adjustment and testing of the basic and auxiliary systems of the reactor installation.

4. Physical and power startups of the reactor, including complex testing of all of the systems of unit I.

5. Step-by-step attainment of design power.

This sequence of startup and adjustment operations also permitted more uniform distribution of the efforts of the personnel for performing the entire volume of startup and adjustment operations in compressed times.

The basic startup and adjustment operations with respect to the turbine division and the electrotechnical devices were performed before the completion of the delivery and assembly of the basic equipment of the first circuit.

The input monitoring is one of the most important preparatory steps for performance of the startup and adjustment operations on the equipment and systems of the nuclear power plants.

When performing input monitoring, the following methods were used: analysis of the certificate data: visual inspection, sample photographing of defective sections on the surface of the metal; color defectoscopy; luminescent-hydraulic monitoring; magnetic-powder defectoscopy; ultrasonic defectoscopy; gamma and x-ray control of the welds; investigation of the microstructure of the basic metal by the indentation method; determination of the hardness of the metal.

The startup and adjustment operations on the equipment of the reactor unit included the following steps: the flushing and functional testing of auxiliary systems and equipment; hydraulic testing and circulation flushing of the primary circuit; hot break-in; physical startup; power startup; step-by-step bringing up to power.

The hydraulic tests on the primary circuit were made up of the following tests of the disconnected part of the individual loops and hydraulic testing of the primary circuit as a whole. This breakdown was caused by the delay in delivery of the equipment during the course of the construction and installation operations to open up the operations front with respect to thermal insulation and reduction of time to eliminate defects discovered during the tests.

The hydraulic tests on the primary circuit on the whole were performed at a pressure of 175 kg/cm^2 with a reactor vessel temperature of more than 100°C. The water was heated by operation of the main circulating pumps (GTsN) and supplying steam to the steam generators from the secondary circuit. Simultaneously with heating, circulation flushing of the primary circuit was carried out.

During flushing the following operating conditions were tested: startup, operation and shutdown of the main circulating pumps (GTsN), determination of their characteristics, heating of the primary circuit with the energy of the operating GTsN; checkout of the thermal expansion of the pipelines of the primary circuit; the closed and open purging mode on the primary special water purification unit.

In the final phase of flushing at a temperature of more than 200°C, the inside surfaces of the reactor vessel and the volume compensator were passivated by introducing hydrazine hydrate into the primary circuit.

The application of the process cover during circular flushing is more preferable by comparison with the standard upper unit, for in this case the operations with respect to closing off the jacket tubes and the heat monitoring connection lines by temporary blind flanges are excluded

In addition, the upper unit is relieved for operations with respect to input monitoring and head installation finishing.

After hot break-in of the primary circuit which confirmed the readiness of the nuclear power plant equipment for the next phase of operations -- physical startup -- the intravessel devices with subcritical core were installed. The loading of the subcritical core was accomplished with the performance of all measures to insure nuclear safety.

The experiments performed during physical startup confirmed the neutron-physical characteristics of the first fuel charge of the reactors obtained by calculation; the reliability of the shielding and blocking, the fitness of the emergency protection system and the process monitoring were confirmed.

The powers of both power units were assimilated in stages.

At the power level of up to 20%, the operations of studying the fuel field were performed; the heat balance of the primary and secondary circuits was compiled; the natural circulation conditions were tested; the rundown conditions of the turbogenerators jointly with the GTsN were studied; the total deenergizing mode of the nuclear power plant was tested; the radiation situation in the process facilities was checked, and the water-chemical regime of the primary and secondary circuits was adjusted.

The experiments with respect to deenergizing and running down the turbogenerators demonstrated the great reliability of the GTsN feed circuit. Rundown was 150 to 180 seconds.

The natural circulation insures the release of up to 9.0% of the power from the reactor (in percentages of the rated value).

The results of the indicated operations confirmed the fitness and the reliability of the basic equipment and the process systems.

During assimilation of the powers of units I and II, the following operations were performed: compilation of the heat balances of the primary and secondary circuits and determination of the efficiency of the unit; the study of the proportion of energy release in the core; the study of the state of the fuel elements by the method of radiation-chemical analysis; checking of the turbogenerators under a load of 230 megawatts; testing and adjustment of the operation of the automatic power regulator; adjustment of the operation of the information computer.

The schedules for assimilation of the design power of power units I and II are presented in the figure.

The experience in performing the startup and adjustment operations at the Kola Nuclear Power Plant indicates that the period of these operations can be reduced. Their volume must be determined by testing the established equipment and by complex tests.

In practice the Kola Nuclear Power Plant has operated since assimilation of the powers of units I and II in the Kola power system primarily in the base source regime, with some reduction in loads during the spring and summer period.

The VVER [water-cooled, water-moderated power reactors] are highly resistant to disturbances as a result of the negative temperature and power coefficients of reactivity. The units of the Kola Nuclear Power Plant demonstrated good self-regulatability of the reactors under such large-scale disturbances as disconnection of the GTsN, disconnection of the turbogenerator from the network, the total load dropped, and so on.

The maneuverability of the nuclear power plant is characterized by comparatively short time expended on bringing the unit to power after a prolonged shutdown connected with cooling of the primary circuit. The total time required for complex testing of the safety and control system (SUZ) of the reactors, achievement of the rated parameters of the primary circuit, heating of the steam generators and synchronization of them with the system is about 15 hours. The same time is required for cooling down the reactor and bringing it to the repaired state.

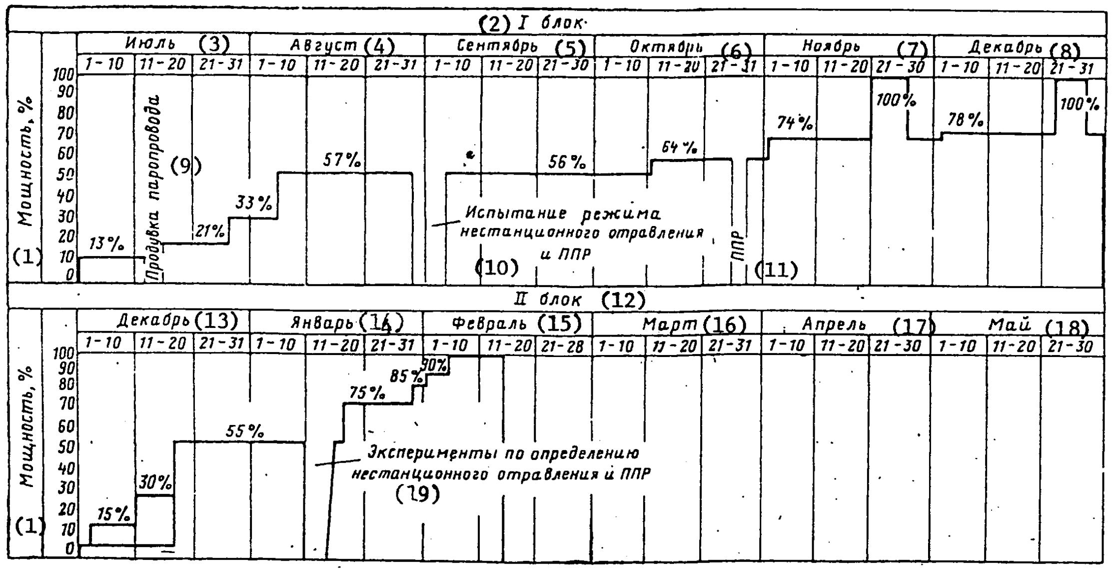
High operating stability of the nuclear power plant is achieved as a result of insuring reliable operation of the main equipment.

The experience in the operation of the Kola Nuclear Power Plant indicates that the nuclear electric power plants with VVER reactors are simple and reliable to control and operate.

In the reactors of the Kola AES, the safety rod control system with 37 mechanical adjustment elements was used for the first time.

At the present time the introduction of an automated system for operative monitoring of the distribution of the neutron flux with respect to the active core volume has ended at the Kola Nuclear Power Plant.

In January 1977, studies were made on both of the units of the Kola Nuclear Power Plant to determine the economically optimal parameters of the main circuits. For example, it was demonstrated experimentally that with a reduction in pressure in the secondary circuit from the rated value of 47 kg/cm^2 to 42 kg/cm^2 (with the corresponding reduction in the temperatures of the secondary and primary circuits) and invariant thermal power of the reactor the efficiency of the unit decreases insignificantly.



Charts for assimilation of the design capacity of a power unit with the VVER-440 reactor of the Kola Nuclear Power Plant

Key:

1 -- Power, %; 2 -- Unit I; 3 -- July; 4 -- August; 5 -- September; 6 -- October; 7 -- November; 8 -- December; 9 -- Purging the steam line; 10 -- Testing the nonstation contamination and preliminary work preparation mode; 11 -- Preliminary work preparation; 12 -- Unit II; 13 -- December; 14 -- January; 15 -- February; 16 -- March; 17 -- April; 18 -- May; 19 -- Experiments with respect to determining the nonstation contamination and preliminary work preparation

However, here the possibility appears for the use of the mode of operation on reduced parameters for lengthening (as a result of the thermal effect of reactivity) the operating run of the unit at power after finding (at the end of the next fuel cycle) the reactivity reserve for burnup. This possibility has been used many times. The lengthening of the run on individual power units has reached up to 84 effective days. Here the average burnup of 34.4 megawatts X days/kg has been achieved as opposed to the designed 28.6 megawatts-days/kg. In the performed operations with respect to optimization of the fuel cycles, the problem of decreasing the fuel component of the cost of the electric power is solved.

The operation of the units of the Kola Nuclear Power Plant on increased power levels has a significant effect on increasing the economy of the operation of the entire electric power plant as a whole.

For the satisfaction of this goal, the following series of organizational-technical measures has been realized insuring stable and reliable operation of the basic equipment:

Separation tests were performed on the steam generators of unit II;

Thermal tests were performed on all of the basic generators of the first phase (TG Nos 1-4);

Installed with respect to the auxiliary safety valve on the volume compensators, and additional protection was introduced with respect to exceeding the pressure in the primary circuits in both units;

The method of continuous monitoring of the activity of the heat transfer agent in the primary circuits and the already-mentioned system for operative monitoring of the power distribution in the core were developed and are in the introduction stage.

From 1 December 1978, the power units of the Kola Nuclear Power Plant have operated constantly on a power to 470 megawatts (with a design power of 440 megawatts), which permits additional generation of more than 400 million kilowatt-hours of electric power annually.

An important area of insuring reliable and safe operation of the nuclear power plants is timely determination of the level of unsealing of the fuel elements. It is necessary to note that the low level of activity discharge into the ventilation tube of the Kola Nuclear Power Plant (hundreds of times less than admissible with respect to the norms) including other factors is explained by sufficient seal of the fuel element jackets.

The monitoring of the jacket seal (KGO) on the operating equipment is carried out without radio chemical release of the elements from the sample and direct spectrometric measurement on a semiconductor detector with high resolution. An automated system has been introduced with semiconductor detector (PPD) in the bypass, which satisfies the requirements of operative monitoring with respect to the tidal activity of the fission fragments. In addition, it is necessary to note that a system with PPD in the bypass permits us to obtain information about the process of washing off -- precipitation -- of radioactive products of corrosion on the inside surfaces of the primary circuit of the operating equipment.

The operation of the nuclear power plant turbines operating on saturated steam has demonstrated the importance of the problem of controlling erosion to which the individual turbine elements are subject. During the operating process, erosion wear of the through-flow section of the high-pressure cylinder, its joints and diaphragms is observed. Accordingly, the joints of the high-pressure cylinder were clad with stainless steel, the moisture-trapping shutters and diaphragms themselves were replaced by stainless steel ones.

