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USSR Report

ENERGY

(FOUO 16/80)

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ELECTRIC POWER AND POWER EQUIPMENT

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SCIENTIFIC PRINCIPLES OF SYSTEMS RESEARCH IN POWER ENGINEERING

Moscow IZVESTIYA AKADEMII NAUK SSSR: ENERGETIKA I TRANSPORT in Russian No 3, May/Jun 80 pp 3-9

[Article by L. A. Melent'yev, Moscow]

[Text] Major principles of scientific fundamentals for systems research in power engineering are considered. It is shown that this research includes theoretical and procedural aspects, and their applications for concise solutions of fundamental problems in power engineering.

The essence of theoretical systems research in power engineering is outlined, and results attained in this field in the USSR are disclosed. The procedural and conceptual aspects of this research are briefly described.

The theory of systems research can be briefly defined as the totality of scientific methods and principles that are most productive for studying especially complicated objects treated as a system. In the general case, a system means a set of elements that are so interrelated and interconnected as to form an integral whole.

Systems research in power engineering is especially important. Today it can be said without exaggeration that power engineering in the modern

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From the Editors: Systems research aimed at the development of scientific principles of effective solution of fundamental problems and the perfection of management of the power industry is one of the central areas of development of the science of energy.

In this issue of our magazine we are publishing six articles dealing with different aspects of systems research in power engineering.

The newness of the problems has led to certain differences in treatment of a number of principles in these articles, which at this stage can be considered natural, and even useful to the reader.

This same issue publishes a resolution passed in 1979 by the All-Union Scientific and technical Conference on Systems Research in Power Engineering, where principles are formulated on which a consensus has been reached in the opinions of specialists working in this field.

scientific sense is actually a complicated aggregate of large, well developed systems[1], and therefore the method of systems research corresponds in greatest measure to the essence of power engineering.

At a certain stage it was necessary to transform systems power research from an art practiced by isolated individuals into a science that is an aggregate of scientific principles, rules, hypotheses, methods and means leading to identical results when applied independently by isolated researchers (under the same conditions). To do this, it was necessary to conceptualize such research, defining methodology, and elaborating: a) the idea of the object and subjects of research; b) the theory of the properties and trends in development of the object of research; c) the methods and means of research; d) purposeful ideas on the foreseeable final goals of the research.

At present the problem of developing the scientific principles of systems research in power engineering has already been solved to a great extent in the USSR. The results achieved in this area are briefly presented below with consideration of the purpose of the article, mainly in application to the theoretical side of systems research.

With some arbitrariness, systems research in power engineering can be divided into theoretical, procedural, and application of systems research for concise solution of fundamental problems of power engineering.

In the modern sense, the theoretical concept of systems power research includes as its principal components: 1) methodology of systems power research; 2) the concept of large power systems; 3) the properties of power systems; 4) major objective trends in the development of these systems. The procedural aspect of systems power research embraces the development and perfection of specific methods and means of studying large power systems.

Theoretical Aspect of Research. It is justifiably emphasized in Soviet literature that the initial methodology of systems research is dialectic materialism and dialectic logic as its component. In this connection, the most important methodological principles in systems power research are the following, characterizing the surrounding environment and its cognition: a) examination of the object of study in unity, development and integrity taken in their totality, and in unity and conflict of opposites; b) the presence of universal causations and continuity in motion (development); c) accounting for the aspect of hisoricity in research, i. e. distinguishing the peculiarities of temporal interactions and the principal link in the given time period; d) examination of the

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[1] Here and below, power engineering is meant in the broad sense of the totality characterizing all kinds of energy transformations from the extraction of energy resources to the energy receivers inclusive.

dialectics of development of our knowledge of relative truths and a gradual approach to understanding of the absolute truth.

Concretization of these general methodological principles in Soviet systems power research has enabled substantiation of the following four initial points.

1. Actual power systems in all the complexity of their past and future development are the object of research, whereas the models of such systems, including mathematical models, are a secondary approximate reflection (including an advance reflection) of our cognition of such actual systems, and give us a powerful means of studying them. Therefore in systems power research considerable attention is given to investigation of the identity between actual systems and their descriptive mathematical and physical models.

2. The directions of development of large power systems are determined by a complex of objective trends whose dynamicity depends on characteristic periods of development of power engineering. Such objective trends are the specific reflection in power engineering of causations (both deterministic and statistical) that lie at the basis of objective laws of development of production forces and production relations. The study of objective trends in the development of power engineering and the strength of their manifestation at different time periods is an important component of theoretical systems research, and a powerful scientific tool for analysis and design (planning, development) of large power systems, and for showing their interaction with development of the nation's economy.

3. Large power systems are taken as conditionally defined, which is a natural consequence of their equilibrium motion under the action chiefly of long years of development of objective trends and deviations from this development under the influence of random and partly indeterminate events (phenomena).

4. The major goal-directed measures (management in the broad sense) for development of power systems have been carried out in the face of incomplete information on forthcoming conditions in which large power systems will develop and operate.

The incompleteness of controlling (as well as orientational) information can be attributed to the inclusion of not only deterministic, but also probabilistic data, as well as incomplete (insufficiently defined) information mainly on external conditions that influence the movement of systems. Incompleteness of the information used cancels out one of the initial mechanistic principles that "everything can be made quantitatively commensurate with any degree of precision," and therefore excludes (as a general case) the feasibility of finding strictly unambiguous solutions for future optimum states of large systems in power engineering.

Such unambiguously optimum solutions would be valid only on the unrealistic assumption that we have unambiguous knowledge of all future conditions that will influence development of the system. In reality, this is not so, and changes in such conditions might make accepted unambiguous solutions non-optimum.

These circumstances limit the applicability of formalized decision-making techniques in systems research, and people remain responsible for final decisions. Therefore the principles used for decision making in systems power research are the so-called heuristic methods that synthesize unformalized and formalized decision-making techniques. The methodological assumption of incomplete information may also lead in large measure to a new conception of the need for continuous systems control, and the development of new optimum decision-making techniques that have already been partly worked out in the USSR.

Formalized principles suggest the following definition for the essence of a large production system (including power systems): a large open system of this kind is an actual integral system, and therefore hierarchically structured and in continuous equilibrium goal-directed movement, an entity that includes man, machine and environment; it has particular properties and consists of a complex set of interacting components and relations that cannot be quantified as a whole[1].

It can be seen that in the main, the essence of the man-machine system and the conditionally defined production system is characterized by reality, integrity and goal-directed dynamicity (in the sense of continuity of movement), as well as by a number of other properties, including specific properties.

Concepts of the structure and state of a system are important for systems power research.

The structure of a system means the way it is put together (organized) as shown (at a given point in time and under given external conditions)

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[1] In this definition it might be useful to explain two concepts: a) "large system" is a concept used in accordance with a proposal by W. R. Ashby, an eminent theoretician of systems research, to consider a system large when it is such for an "observer" who cannot therefore single-handedly look after it, control it, and simultaneously make all its components and relations quantitatively commensurate; b) "integrity" is a fundamental concept of the large system defined as the unity of an object (system) that has particular properties and consists of the totality of hierarchically structured parts, each of which may be an entity with its own inherent particular properties. The integrity of an object (system) is always relative since it has a set of relations with the surrounding environment, and can exist only in concert with that environment.

by the unity of stable interrelations between components. Therefore in the sense of stability of interrelations of the system it can be stated that the concept of structure is an invariant aspect of the system.

The state of a system often means that set of properties defining the system in a given time period.

The properties of power systems, and on the whole those of production systems, have not yet been adequately studied. Therefore the way that these properties will be characterized here can be taken merely as a hypothesis. It is assumed that systems have some set of properties that show up variously and with unequal strength, depending on the aspect of consideration of the system. The statement below applies to the study of systems in the aspect of controlling them.

In the author's opinion, we can differentiate: a) major properties that are common (for the main large production systems) to large power systems and show up in a particular way in these systems, and b) specific properties of power systems that in large measure justify their distinction as a special kind of systems[1].

The first class obviously includes properties of: 1) hierarchism manifested thorugh the properties of centralization and structural complexity; 2) movement (development and functioning), including properties of economy, reliability, adaptation, inertness, stability; 3) decision making, to which we can ascribe properties of inadequate definiteness of optimum decisions and plurality of criteria.

The author deems advisable the following formulation of properties that in the aggregate characterize the specifics of large power systems.

1. Broad mutual interchangeability and interaction of components, relations and goods of systems that transform them into a unified complex.

2. Particular universality of goods produced.

3. Activity of systems in the sense of influence on the development and distribution of production forces.

4. A particular scale of size, and therefore particular complexity of the structures of systems formed as units for a nation or group of nations, including those belonging to different continents (such as petroleum supplying systems).

5. The material nature of basic connections (electric, pipeline).

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[1] For more detail, see for example the author's monograph "Sistemnyye issledovaniya v energetike" [Systems Research in Power Engineering], Nauka, 1979.

6. The uninterrupted (and often uninterruptible) nature of processes of production, distribution and consumption, which dictates operation into a combined load (over the system as a whole, or over its major parts). Therefore treatment of the given large system as a unified whole is especially important.

7. The duality of systems due to transitions from technical-economic to physicotechnical and back, depending on the aspect of study, mainly determined by the material nature of connections between systems and the continuous nature of processes of production, distribution and consumption.

The rising importance of power engineering (the fuel-energy complex) in the development of the national economy, the peculiarity of manifestation pf common properties of large production systems in power engineering, as well as the specific properties of large power systems justify treatment of systems research in power engineering as a relatively independent area of the science of energy.

As stated before, the study of objective trends of development of power systems is an important component of the theoretical aspect of systems research. Studies that have already been done (based on analysis of the period of 1950-1980) enable us to characterize the major objective trends in development of large power systems of the USSR in the following way, differentiating them as to trends: a) on the whole characterizing the proportionality of development of power engineering in the economy, and b) mainly characterizing the tendencies of scientific and technical progress in power engineering.

