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TECHNICAL PROGRESS OF SOVIET POWER ENGINEERING

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/Figures referred to are appended./

Significance in National Economy

Technical progress in power engineering and, more specifically, in electrification plays an exceptionally important role in building the economic and technical foundations of a socialist and Communist society. Electrification is the keystone in the technical reconstruction of all branches of the Soviet economy, including its foremost branch, heavy industry, with its main component, machine building. The introduction of automatic, single-motor and multimotor drives, electrification of assemblies and plants, extensive mechanization of large-scale operations and their widespread automatization, development of power engineering on the most modern principles, wide electrification of traction, extensive electrification of the rural economy and homesteads, all contribute to raising the national economy to a higher level.

The creation of a highly dependable and economical network for countrywide distribution of abundant and cheap electric power is a prerequisite for an even wider application of electricity in industry, transportation, rural economy and daily existence.

It should be remembered that electricity is still the costliest form of energy insofar as initial investment and production costs are concerned. For example, in many high-temperature industrial processes which, due to production conditions involved, can be operated either with electricity (electric furnaces) or with gas (gas furnaces), the initial investment per megacalorie is from two to ten times greater in electrically operated installations than in those utilizing gas. (It is double if we compare a highly efficient steam-electric power station with a gas-generating plant; it is tenfold if we compare

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the cost of a hydroelectric station with that of natural gas.) In many areas having sources of cheap gaseous fuel, such as coke gas or natural gas, and where condensing units are used in the generation of power, production cost per megacalorie derived from gas is also lower than that for electricity. Technical progress, in the power economy, through improvements in production and distribution and reductions in production costs, has a direct and beneficial effect in rapidly solving basic problems relating to the electrification of the country.

This lecture is limited to a review of fundamental technical achievements in the power field, i.e., at electric power stations and in distribution systems. Problems pertaining to technical progress in the electrification of industry, agriculture, transportation, and households should be taken up in other lectures.

Power Engineering in Prerevolutionary Russia

The power industry in prerevolutionary Russia was hopelessly lagging. The total installed capacity of power stations amounted to one million kilowatts; the total electric energy production, to 2 billion kilowatt-hours; and the total fuel balance (including fuel for household use), to 100 million tons of reference [standard] fuel. These figures show the power capabilities of prerevolutionary Russia.

Comparisons with corresponding data from countries such as the USA and Germany demonstrate that Russian capabilities had been less than one tenth those of the USA, and one fifth those of Germany.

The technical level of power engineering in prerevolutionary Russia is further illustrated by the following facts. The power supply of great national centers was derived solely from many small power stations. I. V. Elizarov, in a work published in 1916, gives results of a survey showing that in Petrograd some 105 small power stations were in operation. The four district stations in Petrograd ("1886," "Gelios," "Belgiiskaya," "Tramvaynaya") operated independently with different voltages, number of phases, and frequencies. Furthermore, cables and circuits of different stations intersected within the same district.

Steam power stations were operated at pressures of the order of only 8-14 atm and temperatures of 300-350°C. Boiler output was limited to 10-20 tons of steam per hour; boiler efficiency was less than 65 percent. The maximum power of the turbines then in operation was 10,000 kw, and there were only two of these.

Each of the district power stations at Petrograd, Moscow, and Baku had more than ten water-tube boilers and a great number of steam engines and turbines. All were fueled either with oil or high-grade Donets or imported coal. The maximum efficiency of power stations was 11-12 percent. In 1913, the average fuel consumption per kilowatt-hour produced at the larger power stations was 1.15 kg; in 1917, this figure jumped to 1.35 kg of reference fuel per kilowatt-hour.

The coefficient of industrial electrification in Russia was only 35 percent, group drives being prevalent. Use of electric power in technological processes on a large scale was unknown.

The entire rural economy of Russia was served by power stations having a total of 2,000 kw installed capacity. In cities, the annual power consumption was 15 kw-h per capita.

Finally, it should be remembered that practically all the main equipment of the power stations was imported, and the stations themselves were owned by foreign capitalists.

But even this legacy in the field of power production was largely destroyed by the time it came into the hands of the Soviet state. This was a result of World War I and the periods of civil war and foreign intervention. The Soviet state had to recreate the very power foundations of the national economy.

Basic Power-Engineering Problems as Reflected in GOELRO Plan and Stalin Five-Year Plans

The GOELRO (State Commission for the Electrification of Russia) plan of Lenin superbly outlines the trends and characteristics in the development of power engineering in a socialist economy.

Among the principal novel technical trends of power engineering advanced and formulated in the GOELRO plan were the following:

1. Creation of large regional power plants (30 stations with a total installed capacity of 1,750,000 kw) as the power production framework for the economy of the main regions of the country.

2. Successful utilization of inferior fuel resources as the determining factor in recasting the distorted fuel balance of prerevolutionary Russia.

3. Utilization of water-power resources by construction of large hydroelectric stations.

4. Utilization of high-voltage transmission and the creation of district power systems with an eye to their future integration.

In the Stalin Five-Year Plans, these fundamentals were expanded, with consideration of new tasks in the establishment of the socialist economy. These included:

1. Construction of additional power networks within various areas of the country, based on Stalin's plan for relocating industry and creating new industrial centers.

2. Establishment of a well developed power-equipment industry utilizing the most up-to-date technical methods and capable of meeting all the requirements of a vigorously growing power economy and standardization of power equipment with respect to power, types, and parameters.

3. Development of district heating [combined steam and power supply] as one of the basic trends of socialist power engineering.