Individual electrotechnical devices and systems were improved during operation. For example, step forcing of the excitation of the natural-flow generators was carried out, which significantly increased the operating time of the GTsN in the deenergizing mode.

The system for group startup of the emergency cooling mechanisms with simultaneous cranking of the diesel generators was tested, which permits the startup time for the electric motors on the inhouse machines to be reduced and the reliability of the cooldown of the reactor to be increased significantly.

The nuclear power plant belongs to the power engineering enterprises with complex process equipment, the control of which without automated data processing is complicated. If we consider the factor of responsibility which the operator has for probable consequences of errors, it is possible to state that without the indication of modern measuring devices and automation systems, the operation of a nuclear power plant would be impossible. Automation permits intensification of the technological processes, which offers the possibility of decreasing the labor expenditures on servicing it and a reduction in the operating expenditures.

The water regime of the primary and secondary circuits to a significant degree determines the fitness of the fuel element jackets, the equipment and lines. For the primary circuit of the reactors of units I and II of the Kola Nuclear Power Plant, a mixed ammonia-potassium regime is used with boric acid in the heat-transfer agent.

The advantages of the ammonia-potassium water regime consist in the following:

The pH is maintained higher than 6.0, which satisfies the reduction in corrosion rate of the basic equipment and the deposits on the fuel element jackets;

The required hydrogen concentration is maintained by introduction of an ammonia solution into the circuit, which permits suppression of the radiolysis of the water;

The regime makes it possible to apply hydrazine hydrate for binding the oxygen during startup of the reactor when going up to power;

The maintenance of the reducing environment as a result of the constant presence of alkaline ions prevents oxidation of the zirconium alloys under irradiation.

Table 1

Index for the Primary Circuit	Norm	Actually Unit I	Actually Unit II
Value of the pH	6.0	7.4	7.35
Boric acid, g/kg	-	2.1	2.26
Ammonia, mg/kg	5	8.7	8.3
Chloride, mg/kg	0.1	0.05	0.05
Iron, mg/kg	0.2	0.035	0.03
Potassium, mg/kg	-	6.7	7.5
Oxygen, mg/kg	0.01	0.005	0.005
Hydrogen, nml/kg	30-60	41.4	43.6
Total activity, curies/kg	-	4.10^{-3}	$8\cdot10^{-3}$

The basic quality indexes of the water-chemical regime of the Kola Nuclear Power Plant are presented in Table 1.

The water regime is controlled by using the SVO-1 ion-exchange filters and by the introduction of reagents by the makeup pumps. At the present time means of automated chemical and radiochemical monitoring of the water-chemical regime of the primary circuit are being introduced. Based on the experience in the operation of units I and II of nuclear power plants, it is possible to note that the mixed ammonia-potassium input mode of the heat-transfer agent of the primary circuit is one of the most available and reliable modes making it possible to reduce the corrosion of the construction materials to a minimum.

The performed studies of the possibility of applying correction of the feed water by hydrazine and ammonia made it possible in 1974 to introduce the hydrogen-ammonia, water-chemical regime of the feed water of the second circuit at Kola Nuclear Power Plant. Here the oxygen and carbon dioxide concentrations are below the analytical threshold of the determination, the concentrations of the copper and iron are 3 to 5 times less than the established norms, and the contamination of the tubes and surfaces of the steam generators is significantly below the designed contamination.

Table 2

Monitored object	Year of observation 1973	1974	1975	1976	1977
Discharge channel water, X10-12 curies/liter	2.8-3.2	1.9-3.6	2.3-3.8	2.1-2.9	2.0-3.3
Lake Imandr water (water collector), X10-12 curies/liter	2.4-3.8	1.7-3.3	2.4-2.9	2.0-2.8	1.9-2.7
Layer of air next to the ground, X10-12 curies/liter:					
Industrial site	0.4	1.3-6.7	0.2-2.7	0.3-3.1	0.7-4.0
The village of Polyarnyye Zori (11 km)	0.5	1.4-8.8	0.3-2.9	0.4-3.6	0.8-4.3
Atmospheric fallout, X10-5 curies/km2-day):					
Industrial site	0.9-1.0	1.3-9.0	1.3-6.7	1.0-5.2	0.6-11.6
2-10 km away	0.6-1.2	0.8-8.9	1.1-6.1	0.8-4.4	0.6-14.3
15-75 km away	0.5-1.0	0.8-10.7	1.2-5.2	0.9-4.6	0.6-12.6
Gaseous discharges into the ventilation duct, curies/day	1.72	2.9	3.8	4.96	4.5
Discharges of iodine-131 into the ventilation duct, curies/day	Not detected	Not detected	1X10-4	1X10-4	1X10-4

At the Kola Nuclear Power Plant, for deactivation of the process equipment (the recessed parts of the GTsN, the drives of the safety and control system, and so on), special devices have been installed. Work is constantly being performed on the selection of the more highly effective and less corrosion-active deactivation solutions, and so on.

The radiation situation in the external environment around Kola Nuclear Power Plant is controlled in a radius to 75 km from the Kola Nuclear Power Plant. The gaseous discharges of the Kola Nuclear Power Plant and the results of the environmental studies, and namely the waste water of the industrial site and Lake Imandra, the air and atmospheric fallout and vegetation in 1973-1977 are presented in Table 2.

From the table it is obvious that the gas-aerosol discharges are appreciably below the norm, and the content of the radioactive materials in the basic objects of the external environment does not change after starting up unit I, and it was caused by the products of global fallout and of cosmogenic origin ($Ce^{141,144}$, Ru^{103}, Be^{7}). Here their content in the atmospheric air and water objects is less by 10,000 times than the mean annual admissible concentration for individual people in the population.

In spite of the favorable radiation situation in the external environment, measures have been planned and are being implemented which will permit not only increased sensitivity of the monitoring methods, but also the quality.

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ELECTRIC POWER

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STRUCTURE OF THE ELECTRIC NETWORKS OF USSR POWER SYSTEMS

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[Text] The extent of the electric networks of the 110 kv power systems and higher with respect to the state of the art at the beginning of 1979 was 418,000 km, and the installed power from the transformers at the step-down substations of the indicated voltages was about 560 GV·A. In order to obtain data on the structure and the operating conditions of the electric networks and discover the trends in their development the Energoset'proyekt Institute performed work reflecting the condition of the 110 kv and higher electric networks on 1 January 1979. A number of the generalized indexes of the development of the electric networks turned out to be possible to compare with the corresponding data for the preceding 10-year period.

As is known, for voltages of more than 110 kv two systems have become widespread in the USSR: 110-220-500 and 110(150)-330-750 kv. The first system of voltages is used in the majority of the integrated power systems (OES) of the country, and the second in the integrated power systems of the Northwest and the South. In the electric networks of the integrated power systems which are at the junction of two voltage systems, a mixed system is used (the OES of the Center, the Northern Caucasus). About 70% of the load is in the power systems with the voltage system of 500/220/110 kv.

With respect to the situation on 1 January 1979, for every kilowatt of installed power of the electric power plants in the 110 kv and higher electric networks there were 2.28 kv·A of transformer power, including on voltages of 110(150) kv, 1.31; 220 kv, 0.51; 330 kv, 0.21 and 500(400)-750 kv, 0.25 kv·A. It must be noted that the corresponding magnitude in 1968 was 1.5 kv·A, and in 1975, 2.1 kv·A. The increase in the investigated index characterizes the high rates of development of the electric networks of the power systems and, above all, the high-voltage networks.

At the same time significant growth of the specific installed power of the transformers in recent years indicates the prevailing nature of the trend in the assimilation of new voltage stages with respect to the trend in increasing the use of the deep inputs. Further growth of the indicated value can have negative consequences, for this leads to an increase in the generalized power transformation coefficient in the networks and, as a consequence, to an increase in loading of the transformer plants and an increase in the electric power losses.

The 110 kv networks were developed in all of the power systems and the power junctions operating in isolation in the country. The 150 kv voltage is used only in the Dneprovskaya and Kola power systems and partially, in the regions adjacent to the Dneprovskaya power system. The primary purpose of the 110 kv networks is external electric power supply of the basic group of industrial users,. output of the power of the electric power plants and, above all, the industrial and municipal heat and electric power plants, external power supply of the electrified sections of the railroads, electric power supply of the objects of rural electrification, and so on.

The extent of the 110(150) kv overhead lines on 1 January 1979 in the single-circuit reckoning was 287,000 km. In the first years of the five-year plan (1976-1978) the extent of the 110 kv network increased by 33,700 km, that is, the mean annual increase in extent of the overhead power line was about 11,000 km. The highest rates of construction of the 110 kv overhead line in recent years occurred in the OES of Siberia, Central Asia, the Urals and Central Volga where, along with encompassing new territories, a large volume of purposeful construction of 110 kv networks was realized for the electric power supply of the objects of irrigation, extraction and transportation of oil and gas, the external electric power supply of the electrified sections of the railroads, and so on.

About 27% of the 110 kv overhead lines were made two-circuit with respect to extent. The indicated relation has not in practice changed in recent years, for in spite of the predominant construction in the cities and the industrially developed junctions of the two-circuit overhead lines, the basic volume of construction of the 110 kv lines took place in rural areas where primarily the single-circuit overhead lines are constructed.

The average length of the 110 kv overhead lines in 1968-1978 did not change and amounted to about 30 km. This index was determined by the extent of the overhead lines for one feed center, which include the 110 kv and higher electric power plants and substations having 110 kv distribution stations. The stable nature of the average length is determined by the joint effect of the factors of an opposite nature. Thus, with an increase in density of the network, the index of average length decreases. At the same time the construction of the extended rural lines and the second circuits to the substations in order to increase the reliability of the electric power supply to the users is determined by its growth.

The weighted mean of the wire cross section of the 110 kv overhead lines in 1968 to 1978 in practice did not change and amounted to 146 mm^2. At the same time in the investigated period the proportion of overhead lines with small (70-95 mm^2) and large cross sections (240-500 mm^2) decreased correspondingly from 21.4 to 17.3% and from 8.8 to 6.8% of the total extent of the overhead lines.

The relations with respect to number and installed power of the 110 kv transformers with different combinations of rated voltages are presented hereafter (in percentages).

Combination of voltages	Power	Number
110/35/NN	58.4/52.7	55.8/54.1
110/25/NN	3.7/3.2	2.5/2.2
110/10	16.1/21.2	19.7/24.9
110/6	21.8/22.9	21.0/18.8

Note. The numerator in 1968; the denominator is 1978.

A gradual reduction in the use of the 35 kv networks for external electric power supply of the industrial users and in the electric power supply systems of the large cities of the country was felt in a reduction in the proportion of 110/35/NN triple-winding transformers. In the investigated period the relative proportion of the deep input substations with secondary 10 kv voltage increased, which indicates the higher rates of development of the 110 kv network by comparison with 6 kv. The noted trends will be manifested to a higher degree also during the prospective period.

About 65% of the 110 kv substations have two or more transformers; by comparison with 1968 the indicated value increased by 13%, which indicates an increase in reliability of electric power supply of the users.

The 220 kv networks are available in all of the OES of the country, and only in the unified power systems of the Northwest and the South have they received limited development. The basic purpose of the 220 kv networks is supplying power to the large junctions of the 35-110 kv network, output of the power of electric power plants, the electric power supply for the enterprises of the energy consuming branches of industry, external electric power supply of the electrified sections of the railroads, and so on. In a number of power systems of the country the 220 kv networks perform system-forming functions.

The extent of the 220 kv overhead lines in the single-circuit execution on 1 January 1979 was 82,200 km. In 1971-1978, 31,000 km of 220 kv overhead lines were put in operation (about 4,000 km per year). The highest growth rates of the extent of the 220 kv overhead lines are characteristic of the unified power systems of Siberia, Central Asia and the Far East where this value was 20 to 25% higher than the average for the country.