Among the former, we can distinguish the following objective trends:

1. An increase in the potential of ultimate energy expended by the national economy. This is expressed as an increase in the percentage of energy used on high-temperature, physicochemical and power processes, and a reduction in the percentage used for medium-temperature and low-temperature processes (especially in small facilities with direct fuel consumption). In recent years in the USSR the structure of expenditure of ultimate energy by processes has approximately stabilized due to the relatively rapid development of a number of heat-intensive branches of industry and housing construction.

2. A reduction in the expenditure of consumable energy resources (and also of ultimate energy in certain periods) per unit of national income, which characterizes a systematic rise in the efficiency of energy resources[1].

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[1] Net ultimate energy means the amount of energy directly used by operative (during the given time period) working machines, equipment, apparatus, as well as technological and household processes (including

3. A systematic increase in the percentage of electric energy in the overall consumption of ultimate energy, which is a result of the process of electrification of the national economy.

4. A continued rise in the electric power-to-worker ratio as an important factor in the growth of social productivity of labor.

5. Intensification of motorization of the national economy, mainly in transportation and in agricultural production, as a major factor in raising the efficiency of social production and labor productivity in these sectors of the national economy.

6. A systematic increase in the percentage of energy resources used to produce transformed kinds of energy (electricity, steam, hot water, compressed air), and a reduction in the percentage used by facilities that consume fuel directly, as an important area of improving the energy economy of the nation.

7. A continued increase in the level of energy services to the populace, which is an important source of growth in labor productivity in private life, and improvement of comfort conditions in the life of the people; a gradual reduction in the negative ecological aftereffects from development of power engineering.

Objective trends of scientific and technical progress in the power industry are characterized by:

A. Intensification of systems principles in power engineering, which is expressed in: 1) continual increase in the level of concentration of production of transformed kinds of energy, facilities for transporting energy and energy resources; 2) increased centralization of the distribution of produced energy resources, products made from them, electric energy, steam and hot water. All this together leads to rapid development of large power systems.

B. An increase in the efficiency of utilization of energy resources and transformed kinds of energy, which shows up mainly in three trends: 1) improvement of the structure of utilized resources, which is today characterized chiefly by an increasing percentage of utilization of nuclear fuel; 2) improvement of the utilization of fuel and energy by implementation of an energy-conservation policy where the important thing is to update existing technologies and create new ones, and also timely retirement of outdated and antiquated equipment and structures; 3) a reduction over the long-term period in the expenditure of produced

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heating, lighting, ventilation and so on), that is necessary for their normal operation, or alternatively: the amount of energy used to produce all forms of non-energy goods, operate transportation, and provide industrial services and improve the standard of living of the people.

energy resources per unit of ultimate energy as there is an increase in the percentage of realized labor in expenditures to produce this energy.

It should be noted that in addition to the decisive action of the enumerated objective-progressive trends, the development of power engineering in the USSR is also influenced by certain negative phenomena, mainly associated with an inadequately rapid growth of the level of electrification of the national economy, some delay in retiring outdated equipment, an insufficiently rapid rise in the power of production facilities. Particular attention is now being given to the elimination of these faults.

Procedural Aspect of Systems Power Research. In the main, this aspect is tied up with improving existing methods and means of studying large power systems, and developing new ones. Experience has shown that mathematical models of various types are very important in this research area. It is here that the USSR has made great advances with the creation of linear and nonlinear models for research and extensive practical application in power systems[1]. At the same time, it would be appropriate to mention some of the most difficult scientific problems that still need to be solved. We are speaking primarily of finding criteria for the level of identity between actual systems and their mathematical models. Here one of the paths to solution can be found in studying the properties of large power systems and in their possible complete reflection in mathematical models. A second difficult problem is in the transition from the mathematical optimization models that are now widely accepted to models that simulate possible situations in systems; this involves the development of complex information-simulation facilities that most fully reflect an actual control situation (in the broad sense) for management of systems with incomplete information. It is also important to develop a set of algorithmically and informationally compatible mathematical models (computer complexes) that reflect the major hierarchical and temporal levels of management of power systems. To solve these problems, formalized methods must be perfected that boil down mainly to methods of equivalent reflection of systems, their decomposition, iterative computational procedures, and also to substantiation of methods and means of consolidating (aggregating) information. Heuristic methods of controlling large power systems must also be improved, including management of the Statewide energy system (fuel-energy complex). Pertaining to this, we note that although mathematical models and digital computers are taken as the basic formalized scientific tool for systems power research, we must not forget that there are areas where it is advisable to use analog and hybrid (digital-analog) computers as well as physical models; we have in mind for example the digital-analog complexes for studying physical processes in electrical and pipeline systems; physical models for studying the

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[1] For more elaboration on individual achievements, see the articles by A. A. Makarov, L. S. Belyayev and others in this issue of "Izvestiya Akademii nauk SSSR: energetika i transport."

behavior of two-phase flows in individual elements of systems; models for studying the behavior of particles that contaminate the atmosphere; models for studying measurement errors of instruments in systems and so on. Special procedural aspects involve the perfection of optimization criteria in systems research.

The Applications of Systems Research for Solving Fundamental Problems of Power Engineering. These are quite diverse, and major positive results have already been realized in the USSR. Among the principal areas of such use of systems research are:

1. Solution of complex intersectoral problems of power engineering, including: the intricate group of problems in finding the long-range optimum structure of the fuel-energy complex of the USSR, and optimum levels of electrification of the national economy; multiple-variant calculations of the fuel-energy complex to find the best planned solutions; calculations of prospective levels and structure of energy consumption and so on.

2. Long-term prediction (20-30 years in advance) of the development of power engineering, scientific and technical progress in large power systems, ecological problems of power engineering.

3. Elaboration of scientific concepts and prospects for development of individual functional large power systems (unified electric power system, nuclear power system, gas supply system, oil supply system, the system of the coal industry, local heat supply systems).

4. The investigation, and also the optimization of arrangements and parameters of complex power systems; thermal electric power plants of different types, including nuclear plants; petroleum refineries; the systems of oil and gas fields and so on.

5. Development of scientific principles and methods of optimum control of power engineering (large power systems), having in mind the management (planning) of development and operation of the fuel-energy complex as a whole, perfecting the business management of functional power systems, managing the energy conservation policy and so on.

Systems power research has assuredly been extensively developed in the Soviet Union: the scientific principles of such research are being perfected, methods and means for this research have been created and are being developed, which has enabled a considerable expansion of the conceptual use of systems procedures for solving many fundamental problems of power engineering. However, systems power studies are not yet being coordinated with adequate effectiveness, and there are still relatively few scientific and planning collectives working in this field; the theoretical aspects of systems power research are not yet getting adequate attention.

In planning science and engineering projects for 1981-1985, it is important to give attention to further development of work in systems research in power engineering.

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ELECTRIC POWER AND POWER EQUIPMENT

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SYSTEMS RESEARCH AND METHODOLOGICAL QUESTIONS OF COMPARATIVE ECONOMIC EFFECTIVENESS IN POWER ENGINEERING

Moscow IZVESTIYA AKADEMII NAUK SSSR: ENERGETIKA I TRANSPORT in Russian No 3, May/Jun 80 pp 10-20

[Article by A. A. Beschinskiy, Moscow]

[Text] The author emphasizes the organic unity of the methodology of determining economic effectiveness in power engineering and systems research in this area. He shows how formation of the major principles of the methods [of determining] effectiveness is related to processes of increasing collectivization of production in the power industry, and to the reflection of these processes in the development of systems analysis in the science of energy. An examination is made of major indicators of effectiveness as applied to power engineering. Directions for further research in this field are characterized.

A number of peculiarities of power engineering (the fuel-energy complex) and its part in the reproduction process determine the importance of the problem of economic effectiveness and systems research in this area.

The ratio between the development of the power industry and the economy as a whole is one of the major national economic proportions. Corresponding to 1,000 rubles of national income are about 4 metric tons of standard fuel in consumption of primary energy resources, and 3000 kWh of electric energy. The coefficient of elasticity of energy consumption with respect to the increment in national income is of the order of 0.8, with a corresponding coefficient of 1.3 for consumption of electrical energy.

The annual capital investments that go to the power industry rose from 6.6 billion rubles in 1965 to 13.4 billion in 1978. Somewhat more than 29% of fixed production capital is concentrated in sectors of the fuel-energy complex, but only 9.0% of the industrial output is produced. Such proportions are evidence of high capital intensiveness and the high organic structuring of capital in the subsystems that make up the power industry.

These indicators, average for the power industry, are sharply differentiated with respect to elements of the fuel-energy complex, forming a wide spectrum of possibilities for variant solutions based on different ratios of one-time and running expenditures. These expenditures must be made commensurate and comparable for all sectors of power engineering. It is this characteristic feature that has made the power industry the field where the concept of comparative economic effectiveness of capital investments first was formulated and applied.

The growing national economic significance of power engineering is intimately involved with, and in large measure a result of structural shifts within the power industry that determine the growth of its economic effectiveness and the level of collectivization of industry. Among such shifts are changes in the structure and geography of primary energy resources involved in the fuel-energy balance (of particular importance here are nuclear power and the energy resources of the eastern territories); changes in the ratio between primary and ultimate forms of energy; changes in the structure of energy carriers; processes of concentration and centralization of energy production; formation of large power systems; a rise in the efficiency of energy resources and so on. The complex interrelationship between these processes requires comprehensive optimization of the power industry.

The need of a systems approach to determination of the effectiveness of measures in power engineering is also dictated by the unusual nature of external connections of the fuel-energy complex that predetermine the need of accounting for the consumer effect.

The "output" of the "power industry" system can be taken as the totality of energy carriers going into the power apparatus of consumers. It is on the level of consumer facilities that the final expenditure of energy is determined after deducting all forms of losses including those in the consumer facilities. The higher the energy efficiency, the more primary energy resources that will be set free for additional economic growth. Thus an increase in efficiency is an important factor and indicator not only for perfection of the power industry, but also for growth of the economic potential of the nation. Of course this effect must be evaluated and compared with the expenditures necessary for attaining it.

Analogous estimation and comparison with expenditures must be carried out for other effects by which the national economy benefits from power engineering, in particular the effect of consolidation (concentration) of material production, growth of the power-to-worker ratio and the associated growth in labor productivity, and so on.