4. Development of gasification, particularly with respect to methods for underground gasification of coal deposits.

5. The use of highly productive boilers and turbines operated with steam of high initial parameters.

6. Extensive automatization of power generation and distribution processes.

The law relating to the postwar Five-Year Plan for the period 1946 - 1950 especially provides for the following:

Extensive introduction of the most modern power engineering developments in power stations -- utilization of steam at high pressures and temperatures, utilization of modern extraction turbines, and utilization of the most recent models of boilers, generators, and high-voltage transmission equipment. Extensive developmental work on automatic control of production operations in power stations and power systems, with first priority being allocated to complete automatic control of hydroelectric stations.

Conducting scientific research and practical tests on long-distance power transmission by means of high-voltage dc; production of (1) modern types of electric machines, transformers, and power distribution equipment, (2) protective and automatic relays, and (3) high-voltage equipment; and continuation of work toward achieving underground coal gasification (Law on the Five-Year Plan for the Reconstruction and Development of the National Economy of the USSR During 1946 - 1950, 19th Edition, 1946, pages 21-22).

The rate of development of the Soviet power industry has no equal in the world. In actual power production, the Soviet Union has already reached second place in the world and first in Europe. The power engineering equipment of our country is also the newest in the world. During the prewar Stalin Five-Year Plans (1928 - 1940), the installed capacity of our power stations increased more than fivefold; the schedule for the postwar 5-year period is to double this figure. From the standpoint of engineering, Soviet power industry leads the world.

Steam-Electric Power Stations

Steam-electric power stations are the principal source of electricity in the Soviet economy. In 1940, about 90 percent of the country's total power production was generated at steam-electric power stations. In 1950, in accordance with the postwar Five-Year Plan, and taking into consideration a much higher development rate of hydroelectric installations, steam-electric power stations will still be producing more than four fifths of the country's total power. Eventually, even with further increases in power production and with continued increased development of hydroelectric power, the steam power stations will still produce, according to our estimates, approximately two thirds of the total power output.

Hence, engineering progress in the field of steam-generated power is of special importance in solving basic problems of improving dependability and efficiency of electric power supply.

1. Utilization of Local Fuel Resources

The utilization of local fuel resources, one of the noteworthy achievements of Soviet power engineering, was attained through developing several reliable and efficient methods for producing and using fuels of various types and grades.

The Lenin-Stalin GOELRO plan considered this problem in connection with the proposed construction of new power plants utilizing coal of the Moscow area, coal from the Ural deposits, peat, and shale. The task of discovering and utilizing regional fuel supplies is prominent in the Stalin Five-Year Plans for the development of the national economy.

Stalin, in Problems of Leninism, page 445, states: "Expand to the utmost production from all known coal-bearing areas, and exploit new coal-producing regions." This was one high-priority assignment put forward by Stalin in his report to the 17th Congress of the VKP(b).

The postwar Five-Year Plan also stresses the need for "developing by every means new local sources of coal supply in every region of the country."

Power stations pioneered in the consumption of new low-grade forms of fuel, and were the mainstays of progress in this field. During the Stalin Five-Year Plans, efficient methods of burning over 60 types of fuel were developed and successfully used. Soviet power engineers have also solved a series of complex scientific and technological problems concerning the preparation and combustion of various types of fuel having widely dissimilar characteristics: high moisture content (up to 55 percent), high ash content (up to 60 percent on the dry basis), low volatile matter (3 percent of the fuel mass), low ash fusion temperature, diverse clinkering characteristics, high sulfur content, poor crushing characteristics, etc. Many of these problems were solved for the first time by Soviet power engineers. Prominent foreign concerns, which during the first years of the Soviet regime were called upon to supply power equipment for our power stations suitable for utilizing local fuel resources (Shterovka, anthracite culm; Kashira, Moscow-area coal; Berezniki, Kizel' coal), were unable to develop a successful method for the utilization of such types of fuel. Soviet power engineers solved these problems independently.

Anthracite culm was formerly considered waste, and dumped. The culm banks of the Donets coal region have yielded many millions of tons of this fuel. With an increasing rate of coal production and mechanization in coal mining, the anthracite-culm output increased tremendously (even in the early thirties, the yield of culm reached the 3-4 million ton mark, some 20 percent of the anthracite production of the Donets basin). The very low volatile content (3-3.5 percent of the fuel mass), excessive hardness, and low ash fusion temperature made the use of this form of fuel extremely difficult. Soviet power engineers pioneered the design and successful operation of power stations fueled with anthracite culm.

In 1927, the Shterovka power station of the Donets region started to use pulverized anthracite culm as a fuel. Early in the First Five-Year Plan, the installed capacity of stations using this kind of fuel exceeded one million kilowatts. Soviet power stations are equipped with the world's largest anthracite-culm-burning boilers, which are manufactured by the Soviet industry, and produce 200 tons of steam per hour. Systematic work on improving the efficiency of anthracite-culm combustion has increased the over-all boiler efficiency from about 68-75 percent to 80-82 percent. More than one third of the total prewar output of power generated at the regional coal-burning power stations was produced from anthracite culm. Anthracite culm, a formerly discarded form of fuel, has thus become a basic type of fuel for power plants located in the South, Central, and Volga areas.

The Moscow area coal is high in moisture (32 percent) and ash (25 percent) content, contains relatively large amounts of sulfur (2.4 percent), and has a low heat value (2,540 calories per kilogram). All this greatly complicated the efficient use of this fuel. These difficulties were nevertheless successfully overcome by Soviet power engineers. The Kashira and Stalinogorsk regional electric power stations are outstanding examples of the progress of the Soviet power industry in the utilization of low-grade coal of the Moscow area. Experience gained in attaining consistently productive use of Moscow coal contributed to the efficient utilization of other types of lignite, e.g., those of Bogoslovka and Chelyabinsk in the Urals, of Angren in Middle Asia, etc.