About 15% of the 220 kv overhead lines with respect to extent were made two-circuit. The construction rates of the 220 kv overhead lines on the two-circuit supports are growing constantly. Thus, in the last 8 years the relative length of the two-circuit 220 kv overhead line increased from 12.3 to 15%. In 1976-1978, the introduction of the two-circuit 220 kv overhead line amounted to 31% of the total. The indicated trend is stable and is determined by the increase in the distribution functions of the 220 kv network.

Increasing the density of the 220 kv network leads to a reduction in the average length of the overhead line. Thus, in 1968-1978, the average length of the 220 kv overhead line throughout the country decreased from 130 to 103 km. With respect to the individual unified power systems in 1978 this index changed from 81 to 114 km.

The weighted mean cross section of the wires of the 220 kv overhead lines in 1968-1978 decreased from 398 to 358 mm^2, which corresponds to the ever-increasing nature of the distribution functions of the 220 kv network. During the years of the Ninth Five-Year Plan the construction of overhead lines with a wire cross section of 240 and 300 mm^2 was of a prevailing nature and amounted to 67% of the total input. The weighted mean cross section of the 220 kv overhead line introduced in 1976-1978 is equal to 325 mm^2.

The comparative data with respect to number and power of the transformers and water transformers of the 220 kv substations with different combinations of rated voltages are presented below (in percentages).

Combination of voltages	Power	Number
220/110/NN	88.5/88.0	78.9/77.5
220/35-27/NN	6.6/6.3	17.2/17.7
220/NN	4.9/5.7	3.9/4.8

Note. Numerator 1968, denominator 1978.

The power of the 220/110/NN autotransformers (AT) is about 88% of the total 220 kv transformer power which is determined by the basic purpose of the 220 kv networks -- feed of the large 110 kv junctions. The installed power of the 220/35-27/NN transformers which are primarily used to amplify the feed of the 35 kv distribution network in rural areas and for electric power supply of the electrified sections of the railroad will be about 6% of the total power and 17.7% with respect to number. The latter is determined by the relatively low unit power. The comparative data with respect to use of the unit power of the 220 kv transformers in 1968 (numerator) and 1978 (denominator) are presented below (in percentages).

Rated power of the 220 kv transformers, MV·A	Power	Number
20-32	3.2/3.0	14.7/14.3
40-63	11.5/1.7	22.1/23.7
90-125	43.9/4.7	41.8/38.8
140-200	18.6/2.9	11.2/14.7
240 and higher	22.8/18/7	10.2/8.5

During the investigated period, the introduction of the "low" power transformers (20-63 MV·A) into the OES of Central Asia, Northern Kazakhstan and the Far East where they are widely used for electric power supply for the pumping stations of the irrigation systems, electrified sections of the railroads, electric power supply for the energy-consuming users, and so on, increased significantly. It must be noted that in 1976-1978 the proportion of the 200 MV·A transformers increased, the proportion of which was about 38% of the total input.

The relative weight of the single-transformer substations in 1968-1978 dropped from 47 to 34%. The average power of the substations increased from 169 to 181 MV·A. The insignificant growth of the average power of the 220 kv substations in 1968-1978 is explained by the increase in use of the 220 kv network for the electric power supply of the electrified sections of the railroads and industrial enterprises, at the substations of which the 32-63 MV·A transformers are widely used.

About 74% of the substations are made by the systems with 220 kv breakers, including 25% connected to the network by simplified circuits (1-2 breakers) and 49% have developed bus systems, on which three or more breakers are installed. The number of 220 kv substations with simplified circuit diagrams without breakers decreased from 29 to 26% in the investigated period.

The 330 kv networks received preliminary development at the integrated power system of the South and Northwest, the proportion of which is about 80% of the total extent of the 330 kv overhead lines. The basic purpose of the 330 kv networks is supplying power to the large 110 kv load junctions, distribution of the power of the electric power plants and insurance of intersystem couplings.

The extent of the 330 kv overhead lines in the single-circuit execution on 1 January 1979 was 22,300 km. During the Ninth Five-Year Plan the annual extent of the overhead lines increased by 1,000 km. The total introduction of the 330 kv overhead lines in 1976-1978 was 2,600 km. The average life of the 330 kv overhead lines in 1968-1978 did not change in practice, and is on the level of 128 km. The stability of the indicated index is determined by the fact that along with the increase in the number of 330 kv substations and, as a consequence, reduction in average length, the construction of a number of extended 330 kv overhead lines and also the introduction of the secondary circuits for the operating substations into operation were realized. In the future it is necessary to expect a reduction in average length of the overhead lines.

For the 330 kv lines basically wires 2x300 and 2x400 mm^2 in cross section are used, the proportion of which is about 81% of the entire extent of the overhead line data. In spite of the broad use of the 330 kv voltage for distribution of power of the largest nuclear power plants of the South and Northwest and, the corresponding large introduction of 330 kv overhead lines with wires 2x400 mm^2 in cross section, the weighted mean cross section of the 330 kv overhead lines in 1968-1978 in practice remained unchanged (698 mm^2 in 1968; 694 mm^2 in 1978).

The ratio of the indexes of the 330 kv AT with respect to combinations of rated voltages in 1968 (the numerator) and 1978 (the denominator) is presented below (in percentages).

Combination of voltages	Power	Number
330/110/NN	66.2/55.9	53.2/65.3
330/150/NN	19.6/18.9	27.2/14.9
330/220/NN	14.3/25.2	19.6/19.8

About 75% of all of the installed transformer power to 330 kv is fed by the 110-150 kv network junctions. The relative magnitude of the 330/220/NN AT, which are the junction units for the two systems of voltages, is highly significant with respect to power and number. It can be noted that the introduction of the 330/220/ kv transformers, providing for the junction of two systems of voltages, during the years of the 10th Five-Year Plan was reduced, which must be considered a favorable phenomenon.

The data on the use of the unit power of the 330 kv AT are presented below (in percentages).

Unit power of the AT, MV·A	Power	Number
60	1.8/0.4	5.2/1.0
125(120)	30.2/21.4	42.8/32.3
200	19.6/32.1	16.8/30.5
240	48.4/39.5	35.2/31.3
250	-/6.0	-/4.6
400	-/0.6	-/0.3

Note. The numerator -- 1968; the denominator -- 1978.

The average power of the 330 kv AT in 1968-1978 increased from 175 to 187 MV·A. In the unified power system of the South, the power of the "average" AT is above average with respect to the country, and it amounts to 196 MV·A. What has been indicated is determined by the energy-consuming nature of the large group of users. In 1968-1978 the relative magnitude of the substations with one AT was decreased from 55 to 23%, and with two, increased to 58%, and with three or more, to 19%. The reduction in the number of single-transformer substations indicates an increase in the operating reliability of the feed centers of the 110 and the 150 kv network. The growth of the number of substations with three or more transformers is determined by the absence up to the present time of the three-phase 330/110 kv AT with a power of 400 MV.A and also the favorable technical-economic indexes of the 4x200 MV·A substations. The average power of the 330 kv substation in 1968-1978 increased from 272 to 385 MV·A.

About 80% of the 330 kv substations are substations with developed bus systems (one and a half, and so on), 17% of the substations have simplified circuit diagrams (up to three breakers), and the rest are attached to the network without breakers.

The 500 kv networks received development at the OES of the Center, the Central Volga, the Urals, Siberia, Central Asia, Northern Kazakhstan, the South, Trans Caucasus, Far East and Northern Caucasus. The basic purpose of the 500 kv network is the system forming and intersystem functions and also the distribution of power of the largest electric power plants. Along with the unified power systems indicated in the series where the 500 kv networks operate for a prolonged period, their distribution functions are gradually manifested. This function of the 500 kv network will be intensified in the future. The 400 kv electric networks are used only in the unified power systems of the South, and the realized communications with the networks of the CEMA member countries.

The extent of the 500 (400) kv overhead lines on 1 January 1979 was 23,700 km, and the mean annual introduction in the last 10 years was about 1,200 km. The average length of the 500 kv overhead lines in 1968-1978 varied insignificantly, and in 1978 it was about 280 km. The stability of the indicated index, in spite of the growth of the number of substations was determined by the construction during this period of the number of extended 500 kv overhead lines which can include the Konakovskaya State Regional Hydroelectric Power Plant -- Cherepovets, the Yermakovskaya State Regional Hydroelectric Power Plant -- Omsk, the Votkinskaya Hydroelectric Power Plant -- Kirov and others. In the unified electric power plants of the Center and the Urals, the average length of the 500 kv overhead lines are 10% lower than on the average throughout the country.

All of the 500 kv overhead lines are made with steel-aluminum wires. The trend in the structure of the used cross sections of the current conducting part is characterized by a reduction in the weighted mean cross section of the wires of the overhead lines. Thus, in 1968-1978, the weighted mean cross section dropped from 1488 to 1253 mm^2. The proportion of the

3x300 and 3x330 mm^2 cross sections is about 62% of the total introduction of the 500 kv overhead lines in 1976-1978.

The variation in structure of the installed transformer power with respect to combinations of rated voltages in 1968-1978 is presented below (in percentages)

Combination of voltages	Power	Number
500/110/NN	39/15.4	51.4/26.6
500/220/NN	61/83.9	48.6/72.7
500/330/NN	-/0.7	-/0.7

Note. Numerator -- 1968; denominator -- 1978.

The growth of the use of AT with a combination of voltages 500/220 kv and a corresponding decrease in the relative amount of use of the 500/110 kv AT leads to a reduction in the economic indexes of the network as a result of an increase in the installed transformer power on a voltage of 220 kv and growth of the electric power losses during transformation. In 1976-1978, the introduction of the AT 500/220 kv was about 93% of the total.

The data with respect to the use of the unit power of the 500 kv AT are presented below (in percentages).

Unit power of the AT, MV·A	Power	Number
250-270	28.3/12.3	40.5/22.4
300-405	49.9/17.7	48.6/21.2
501	-/44.8	-/41.5
750-801	21.8/25.2	10.9/14.9

Note. Numerator 1968; denominator, 1978.

Out of the 500 kv substations operating on 1 January 1979, the single-transformer substations amount to 21%, the two-transformer substations amount to 63%, and with three or more transformers, 16%.

The majority of the substations are executed with developed bus systems, which is determined by the high reliability requirements imposed on the 500 kv network. About 15% of the substations are connected to the network by the simplified circuits (1-2 breakers), and one substation, without breakers.

The 750 kv networks received development in the unified power systems of the South, the Northwest, and the Center and performed system-forming functions.

The total extent of the 750 kv overhead lines on 1 January 1979 was 1,930 km. About 68% of the extent of the overhead lines was made up of a cross section of 4x400 mm^2; there are overhead lines with a cross section of 5x240 mm^2, and overhead lines are being constructed with a cross section of 5x300 mm^2. The average length of the 750 kv overhead lines on 1 January 1979 was 323 km.

In 1978 the installed power of the 750 kv AT was 13 GV·A, including 11.7 at the 750 kv substations and 1.3 GV·A at the electric power plants. About 68% of the power of the AT installed at the substations have a combination of 750/330 kv voltages, and the rest, 750/500 kv, by means of which junctions of the two voltage systems are realized.

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QUALITY STRUCTURAL DESIGNS OF 750 KV LINES, EFFICIENCY IMPROVEMENT

Moscow ELEKTRICHESKIYE STANTSII in Russian No 7, 1980 pp 41-45

[Article by V. V. Burgsdorf, doctor of technical sciences, N. P. Yemel'yanov, candidate of technical sciences, L. V. Timashova, engineer]

[Text] The extent of the 750 kv lines which are acquiring decisive significance for the power output of the largest stations and development of the unified power system of the European part of the Soviet Union and its coupling to the power systems of the countries of the socialist alliance is increasing greatly. It is therefore very important to develop measures for further improvement of their efficiency.