A number of questions of power-economic effectiveness arise in connection with the particulars of conditions of energy consumption. Nonuniformity of these conditions on a daily, weekly and yearly basis causes a number of complicated problems in the power industry with respect to optimizing the structure of equipment and the functional specialization of various types of power plants within the framework of large power systems.

All calculations of effectiveness are complicated by the necessity for doing them with consideration of dynamics. Investment processes and "maturation" of large complexes in the power industry frequently unfold over a prolonged period of 20-30 years (acquisition of the Kansk-Achinsk Basin, the Tyumen' territories, realization of extensive hydropower projects and so on). Elaboration of a strategy for the development of nuclear power based on finding a combination of thermal and fast reactors requires calculations that consider a number of decades.

Nor should we forget the great significance of the energy factor in solving problems of territorial organization of production. Extensive measures in the field of power construction play a major regionalizing role, predetermining the directions of capital investments in production and in the area of services, many times greater than the investments in the power industry proper.

All this shows that the systems approach is organically, "essentially" associated with utilizing the category of economic effectiveness in power engineering. This approach reflects the objective processes of collectivization that are inherent in power engineering and that deepen and broaden with time.

Development of the Systems Approach in the Methodology of Evaluating Economic Effectiveness in Power Engineering. The initial principles of technical-economic calculations and the search for optimum solutions were embodied in the plan of the State Commission for Electrification of Russia [GOELRO] and in a number of Lenin's articles, letters and speeches in connection with the elaboration and discussion of this plan. Of especially great methodological significance for the entire theory of effectiveness (and power engineering in particular) was the central aspect of the GOELRO plan -- the aspect of a radical, decisive connection between electrification and the growth of productivity of social labor. This clearly defined the criterion of effectiveness of social production and its relation to electrification and development of the power industry.

The Leninist concept of electrification enabled not only formulation of the criterion of effectiveness, but also determination of methods of using this criterion. Of considerable significance in this connection is V. I. Lenin's letter to G. M. Krzhizhanovskiy, dated 14 March 1921 [Ref. 1], giving the basics of the structural systems approach to analysis of the effectiveness of electrification. Its characteristic features are:

variance of economic analysis;

juxtaposition in this analysis of national economic structures with different values of the electric energy component, rather than the individual objects;

in this comparative analysis, tracing expenditures and results with respect to the entire cycle of the power industry with consideration of the consumer effect, i. e. with involvement of the entire national economy in the analysis rather than merely within the framework of expenditures and effects in power engineering proper.

The relation between effectiveness and the systems approach was shown with particular force and originality in the GOELRO plan in questions of zoning. All zoning was subject to what was known as the "energy" principle, which was interpreted as a principle of achieving "maximum overall efficacy," i. e. maximum economic effectiveness. Electrification and fuel supply were incorporated into this general systems plan as a primary factor for attaining the formulated goal [Ref. 2].

The GOELRO plan formulated the problem of commensuration of the additional capital expenditures and economy on annual outlays, in particular for such capital-intensive projects as hydroelectric plants. Thus the category of the payoff period of additional capital investments first made its appearance. In other words, in the GOELRO plan the problem of maximizing the increment in labor productivity acquired a national economic aspect in coordination with the level of the capital-output ratio of the versions to be compared.

Not all principles of the GOELRO plan in the area of economic theory were immediately developed and put to use. For a number of years, individual economists saw the criterion of effectiveness in minimum production cost, without consideration of the payoff period of capital investments, adjusted expenditures, depreciation and so on.

In power engineering, the principles of the GOELRO plan were most systematically developed and used. This work was promoted by long years of fruitful effort on the part of the director of the GOELRO Commission, G. M. Krzhizhanovskiy. Besides, life itself, as well as practical planning in the power industry made it necessary to implement the economic principles of the GOELRO plan more extensively.

In the first instance, this applied to the problem of commensuration of one-time and running expenditures. Use of the method of the payoff period in evaluating comparative effectiveness was supported in particular by the works of S. A. Kukel'-Krayevskiy [Ref. 3], V. I. Veyts and others. An All-Union Conference on Problems of Effectiveness (1957) [Ref. 4] legalized the use of the payoff period and other categories of economic effectiveness of capital investments. The methodology set up on the basis of the conference's recommendations delineated categories of absolute and comparative effectiveness, proposed the increment in national income (in comparable prices) with respect to the capital investments leading to this increment as a criterion of economic effectiveness of capital investments in the national economy, and played an important part in the development of economic considerations and in improvement of all economic work both in the power industry and in other production sectors.

Important contributions to development of the principles of effectiveness in power engineering were made in this period by L. A. Vaag [Ref. 5], L. A. Melent'yev, T. L. Zolotarev and V. V. Novozhilov [Ref. 6], A. I. Notkin and A. Ye. Probst [Ref. 7], M. A. Styrikovich, N. P. Fedorenko, T. A. Khachaturov and others. Research done in the late fifties and early sixties dealt with the theoretical comprehension of introduced concepts of economic effectiveness, and imbuing them with specific technical-economic meanings. The work covered numerous situations of commensuration of one-time and running expenditures inherent in power engineering; normative values of the payoff period and the coefficient of effectiveness were worked out on the basis of generalization of Soviet and world-wide practice in planning, and these values were gradually changed toward more rigid limitations of highly capital-intensive decisions (from $E_H = 4\text{-}7\%$ to $E_H = 12\text{-}15\%$). Principles of discounting capital investments and expenditures were then extensively introduced into scientific and planning practice to account for the time factor. On the basis of the "Model Technique" [Ref. 8], about 40 sector-wide sets of instructions on calculating effectiveness were compared and approved for use, including instructions on electric power and a number of sectors of the fuel-energy complex. Development of the method of incremental limiting values of the payoff period (the "chain" method) was of definite importance. This method showed that it is when the limiting values of the normative payoff period are reached that the optimum value of the energy parameter is realized. This meant that the minimum adjusted expenditures do not coincide with the minimum payoff period, that the optimum solutions are reached at the normative payoff period of the increments rather than at the minimum value. In other words, it is advisable to economize on living labor by one-time additional expenditures until the normative payoff period of the increment in the parameter is reached. This result was automatically attained by using the formula for adjusted expenditures: $З = C + E_H K = \min$, and the general tendency in using different methods of calculation of economic effectiveness was to make wider and wider use of this formula instead of the formula for the payoff period.

Further research on questions of economic effectiveness in the power industry involved developing methods of systems analysis in working out the structure and the prospects for development of power engineering. The works of V. V. Bolotov and L. A. Melent'yev were especially important in this connection.

The objective basis for expansion of the systems approach in the power industry over the last thirty years has been the restructuring of the energy balance of the nation due to the utilization of resources of petroleum and natural gas. Because of this and on the basis of technical progress in all links of the power industry, there has been a sharp increase in the interchangeability of utilized energy resources; at the same time there has been a considerable increase in the centralization and concentration of power production.

Formation of the electric power system and functional specialization of electric power plants of different types in this framework (peak, base, semi-base, regulated or with forced power output and so on) have made it obvious that it is incorrect to compare, for example, a hydroelectric plant with a small number of hours of utilization for performing so-called "power" functions, with a large fossil-fuel plant designed for base operation. Therefore the comparison between isolated electric plants was replaced by economic comparison of power systems of different structures providing the same power and energy output in accordance with the schedule of power consumption.

Structural analysis of the effectiveness of capital investments in power engineering inevitably led to the need for development of a dynamic system of technical-economic calculations, and related it to a certain extent with long-term predictions of development of the power industry.

Dynamics began to be taken into consideration more fully by analysis of more detailed stages (right up to annual stages), more careful consideration was given to modifications, changes in the structure of equipment and fuel supply conditions, different sequences of introducing power facilities, changes in conditions of energy consumption, the consequences of decisions and so on. Systems analysis in electric power engineering was promoted by the development of modeling, linear and dynamic programming. Under conditions where the development of electric power engineering is optimized in models of the fuel-energy complex, one of the important aspects of dynamic economic analysis was accounting for the time factor in technical-economic calculations. The urgent need for such consideration was brought about by the economic nonequivalence of expenditures (and resultant effects) made at differenc times.

In general form, the technique of comparing variants must account for changes of capital investments in time, annual outlays and output, beginning with different construction periods, acquisition, and reaching production capacities, and ending with the change in sequence of alternation of objects and corresponding expenditures in the course of the calculated period and beyond its limits.

The "Model Technique" [Ref. 8] for adjustment of expenditures in time legitimized the use of the method of complex percentages, extending it both to capital investments and to time-variable annual outlays. As applied to power engineering, these principles were most completely expressed in the famous formulas of V. V. Bolotov and D. S. Shchavelev

[Ref. 10] that account for the increment in capital investments and outlays over the construction period and during operation. There have been no fundamental difficulties in referring capital investments and running expenditures to a single instant of time even in cases where the values of capital investments, annual outlays and volumes of output change continuously in the course of the computational period.

Extensive development of the program-goal approach and development of long-range complex programs intensify the requirements for methodology of evaluating the effectiveness of comprehensive measures.

D. S. Shchavelev, M. P. Fel'dman, A. A. Beschinskiy [Ref. 11], Ye. A. Yelokhin and others developed the theory of the problem and formulas for determining the effectiveness of comprehensive projects and measures, and proposed a method of distributing expenditures among the elements of a complex. The starting point here is examination of the complex as an organic whole with all parts interacting, changing in the interest of optimizing characteristics and parameters of each component as compared with those that it would have away from the complex.

While the theoretical aspect of the problem is fairly clear, the practical difficulties of dynamic analysis of the effectiveness of a complex are quite appreciable. This applies first of all to the makeup of alternative variants, which may constitute an arbitrary set in the complex. It is necessary before working out the development of large comprehensive programs to develop the corresponding alternatives on the basis of scientific and feasibility studies, and then to have them approved by Gosplan SSSR.