The Soviet power industry attained world-wide leadership in the utilization of peat. The Soviet Union has established priority in, and development and efficient utilization of, milling and hydraulic mining methods for the production of peat.

For the efficient combustion of lump peat, Soviet power engineers have created the original chain-shaft stoker system of Makar'yev. Operating methods for the joint combustion of milled and lump peat in conventional fireboxes designed solely for lump peat, and also new burners for milled peat (Shershnev system, VTI-Mosenergo chamber shaft-pulverizer type) were developed.

Prior to the development and introduction of the Soviet methods, combustion of milled peat in the furnace chamber had not been achieved in any capitalist country.

The Soviet power industry has the world's largest peat-buring power stations, with a capacity of about 200,000 kw, and boilers producing 200 tons of steam per hour. The efficiency of the best peat boilers reaches 90 percent and can be maintained at 85 percent over prolonged operating periods.

The decision, formulated in the law on the postwar Five-Year Plan, to undertake large-scale coal enrichment, has posed the problem of providing effective methods for the combustion of the residual tailings having a high ash content. At present some of our power stations are successfully using such by-products of coal enrichment as fuel.

Considerable success has been attained in the development and introduction of fuel-combustion methods with removal of the slag in liquid form. In 1946 and 1948, two developments in this field earned the Stalin Prize.

The results of technical progress in the use of local fuel supplies are indicated by the data shown in Figure 1, which illustrates the changes that have occurred in the allocation of various types of fuel resources to support the output of regional power stations.

In the postwar years, more than three fourths of the total power generated at the regional steam power stations was derived from local fuel resources.

From standpoint of national economy, the significance of technical progress achieved by the Soviet power industry in the use of local fuel resources was demonstrated during the war years when Donets coal was excluded temporarily from our fuel balance, and it was necessary to shift swiftly and effectively a substantial portion of our power economy to other types of fuel. Soviet power engineers met this emergency. Power plants that were hastily converted to the use of local fuels during the first months of the war were soon operating reliably and economically.

Further improvements in the degree of local fuel utilization pose new problems for power engineers. These include development and introduction of improved methods of ash and sulfur recovery, methods for combined chemical and power utilization of various types of fuel by the power stations, with the aim of separating out valuable chemical gases and tars; new methods for making use of the ash derived from various types of fuel as an industrial raw material, etc.

2. District Heating

District heating, the utilization of fuel for the joint production of electric power and steam heat, can be considered, from the standpoint of the national economy, as a major achievement of Soviet power engineering. None of the attainments of modern steam engineering yields greater over-all power efficiency than that secured by applying the district heating principle.

District heating ensures very high fuel economy. Each megacalorie extended for heating purposes or for low-temperature industrial processes can yield an additional 240-320 kw-hr of power (the former figure refers to mediumpressure plants, the latter to high-pressure, plants). Specific fuel consumption per kilowatt-hour produced in heat and power plants is about two and a half times less than for the equivalent amount of power generated in a modern steam power plant. Moreover, the change from individual heating plants to centralized heat supply from a heat and power station (TETs) saves (due to higher boiler efficiency) about 0.3 megacalorie for each megacalorie of heat produced. Under actual operating conditions, the annual mean efficiency of power generation by TETs exceeds that of steam power stations by about 40 percent in the case of industrial TETs (where heat is utilized primarily for manufacturing purposes) and by about 25 percent in the case of urban stations (where heat is used mostly for heating buildings), other conditions being equal.

District heating makes possible the use of local low-grade fuel resources for heating purposes. The combustion of such fuels in individual furnaces is uneconomical and also inadmissible for sanitary reasons. District heating lowers the cost of power, and is more flexible in meeting the everyday needs of the population.

The extent of development of TETs during the prewar decade (1930 - 1940) is indicated by the following data: the number of TETs increased from 14 to 100 and their installed capacity reached 2.5 million kw, about 70 percent of which was derived from extraction turbines. The length of district heating networks increased 30 times during this period (from 20 to 600 km), and the annual heat output of TETs increased 17 times to 27 million megacalories.

One characteristic feature of Soviet district heating is the integration of TETs with the regional power systems, a scheme which effects increased economy for both the stations and the systems.

The law relative to the postwar Five-Year Plan provides for the construction of 37 new regional steam power plants, 21 of which are to be of the TETs type. The TETs installed capacity has already reached about 30 percent of the total installed capacity of steam power stations (as compared with 22 percent in the prewar period), and their heat output is more than double the maximum prewar level. At present, 2 million tons of reference fuel a year are saved as a result of district heating.

A remarkable achievement is the series production at Soviet plants and the putting into operation of heavy-duty extraction turbines with single or dual controlled extraction. The first extraction turbine of 25,000 kw operating at 29 atm and 400°C and yielding 100 tons of steam per hour at 1.2-2.0° atm pressure was produced as early as 1933 at the Leningrad Metal plant imeni Stalin. At that time it was the world's most powerful extraction turbine.

Before the war, a steam-extraction turbine yielding steam at 7 atm pressure was widely used in industry. In 1939 the world's largest and most efficient turbine, a 50,000 kw, 3,000 rpm extraction type, was put into operation. This was designed to deliver 200 tons of steam per hour. Since the war, Soviet power engineers made further progress in the production of extraction turbines. In particular, they produced and put into operation extraction turbines which delivered steam for industrial heating applications, developed turbines with high initial pressure and temperature (90 atm and 480-500° C) and introduced a high-pressure 25,000-kw dual-extraction turbine yielding 60 tons of steam at 1.2-2.5 atm and 80 tons at 8-13 atm.

Postwar extraction turbines include very efficient types with varying back pressures and initial and final steam parameters. The Leningrad Metal Plant imeni Stalin has attained world-wide leadership with regard to production techniques for series production of extraction turbines.