The scientific studies of recent years have provided for significant limitation of the overvoltages and the reduction of the insulation distances, the availability of electric field intensity of approximately 15 kv/m at ground level has been confirmed. The production of economical insulators for high loads permitting the application of the most expedient single-circuit chains has been mastered. Significant progress has been made in the construction of supports. All of this is opening up the prospects for creating more compact lines which will be essentially promoted by the introduction of synthetic insulators.

It is especially important for improvement of the 750 kv lines correctly to select the wires, the structural design of the phases and the distance between them. Accordingly, the new data with respect to the actual levels of radio and acoustic interference and losses to corona are acquiring great significance.

At the present time on the 750 kv lines splitting of the phase into four and five wires is used. The splitting into four wires was used on all of the 750 kv lines built in Canada, the United States and in the southern power systems of the USSR. The splitting into four wires is simple and constructive. It insures good technical and economic indexes, especially for the wires of large cross section on which emphasis has been placed abroad in connection with an increase in the transmitted power.

The wires 32-35 mm in diameter permit us to obtain comparatively small losses and interference to corona with spacings of 12 to 13 meters between phases which are sufficient also for preventing flashovers on the support and in the span.

When using wires of smaller diameter to limit interference and losses to corona, it is required to increase the spacing between the phases. As the experience of the USSR has demonstrated, this path is expedient for economy of conductor materials and reduction of the load on the supports make it possible to decrease the cost of the lines.

The next step in the development of the 750 kv electric power transmission lines is the use of five wires in a phase. The construction of the phases from five wires on the 750 kv lines as highly prospective was proposed by the VNIIE Institute in 1967 [1], but there were insufficient available data then for completed development of it.

The studies performed by 1970 permitted the VNIIE Institute to develop a structure with five wires in a phase on the 750 kv lines and to make constructive proposals to the Energoset'proyekt Institute insuring economy of conducted materials with good corona indexes. In particular, the construction of a line with minimum consumption of aluminum with splitting of the phase into five ASU-240 wires (d=22.4 mm) arranged with a spacing of 30 cm and an interphase distance of 19.5 meters was completely substantiated. The phase cross section with respect to the aluminum was a total of 1200 mm^2, that is, it turned out to be even less than in a number of the constructed 500 kv lines. This construction was used later on the 750 kv electric power transmission line between Leningrad and Konakovo on which the northwest branch of the Energoset'proyekt Institute achieved very high technical and economic indexes.

Subsequent statistical studies of the VNIIE Institute on the 750 kv lines and experimental sections at 1150 kv confirmed the correctness of the decisions made and made it possible to advance new proposals with respect to the construction of 750 kv lines. They are based on maintaining the noise levels within admissible limits and restricting the energy losses to heating and corona to economically expedient values.

Interference Levels. According to the requirements of the All-Union State Standard for Industrial Interference (All-Union State Standard 22012-76, 16842-76) their intensity from the electric power transmission lines must not exceed 45 decibels (CISPR)[1] at a distance of 100 meters from the projection of the edge phase on the ground for 80% of the time in the year on a frequency of 0.5 megaHertz. The observation of this condition insures maintenance of admissible levels of radio interference in the entire frequency spectrum.

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1 With respect to the instrument satisfying the requirements of the International Special Committee on Radio Interference (CISPR).

Abroad usually requirements are imposed on radio interference at a frequency of 1 megaHertz. For the 750 kv lines in Canada 26 meters from the edge phase the intensity of the radio interference must not exceed 67 db (ANSI)[1] for 99% of the rain time [2], and in the United States, 55 db (ANSI) for 50% of the rain time and a distance of 30 meters from the edge phase [3]. For the 1200 kv lines in the United States the same norm is maintained, but at a distance of 43 meters, that is, more intense interference is permitted. The interference level with 50% guarantee with respect to rain is classified as interference from wet wires.

Thus, it is natural that all of the recommendations are based on statistical laws for which one-time measurements are entirely inadequate. Therefore in the USSR and abroad special significance is attached to the mass recording of interference. In the Soviet Union it was organized by the VNIIE Institute in 1963, on the 500 kv lines in 1968, on the 750 kv lines with phase splitting into four wires and in 1976 with five wires in a phase. As a result, a large amount of factual material has been obtained which includes many tens of thousands of recordings for each type of line.

The interference was recorded with intervals of 5 minutes and encompassed all of the encountered forms of weather. With respect to scales of the studies and the materials obtained, this work plays one of the primary roles in the world and its results must be considered as entirely reliable for characterization of the interference levels from electric power transmission lines. In order to determine the intensity of the interference as a function of voltage, line parameters and remoteness of the investigated object, the formula can be used which is presented in the "Guidance Instructions for Considering Losses to Corona and Interference from Corona when Selecting the Wires of the AC, 330-750 kv and DC 800-1500 kv Overhead Electric Power Transmission Lines" (1975)

$$E_{п}^{(1)} = E'_{п} + K_E(E - E') + 40\lg\frac{d}{d'} + 20K\lg\frac{R'}{R} + 20(K-1)\lg\frac{H}{H'}, \quad (1)$$

Key: 1. π

where E_{π} is the interested level of radioactive interference at a distance R from the line with wires having a diameter d, height of suspension of the wires (dimensions) H and electric field intensity on the wire surface E; E'_{π} is the measured statistical level of radio interference at a distance R' from the line having a wire diameter of d', a height of suspension of the wires H' and electric field intensity on the wires E'; K_E is the

[1]According to the instrument satisfying the requirements of the National Standards Institute of the United States (ANSI).

coefficient of the rate of variation of the radio interference level with variation of the electric field intensity on the wires; K is the coefficient of transverse damping of the radio interference equal to 1.6 for lines with horizontal arrangement of the phases.

The coefficient K_E was investigated in detail by the VNIIE Institute. New numerous measurements with fast voltage variations made it possible to be convinced that the previously obtained value of 1.8 [4] is confirmed well by recent data. When using the coefficient 1.8-2, the results of the measurements are well generalized for various 500 kv lines in Moscow Oblast and also the 750 kv lines from Leningrad to Konakovo and the Donetsk Basin to the Dnepr. Good results were also obtained when comparing our data with the results of recordings in the United States on the industrial and experimental 750 kv line and on the experimental 1200 kv lines with splitting of the phases into 8 wires 41 mm in diameter [5, 6].

Thus, the suitability of formula (1) was confirmed by the data for essentially different structural designs of the lines, electric field intensities, number of wires in the phases and distances between them. For its use in practice it is necessary to take as the basic lines, those for which sufficiently complete measurement data are available and those which operate under similar conditions to the ones in which we are interested. The fact is that in addition to the line parameters the intensity of the radio interference is affected by air pollution and humidity along the route.

According to the data obtained by the VNIIE Institute it is necessary to distinguished especially clean, clean and moderately polluted areas. For each of them, being guided by the previously presented requirements of the norms and the obtained distribution curves for the noise intensity during the year, the admissible field intensities were determined on the middle phase depending on the radius of the wire for horizontal arrangement of the phases. When constructing the curves in Fig 1, the value of K_E=2.0 was used. This value is close to the practical upper limit with respect to the measurements made, and it insures a reserve by comparison with 1.8. For electric power transmission lines with phase arrangement differing significantly from horizontal, it is necessary to consider the difference in the damping coefficients of the radio interference with distance.

In Fig 1 curve 5 is characteristic for the 750 kv Donbass-Dnepr and Konakovo-Leningrad (in the Konakovo-Kalinin section) lines subject to moderate industrial pollution. The investigated segment of the Konakovo-Leningrad line runs through the swamps, that is, it is in a zone of increased moisture.

Curve 2 was constructed by the measurements on the 500 kv lines in the agricultural zones of Moscow Oblast. Finally, curve 1 was obtained for the

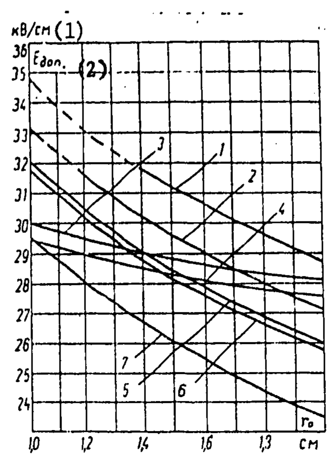

Figure 1. Admissible electric field intensities on the surface of a wire as a function of its radius.
1 -- especially clean area; 2 -- clean area; 3 -- by the criterion $E_{ad} \leq 0.9\ E_0$ for $\delta=1.04$; 4 -- by the criterion $E_{ad} \leq 0.9\ E_0$ for $\delta=1.02$; 5 -- moderately polluted area; 6 -- 1150 kv overhead line according to the American normatives; 7 -- 750 kv overhead lines according to the American, Canadian normatives.

Key:
1. kv/cm
2. E_{ad}

route of the Konakovo-Moscow line. It characterizes an especially clean area where the highest field intensities can be permitted. According to many years of data, they turned out even to be somewhat higher than previously recommended in the guidance instructions.

It is expedient to compare the curves obtained with the previously presented requirements adopted in Canada and the United States where there is significant experience in the construction, operation and maintenance of the 750 kv lines.

The analysis of the Canadian recommendations has demonstrated that in practice they coincide witht he American recommendations for 750 kv. The requirements for the 1200 kv lines are lighter in the United States Beginning with these recommendations, admissible electric field intensities on the wires were defined for the 750 kv (curve 7) and 1200 kv (curve 6) lines in Fig 1.

Considering the entire set of relations obtained, it is possible to draw the following conclusions.

The most rigid requirements are being imposed in Canada and the United States for the 750 kv lines. The admissible field intensities beginning with the intensity of the radio interference required in the USSR for moderately polluted areas and in the United States for 1200 kv lines in practice coincide. In rural areas (Fig 1, curves 1 and 2) according to the data of the VNIIE Institute the admissible intensity can be increased by 1-2.5 kv/cm.

It is improper to be oriented to the Canadian and American recommendations with respect to the 750 kv lines. These requirements do not correspond to the positive experience in the maintenance of lines in the USSR and the majority of 750 kv lines (first phase) in the United States successfully operating about 10 years with higher field intensities. These recommendations are oriented essentially to the electric power transmission lines recently built in Canada and the United States with very large wire cross sections.

Acoustic noise, according to measurements in the USSR and the United States, is not defining for the 750 kv lines when the phase is split into four or five wires. If we take them as the criterion, it would be possible to permit higher field intensities on the wires than by the condition of restriction of the radio interference to the normalized level. The acoustic interference can, however, have a serious value for the 1200 kv lines.

In addition to what has been stated, in the USSR the practical criterion of limiting the field intensity of the wires to 90% of the initial corona intensity is used for average operating conditions, that is,

$$E_{доп}^{(1)} \leq 0{,}9 E_0, \qquad (2)$$

Key:
1. ad

where E_0 is the initial field intensity of the occurrence of corona on the wire with a mean annual air intensity δ on the route of the line. The magnitude of the latter in the central and northern parts of the European territory of the USSR is equal to about 1.04, and in the southern part, 1.02.

Curves of the admissible field intensities with respect to the criterion (2) were constructed for these values of the air density in Fig 1 in addition to the curves of the electric field intensities on the surface of the wires admissible by the condition of restricting the radio interference. The results obtained are of great interest. As is obvious from

Fig 1, the admissible values of the electric field intensity on the surface of the wires even in the regions with atmospheric pollution are determined from the condition of restricting the radio interference only for large-diameter wires (to the right of the point of intersection of curves 3 or 4 with curve 5). For the wires of smaller diameters (radius less than 1.4 cm with respect to curve 3) the criterion (3) is decisive for selection of the wires. In especially clean areas the values of the admissible electric field intensities are entirely defined by the criterion (2).