Of considerable long-range significance for optimization of the fuel-energy complex is research being done by the Central Institute of Mathematical Economics of the USSR Academy of Sciences in the field of economic evaluation of natural resources [Ref. 12]. The corresponding method, based on rental estimates, will enable inclusion of an extensive class of material factors of power production in optimization calculations that heretofore have been only qualitatively considered.

The results of considerable work done in the field of methodology of evaluating economic effectiveness in power engineering have stood the test of time. They are extensively used in planning and design and have been enriched by this use. They have been the basis for economic justification of a great many large power projects that have been built. Optimization calculations have become part and parcel of planning and design. At the same time, a number of complicated issues have come up that require further elaboration.

The Direction of Future Systems Studies of Effectiveness in Power Engineering. 1. One of the unresolved issues is the value of the normative coefficient of effectiveness E_H and the normative coefficient of adjustment E_{Π} and establishment of their equality or difference. The value of E_H should have been obtained from the optimum plan of development and operation of the economy of the nation for the long term. However, there is no such plan as yet, and there is no unanimous opinion on the values of these coefficients. The "Model Technique" [Ref. 8] and the Instructions on Economic Effectiveness of Capital Investments in Power Engineering [Ref. 13] take values of $E_H = 0.12$ and $E_{\Pi} = 0.08$ (depreciation is not discounted). The Basic Procedural Principles of Technical-Economic Calculations in Power Engineering [Ref. 14] takes $E_H = E_{\Pi} = 0.12$[1]. Temporary Instructions on Determining the Effectiveness of a Hydroelectric Plant (1978) reduce E_H to a value of 0.08 and take it as equal to E_{Π}. The Method of Determining the Effectiveness of New Equipment [Ref. 15] uses values of $E_H = 0.15$ and $E_{\Pi} = 0.10$.

Nor has a consensus been reached on questions of equality or differentiation of sector-wide values of coefficients E_H. For example a recently published large work by T. S. Khachaturov [Ref. 16] systematically defends the position of different sector-wide values of E_H. At the same time, many scientists take the standpoint of one value of E_H for all sectors. It can be shown mathematically that the sector-wide values of E_H should be equal. All the same, keeping further discussion in mind, it should be noted that obviously in the given instance we have come up against a situation where simplified mathematical formalization does not exhaust the economic essentials of the question.

Apparently a prerequisite of the equality of sector-wide values of E_H is the presence of ideal conditions of complete equivalence and comparability of versions of distribution of capital investments in different sectors and territories. However, the problem is that for practical purposes these conditions cannot be realized as a rule. Differentiation of the values of E_H represents an attempt to reflect specific technical and economic conditions of sectors on different stages of their development. This is the reason, for example, that different sector-wide values of E_H are stated in all forty sector-wide instructions on determining the economic effectiveness of capital investments as approved by Gosplan SSSR in accordance with the principles of the Model Technique.

At the same time, the trend toward equalization of the technical level of sectors, closer conditions of the economic development of territories, an increase in the part played by comprehensive programs, improvement of planning and other factors are certainly conducive to bringing the normative values of sector-wide coefficients of effectiveness closer together, and to reducing the spread of these values.

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[1] Calculations have shown that engineering and design modifications in the power industry in accordance with Ref. 14 and the Instructions of 1973 [Ref. 13] give results that are close for practical purposes if discounting of depreciation is taken into account at $E_{\Pi} = E_H = 0.12$, as provided in the Method of Ref. 14.

In particular, when dealing with complex problems of optimization of the energy balance, we feel that the same values of E_H should be used in all optimization calculations.

In our view, more study is needed on the question of the feasibility of adjustment in time in outlays of power production like capital investments are adjusted by using an appropriate coefficient (such a procedure is provided for example in Ref. 13 and in other methods). Let us recall that outlays are running expenditures of enterprises on production and sale of goods. It is possible that the time adjustment should apply to the increment in working capital rather than to the increment in outlays.

2. In connection with the expansion of temporal and territorial aspects of systems analysis of effectiveness (especially in connection with the development of long-range target-production programs) it is necessary to perfect the category of adjusted expenditures, and on the other hand one should consider possible limits of its full utilization, beyond which it is necessary to supplement cost analysis with other methods.

In this connection we must note a number of conditionalities inherent in modern cost analysis. First among these is the incompleteness of accounting for expenditures of living labor. In the structure of expenditures of versions to be compared, living labor is accounted for only by the payment of wages, which expresses the expenditures of necessary labor (and even at that, incompletely). Acounting for complete expenditures would introduce the necessary corrections in the estimates of capital-intensive and labor-intensive variants that are being compared. The resolution of this problem, formulated by S. G. Strumilin [Ref. 17] has been needing profound scientific study for a long time. In this connection we should also evaluate the proposals to introduce coefficients into the calculations that account for the limited nature of labor resources, like the coefficient E_H that reflects the limited nature of capital investments.

However, such a proposal could scarcely be valid since the coefficient E_H already balances the resources of capital investments and labor, and the introduction of a special coefficient for labor would lead to duplication. At the same time, in calculations of effectiveness, expenditures of living labor should be accounted for as completely as possible (initially at least by adding the expenditures from public consumption funds to wage payment). In dynamic analysis it is also necessary to consider the pattern of increasing wages which, other things being equal, will reduce the effectiveness of highly labor-intensive variants in time.

One other conditionality of cost analysis is due to the fact that the method of comparative effectiveness is based on the tacit assumption of the possibility of numerous "transfusions" of capital investments and labor resources into alternative variants. This ignores the fact that capital investments are frequently quite fixed, and that the material and physical structures of reproduction are highly resistant to change. In economic comparisons of the use of natural gas, coal from underground mines and open pits, petroleum fuel and so on, the difference in structure of material expenditures in related production should also be taken into consideration.

The conditionality of adjusted expenditures as a national economic criterion is especially perceptible at "turning" points, for example in the case of an abrupt increase in demand for goods of a related sector whose development depends on the given variant. It should also be taken into consideration that the same value of adjusted expenditures may result from different combinations of the components of overhead expenses and deductions from capital investments. And at the same time the value of a ruble of capital and running expenditures may be nonequivalent from the national economic viewpoint at different stages of economic development.

From this presentation we see the need for supplementing cost analysis of large production programs with comparative estimates of scales, structure and the possibilities in time of realizing the associated material and labor expenditures and their relative significance at different stages of program realization.

Also requiring careful analysis and accounting are questions of the reproduction process — the time-variable proportions of simple and expanded reproduction in sectors of the fuel-energy complex. The adjusted expenditures also catch expenditures on expanded reproduction, but not the overall amount of expenditures per unit of increase in output. Although in a formal sense expenditures on reimbursement are reflected in depreciation deductions, the State is still faced with the need for sharply rising capital investments on the increment of the physical volume of production. Suffice it to say that in the long range the overwhelming part of expenditures on petroleum extraction will reflect the process of reimbursement of retired capacities. Under these conditions, a careful check is needed on the correctness of the value of depreciation deductions, the value of expenditures on "supporting" extraction and so on.

As we said, the value of the coefficient of effectiveness of capital investments E_H should, in theory, be obtained from the optimum plan of development of the national economy. In actual practice, the value of E_H is established experimentally. Therefore there are often cases where the variant recommended as effective (with respect to minimum adjusted expenditures) sometimes cannot be realized due to the lack of capital investments, and sometimes due to a labor shortage.

But even if the value of E_H were determined in the optimum plan, it would correspond to certain static conditions to which the actual conditions would soon cease to correspond. Solutions are needed under conditions of dynamics, which would give "sliding values" of E_H with application to certain discrete time stages.

An important advance in calculations of effectiveness in power engineering is the introduction of closing expenditures for fuel and energy, the conception of which is closely related to the systems treatment of the fuel-energy complex [Ref. 18]. In this connection, when indices of adjusted closing expenditures are used in calculations, the conditions and sphere of their application must be clearly accounted for. It seems in particular that under conditions of limited high-quality energy resources the use of closing expenditures may also be extended to the selection of fuel for electric power plants. Also needing study is the question of the extent to which export prices for hydrocarbon fuel are taken into consideration in establishing the closing estimates for fuel.

Along with this, we feel that the "suppliers" of the closing fuel may be (in the capacity of "balancing" supply and demand) fields that are not under development but have a considerable volume of new construction that is necessary for compensating retired capacities. This could be the situation at present in Donbass.

3. Considering the definite conventionalities inherent in cost comparisons we should recognize the possibilities of doing variant comparisons with respect to complete labor expenditures as worthy of study. Such comparisons may be of particular interest in cases where the results of cost comparisons do not lead to single-valued solutions.

The idea of the fundamental feasibility and advisability of direct commensuration of living and embodied labor (by variants) has been expressed by V. S. Nemchinov [Ref. 19], S. G. Strumilin [Ref. 17], A. Ye. Probst [Ref. 7], T. S. Khachaturov [Ref. 16], Ya. Kvasha and others. In particular, S. G. Strumilin suggested determining the value of the national income falling to each working day, and summing the past and living labor on the basis of this equivalent.

One could imagine comparing variants in the form of series of integral expenditures of labor, where the point of intersection would give the time of equalization of labor expenditures by variants.

4. The problem of calculating integral expenses (capital investments and outlays) can also be formulated independently of the use of calculations on complete labor expenditures. These computations are not set off against calculations on adjusted expenditures. They should apparently be done only in application to large national economic programs. The positive aspects of calculations of the integral effect are the possibilities of giving a developed definition of the effect for a given construction period, acquisition and exploitation of investment objects considering both the gradual rise of this effect in the process of acquiring new enterprises or extensive new technical facilities, and a possible abatement of the effect in connection with obsolescence of these

facilities. Such calculations can also account for changes in expenditures on reimbursement and new construction, and differentiate effects due to change of structure of complex programs and technical progress proper. Close track is kept of the process of reimbursement of expenditures by reduction of overhead.

In doing this, faults such as extreme concentration of highly capital-intensive investment programs are clearly discerned. For example the annual introduction of large capital-intensive projects that is justified for each of them by the index of adjusted expenditures (or reduction of running expenditures over the "sliding" computational period) may lead to impermissible overloading with capital investments for the next specific five-year or ten-year plan period.