Soviet power engineers have developed the theory of heating networks and solved practical problems pertaining to distribution of superheated water (temperature of 110-150° C). Extensive hot-water heating networks have been installed. Soviet methods of computing the hydraulics of long and intricate heating networks were developed.

During the postwar years, automatic regulation of essential control operations in municipal heating networks (whereby the temperature within buildings is automatically maintained at a set level and the pressure kept constant) was likewise developed. In Moscow, several score automatically controlled heating mains are now in operation. At TETs and industrial installations, steam-jet compressors are widely used. These heat transformers make possible a reduction of the live-steam output of boilers and thus increase the output of electric energy produced at heat and power stations.

Today, the Soviet power industry is faced with new scientific and technical problems, the solution of which will raise the quality of our district heating methods to still higher levels. First of all the efficiency of the operating TETs must be increased. This can be effected by (a) better utilization of steam extracted from turbines, thereby increasing electric power production, (b) electric power production at efficient condensing-type stations near fuel bases instead of at TETs in cities, and (c) by the introduction of comprehensive automatization. Estimates indicate that fuel economy can be increased approximately one and a half times by drawing upon unutilized reserves.

The expenditures necessary to increase the efficiency of operational TETs can be rapidly amortized. This is apparent from the following example: one ton of metal used for heating systems to increase utilization of steam extracted from the turbines of operational TETs can yield an average annual saving of about 25 tons of reference fuel.

Further development of district heating in cities with difficult fuel supply conditions involves certain difficulties. Placing the TETs within city limits and burning of low-grade fuel having high ash and frequently high sulfur content would be disadvantageous from a hygienic viewpoint. A satisfactory solution of this problem requires the transfer of TETs outside city limits and the selection of sites having a water and fuel supply. This will improve sanitary conditions in the city and ensure maximum fuel economy by providing the best operating conditions of the TETs. However, on the other hand, it involves switching to distant heat distribution within a radius of 20-30 kilometers in lieu of maximum effective heat distribution -- by hot water -- within 8-10 kilometers. Investigations have demonstrated the technical feasibility and, under certain conditions, the economic advantages of heat distribution remote from the so-called suburban TETs.

Concurrently, a number of localities are faced with the problem of adopting joint parallel operation of different sources of steam-heat supply (TETs and steam boilers), i.e., of developing heat supply systems similar to electric power systems. This would make possible a further increase in dependability and economy of heat supply.

Investigations have shown the potentialities of district heating in a number of industrial fields with respect to high-temperature processes such as the utilization of gas, air, or mercury turbines in power systems, i.e., utilization of fuel to obtain both high-temperature heat carriers (at temperatures in excess of 250° C) and electric power, instead of their separate production in furnaces or special burners and electric power plants. High-temperature district heating also ensures substantial fuel savings and, under certain conditions, lower capital investments (for instance, in replacing the Cowper system and turboblowers in the preheating and compression of air admitted into blast furnaces with a new composite power system, using gas, air, or mercury turbines and suitable heat exchangers).

A number of the fundamental problems listed above were first formulated and solved in Soviet scientific-research work.

3. Steam at High Pressures and Temperatures

A substantial increase in the efficiency of steam power plants results from the operation of turbines at high initial steam pressures and temperatures.

The change-over in steam power stations from initial steam parameters of 15 atm and 350° C to 30 atm and 400° C results in a 25-30 percent fuel saving. A change from 30 atm and 400° C to 90-100 atm and 480-500° C gives a further fuel saving of 13-14 percent as compared with operation at 30 atm and 400° C. Of great importance are high initial steam pressures in TETs, since they increase electric power output per megacalorie produced for heating purposes. This is shown in Fugure 2.

During the years preceding the First Five Year Plan, typical equipment of USSR power stations had initial steam parameters of 13-16 atm and 325-350° C. The first prewar stage in the development of the power industry was the large-scale conversion to operational standards of 29 atm and 400° C. As a result of the first two Five Year Plans, the Soviet power industry reached a world-wide position of leadership with respect to the ratio of the contribution of high-pressure installations to the total installed capacity of steam power plants.

A few installations which operated at high initial parameters were built in the USSR before the war. Among these was the high-pressure installation at the steam power plant of the All-Union Thermal Engineering Institute, operating at 140 atm and 500° C.

A valuable contribution of Soviet power engineering was the creation by L. K. Ramzin, of a uniflow boiler of original design, which was awarded a Stalin Prize in 1934.

The contribution of the 100-atm installations to the total capacity of steam power stations was quite negligible during the prewar period (1-2 percent). Even under the difficult wartime conditions, our scientific-research institutes and plant design departments continued their work on the production of high-pressure power equipment. For example, a number of uniflow boilers of the Ramzin type were built and put into operation in record time at power stations in the Ural Mountains.

During the postwar Five Year Plan, a basic charge in the utilization of high-pressure installations has taken place. Soviet plants have produced high-power boilers and turbines (both the condensing and the heat and power type) which operate at 90-100 atm initial pressure and 500-480° C (the first figures refer to boilers and the second to turbines).

In 1950, in accordance with the Five-Year Plan, the installed capacity of high-pressure installations will reach approximately one third of the total installed capacity of steam power plants. In the USA, this ratio was only about one to six before the war.

Concurrently with efforts to increase further the dependability and efficiency of installations operating at 100 atm and 500° C, theoretical and experimental investigations are being conducted on the utilization of steam at the very high initial parameters of 170-250 atm and 550-500° C. Estimates show that the use of steam at these pressures and temperatures results in a fuel saving amounting to 10-14 percent compared to fuel consumption of installations operating at 100 atm and 500° C.