The correctness of this in practice steady-state criterion, considering its defining significance, will be in need of special analysis.

Losses to Corona. The problem of determining the losses to corona for a significant phase is highly complicated inasmuch as the conditions of development of corona on the surface of the wire vary with variation of the electric field intensity around its periphery and the number of split wires. Therefore direct measurements of losses under field conditions considering the statistical relations of each type of weather had especially great significance. Similar measurements were performed on a broad scale by the VNIIE and NIIPT Institutes for splitting of the phase into three and four wires on experimental spans and by the ENIN Institute on the existing lines. They introduced significant clarity into the loss characteristics for such lines and made it possible to propose generalized calculated functions which were used to determine the losses to corona on the 750 kv lines [4, 7, 8].

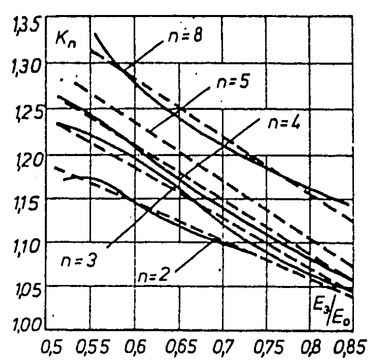

Figure 2. Graphs of the splitting coefficient K_n as a function of the ratio $E_э/E_0$ for a different number n of wires in the phase

When determining the losses to corona according to [5, 7, 8] the most significant differences are included in the procedure for determining the equivalent intensity of the electric field and the exponent for the number of split wires. The VNIIE Institute has used values of the equivalent field intensity $E_э$ obtained by integration of the loss characteristics $P=f(E)$ around the circumference of the wire. However, this turned out to be insufficient, for the differences in the processes of the formation of the volumetric charge of single and split wires and the polarization of the charge on the surface were not taken into account. Therefore it was necessary to introduce the correction factor K_n which depends on the number of wires and the degree of development of the corona $E_э/E_0$.

It is possible to take the intensity $K_nE_э$ as the calculated intensity. With this approach the loss characteristics for a single wire and a split phase can be represented by one generalized function. Fig 2 gives the experimentally obtained values of the coefficients K_n with splitting of the phase to eight wires. They can be represented with sufficient accuracy by straight lines. The relation for the five wires was obtained by interpolation.

For precipitation the ratio $E_э/E_0$ increases as a result of a decrease in the actual value of E_0, and the coefficient K_n approaches one; therefore with precipitation it can be neglected and the calculation performed using the guidance instructions.

In [4] the losses were taken proportional to the number of wires in the phase at the same time as in [7] a quadratic function was used. In the latter paper no significant reduction in losses to corona with a decrease in the splitting step size was discovered. In [4] the effect from variation of the step size and the number of wires of the split phase was significant. This result is very important for constructing the 750 kv lines, and it discovered limited growth of losses in such transmissions. The moderate level of losses to corona in the 750 kv lines was predicted also in [9].

The calculated values of the mean annual losses in power to corona for areas with temperate climate in the 750 kv lines are presented in the table.

Selection of the Parameters of the 750 kv Lines. For the characteristic of practical leads from the performed studies in the table a study is made of the number of the structural designs of the 750 kv lines, both applied and certain prospective ones. The electric field intensities on the wires are presented for horizontal and triangular arrangement of the phases which are compared with the admissible ones according to Fig 1. It was assumed that the mean annual air density is 1.04, and the interference must be calculated for conditions of a moderately polluted area. The natural power of the lines of different structural designs and the power transmitted over them beginning with economical current density of 0.7-0.8 amps/mm^2 are defined, and the losses to corona and heating of the

Провод (1)	Радиус провода r_0, см (2)	Допустимая напряженность электрического поля на проводах, кВ/см (3)	Расстояние между фазами, м (4)	Шаг расщепления, см (5)	Индуктивное сопротивление, Ом/км (6)	Наибольшая напряженность электрического поля на проводах средней фазы E_{2m}, кВ/см (7)	$\frac{E_{2m}}{E_0}$ (8)	Натуральная мощность $P_н$, МВт (9)	Потери на корону, кВт/км (10)	Расчетная передаваемая мощность, МВ·А (11)	Потери на нагрев, кВт/км (12)
5×AC-240/56 (13)	1,12	29,7	16,5	30*	0,30	29,4	0,89	2030	13,9	1070—1230	22,4—29,4
			19,5	30	0,309	28,9	0,88	1970	11,6		
				40*	0,295	28,9	0,88	2070	14,5		
5×AC-300/39	1,2	29,5	12	30*	0,280	29,5	0,9	2160	16,4	1350—1550	28,6—37,4
			13,5	30	0,285	29,6	0,9	2120	15,1		
				30*	0,286	29,1	0,89	2110	14,8		
				40*	0,272	29,4	0,9	2230	17,6		
			16,5	40	0,283	28,8	0,88	2150	14,6		
				60*	0,264	29,4	0,9	2310	19,8		
			19,5	40	0,293	27,8	0,85	2080	12,4		
				60	0,273	28,9	0,88	2240	17,3		
5×AC-400/93 (13)	1,455	28,7	10	30	0,264	27,4	0,85	2280	13,9	1850—2110	39,3—51,3
				40	0,249	27,8	0,86	2410	17,1		
				30*	0,266	26,6	0,83	2250	12,7		
				40*	0,252	26,9	0,84	2390	15,5		
				60*	0,232	28,2	0,88	2600	21,8		
			12	30	0,276	26,1	0,81	2190	10,9		
				40	0,260	26,5	0,82	2320	13,2		
				60	0,240	27,6	0,86	2510	19,1		
				80*	0,227	28,1	0,87	2660	24,4		
			13,5	40	0,268	25,7	0,8	2250	10,8		
				60	0,247	26,7	0,83	2450	14,8		
				80	0,233	27,9	0,87	2600	22,0		
			16,5	40	0,281	24,5	0,76	2150	8,5		
				60	0,260	25,4	0,79	2330	11,3		
			19,5	40	0,291	23,7	0,74	2090	7,1		
				60	0,271	24,5	0,76	2260	9,4		
5×AC-500/64	1,53	28,3	10	40	0,248	26,7	0,84	2420	15,2	2230—2550	47,5—62,5
				60	0,228	28,0	0,88	2640	22,4		
				40*	0,252	25,9	0,81	2390	13,8		
				60*	0,231	27,0	0,84	2610	20,5		
			12	60	0,239	26,5	0,83	2520	16,9		
				80	0,225	27,7	0,87	2690	23,2		
			13,5	40	0,267	24,7	0,77	2260	9,6		
				60	0,246	25,6	0,8	2460	14,2		
				80	0,232	26,7	0,84	2610	19,4		
				100	0,221	27,8	0,87	2750	25,4		
			16,5	40	0,280	23,5	0,74	2160	7,6		
				60	0,259	24,3	0,76	2340	10,0		
				80	0,245	25,3	0,79	2490	14,6		
				100	0,234	26,3	0,82	2610	18,9		
			19,5	40	0,290	22,8	0,71	2100	6,4		
				60	0,270	23,4	0,73	2270	8,3		
4×AC-400/93 (13)	1,455	28,7	16,5	40	0,299	28,3	0,88	2030	17,7	1480—1690	31,6—41,4
			19,5	40	0,309	27,4	0,85	1970	15,0		
				60	0,290	28,1	0,87	2110	18,0		
4×AC-500/64	1,53	28,3	16,5	60	0,279	27,9	0,87	2180	19,0	1780—2040	38,0—49,6
			19,5	60	0,289	26,9	0,84	2120	15,8		
				80	0,275	27,8	0,87	2220	21,9		

[See key on following page]

[Key to table on preceding page]:

1. Wire
2. Wire radius r_0, cm
3. Admissible intensity of the electric field on the wires, kv/cm
4. Distance between phases, meters
5. Splitting step size, cm
6. Inductive resistance, ohm/km
7. Greatest intensity of electric field on the wires of the middle phase E_{2m}, kv/cm
8. E_{2m}/E_0
9. Natural power P_H, MVt
10. Losses to corona, kilowatt/km
11. Calculated transmitted power, MV·A
12. Losses to heating, kilowatt/km
13. AS

*Middle phase raised by 4 meters, spacing between adjacent phases indicated among the horizontal.

Note. Value of the admissible electric field intensity on the surface of the wires, ratio of the greatest intensity of the electric field on the wires of the middle phase to the initial intensity E_{2m}/E_0 and the losses to corona are presented for relative air density of 1.04.

wires with the indicated current densities and τ=4000 hours are estimated. Thus, the data in the table give an exhaustive characteristic of the basic parameters of the 750 kv lines and the losses in them with different structural execution.

The natural power of the 750 kv lines of the structures presented in the table varies from 2000 to 2700 megawatts. Its increase (to 25%) is achieved by increasing the splitting step and decreasing the spacing between phases, that is, using entirely construction solutions. The increase in natural power is limited to an increase in the field intensity on the wires and an increase in losses to corona. The losses to corona essentially depend on the structural design of the line, and they can vary from 6 to 26 kilowatt/km, that is, by 4 times.

By corresponding combination of the splitting step and the spacing between the phases it is possible significantly to limit the losses, achieving this by inexpensive means by comparison with increasing the wire cross section, but the natural power of the line decreases simultaneously.

On transmission of relatively low power and with small phase cross section the reduction in losses is highly effective inasmuch as in these cases the natural power significantly exceeds the economical power and, consequently, in this sense there is a defined reserve. As the phase cross section is increased, the natural and economic powers approach each other;

therefore an increase in the splitting step and reduction in distances between the phases are justified. If for the structural design of 5xAS-240/56 distances between phases of 16.5 and 19.5 meters can be used with step of 30 or 40 cm, on a line with 5 wires AS-300/39 it is possible to obtain good solutions not only with an interphase distance of 13.5 m, but even for 12.6 meters, raising the middle phase by 4 meters.

The triangular arrangements of the phases were investigated abroad both by lifting the middle phase [10] and by lowering it [11]. In the USSR the structural design with lifting of the middle phase was realized by the Northwestern Department of the Energoset'proyekt Institute with wires 5xAS-300/39 with a step of 30 cm on the Leningrad Nuclear Power Plant to Leningrad line. According to our data, raising the middle phase with step of 40 cm would be effective for increasing the natural power.

It is expedient to use raising of the middle phase to decrease the intensity of the electric field on it and prove the line characteristics.

The lowering of the middle phase can be of interest in the presence of reserves with respect to electric field intensity on the middle phase (application of wires of larger cross sections 5xAS-400/93 and 5xAS-500/64 with diminished splitting step). The effect of equalizing the intensity of the electric field on the ground level under the edge and middle phases achieved when doing this offers the possibility of decreasing the distance to the ground.

With large wire cross sections the distances of 12 and 13.5 meters between phases become the basic structural solution. Moreover, from the corona conditions they can be reduced to 10 meters. However, the practical implementation of these solutions requires special investigation of the degree of danger of the coming together of the phases in the span. When splitting the phases into four AS-400/93 wires, a distance between phases of 16.5 m can be used only with step of 30 cm, and for the 4xAS-500/64 circuit both with a 40-cm step and a 60-cm step. In all of these cases, however, the line characteristics are noticeably inferior to the design with splitting into five wires with respect tothe maximum attainable natural powers, energy losses and dimensions. When constructing the lines it is necessary to consider that with maximum increase in natural power for the selected spacing between phases, the losses to corona increase noticeably.

Conclusions

1. Long-term measurements of the actual levels of radio interference from corona on the 750 kv lines built in the USSR with four and five wires in the phase permit sufficiently reliable characterization of the admissible values of the electric field intensity on the wires for design.