3. One of the important components of analysis should be a probabilistic[1] approach to the quantities that go into the calculation of economic effectiveness.

The existence and decisive significance of objective deterministic principles does not negate the presence of a variety of individual factors that act on the development of the national economy and the course of various economic processes. A consequence of this is a complex of properties in the field of dynamic evaluation of the economic effectiveness of production that enable unambiguous prediction of future conditions and methods of development, and hence the values of a number of quantities included in calculations as well.

In cases where the characteristics of the distribution of probabilities can be established on the basis of statistical processing of data on the past, the choice of the best version should be ascertained with consideration of the minimum mathematical expectation of expenditures. However, in some cases this cannot be done because of a lack of sufficiently complete data on the past or because of the inadmissability of extrapolating them to the future.

At the same time, experience shows that large complex systems are characterized by a relatively flat slope of the functional to be optimized (minimum adjusted monetary expenditures). The combination of this property with the presence of incomplete information creates a zone of indeterminacy of optimum solutions, i. e. a zone of such solutions each of which corresponds to the minimum adjusted expenditures with different combinations of actually possible conditions.

Research now being done suggests replacement of the traditional criterion with a criterion of average expenditures, ensuring approximate mutual compensation for the scatter of initial data. This is accomplished by

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[1] The term "probabilistic" has come into wide use, but is quite conditional in application to the social processes of the socialist system. Perhaps the term "statistical" would be more proper.

summarizing locally optimum solutions in a table of expenditures, or a matrix of conditions versus variants with differentiation of the average expenditures for each variant with changes in predetermined conditions.

If the average values of the adjusted expenditures are close, it is recommended that the final solution be found by using other criteria: the technical progressivness of the variant, operational reliability, conservation of the environment and so on. The difficulty is in the variety of the combinations of conditions for each variant and the associated necessity for finding the additional expenditures for adapting the variant to different conditions [Ref. 20]. Also deserving study is the problem of whether there are areas in power engineering where it is feasible to use the Wald criterion of minimax expenditures, the Savage criterion of minimax risk, and the Bayes test in combination with designation of expertly estimated probabilities of factors of selecting the corresponding strategies, and so on.

On the whole, further research is needed in the entire field of evaluating effectiveness under conditions of indeterminacy.

6. Estimates of the economically optimum level of reliability of the chosen solution are also constructed on the basis of the statistical approach. For example, optimization of reserves of production capacities is based on using a binomial law of distribution of the probabilities of a simultaneous emergency shutdown of production facilities, and indices of specific loss from underproduction. A number of researchers have suggested treating the loss from reliability disruption as the mathematical expectation of additional annual outlays borne by the national economy with disruption of reliability in addition to the basic expenditures involved in construction and normal operation of energy facilities.

The practice of indirect accounting for loss to the consumer due to short supply of power and water has been in operation for some time in hydraulic power and water management, e. g. in setting the guaranteed energy output of hydroelectric plants.

The search for more adequate indicators continues. Obviously these efforts need to be more closely tied in with research in the area of reliability theory in other sectors.

7. Comparison of expenditures and results by variants has the purpose of selecting a solution that minimizes expenditures per unit of the final economic effect. In some cases, for example when selecting the energy carrier, this requires calculations as applied to the useful consumption of energy. In this regard, the coefficients of energy utilization must be more precisely determined throughout the energy network of each variant, especially as applied to the ultimate energy-using equipment.

8. The attainment of economic goals in a socialist society always entails a certain social effect. However, the many-faceted nature of the

results of large production programs means that we can have a national economic, socio-economic and social effect (although the boundaries between these effects are conditional, and they merge into one another).

However, there is no doubt that the significance of the social results of production and scientific-technical progress during the period of developed socialism takes on especially important significance [sic], and the development of methods of reflecting these results in a system of estimates of effectiveness of expenditures becomes an urgent scientific task.

The problem of accounting for social results along with economic results in many instances can be solved in comparison of variants. For example in comparing hydroelectric plants and fossil-fuel electric plants an equal ecological effect is attained by additional expenditures on the fossil-fuel plant to handle trapping of sulfur and ash, and so on.

Sometimes it is possible to account for the effect of expenditures of a social nature indirectly via the increment in labor productivity, the decreased rate of illness and so on.

In a number of cases, the appropriate social requirements are included in the model as constraints, or are taken into consideration qualitatively, especially as applied to zones of equal economy of variants. However, in this case one may face the problem of ranking the constraints and of a criterion for such ranking, i. e. development of a priority function.

The multifaceted nature of large dynamic production programs has given rise to proposals on multicriterial optimization of their development. This means including in the optimization criterion a number of economic and social factors such as minimum one-time expenditures, maximum reliability, optimum ecological effect and so on. In this event, each of the factors is given some specific weight K_i in the resultant criterion that is established, for example, by expert estimates. There are also other methods of "putting together" a criterion. The optimum variant of program realization is the one for which the optimization criterion most closely approaches unity.

The complexity of multicriterial optimization for practical use lies in determining the number of factors, the fundamental difficulty of quantitative ranking of these factors, and the conditionality of "charging" each factor with a certain percentage of the criterion [Ref. 21, 22].

Perhaps multicriterial optimization could be used as a method of supplementing the system of cost and labor estimates of large production programs, mainly when the factors are incommensurate with expenditures.

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ELECTRIC POWER AND POWER EQUIPMENT

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OPTIMIZATION, MANAGEMENT OF LARGE POWER SYSTEMS

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[Article by L. S. Belyayev, Yu. M. Gorskiy, L. A. Krumm, A. A. Makarov, A. P. Merenkov, L. S. Popyrin, Yu. N. Rudenko and I. A. Sher, Irkutsk]

[Text] The paper gives the characteristics of basic scientific and practical research in the field of development of the theory and methods of optimization and management of large power systems done under the auspices of the Scientific Council of the USSR Academy of Sciences on Complex Problems of Power Engineering. Problems of research development are formulated.

The current state, and especially the prospects of development of large power systems -- The Unified Electric Power System (UEPS), the Unified Gas Supply System (UGSS), the Unified Petroleum Supply System (UPSS), coal supply systems, local heat supply systems, the nuclear power system that is now being formed, which in the aggregate make up the fuel-energy complex (FEC) of the nation -- demand development and improvement of the theory of optimization and management of these systems as a specific class of large artificial systems.

Research in the field of development of the theory and methods of optimization and management of power systems covers [Ref. 1-6]:

formation of the hierarchical structure of the FEC (with consideration of technological, territorial and temporal relations) and definition of the problems to be solved on different levels of the hierarchy (structuring of the research object);

investigation of the properties of the complex: structural, developmental, functional (study of the research object);

working out methods of getting solutions that are in some sense optimum answers on development and operation of the FEC;

development of the corresponding mathematical models, algorithms and computer-program complexes, and also hardware control facilities;

development of specific practical recommensations using these models, algorithms and computer-program complexes.

The enumerated problems merely determine the logic of interaction of individual aspects of the research complex, but not their stages since, for example, the corresponding methods must be used for studying the properties of systems, and development of these methods must be based on formalizing the corresponding properties and so forth.

Development of the theory and methods of optimization and management of power systems is aimed in the final analysis at perfecting processes of forecasting their development, projection, planning and operational management on all temporal and territorial levels. These studies have been done in the system of the USSR Academy of Sciences under the scientific and procedural guidance of the Science Council of the Academy on Complex Problems of Power Engineering since 1971. Taking part in the research are about 25 organizations of the USSR Academy of Sciences, the Siberian Department of the USSR Academy of Sciences, the Latvian SSR Academy of Sciences, the Lithuanian SSR Academy of Sciences, the Estonian SSR Academy of Sciences, the Ukrainian SSR Academy of Sciences, the Belorussian SSR Academy of Sciences, the Far Eastern Science Center of the USSR Academy of Sciences, the Kola and Komi affiliates of the USSR Academy of Sciences, various ministries and agencies, and also institutions of higher education. The research is coordinated by the Siberian Power Engineering Institute, Siberian Department of the USSR Academy of Sciences[1].

The purpose of this article is to examine the major scientific and practical results obtained in the field of investigation of the theory and methods of optimization and management of large power systems, and also to formulate problems of further development of these studies.

Hierarchy of Large Power Systems, Investigation of Hierarchical Properties, Interlevel Matching of Solutions. Development of the hierarchy of a power system (including the formation of management tasks) is the

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[1] The only ones taking part in the preparation of the text of the article were members of the Siberian Power Engineering Institute who are in charge of the research topics of the given problem. However, the research results published in the article are the result of activity of all organizations involved in the research. In this connection, the authors have deemed it necessary to include in the references the major monographs and collections of papers published for 1971-1979 by the members of these organizations.

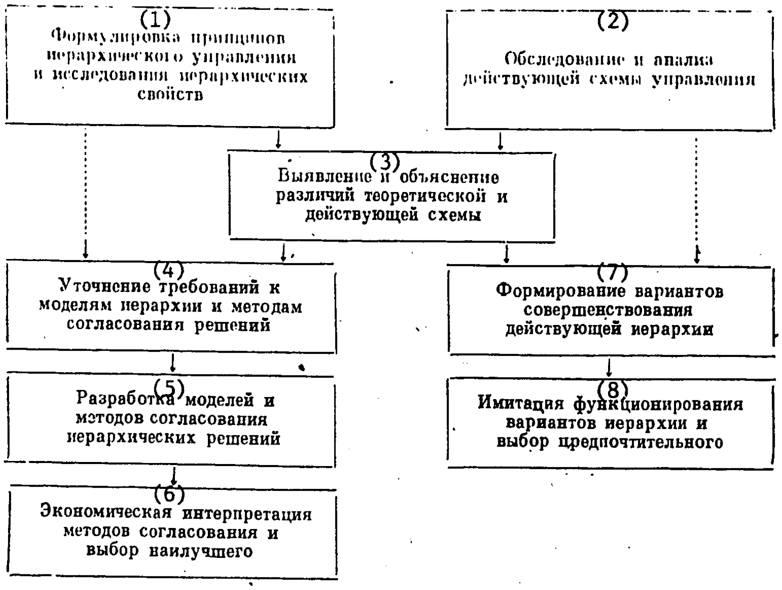

Fig. 1. Schematic diagram of investigations of the hierarchy of large power systems

KEY:
1--Formulation of principles of hierarchical control and investigation of hierarchical properties
2--Investigation and analysis of the existing system of management
3--Delineation and explanation of the differences between the theoretical system and the existing system
4--Precise definition of requirements for models of the hierarchy and methods of matching decisions
5--Development of models and methods of matching hierarchical decisions
6--Economic interpretation of matching methods and selection of the best method
7--Formation of variants of improving the existing hierarchy
8--Simulation of the operation of variants of the hierarchy and selection of the preferable variant

foundation of all future research. This research establishes the major factors in organization of hierarchical management of complex production systems (including power systems); the principles of organization of power engineering are delineated based on analysis of the existing system of management and planning. The hierarchical properties of complex production systems are formulated, and mathematical methods are proposed for studying the mechanisms of vertical and horizontal matching of optimum decisions in a deterministic situation and under conditions of indeterminacy [Ref. 3, 5, 7]. All this has enabled formulation of a schematic arrangement for research aimed at determination of a rational hierarchy for large power systems [Fig. 1].