The problem of converting existing steam-turbine power stations from 30 atm to 100 atm is also being successfully solved by coupling high-pressure turbines (90 atm, 500° C and back pressures of 29-33 and 15-21 atm) with low-pressure units.

The same problem is being successfully solved by means of the binary installations developed at the Power Engineering Institute of the Academy of Sciences USSR, making use of existing medium- and low-pressure boilers. This new engineering method for the production of high-pressure steam by means of binary two-component boilers can be applied to various types of low-pressure boilers.

Successful utilization of steam at high pressures and temperatures is one of the remarkable attainments of Soviet power engineers in the postwar period.

4. High-Output Units

Increased output by boiler and turbine units is not only a means of boosting efficiency (fuel economy) but is also of utmost importance in lowering capital investment per kilowatt of power, in raising the power production rate, and in scaling down operational costs, mainly by a reduction in personnel.

Figure 3 shows capital investments and metal expenditures per kilowatt of installed capacity in relation to units of power and number of units (machines) in a condensing-turbine steam-power plant.

Usually the selection of a particular capacity of a TETs and of the individual units is limited by the magnitude, the nature, and the distribution of heat loads within a radius of a few kilometers from the station. The selection of total and unit capacities for a condensing-turbine steam-power plant located at a fuel supply base is determined mainly by the size and type of the electric power system that includes the power station. Naturally, important consideration is also given to other factors, such as fuel supply etc. Electric power systems covering large industrial areas, extending over hundreds of kilometers, have total capacities of millions of kilowatts. This figure tends to increase as power systems combine.

Low-power units can be economically justified in TETs installations. However, at the regional condensing-turbine power stations, single units of 50,000 kw capacity, and, in isolated instances, even of 100,000 kw capacity can be economically justified.

Technical progress of Soviet power engineering in the field of production and use of high-output boilers and turbines is illustrated by the following figures. In 1917, the largest unit in a power station had a power of 10,000 kw. In 1925, a 16,000-kw unit was put into operation; in 1927 - 1928, 44,000- and 50,000-kw units were introduced.

In prerevolutionary Russia, boilers which produced a maximum of 10 tons of steam per hour were manufactured; the maximum output of turbines built at the St Petersburg Metal Plant, now the Leningrad Metal Plant (LMZ), was only 1,200 kw. The entire prerevolutionary production consisted of 26 turbines with a total capacity of 9,000 kw.

During the years preceding the First Five-Year Plan, the maximum capacity of turbines and power generators manufactured in Soviet plants was 10,000 kw. In the prewar years, the first 100,000-kw turbogenerators were built and put into operation. The 100,000-kw turbine built in 1938 - 1939 at the LMZ was then the only two-cylinder, high-speed (3,000 rpm) machine in the world. Its initial parameters were 29 atm and 400° C.

A 50,000-kw extraction turbine built at the LMZ has been in operation since 1940. This is the only one of its kind in the world. The individual output of the boilers mass-produced in Soviet plants reaches 230 tons per hour, that of the condensing turbogenerators. 100,000 kw.

An important achievement of Soviet power engineering in the course of the postwar Five-Year Plan was the production in 1946 at the LMZ and "Elektrosila" plants of the record-breaking 100,000-kw, 3,000-rpm, single-shaft turbogenerator unit. The initial parameters are 90 atm and 480° C. Its weight is 265 tons, the same as that of a 29-atm turbine of the same power. With respect to speed, weight, dimensions, and other characteristics, this turbine outstrips the best foreign models of this type.

A 100,000-kw hydrogen-cooled generator was built for this unit at the "Elektrosila" Plant. Cooling with hydrogen instead of conventional aircooling results in better heat dissipation at the generator windings, lower ventilation losses, increased efficiency, and lower materials costs.

5. Automatization

Automatic control of production processes is of especially great importance in making more economical and dependable the operation of power plants, particularly steam power plants.

The power industry, unlike other industrial enterprises, cannot store its finished product (electrical energy). Under the changing conditions of power consumption, automatic regulation must be widely used.

Automatic control of power-generating processes keeps damage to equipment and breakdowns to a minimum. It decreases the number of service personnel and raises efficiency (for instance, automatic control increases boiler efficiency by 2-3 percent, which in a 200,000-kw station amounts to a yearly saving of about 10,000 tons of reference fuel).

The Soviet power industry has at its disposal many excellent series-produced complete units of automatic control equipment for use in steam power stations (VTI, TsKTI, Teploavtomat, and other systems). The comprehensive automatization of boiler plants includes automatic regulation of feedwater, combustion, superheat temperature, fuel preparation etc., in combination with remote control. Two groups were awarded the Stalin Prize in 1946 and 1948 for the construction and industrial adaptation of automatic boiler control devices.

Automatic regulation has been developed extensively in the electrical part of power plants (protective relays, automatic repeated reclosing, automatic emergency-power switches, etc.).

In the course of the postwar Five Year Plan, remarkable results have been obtained in the automatic control of steam power stations. However, the full use of automatic control at all steam power stations still remains one of the most acute and urgent problems of the Soviet power industry.

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6. Efficiency

Technical progress in steam power stations is measured mainly by the specific fuel consumption per kilowatt-hour. Figure 5 shows the correlation of average efficiency and specific fuel consumption per kilowatt-hour in USSR regional steam power stations.

It can be seen that efficiency has been increasing steadily, as specific fuel consumption becomes lower. During the years of the Soviet regime, the average efficiency of our steam power stations has more than doubled. During the period of the Five-Year Plans, it has increased approximately one and a half times.