2. The curves of the electric field intensities that are admissible with respect to radio interference must be classified by areas with different degree of pollution. The greatest values of the admissible gradients can be assumed in especially clean areas.

In the areas even with moderate atmospheric pollution admissible intensities decrease by 2.5 kv/cm and limit the selection of the wires with radii of more than 1.4 cm.

The acoustic interference from the 750 kv lines is not defining.

3. For selection of the wires of small cross sections, the practical criterion $E_{ad} \leq 0.9\ E_0$ is the limiting criterion, which can be considered as the safety margin preventing visible corona in good weather with flucutations of the relative density of the air during the year and operating changes in voltage in the line.

4. The losses to corona in the 750 kv lines have great significance and must be considered when selecting the wires. Their values can be defined by the procedure from the guidance instructions and are more precisely defined in accordance with the data of this article.

5. The performed studies have demonstrated that by varying the arrangement of the phases and the splitting step, it is possible significantly to increase the natural power of the 750 kv line and reduce the losses to corona in it. This is a simple and cheap method.

6. Splitting of the phase into five wires significantly improves the 750 kv transmission parameters. It permits an increase in natural power, a reduction in spacing between phases and losses to corona by comparison with splitting into four wires. With small transmitted power the splitting into five wires insures significant savings of conducting materials.

7. The spacing between phases on the 750 kv lines can be reduced significantly by comparison with existing practice.

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ELECTRIC POWER

PETR STEPANOVICH NEPOROZHNIY -- SEVENTIETH BIRTHDAY

Moscow ELEKTRICHESKIYE STANTSII in Russian No 7, 1980 p 75

[Unsigned article]

[Text] Pet Stepanovich Neporozhniy--minister of power engineering and electrification of the USSR, member of the Central Committee of the CPSU, deputy of the Supreme Council of the USSR, Lenin Prize Laureate, corresponding member of the USSR Academy of Sciences -- celebrated his 70th birthday on 13 July 1980.

He has devoted more than 50 years of his life to the development of power engineering and electrification of our country, traveling the path from construction worker to minister and prominent power engineering scientist.

Petr Stepanovich Neporozhniy was born in 1910 in a peasant family. On graduation from Kiev Polytechnical School and later, Leningrad Water

Transportation Engineers Institute specializing in hydraulic engineering, until 1941 he worked in construction and the operation and maintenance of the irrigation systems in Central Asia, on the construction of the Kadyr'ya Hydroelectric Power Plant and Chirchikstroy, in the Leningrad Department ofthe Gidroenergoproyekt Institute, chief of the technical division of the Glavgidroenergostroy Administration of the People's Commissariat of Electric Power Plants and chief construction engineer of EnsoGES Hydroelectric Power Plant.

During World War II P. S. Neporozhniy was named director and chief engineer of the Central Asian Department of the Gidroenergoproyekt Institute, where he headed up the work on the design of hydroelectric power plants, the construction of which took place on a broad front during the war in Uzbekistan, and in 1944 he was in charge of the construction of the EnsoGES Hydroelectric Power Plant and restoration of the Raykhial Hydroelectric Power Plant.

In 1946 Petr Stepanovich was appointed chief construction engineer of the Verkhne-Svirskaya Hydroelectric Power Plant. He is simultaneously chief engineer of the Svir'stroy Trust, the composition of which included the construction organizations of Enso, Raukhial, Nizhne-Svirskaya and Verkhne-Svirskaya Hydroelectric Power Plants. Since 1952 he has worked as chief construction engineer of the Kakhovskaya Hydroelectric Power Plant.

Under the direction of P. S. Neporozhniy, the method of continuous pouring of concrete was developed and implemented for the first time in Soviet hydraulic engineering construction, a number of scientific research projects were carried out proving the actual possibility of building the Kakhovskiy Hydroengineering Complex on the fine-grained sand, and advanced methods of organizing construction and performance of operations were developed and applied.

Simultaneously, he was a teacher, first the docent of the Central Asian Polytechnical Institute and later department professor of Odessa Polytechnical Institute.

The high businesslike qualities, exceptional physical fitness, energy, comprehensive engineering wisdom, skill in working with people advanced P. S. Neporozhniy to the first ranks of the leaders of power engineering construction. In 1954 Petr Stepanovich was appointed to the job of deputy chairman of the Ukrainian SSR Council of Ministers and representative of the Ukrainian SSR Gosstroy, and in 1959, first deputy minister of electric power plant construction of the USSR. In 1962 P. S. Neporozhniy was appointed minister of power engineering and electrification of the USSR. He has worked at the job to the present time.

During these years Soviet power engineering went through exceptional growth. The production of electric power in 1979 was 1239 billion kilowatt-hours as opposed to 369 billion kilowatt-hours in 1962, and the power of the electric power plants increased from 82.5 million kilowatts to 255 million kilowatts.

An enormous amount of work has been done directly under the supervision of P. S. Neporozhniy to introduce the achievements of scientific and technical progress into power engineering construction. Its direction is characterized by broad application of units with high unit power operating in heat engineering on high and superhigh pressure steam, broad introduction of automation and technical remote control means, mass application of prefabricated reinforced concrete both in the construction of the thermoelectric power plants and networks and in hydroengineering construction, the creation of powerful base for the construction industry.

The scientific-research, planning and design work has been performed, and powerful nuclear power plants have been built such as Beloyarsk, Novovoronezh, Chernobyl', Leningrad, Kursk, Armyanskaya, Smolensk, and so on.

The new structural designs and advanced methods of organizing construction and performance of operations developed under the supervision of P. S. Neporozhniy have made it possible to reduce the times and increase the quality of power engineering construction.

Along with a great deal of organizational work with respect to the development of power engineering in the USSR, P. S. Neporozhniy has directly managed the construction of the most important national economic industrial complexes charged to the power engineering construction collectives. Among them are projects such as the Bratsk and Ust'-Ilim Forestry Complexes and Aluminum Plants, the largest enterprises of the chemical industry in Saratov, Tol'yatti, Nizhnekamsk, Orenburg and other cities and also the largest Volga and Kama Automobile Plants built in unprecedentedly short times.

For all of these years Petr Stepanovich has fruitfully combined engineering and management activity with scientific work. He has hundreds of scientific works published in many books, brochures and power engineering journals to his credit. The most important of them are devoted to the solution of the problems of electrification of the USSR, acceleration of scientific and technical progress in power engineering and power engineering construction, the analysis and the directions of development of the fuel and energy complex of the USSR, all around utilization and conservation of the water resources of the USSR. The materials of his scientific works reflect many problems of construction and technology, they generalize the Soviet and foreign experience in construction and the operation and maintenance of electric power plants, the direction and prospects for the development of power engineering of the USSR. P. S. Neporozhniy has given a great deal of attention to the problems history of development of Soviet electric and power engineering and popularizing Lenin's ideas about electrification of the country.

For his great invaluable scientific work he was elected corresponding member of the USSR Academy of Sciences.

P. S. Neporozhniy is a deputy of the Supreme Council of the USSR of several convenings. He is chairman of the CEMA Commission on Electric Power and director of its Soviet section, chairman of the Council for All Around Utilization of the Water Resources of the Country of the State Committee of the USSR on Science and Engineering. He is initiator of the creation of the Council of the Senior Power Engineers that joins the efforts of more than 30,000 veterans of Soviet power engineering who, under the direction of the council chairman P. S. Neporozhniy perform a great deal of work to popularize Lenin's ideas on electrification.

The tireless engineering, scientific and social activity of Petr Stepanovich has been recognized by high awards from his homeland. He has been awarded the Orders of Lenin, the Red Banner of Labor, the "Symbol of Honor" and many medals of the USSR.

P. S. Neporozhniy is a man with a brilliant biography whose modesty and achievements serve as an example for all who know him. He is a worthy example of a modern leader. High party morals, an attentive attitude to people, outstanding talent as an engineer, scientist, organizer and leader have brought P. S. Neporozhniy great recognition and deep respect.

Soviet power engineers and all who have worked and do work with Petr Stepanovich congratulate him on his 70th birthday and wish him with all their heart good health, happiness, new labor and creative success in the electrification of the country.

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FUELS

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NEW METHOD SUGGESTED FOR ESTIMATING OIL, GAS RESERVES IN ESTABLISHED ZONES

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[Article by V. A. Leshchenko and V. I. Myasnikov, Poltavaneftegazrazvedka: "Technique for Estimating Long-Term Reserves and Their Confirmability in Established Industrial Oil and Gas Bearing Regions"]

[Text] For the geological exploration enterprises the main summary indicator of activity is the fulfillment of the plan for increase and confirmation of oil and gas reserves in the GKZ [State Commission for Mineral Reserves]. However, until now the technique for planning this indicator has been based on imprecise instructions. The reason for such a situation is the insufficiently flexible classification of reserves that does not permit planning of their gradual transfer to higher categories.

In the modern classification [1] category C_2 includes long-term reserves with a very broad range of reliability. Therefore it is practically impossible to plan increases according to the sum of the long-term reserves without their additional classification.

As a result we suggest specifying the available classification of the reserves in category C_2 after isolating the following subgroups.

I subgroup (C_2^I)--visible reserves of category C_2 that can be estimated at the fields and drillable structures from the stripped beds. The output of the beds is conjectured from data of geophysical studies in the wells; in individual wells influxes were obtained for testing in the drilling process.

The reserves are estimated by the volume method within a contour made at the base of the oil and gas saturation interval.

II subgroup (C_2^{II})--expected reserves of category C_2 estimated from individual beds at the fields and structures being drilled, on sections and in tectonic blocks adjacent to the areas with $B+C_1$ reserves or subgroup I. Generally these are reserves on areas delimintèd by reliably set and hypothetical contours. The latter are defined from the coefficient of trap filling or from the gage pressure in the deposits.

III subgroup (C_2^{III})--hypothetical reserves of category C_2 that can be estimated at the fields from promising layers not stripped by the date of the estimate, as well as reserves on the exposed structures whose output is substantiated by their position in the structural-facial zone with established oil and gas content. For purposes of long-term planning subgroup III can include reserves of poorly prepared structures, if there are data on their dimensions and if laws governing the correlation of structural plans for different stratigraphic levels have been established in the studied region.

Based on the suggested classification one can judge the time and volume of work necessary to transfer the reserves of the isolated subgroups into the industrial categories.

Thus, subgroup I reserves can be transferred to cateogry C_1 after testing of the exposed levels. The quantity of these reserves is the basis for fulfillment of the current growth plan.

Subgroup II reserves can be transferred to the industrial categories after drilling of development wells; the number and time of drilling these wells can be stipulated based on their dimensions and the complexity of the promising section.

The periods and volume of work in transferring the subgroup III reserves to industrial categories are governed by the dimensions and complexity of the structural formation, the duration of the prospecting and exploration stages, and the concentration of work.

It is recommended that the subgroup III reserves be estimated in regions with established oil and gas content by the method of evaluating the long-term reserves from an expected productive area and the density of reserves.

The method manual for a quantitative assessment of the outlook of oil and gas content [2] presents it as a method for evaluating the oil and gas content of individual structures according to area. Another name is suggested for this method, which is primarily due to the attempt to pinpoint the estimate formula.

The methods of density evaluation are defined in the manual as additional and auxiliary. In fairly explored regions they need to be used on a par with the main recommended methods. The density method is supported by the findings that at depth 3200-5000 m in gas deposits the product $p_{пл}\alpha f$ rises only by 10%, and this means that the quantity of gas reserves is predetermined not by the depth of the deposit location, but by its gas-saturated volume (mhB) and area.