For purposes of qualitative evaluation and comparison of proposed variants of the hierarchy of power systems, four major hierarchical properties were used: integrity, agreement of purpose, centralization and complexity. Ref. 7 demonstrates the completeness of this set of properties from the standpoint of the characteristics of various aspects of the hierarchy, formulates them, introduces major parameters, establishes the mutual correspondence of these properties and shows methods of using them to evaluate the quality (compare) variants of the hierarchy.

One of the most serious problems is the mutual coordination (matching) of decisions made on different hierarchical levels. To this end, methods of block programming and iterative aggregation have been developed for a deterministic situation and under conditions of indeterminacy [Ref. 7, 8].

The practical results of research that has been completed are first of all determination of the rational content of exchange information in matching hierarchical decisions; secondly, development of principles and specific techniques for organizing comprehensive planning of fuel-energy sectors in Gosplan SSSR, which have now been accepted for practical realization.

The following should be taken as major areas for further research [Ref. 8]: qualitative investigation and quantitative evaluation of the force of manifestation of the hierarchical properties of power systems; in-depth study of the principles of organization of the actual hierarchy of management, and development of adequate methods of modeling and simulating this organization; development of proposals on organizing a rational hierarchy of management in power engineering.

Principles of Information-Systems Analysis as Applied to Management of Power Systems. These principles have been under development for a number of years [Ref. 2, 9]. Analysis is based on three principles: development of methods of information theory, primarily with respect to accounting for the quality of information; accounting in systems analysis for such factors as poor definition of goals, incomplete attainment of these goals, the degree of responsibility of management agencies for attainment of goals and so on; unification of the methods of informational and systems analysis to enable examination of the value of information from the standpoint of how it is conducive to the attainment of goals.

The principles of information theory of management and modeling have now been formulated [Ref. 9], including the classification of goals, methods of quantifying lack of order and disorganization, analysis of the forms of manifestation of information in management processes, and the

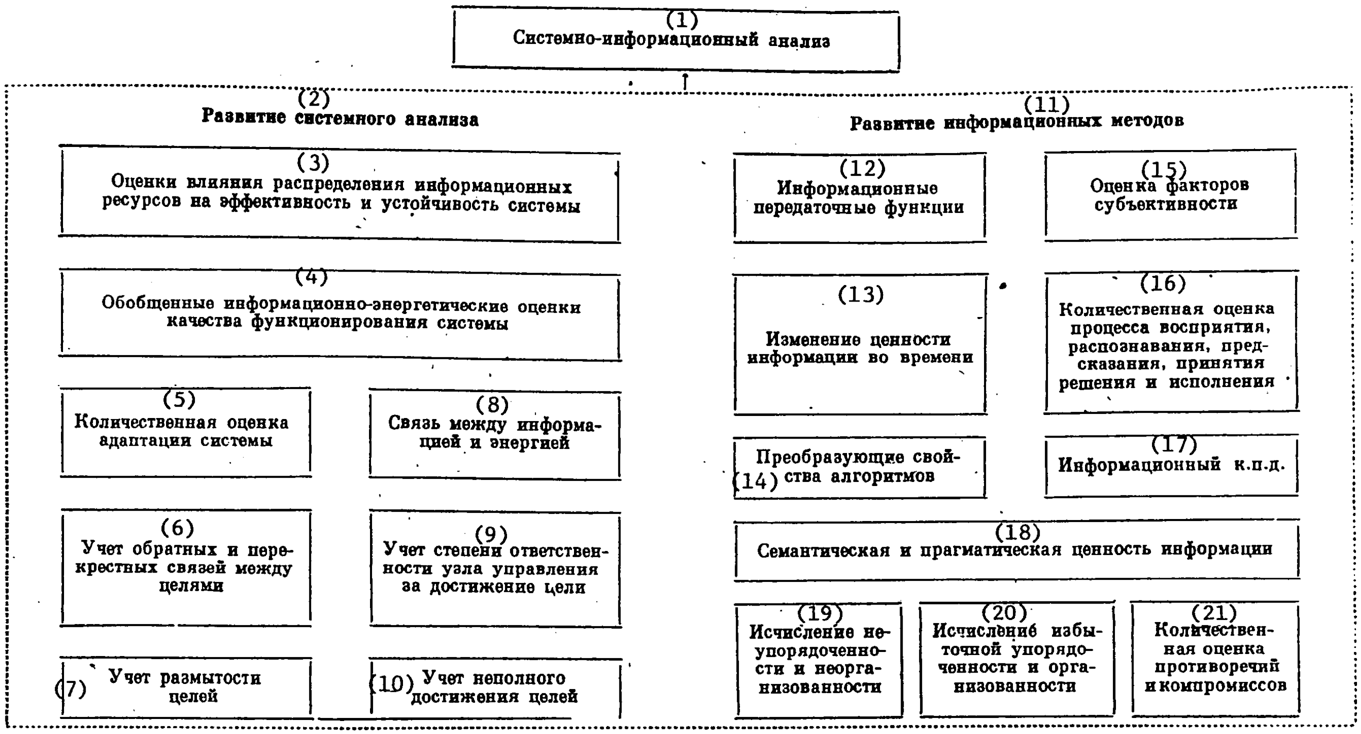

Fig. 2. Schematic diagram of information-systems analysis as applied to large power systems

(See the following page for the key to the figure)

Key to Fig. 2:

1--Information-systems analysis
2--Development of systems analysis
3--Estimates of the influence that the distribution of information resources has on the efficiency and stability of the system
4--Generalized information-energy estimates of the quality of operation of the system
5--Quantitative evaluation of adaptation of the system
6--Accounting for feedback and cross connections between goals
7--Accounting for lack of clarity of goals
8--Relation between information and energy
9--Accounting for the degree of responsibility of the managerial unit for goal attainment
10--Accounting for incomplete attainment of goals
11--Development of informational methods
12--Informational transfer functions
13--Time change in information value
14--Transforming properties of algorithms
15--Evaluation of factors of subjectivity
16--Quantitative evaluation of the process of perception, recognition, prediction, decision making and execution
17--Informational efficiency
18--Semantic and pragmatic value of information
19--Calculation of lack of order and disorganization
20--Calculation of redundant order and organization
21--Quantitative evaluation of contradictions and compromises

possibilities of evaluating information as a means of eliminating disorganization (Fig. 2).

The theoretical start that has been made enables us to find the solution of a number of practical problems such as systems analysis of management of a nuclear power facility, development of a system of data representation for a dispatcher, formation of principles of systems design of large-scale control and so on.

Further development of information-systems analysis presupposes accounting for the specifics of systems of power engineering and solution of practical systems problems. Realization of these goals may well enable development of a base for applied information-systems analysis in control of power systems.

Methods of Arriving at Solutions on Development of Power Systems in the Case of Information Deficiency. The incompleteness (indeterminacy) of information that is invariably involved in managing the development of power systems is an impediment to sound decision making, and as a consequence such decisions are not always the most effective ones. The detriment due to incomplete information cannot be completely overcome, but it can be minimized by improving the organization and methodology of

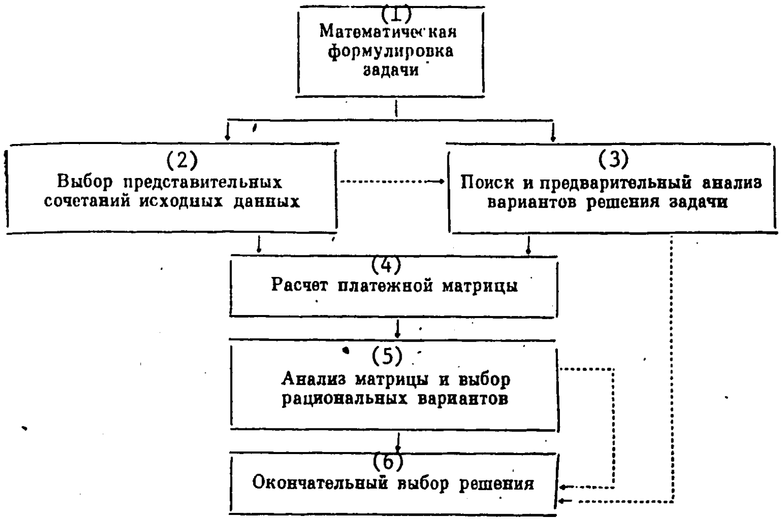

Fig. 3. Schematic diagram of the solution of optimization problems under conditions of indeterminacy

KEY: 1--Mathematical formulation of the problem
2--Selection of representative combinations of initial data
3--Search and preliminary analysis of variants of solution of the problem
4--Calculating the payment matrix
5--Analysis of the matrix and selection of rational variants
6--Final selection of the solution

management, and also by using appropriate methods for taking account of the uncertainty of information. This is in fact the goal of the research.