Soviet power stations have considerable unutilized resources for further increasing efficiency and decreasing specific fuel consumption. Fuel consumption can be reduced to about 0.45 kg of reference fuel per kilowatt-hour (approximately 27 percent efficiency) by enlarging the heat load extracted at heat and power stations and raising the combined output of heat and power, by improving operational conditions, by raising the proportion of high-pressure equipment, and by comprehensive automatization.

Great potentialities for increased efficiency in producing power at steam power stations are revealed by modern power production techniques. The potentialities are:

a. The development and installation of high-output boilers and steam turbines operating at initial steam pressures of 170-250 atm and temperatures of 550-600° C. The efficiency of such power plants could reach 38 percent.

b. The development and adaptation of new systems of comprehensive automatization of steam power plants.

c. The introduction of mercury-steam turbines as the central heat supply for high-temperature processes in industrial enterprises as well as in existing power stations in order to modernize both types of plants.

d. The introduction, at low- and medium-output power stations, of gas turbines operating on solid fuel (with preliminary gasification or by direct combustion). The use of gas-turbine power plants in conjunction with underground coal gasification will provide operational conditions and automatic control potentialities for steam power stations approximating those existing at such advantageous power-supply sources as hydroelectric stations.

e. The wide use, in power plants, of fuel for the production of both power and chemicals, particularly in accordance with methods developed at the Power Engineering Institute imeni Krzhizhanovskiy of the Academy of Sciences USSR. By these methods, it is possible to produce power, steam, hot water, high-calorific gas, and resins in a heat and power plant.

f. Introduction of new methods for obtaining electric power, such as those developed at the Power Engineering Institute imeni Krzhizhanovskiy of the Academy of Sciences USSR, which would salvage waste industrial heat. The aim is to develop the so-called "fuelless" power stations for a number of manufacturing enterprises, where power is generated not from special fuel but by utilizing secondary power resources.

Hydroelectric Power Stations

From the viewpoint of engineering economics, hydroelectric power stations (GES) are the most satisfactory sources of power. The desire to develop GES to the utmost is prominent throughout all the Five-Year Plans and originated with the GOELRO plan. In 1940, 39 GES installations with an annual output equaling 10.5 percent of the total power generated in this country were already in operation. GES operation was then saving more than 3 million tons of reference fuel per year.

The first Soviet GES was the Volkhov station which began operations in 1926. The subsequently established Dnepr (May 1932) Svir, Rybinsk, and other GES are outstanding examples of Soviet technical progress.

The magnitude of the job of constructing the Dnepr station is illustrated by the following figures. Workers excavated 2.8 million cubic meters of earth and rock, poured 1.2 million cubic meters of concrete, and manufactured and erected 35,000 tons of structural steel. Between 1 May 1932 and 18 August 1941 the Dnepr GES provided the country with approximately 16 billion kw-h of energy, thereby saving approximately 10 million tons of high-grade fuel. The power station had only 290 personnel; 8 million kw-h per annum were produced for each worker, approximately 8-10 times the corresponding figure in regional steam power stations.

The Svir GES was built under extremely difficult geological conditions. Erected on settling ground, its foundations had to be slanted at such an angle as to gradually assume a vertical position upon subsequent settling during the course of completion. A construction enterprise of this nature was achieved for the first time.

During the prewar years, the Soviet power-equipment-machine-building industry had created hydraulic turbines of original designs (in particular for the Rybinsk and Uglich GES). Outstanding progress was made by the "Elektrosila" Plant in producing generators for GES.

Under trying wartime conditions, GES construction continued in the eastern regions of the country. GES installations were built in Central Asia in record time.

The Germans inflicted tremendous damage to the country's hydroelectric plants; they destroyed and crippled a number of stations with installed capacities of more than one million kw, including the Dnepr GES. The scope of GES construction during the postwar Five-Year Plan can be judged from the law relative to this plan, which provides for reconstruction of six GES destroyed during the war, for the completion of 30 GES, and for the building of 13 new GES. In 5 years, large GES with a total capacity of 2.3 million kw and small rural stations with a total capacity of one million kw had to be put into operation.

The greatest achievement of Soviet power engineers in the postwar period was the complete reconstruction of the Dnepr GES. On 3 March 1947, the first hydrogenerator of the new Dnepr GES began feeding power to the industrial installations of the Dnepr area. The Leningrad Metal Plant built a unique, 102,000-hp turbine for the Dnepr GES. The hydraulic turbines originally installed in the old Dnepr GES developed 91,000 hp and had an efficiency of 90.3 percent. The Leningrad Metal Plant provided a 102,000-hp hydraulic turbine with the same installation dimensions, and with an efficiency of 93 percent. Considerably improved also, as compared with the prewar equipment, are the generators manufactured for the Dnepr GES by the "Elektrosila" Plant.

One of the important achievements of postwar power engineering is the development of a uniform scale of hydraulic turbines having a minimum number of types and dimensions within the power range from 600 to 125,000 kw and pressure heads ranging from 3 to 250 meters.

Many of the GES built after the war are unique in some of their technical features. The original construction of the Kama GES is important as a model for a number of other stations. At the Mingechaur GES, under construction as a part of the Azerbaydzhan Electric Power System, an earth dam with a 70-meter pressure head was built. The technical characteristics make the dam unique.

Even before the war, there were some fully automatic GES in the Soviet Union. One of these, a two-unit GES in the Moscow power system, operates entirely without attending personnel; in fact, the main station area is usually restricted. Machines are started and stopped by push buttons from a central control board quite remote from the station itself. All disturbances in operation are signaled instantly on this board. In the postwar period, extensive work has been done on automatization of Soviet GES, and the automatic control systems themselves have been improved considerably.

An unprecedented expansion during the postwar period was experienced also in the construction of small GES in farm areas. As a part of the Five-Year Plan, 18,000 small GES will be built.