The hypothetical geological reserves of the promising layer on the studied structure are estimated by the formula $Q_T = S_{и.т.} k_{пл.т.} q_T$, where $S_{и.т.}$--area of the studied structure according to the estimated promising layer;

$k_{пл.т}$--average maximum area coefficient of trap filling for the given layer for the zone (reference section), i.e., the ratio of the maximum (total if the areas of the deposits do not coincide in the plan) productive area of the given layer S_{cym} to the area S_m of the trap (field). At the field $k_{пл.т_i} = \frac{S_{cym}}{S_m}$ for n fields in the zone $k_{пл.т} = \frac{\Sigma k_{пл\ т_i}}{n}$, $q_т$--average density of the geological reserves of the fields in the zone for the given productive layer; it is defined by the ratio of the reserves of all deposits of the given layer to the total (maximum) productive area, i.e. on one field

$q_{т_i} = \frac{\Sigma Q_{зал}}{S_{cym}}$, in the zone $q_т = \frac{\Sigma q_{т_i}}{n}$.

The hypothetical geological reserves of the studied structure ($Q_и$) are defined either from the sum of the reserves in the promising layers $Q_и = \Sigma Q_т$ or from the expected productive area ($S_и k_{пл}$) and density of reserves that are the average for the fields in the zone, i.e., $Q_и = S_и k_{пл} q$, where $S_и$--area of studied structure; $k_{пл}$--area coefficient of trap filling that is the average for the zone, i.e., the ratio of the maximum (total) productive area of the field to the area of the trap; q--density of the geological reserves that is the average for the fields in the zone. The extractable reserves of oil and gas are found by multiplying the geological reserves of the layer (structure) by the corresponding coefficient for correlation of gas and oil reserves in the given zone for the layer (structure).

The total reserves in the group of promising structures in zone ($Q_з$) are defined as the sum of either the reserves of the structure, or of the hypothetical reserves in the productive layers on the structures: $Q_з = \Sigma Q_и = \Sigma\Sigma Q_т$.

The results of the estimate of long-term reserves for the entire fund of structures are generalized by constructing maps of their distribution according to quantity of reserves and groups of reliability. On their basis the volume of geophysical work, parametrical, search and exploratory drilling is distributed.

The next stage is estimating the expected increases in reserves from the isolated promising groups, i.e., introduction of the coefficient of confirmability. It is suggested that this coefficient be computed for subgroup I reserves according to the reliability of the geophysical recommendations (see table).

The general confirmability of the levels planned for testing is 70%. Consequently, it is recommended that for the subgroup I reserves the coefficient of their confirmability be introduced; on the average it equals 0.7.

It is recommended that the coefficient of confirmability of the subgroup II reserves ($П_{II}$) be computed according to the confirmability of the areas

Types of recommended objects from results of GIS	Total objects tested	Results of test			Percentage of objects with positive results %	Recommended Π_I
		Gas (Oil)	Gas (Oil), water	Total number of objects with positive results		
Recommended as productive	156	115	10	125	80	0.8
Recommended for study of collector properties, nature of saturation, and critical parameters	129	57	3	60	46.5	0.47
Total	285	172	13	185	70.3	0.7

with the supplies of this subgroup. The calculated productive areas of deposits measured within the contour corresponding to the high-level coefficient of trap filling ($k_{з.л.в.}$) in the majority of cases proved to be smaller than the actual productive areas due to the appearance of zones of facial substitution, elevated and lowered blocks. The size of the correlation of these areas is determined either for each level or (with a complicated multiple-bed nature of the deposits in the productive layer) as the average from all the deposits in the layer. Thus, in the middle section of the DDV for all the studied deposits the ratio of actual productive areas to the calculated fluctuates from 0.2 to 0.77.

The approximate amount of Π_{II} can be obtained from the correlation $k_{пл}/k_{з.л.в.}$ of the studied deposits. For 21 fields of the middle section of the DDV this correlation fluctuates from 0.23 to 1; on the average it is 0.67.

The reliability of computing Π_{II} by this method is increased in that case where the correction coefficient that takes into account the profile of the bed surface is introduced into the correlation $k_{пл}/k_{з.л.в.}$.

It is recommended that the coefficient of confirmability of the subgroup III reserves (Π_{III}) be computed for the promising layers, structures and zones.

The coefficient of confirmability of the hypothetical reserves of the promising layers equals

$$\Pi_{III} = \frac{Q_{Т.Ф}}{Q_{Т.З}},$$

where $Q_{Т.Ф}$ --actually explored (categories $A+B+C_1$ of the studied fields) reserves of the promising layer in the zone; $Q_{Т.З}$ --hypothetical reserves

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of this layer for all the explored structures in the zone before they are drilled.

The coefficient of confirmability of the hypothetical reserves of a structure taken separately in the given zone is computed according to the formula

$$\Pi_{III\ c} = \frac{Q_{\text{ф.т.}}}{Q_{\text{и.т}}},$$

where $Q_{\text{ф.т}}$--actually explored reserves in the group of fields of the zone; $Q_{\text{ит}}$--hypothetical reserves on these fields before the beginning of their drilling out.

The coefficient of confirmability that is computed in this way is essentially the maximum for the given zone, a real coefficient with regard for the negative results of work on individual structures, and is defined by the formula

$$\Pi_{III\ o} = \frac{Q_{\text{ф.т}}}{Q_{\text{и.о}}},$$

where $Q_{\text{и.о}}$--hypothetical reserves of all the explored structures in the zone before their drilling.

The advantage of the coefficient of confirmability of the subgroup III reserves that is computed by this method over the coefficient of industrial discoveries $k_{\text{п.о}}$ is obvious. For $k_{\text{п.о}}$ is always ≤ 1, while Π_{III} can fluctuate in broad limits (from 0.1 to several units).

It is most correct to view $k_{\text{п.о}}$ as a qualitative indicator for the degree of success of the prospecting work. In order to transfer the long-term reserves into the industrial categories it can be used in that case where the long-term reserves are estimated by the method for an averaged structure.

It is necessary to bear in mind that the corresponding Π_{III} has to be determined for each method of estimating the long-term reserves of the III subgroup with a significant difference in the estimates.

The indicated computation methods of confirmability of the III subgroup reserves are applicable for the fund of reliably prepared structures. Since not all the structures, conditionally and insufficiently prepared, are confirmed by the subsequent work, then it is neceessary to introduce the coefficient of their conf rmability (D) that is the correlation of the number of confirmed structures to the number of structures studied in detail by the methods verified in the studied region.

For example, in the studied region, out of 124 structures 21 were excluded (eliminated) as unconfirmed by the data of drilling or subsequent geophysical work. From these data one can assume the coefficient D to equal 0.83.

In an analogous method one can find the coefficient of confirmability of the prognosis structures.

The expected increase in Q_{c_1} for the fund of conditionally and insufficiently prepared structures is determined according to the formula

$$Q_{c_1} = \Sigma_{\text{и}} D \text{П}_{III\ o}.$$

It is more reliable to determine D not from the number of structures, but from the confirmability of the areas of the structures, i.e.,

$$D_S = \frac{\Sigma S_{\text{и}}}{\Sigma S_{\text{пр}}},$$

where $\Sigma S_{\text{и}}$--sum of areas of confirmed structures; $\Sigma S_{\text{пр}}$--sum of areas of insufficiently and conditionally prepared structures before their study.

In conclusion it is necessary to note those advantages that the given method of estimating long-term reserves has.

1. The estimation process is easily automated since the original data (coefficients of trap filling and density of reserves) are computed statistically, which excludes subjectivism in the estimate of reserves that inevitably appears in selecting the initial data by the method of analogies.

2. The data on the coefficients of trap filling and densities of reserves that can be accumulated for the estimate will be constantly employed in selecting the sites of placement of exploratory and development wells.

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FUELS

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ESTIMATED DRILLING DURATION, RESERVE PREPARATION COSTS

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[Article by V. Z. Karpushin, VNIGNI: "Technique for Prediction Evaluation of Duration of Exploratory Drilling and Cost of Reserve Preparation in Different Oil and Gas Regions"]

[Text] Among the most important planning indicators on which the level of optimization of exploratory work depends one should include the duration of drilling and the planned cost of reserve preparation. The majority of the known procedures for evaluating these parameters are based mainly on especially economic average branch indicators and do not make sufficient consideration for the geological aspects of the conducted studies in the limits of a certain oil and gas region.

The high degree of study of the upper complexes in oil and gas deposits makes it possible to use the accumulated statistical material to reveal the link between the duration of exploratory work and the cost of reserve preparation and the different geological-technological parameters, as well as to predict the nature of change in the size of these indicators during the drilling out of deep layers.

For a method solution to the set task we generalized and analyzed the actual data for 94 fields (approved in the USSR GKZ [State Commission for Mineral Reserves]) that are confined to different oil and gas regions of the country: Central Asia, Udmurtskaya ASSR, Caspian and Timano-Pechora provinces, South Mangyshlakskaya, Orenburgskaya and Pripyatskaya oblasts, and the southeast section of the DDV [Dneiper-Donets Basin].

Taking into consideration that the duration of exploratory drilling and the reserve preparation cost depend on many geological-technological and organizational factors that significantly differ from each other within the regions, the nature of their link to the analyzed indicators of exploration has not been studied for the entire data file, but in a differentiated manner, for individual oil and gas regions. This permitted, on the one hand, more complete consideration for the features of the exploratory process in each region, and on the other hand, increase in the reliability of the results oı the conducted studies.

The prediction evaluations for the duration of exploration and reserve preparation cost are designed for use in engineering calculations. Therefore among the numerous factors that determine the dynamics and size of these indicators analysis has mainly been made of those that are easily subject to quantitative computation, significantly change on individual areas, and reflect to the maximum the geological and technological features of the exploratory process: the maximum depth of the deposits exposed at the fields (Γ_3); the total number of drilled wells (N); the coefficient of drilling success (k_y) that is the ratio of the number of intracontour wells to all the drilled ones; the total volume of drilling ($O_б$); the average depth of wells (Γ_c) and the reserves of comparison fuel per 1 m of drilling (3_m).

The duration of the exploratory drilling (Π_p) in each region depends on the absolute amount of expression $N\Gamma_3/k_y$ that is conditionally called the complex coefficient that determines the duration of exploratory work ($k_п$). Π_p is directly proportional to the product of N times Γ_3 and is inversely proportional to k_y.

The reserve preparation cost (C) is linked to the absolute amount of expression $\frac{O_б \Gamma_c}{3_m k_y}$ that is conditionally called the complex coefficient that determines the cost of preparing a unit of comparison fuel (k_c). For each explored object it is directly proportional to the product of $O_б$ times the average Γ_c and inversely proportional to the product of 3_m times k_y.

The indicators that determine the statistical characteristics of the named links are given in table 1.

The high values for the correlation coefficients that characterized the close link between Π_p and $k_п$, as well as C and k_c indicate the sufficient reliability and representativeness of the detected relationships for each oil and gas region separately, and their universality in relation to the entire studied territory.

The detected relationships between the duration of exploratory drilling, the cost of preparation and the complex coefficients $k_п$ and k_c make it possible to recommend the following technique of prediction assessment of these indicators for planning exploratory work in drilling out deep fields.

At the first stage of calculations, for each oil and gas area to be drilled out planned amounts should be set for the parameters N, Γ_3, $O_б$, Γ_c, 3_m and k_y in expressions $(N\Gamma_3)/k_y$ and $\frac{O_б \Gamma_c}{3_m k_y}$ in order to define the absolute values of the complex coefficients $k_п$ and k_c. By using the latter as the argument x in the corresponding regression equations (see table 1), it is further necessary to compute the values for the function y that

Table 1. Statistical Characteristics of Detected Links

Oil and gas region	Correlation coefficient (R) of dependence of		Regression equation between	
	$П_p$ on $k_п$	C on k_C	$П(y)$ and $k_п(x)$	$C(y)$ and $k_C(x)$
Central Asia	0.828	0.836	y=0.73x+24.5	y=0.79x+12.6
Orenburgskaya oblast and Udmurtskaya oblast	0.769	0.891	y=0.65x+30.5	y=0.80x+9.4
Caspian province and South Mangyshlakskaya oblast	0.795	0.690	y=0.73x+24	y=0.68x+18.8
Timano-Pechora province	0.688	0.711	y=0.63x+26.3	y=0.87x+19.8
Pripyatskaya oblast	0.775	0.810	y=0.96x+0.4	y=0.84x+2.7
DDV	0.902	0.971	y=0.48x+30.3	y=0.92x+2.7

corresponds to it and thus obtain prediction assessments of the drilling duration and reserve preparation cost on the studied field.