The following steps can be taken to "combat indeterminacy": improvement of the reliability and quality of the information itself; reducing the lead time in justifying and making decisions to the permissible limit; developing special approaches and methods of accounting for the uncertainty of information that remains (cannot be eliminated) after taking the first two steps in justifying and making decisions. Research has been done in all three of these areas, but most intensively in the third.

As a result of these studies, a general conception has been formed about controlling the development of power engineering under conditions of incomplete information that presupposes: a) tying in decisions in the hierarchy of the power system with consideration of the uncertainty of exchange information; b) transforming the process of planning and projecting the development of power systems to a continuous process of justifying and making immediate (imminent) decisions with minimum admissible lead time; c) using special approaches and methods for justifying and making individual decisions on development of power systems [ref. 1-3, 5, 10-12].

Work on perfecting the process of controlling the development of power systems (from the standpoint of accounting for incompleteness of information) has been done mainly with application to the planning of electric power systems [Ref. 10, 13-16]; some recommendations have also been worked out in application to other power systems [Ref. 17, 18, and others].

The greatest scientific and practical results have been attained in the area of methods of solving the problems of development of power systems with consideration of incompleteness of information. A general approach and scheme have been worked out for solving optimization problems under conditions of indeterminacy [Ref. 10-12] that provide for multiple-variant calculations, compilation of a "payment matrix" and subsequent analysis using special criteria (Fig. 3), preparation and publication of special "Procedural Principles" [Ref. 19]. The corresponding methods have been applied to practical research and calculations on long-range development of the FEC, electric power systems and certain other power systems, as well as their components.

The most important areas of this research are the following:

1. Extensive practical testing of the approach formulated in the "Procedural Principles" [Ref. 19] to accumulate experience and perfect methods.

2. Intensification and more precise coordination of work on the development of an information base in power engineering, including the study of probabilistic properties of specific kinds of information, systematic publication of information sheets and statistical materials and so on.

3. Research on perfecting the process of controlling the development of power systems from the standpoint of deeper and more complete accounting for the factor of indeterminacy.

4. An in-depth study of criteria for decision making under conditions of incomplete information, including accounting for both economic and other factors.

Methods of Studying and Optimizing Reliability in Power Systems. The purpose of work in this area is to formulate the major principles of the theory of reliability of power systems, to develop principles and methods of finding solutions in designing, planning and operating power systems that guarantee the required reliability of supply to consumers and that are optimum from the standpoint of the FEC as a whole. In its applied aspect, this research is aimed at developing the corresponding procedures and guidelines, normative requirements and computer software packages, and also at forming specific recommendations on ensuring reliability in developing and operating various power systems.

In recent years, reliability research on power systems has acquired an intersectoral format (within the FEC framework). This has demonstrated the advisability of intersectoral formulation of the problem, the necessity and possibility of solving problems of studying and optimizing the reliability of objects such as the fuel-supply system of the nation and the FEC as a whole; an analysis has been made of common and distinguishing features of the different power systems that make up the FEC (electric power, gas supply, local heat supply systems), and methods of accounting for them in mathematical models of reliability research and so on [Ref. 3, 20-22]; intersectoral terminology has been worked out in the field of power systems reliability [Ref. 23].

With reference to electric power systems, methods have been developed for gathering, processing and analyzing data on the reliability of systems equipment, based on the method of statistical sampling, and on methods of analyzing the uniformity, certainty and confidence of data, and using programs of experiment planning as well. Research has been done in the direction of working out procedural principles for predicting and ensuring the reliability of the major equipment of electric power systems. Procedures, algorithms and programs have been developed for studying and optimizing the reliability of electric power, gas supply and local heat supply systems. A technique has been worked out for efficient utilization of the available reserves of generating capacity of electric power systems ensuring maximization (within the limits of the available capabilities) of the reliability of supply to consumers [Ref. 14, 21, 24, 25, 27]. The procedural results of research in the field of reliability of electric power systems are generalized in Ref. 24.

It will next be advisable to develop research in the field of reliability of power systems in the following directions.

1. Work out methods of ensuring reliability and controllability of the fuel supply system of the nation both during developmental planning and in the stage of actual operation. By this we mean principles, methods and algorithms for ensuring reliability and controllability by mutually agreeable determination of the reserves of production capacities of the power systems that make up the FEC, and selection of a rational structure of fuel reserves, including determination of the capacities and placement of storage reservoirs.

2. With reference to one of the most complex specialized power systems, that of electric power, it is necessary to concentrate attention on methods of studying reliability "on the whole" (as a complex property that includes viability, stability and controllability in addition to

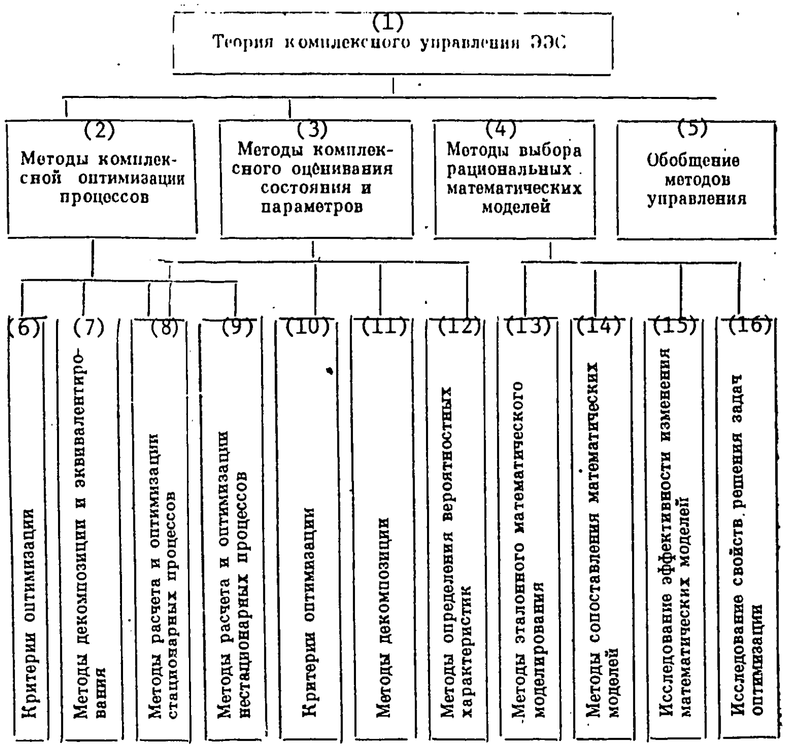

Fig. 4. Major principles of the theory of comprehensive management of an electric power system

KEY:
1--Theory of comprehensive management of electric power system
2--Methods of complex optimization of processes
3--Methods of complex evaluation of condition and parameters
4--Methods of choosing rational mathematical models
5--Generalization of methods of management
6--Optimization criteria
7--Methods of decomposition and equivalentization
8--Methods of calculating and optimizing steady-state processes
9--Methods of calculating and optimizing unsteady processes
10--Optimization criteria
11--Methods of decomposition
12--Methods of determining probabilistic characteristics
13--Methods of standard mathematical modeling
14--Methods of comparing mathematical models
15--Investigation of the efficacy of changing mathematical models
16--Investigation of the properties of solution of optimization problems

failsafe operation, repairability and other properties. In this connection, it is necessary to give attention to development of methods of ensuring reliability in operation of the electric power system, and at present there has been little work on developing such methods.

3. Provide for practical use of the proposed methods, algorithms and computational programs in working out specific recommendations to ensure reliability in development and operational management of power systems (especially the system of fuel supply to the nation and the UEPS of the USSR).

Theory and Methods of Process Control in Electric Power Systems. The purpose of the research is to formulate major principles of the theory and methods of complex control of electric power systems. In its applied aspect, the research is aimed at generating mathematical software for automated dispatcher control and enterprise management systems, and also at direct development of the corresponding computer software packages.

Research in this area is characterized by fairly complete and comprehensive accounting for the limitations of the physical state of the electric system in optimization of processes in the electric power system; consideration of the hierarchy of problems of optimization and control of the electric power system not only in the spatial-temporal aspect, but also with consideration of conditions of operation (optimization of processes under normal, emergency and post-emergency conditions); accounting for incompleteness of initial information, making it necessary in controlling processes of the electric power system to use probabilistic methods and methods of decision making under conditions of uncertainty; use of specially developed methods of evaluation, identification and prediction for complex software.

As a result of this research, the major indices of the theory of complex multistage adaptive control of the operation of an electric power system have been formulated (Fig. 4) [Ref. 28]. The research has been done in four directions with the following respective results:

major procedural principles have been developed for complex optimization of processes in electric power systems in a multistage hierarchical approach with consideration of incomplete information [Ref. 28-31]; methods of controlling steady states have been developed as well as methods of equivalentizing and studying unsteady processes in electric power systems (static stability in the probabilistic formulation, and dynamic stability). These methods have been put to extensive practical use in cycles of short-term and operational control, so far mainly with deterministic initial information [Ref. 4, 13, 32-39];

adaptive methods have been developed for evaluating the state and identifying the parameters of electric power systems that are used in complex optimization [Ref. 30, 40, 41];

major approaches have been developed to the methodology of choosing rational methods and mathematical models intended for controlling processes in electric power systems [Ref. 41];

mathematical models have been generalized for solving individual problems of complex optimization in controlling steady states of electric power systems [Ref. 28, 29].

The main areas for further research are:

1. Generalizing formulation of the problem of complex optimization of processes in electric power systems with consideration of the relation to problems of controlling the operation of other power systems, and business management of the electric power system.

2. Development of mathematical tools for solving problems of complex optimization of steady-state processes of electric power systems in the case of incomplete information.

3. Development of principles of complex optimization of processes in concert under normal, emergency and post-emergency working conditions of the electric power system, including development of principles and methods of optimum controlling actions under emergency conditions.

4. Generalization of software methods in all management cycles, in particular for evaluating the state and identifying the parameters of the electric power system.

5. Development of methods of choosing rational mathematical models and control systems, including systems of metrological support.

6. Development of principles and methods of complex support of controllability of electric power systems (with generalization of the results of research in the above-mentioned areas).

The main applied result should be development of the corresponding computer software packages for automated dispatcher control and enterprise management systems of the UEPS.