Electric Power Systems

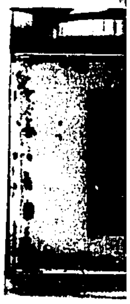
Planned development of electric power systems is one of the main foundations of our technical policy, as enunciated in the GOELRO plan that was evolved and put into effect during the Five-Year Plans.

An electric power system consists of power stations linked by a high-voltage network, having a single operational [dispatching] control center and common power reserves.

Electric power systems afford substantial advantages over isolated power stations. These are: most effective use of water power resources, TETs, and condensing-turbine power stations operating on local fuels; considerable fuel savings and lower capital investments, and power production costs; more rapid development of the power production base due to the faster expansion of capacity; and increased reliability and flexibility of the power supply.

Soviet power engineers did not fall heir to any appreciable experience in the development and operation of power systems. The development of a power base during the Five-Year Plans therefore had as a primary aim the construction of electric power systems. During the first Five-Year Plan, about one third of the total installed capacity was in electric power systems; in the prewar years, this figure had increased to three quarters, and about four fifths of the total energy output (kw-h) was developed in electric power systems. About 50 power systems have been built and are in operation in various parts of the country. By the beginning of the third Five-Year Plan, seven power systems each had a yearly output in excess of a billion kw-h. The Moscow power system is the largest system with steam-electric power stations in Europe and the second largest in the world. Power systems extend over several hundred kilometers, in some cases over 12,000 km.

Figure 6 shows diagrammatically the different types of power systems as they exist in various regions of the country. The first type is essentially a single chain of high-voltage lines. The second type is a grid, the junctions



of which are the generating power stations and the large substations of consumer centers. The third type is a centripetal flow system directed toward a main consumer center.

The electric power systems of the USSR differ substantially from those abroad due to the peculiarities inherent in a planned socialist economy. The capitalist system creates insuperable obstacles to the development of power systems.

Creation and expansion of socialist power systems is correlated with a planned development and distribution of the productive forces within the zone serviced by the system and with efficient utilization of individual types of power resources. The Soviet power systems further differ from those of other countries in their structure because of the joint operation of heat-and-power, condensing-turbine, and hydroelectric stations.

The outstanding features of our electric power systems were strikingly displayed during the war years. The planned construction of systems in the eastern areas of the country ensured an uninterrupted supply of electric power to industrial enterprises evacuated to the east. Installations evacuated to the Urals were dispersed over 1,000 kilometers -- from Solikamsk to Magnitogorsk -- and resumed operation at the new sites in record time, primarily due to the highly developed Ural power system. Under the trying wartime conditions, the regional power systems provided power to the national economy without interruption.

In the years following the war, the development of power systems in the USSR resumed with new force. Construction and development of power systems continued, as did the work already begun during the Third Five-Year Plan, of interconnecting regional systems by means of high-voltage networks. These interconnections are opening a new phase in the development of the Soviet power industry.

High-voltage networks are the basic links which make up power systems. Even in the last years of the Second Five-Year Plan, the Soviet power industry had introduced high-voltage transmission with voltages ranging up to 220 kv. This is illustrated by the graph in Figure 7, showing the development of industrial utilization of high-voltage networks in Tsarist Russia and in the USSR. The diagram also includes the corresponding data for the USA (in 1936 the USA put into operation a 287-kv transmission line connecting the Boulder Dam hydroelectric station with Los Angeles).

In the introduction of high-voltage networks, the Soviet power industry has done in 10 years what it took the USA three decades to do. The total length of high-voltage lines in the USSR increased twelvefold during the prewar period.

A number of original solutions have been provided for various basic problems pertaining to construction of high-voltage networks. Extensive use has been made of wooden supports for 110-kv transmission lines (and for 220-kv lines in certain cases) and metal towers of new design have been constructed, including those used in the long spans over the Dnepr and Neva rivers. In their characteristics, many of these Soviet structures are superior to those of foreign design.

Soviet engineers are successfully conducting studies on industrial utilization of high-voltage power transmission at 400 kv ac using compensating devices. This permits effective transmission over one circuit of up to 550,000-

600,000 kw power over distances of about 1,000 km. The problem of industrial utilization of high-voltage dc transmission is under study. Its solution will provide economical transmission of even greater amounts of power over longer distances.

The Soviet power industry has made very substantial progress in increasing the reliability of power supply. Theoretical and experimental investigations by Soviet engineers of basic problems pertaining to power system stability are universally recognized as outstanding.

Our power systems have solved the problem of increased stability in parallel operation of power stations by the practical application of new techniques along the following three lines: (1) introduction of high-speed protective devices, which ensure rapid power cutoff in emergencies; (2) introduction of special devices for boosting excitation of synchronous machines (automatic regulators, high-speed excitation) to eliminate breakdowns due to static stability disturbances and, in conjunction with other measures, to increase the dynamic stability of the system; (3) the use of devices for automatically dumping the load in response to frequency changes, whereby some of the lower priority consumers are automatically cut off if the frequency drops below the lowest permissible level.

Soviet power systems make wide use of automatic repeated reclosing devices (APV) which rapidly reconnect the line following a disconnection due to breakdown. These devices helped greatly in providing uninterrupted power supply to industrial installations during the war. A substantial achievement of postwar years is the use of APV in conjunction with repair by phases of circuits with a grounded neutral. The group responsible for this work was awarded the Stalin Prize.

The list of outstanding achievements honored by Stalin Prizes in 1950 includes two relating to improvements in the reliability of electric power systems. These were the development and installation of new protective relays which increased the reliability of power systems and the development and introduction of a compounding system for power station generators to increase the stability of power systems.

Figure 8 illustrates the decrease in the number of breakdowns due to electric storms in Soviet power networks during the period 1934 - 1946. The number of breakdowns and the resulting power loss in 1934 are taken as 100 percent. Even before the war, these failures had been reduced more than tenfold by the application of new protective equipment.