In addition, according to the regression equations compiled for each oil and gas region one can construct theoretical direct regressions that graphically depict the nature of the link between the predictable indicators and the coefficients $k_п$ and k_c corresponding to them. It is expedient to use the obtained graphs as nomograms in evaluating the duration of exploration and the cost of preparing a unit of comparison fuel. In this case for convenience of calculations it is more efficient to express the original indicators of exploration (N, $Г_з$, k_y, etc.) in a percentage relationship of the maximum value for each of them on one of the fields in the oil and gas region.

As an illustration of what has been said, table 2 presents the results of a prediction assessment $П_p$ and C for different depth intervals in the examined oil and gas regions that was made according to the suggested technique. Here it is necessary to note that in the corresponding calculations values were changed only of those parameters that to the maximum degree are only a function of depth ($Г_з$, $Г_c$, $O_б$ and $З_m$), while N and k_y are conditionally assumed to be constant, and their amounts were defined as the average statistical for the region.

As indicated by the data presented in table 2, practically for all the oil and gas regions with an increase in depth of exploratory drilling an increase is expected in the average duration of the process as compared to the actually attained amount of this indicator. An exception is the southeastern section of the DDV within which even during exploration of deposits at depths roughly of 5000 m the prediction assessment for drilling duration is about 94 months, while with the actually attained average drilling depth of 3537 m the latter equals 108 months. The significant disproportion in the actually attained and the prediction assessments for drilling duration for the DDV is explained by the fact that its average value for the region, computed from the results of exploratory work proved to be considerably exaggerated due to the unsubstantiatedly long exploration of small-sized Kegichevskiy and West Medvedovskiy fields (respectively 143 and 144 months) due to the imperfection of the employed technique. This is graphically confirmed by the low k_y values for these fields (respectively 0.40 and 0.38).

Table 2. Values for Exploration Indicators at Different Depths of Drilling

Oil and gas region	Indicators											
	Actual determined from average statistical data									Prediction, computed from regression equat.		
	Number of fields	Γ_3	N, un.	k_y	Γ_c, m	α, m	$З_m$, thous. r	Π_p, month	C, R	Γ_c, m	Π_p, month	C, R
Central Asia	22	2141	23	0.68	2537	55319	26	78	0.246	2500	90	0.241
										3000	100	0.263
Orenburgskaya obl. and Udmurtskaya ASSR	26	1902	28	0.66	2129	61209	14	61	0.154	2500	66	0.121
										3000	72	0.164
Caspian province and South Mangyshlaksaya oblast	14	1684	32	0.81	1806	50385	22	63	0.30	2000	72	0.195
										2500	81	0.211
										3000	92	0.236
Timano-Pechora province	16	2353	22	0.71	2416	55112	29	76	0.38	2500	78	0.264
										3000	86	0.315
										3500	94	0.386
Pripyatskaya oblast	8	3004	20	0.48	3203	63220	54	67	0.47	3500	74	0.516
										4000	85	0.758
DDV	8	3537	18	0.57	3618	61024	22	108	0.99	4000	84	0.479
										4500	89	0.648
										5000	94	0.865

At the same time for all the analyzed oil and gas regions, with the exception of the Pripyatskaya oblast the prediction assessment C will significantly exceed the average amount of this indicator computed from actual data. The noted circumstance is also explained to a certain measure by the fact that for each oil and gas region there is a characteristic exaggeration of the average cost of preparing a unit of comparison fuel caused by the effect of extremely high values of the examined parameter for individual fields that are distinguished by low potential output and considerable overexploration. Such fields in the DDV can include the Sosnovskiy and Lannovskiy; in Central Asia the North Achak, Kultakskiy and Zeagli-Darvazinskiy; in the Caspian region the Tasbulatskiy, South Zhetybay and Aktyubinsk; in the Timano-Pechora province the Pechorokozhvinskiy , Pechorogorodskiy and Michayuskiy; in the Volgo-Ural'skaya oblast the Sovkhozniy, Kurmanayevskiy and Vorontsovka.

In the Pripyatskaya oil and gas olbast the explored fields are differentiated according to specific density of the reserves per unit of productive area (k_y) considerably less, and therefore the average cost for the region for preparing a unit of comparison fuel in relation to the entire group of fields reflects the value of this indicator in a more real manner and noticeably rises with a rise in the drilling depth.

It should be noted that the prediction assessments presented in table 2 for Π_p and C can diminish with an increase in drilling depth in the process of exploratory work. This can be attained by perfecting the technique of exploratory drilling, as a result of which it is possible to curtail N and increase k_y, which in turn entails a reduction in Π_p and C on the drilled out field. In addition, in these calculations the condtion was adopted that the potential output of the detected fields was assumed to be equal to the average for the region, and consequently, $З_m$ must be reduced with an increase in the depth of occurrence of the explored fields. However, in the practice of exploration fields can be encountered whose potential output considerably surpasses the average value of this indicator for the region, by means of which the size of the prediction assessment for the given field is reduced.

Thus, the suggested technique for computing Π_p and C with an increase in drilling depth, based on the results of statistical processing of the actual materials of exploration guarantees a fairly reliable prediction of the rated amounts of these indicators with regard for the different geological and technological factors, and the possibility of correcting their values directly in the course of implementing the work.

The practical use of the technique will permit more efficient planning of the volume and duration of exploratory drilling, and as a result will promote an increase in the efficiency of geological exploration for oil and gas.

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FUELS

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NEW METHODS OF WORKING FIELDS INCREASE FINAL OIL OUTPUT

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[Article by V. S. Klyucharev, VNIIKTEP: "Prediction Evaluation of Final Oil Output"]

[Text] In predicting the final oil output (FOO) of a deposit in the old oil extracting regions of the country it is necessary to bear in mind that a further increase in the industrial reserves is possible here due to the discovery of fields and beds in the carbonate and terrigenous strata with deteriorated collector properties [4]. The working of these fields will be accompanied by a reduction in the FOO which needs to be considered in the planning. The perfected methods of working oil fields must guarantee an increase in the degree of oil extraction from the depths, i.e., result in a rise in the FOO.

Currently the main method for working oil fields in the USSR is the flooding method. About 85% of all the oil extraction is done on fields that can be worked with the use of different methods of flooding, perimeter, intra-contour, area, focal and others. The broad use of flooding in our country was started for the first time over 30 years ago on the Tuymazy field. It increased the FOO as compared to the FOO with the method of working fields by the depletion pattern from 20-25 to 43-46% [1]; at the same time the density of the well groups was significantly reduced.

Among the important geological and technical measures to perfect oil output of the beds one should include the broad introduction of selective, focal and cyclical flooding and flooding with a change in the direction of the filtering streams. These measures permit an increase in the rates of oil recovery and involve in the development a portion of the reserves from the blind and dead zones.

At the modern stage of development of the oil industry perfection of the extant, creation and introduction of new,more advanced methods of working that guarantee more complete extraction of oil from the depths acquire special value. It is also necessary to have the strictest observance of the technological regulations for operating the fields [3]. The flooding method for a long time has remained the primary method for intensifying oil extraction and increasing the FOO. However flooding yields the best results when working deposits of low-viscous oils; flooding of deposits containing oil of increased viscosity (5-25 cP) is less effective, and when working oil deposits with viscosity over 25-30 cP the pumping of cold untreated water becomes ineffective. The FOO is low in deposits of beds 2-4 m thick with reduced collector properties.

The increasing percentage of reserves of viscous oils and oils in deposits associated with heterogeneous, less permeable beds determines the need for broad introduction of effective methods for increasing the oil output in the fields both with decreasing extraction and on new fields.

The currently known new methods for increasing oil output can be divided into two main groups: thermophysical (thermal and thermal-shaft) and physicochemical [2].

The thermophysical methods are used to influence both the critical zone (thermal processing of producing wells) and the bed as a whole (displacement of oil by hot water, steam and intrabed combustion). The physicochemical methods guarantee an increase in the oil output thanks to the addition of chemical reagents to the pumped water that improve the washing and displacing properties of water: surface-active substances (SAS), polymer-thickeners, carbon dioxide, sulfuric acid and others, as well as by means of using smoke and hydrocarbon gases as injected agent and creating gas-water repression.

Analysis of the experimental-industrial work done at different fields shows that the FOO rises with the use of the new methods. Thus, according to the data of laboratory and experimental studies injection of a polymer solution increases the oil output on the average by 7-10% as compared to simple flooding, injection of carbon dioxide--by 8-12%, mixed displacement--by 10-15% and gas-water repression--by 5-6%.

The new working methods were used at the late stage of working at practically all of the examined fields. The increase in extraction due to the use of the new methods of raising the FOO in the regions with declining extraction raises the question of reducing the expensive and not very effective geological exploration in the well-studied regions of the Tatar ASSR, western section of the Bashkir ASSR, Kuybyshevskaya oblast, etc. and the use of these resources to increase the FOO of the workable deposits.

The experimental-industrial work done in the USSR and abroad has demonstrated that all the methods for increasing oil output yield a greater effect when when they are used from the beginning of working the fields. Therefore at all the introduced fields it is necessary to immediately provide for their use.

In recent years at the known oil fields of Uralo-Povolzh'ye, Mangyshlak and others, in order to slow down the rates of drop in oil extraction and improve the output of reserves from the heterogeneous beds the well groups have been concentrated 2-3-fold [5]. However the concentration has been done primarily on those sections of the deposits where the main stratum is highly productive, which results in depletion of the reserves. The strata of low thickness that can be exposed with the main stratum by a single filter, during joint operation are not involved in active development. For example, drilling of the development test wells after a 25-year period of working the stratum of the D_I Tuymazy field demonstrated that the lenticular sandstones of the upper block that were exposed jointly with the middle and lower blocks of one group almost everywhere are not worked. The water-oil zones and the sections of the main beds with reduced collector properties are also not involved in active working. Thus, after the drilling of additional wells at the Tuymazy field the specific area per one well for the D_I stratum within the original oil zone was 21.5 ha, and in the water-oil zone 48.6 ha, i.e., 2.26 times greater. At the Abdrakhmanovskiy area of the Romashkinskiy field about 17% of the extracted reserves concentrated in the lenses, blind and water-oil zones, as well as on the sections of development of the poorly-permeable collectors was not covered by the effect of injection.

Concentration of the well groups will yield a small increase in the amount of FOO. Thus, the introduction of 142 additional wells on the beds in the terrigenous deposits of the Devonian period in the Tuymasy field will provide a 2.3% increase in FOO, while the introduction of 867 producing wells at the Arlanskiy field with oil deposits in the terrigenous carbon (μ =13-32 cP) will increase the FOO only by 1.3%.

Thus, the further scientific and technical progress in the field of development will lead to a rise in the FOO despite the increase expected in the future in the percentage of fields with small reserves with deteriorated geological and physical parameters. A certain increase in the FOO will also be attained thanks to the drilling of additional wells in the blind and dead zones, and intensification of the effect on zones that are difficult to work by perfecting the extant traditional methods of flooding the beds.

Preliminary calculations show that perfection of the extant, creation and introduction of new methods for working will guarantee a certain increase in the average amount of FOO in the USSR by 1990.

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