The Soviet power industry has entered a new phase of development, namely, the interconnection of the regional power systems into future components of an integrated high-voltage network (YeVS). Such interconnection of regional systems will further increase reliability and flexibility of the power supply, with system reserves lower or identical to those required in separate operation of individual systems. This interconnection will ensure the fullest utilization of water-power resources, improvement of fuel balance, and reduction of operating costs.

A central power system which has the Moscow power system as its core, and which includes the Gor'kiy, Ivanov, and Yaroslavl' power systems, has been under development during the postwar years. A higher stage of development is being attained by the interregional Urals power system, due to the construction of the huge Molotov GES. The Southern interregional power system, which includes the Donets, Dnepr, and Rostov power systems, is also being further developed. Foundations are being laid for a future Transcaucasian interconnected power system.

The large GES on the Volga will be of great importance in the formation of the integrated high-voltage network in the main regions of the European USSR. The formation of interregional electric power systems will go hand in hand with the electrification of the principal railroad lines.

Technical progress in the use of high-voltage dc and ac transmission will greatly facilitate the development of an integrated high-voltage network.

It is not possible in a single paper to review fully the technical progress of our national power industry. Most significant is the steady increase during the postwar years of the number of Stalin Prizes awarded for outstanding creative work in the field of power engineering. On considering only those pertaining to power stations and networks, the following figures are obtained: in 1945, two contributions received the Stalin Prize; in 1946, three; in 1947, seven, and in 1948, eight. The published list of outstanding works which earned the Stalin Prize in 1949 includes nine relating to electric power stations and power networks.

[Figures follow.]

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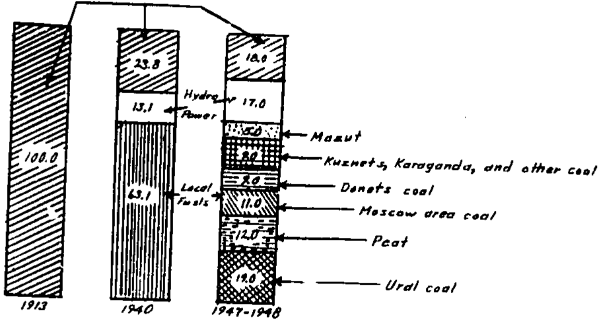

Figure 1. Conversion to local fuels: Change in the structure of power production by regional power stations in USSR with respect to power production sources

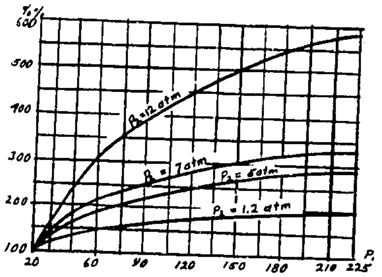

Figure 2. Effect of initial steam pressure on power production at TETs (P_1 = 20 atm equals 100 percent)

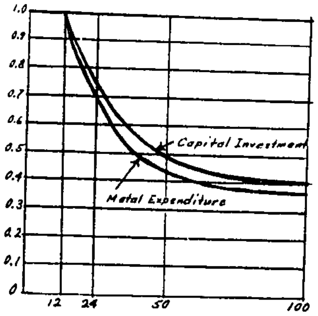

Figure 3. Relationship between station and unit powers and specific capital investments and metal expenditures per kilowatt installed capacity of condensing-turbine power stations. Data on a 12,000-kw station is taken as unity. Installed capacity of two-unit power stations in 1,000 kw increments are plotted on abscissa

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Figure 4. Photograph showing general view of 100,000-kw, 3,000-rpm high-pressure turbine [not reproduced; available in original document in CIA]

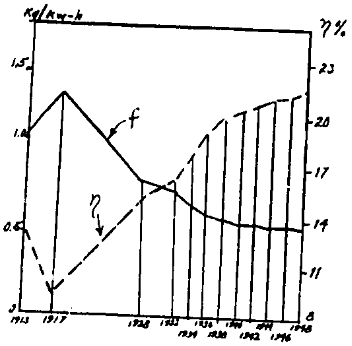

Figure 5. Average efficiency (η) and fuel consumption (f) per kilowatt-hour produced at regional steam-electric power stations in USSR

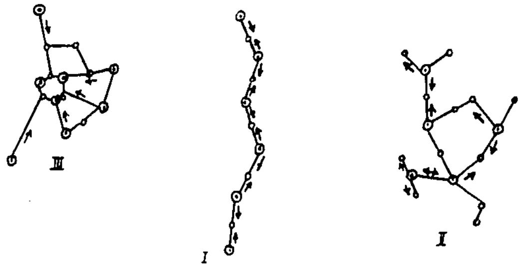

Figure 6. Three basic types of configuration of electric power systems

⊙ Electric power stations
° Substations
⇄ Direction of current flow

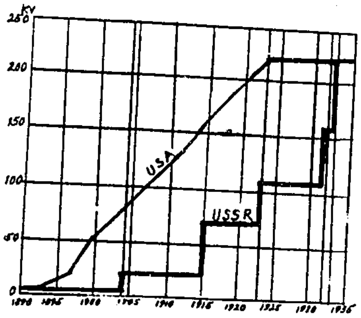

Figure 7. Development of industrial utilization of high-voltage networks

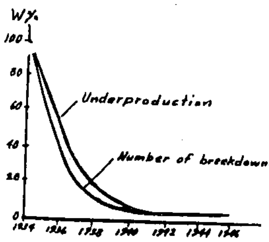

Figure 8. Decrease in number of breakdowns due to electric storms and resulting power losses in USSR electric power systems

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