The Theory of Hydraulic Circuits and its Application to Optimizing and Controlling Pipeline Systems. The general procedural principles of systems research and management of power systems have great significance for the classification of pipeline systems and problems of controlling them, distinguishing their essential properties, external and internal connections, creation of a matched information base, and also on the whole for sound construction of a hierarchy of levels, goals and control facilities and the corresponding set of mathematical models.

The main purpose of research in this area is to examine the principles and methods of controlling the development and operation of pipeline systems and to develop scientific principles of algorithmic and informational software for this research. A decisive point in this connection is that the same types of problems in calculation, optimum synthesis and control are involved in working with pipelines and other hydraulic systems. The common nature of these problems becomes obvious on the level of their mathematical modeling, and this is the subject of a new scientific discipline, the "theory of hydraulic circuits," which has a common heritage with the theory of electric circuits.

The theory of hydraulic circuits has given a number of fairly general results on a unified basis [Ref. 43, 44 and elsewhere], namely:

development of the algebra of hydraulic circuits as a unified language for describing systems of this kind, and showing that the whole set of pipeline and hydraulic systems can be studied by using three types of mathematical models: models of hydraulic circuits with lumped, controllable and distributed parameters;

proposal and realization (as automated systems of programs) of general methods of analyzing normal and emergency working conditions of complex multiple-loop pipeline systems;

differentiation of a new class of inverse problems of flow distribution, and development of systems methods for determining the actual parameters of pipeline systems;

development of a number of methods of discrete optimization for purposes of optimum design of these systems with consideration of their reliability requirements;

development and extensive practical introduction of research by many design, operational and adjustment organizations that work in the area of pipeline transport, and a complex of mathematical models and programs.

Thus the theory of hydraulic circuits is developing as a scientific and technical discipline within which mathematical, algorithmic and also procedural developments are in progress that have practical significance for analysis, optimization and control of pipeline systems for different types and purposes (heat, water, gas and petroleum supply, ventilation, gas-field, central heating, grouped water lines for irrigating a region) (Fig. 5). These systems can be treated as independent objects, and also as subsystems of various levels in large power systems.

The main task of further research is:

1. Development of a theory of hydraulic circuits with controllable and distributed parameters for elaborating new mathematical models and methods and perfecting existing ones, which includes mathematical modeling of systems with flow of both incompressible and compressible energy

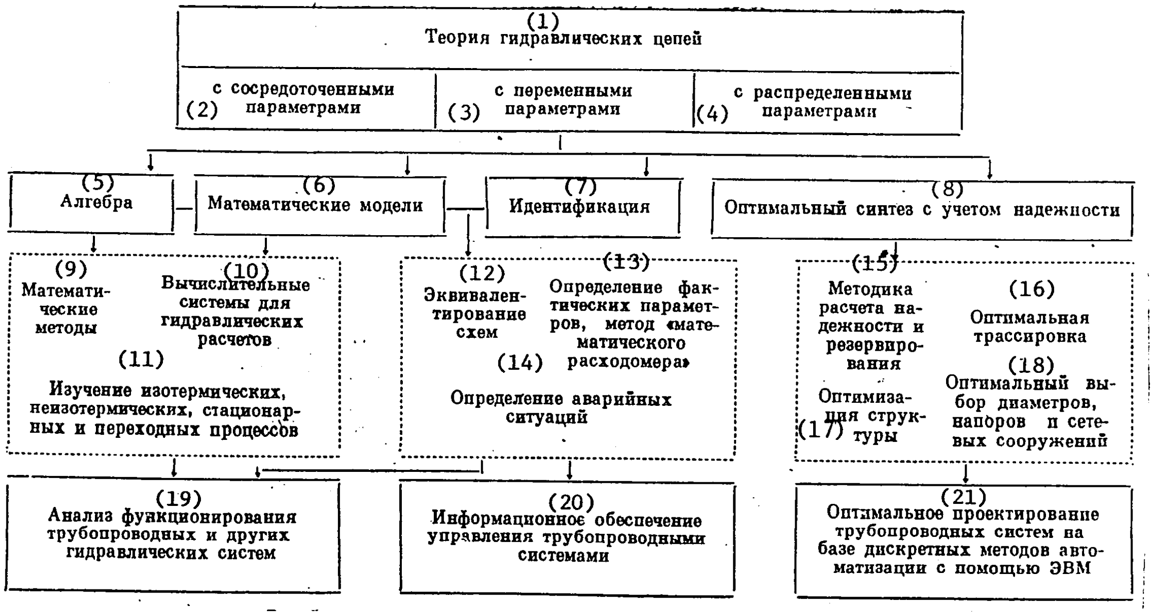

Fig. 5. Content and applications of the theory of hydraulic circuits

(See the following page for the key to the figure)

Key to Fig. 5:

1--Theory of hydraulic circuits
2--with lumped parameters
3--with variable parameters
4--with distributed parameters
5--Algebra
6--Mathematical models
7--Identification
8--Optimum synthesis with consideration of reliability
9--Mathematical methods
10--Computer systems for hydraulic calculations
11--Investigation of isothermal, nonisothermal, steady-state and transient processes
12--Equivalentization of systems
13--Determination of actual parameters, the "mathematical flowmeter" method
14--Determination of emergency situations
15--Method of calculating reliability and redundancy
16--Optimum routing
17--Optimization of structure
18--Optimum selection of diameters, heads, and line structures
19--Analysis of the operation of pipeline and other systems
20--Software for control of pipeline systems
21--Optimum design of pipeline systems based on discrete methods of computerized automation

carriers (such as gas), different grades of petroleum, with dynamic processes and so on.

2. Effective realization of methods of optimum synthesis of multiple-loop systems with standby redundancy in the form of the corresponding program-computer complexes and interactive systems.

All this will enable expansion of general power research associated with analysis, developmental optimization and control of pipeline systems.

Methods of Complex Optimization of Parameters and Designs of Thermopower Plants. Research in the area of thermopower systems is being done in the direction of developing a theory and methods for thermodynamic and technical-economic analysis and complex optimization of the parameters of thermopower plants based on mathematical modeling. This problem is very important for solving planning problems and for long-range development of thermal electric power plants that utilize fossil and nuclear fuels with consideration of the totality of influencing factors and engineering constraints.

At the present time, the following developments have been realized [Ref. 45-48]: theoretical principles of constructing mathematical models of various kinds of power plants; procedural principles of using mathematical programming to solve problems of optimizing power plants; practical techniques for applying mathematical modeling methods to the improvement of economy of different types of power plants through the selection of optimum parameters and a rational form of technological arrangement.

The mathematical models that have been developed for thermopower plants have been used in particular to study base and peak fossil-fuel steam turbines with power of 500, 800 and 1600 MW; nuclear electric plants with graphite-moderated boiling water reactor, with pressurized water reactor, and with nuclear superheating in a graphite reactor.

In recent years appreciable advances have been made in automating mathematical modeling of complex thermopower facilities.

The results of theoretical and practical research in the form of developed principles and techniques for construction of mathematical models and optimization methods, and in the form of completed algorithms and programs, as well as recommendations for choosing parameters and the profile of power plants are being successfully used by sector-wide, scientific research and planning institutes, as well as by the design offices of power machinery plants.

However, the potential capabilities of methods of mathematical modeling and complex optimization of power plants are a long way from being completely utilized at present. Most of the problems that have been solved are isolated cases corresponding to the requirements of different institutes and design offices. They play a relatively small part in the general process of development and planning of power plants.

A further improvement in the effectiveness of the method of mathematical modeling requires development of research in areas of perfecting methods of investigating, processing and forecasting data, development of decision making methods with insufficient information, accounting for the reliability factor, automating the design of mathematical models and developing an automated system of planning and optimum design of power plants.

Problems of Developing Automated Control Systems in Power Engineering. Practical implementation of methods of optimization and control of power systems on various territorial and temporal levels is handled by a variety of automated systems that are realized as program packages for computers.

The links of the automated control systems in power engineering that are under development for practical applications of the theoretical research that is being done are: the FEC subsystem in the automated system of plan calculations of Gosplan SSSR; automated systems for solution of planning and design problems on developing functional power systems (UEPS, UGSS, etc.); automated dispatcher control systems for various processes of these systems; automated systems for designing power facilities.

The content of research on developing automated control systems in power engineering is development of the concept of control with availability of automation facilities; determination of sources of information and creation of an information base; formulation of control problems in a unified mutually coordinated complex and development of the corresponding mathematical models; development of software and a data base; introduction of methods and means of automated control systems into practice and perfection of the process of management of the power industry on this basis. Even a brief characterization of developments in this area is beyond the scope of this article. Therefore we will only give a few examples of work on developing automated control systems done with the participation of the Siberian Power Engineering Institute.

In the field of automating plan calculations, studies have been done on decision making procedures and a system of informational interaction in planning the development of the FEC. A publication has been prepared entitled "Major Areas of Planning of Sector-wide Complexes in the Automated System of Plan Calculations of Gosplan SSSR." The concept of the FEC subsystem in this automated system has been developed, the engineering project of this subsystem has been completed as well as the first phase of the subsystem (accepted by Gosplan SSSR) in the makeup of the program package and data base necessary for optimizing the FEC of the nation.

In the area of controlling the development of individual functional power systems, we have achieved an understanding of the makeup and principles of design of automated informational planning systems of electric power systems and have developed computer program complexes for solving major problems in the development of electric power systems [Ref. 10]. In particular, such complexes are being systematically used to optimize the long-range structure of the UEPS, to optimize the development of electric power grids, for operational correction of variants of development of electric power systems, and for certain other purposes.

Work is in progress on a wide front in the area of development of the automated dispatcher control system for the UEPS; the major thrust is at producing highly effective program and informational software for an extensive class of control problems [Ref. 4, 37].

Software is being developed for automating the solution of problems of controlling various types of pipeline systems. One example of a program package for optimum design of pipeline systems is the SOSNA computer program complex developed by the Siberian Power Engineering Institute of the Siberian Department of the USSR Academy of Sciences [Fig. 6].

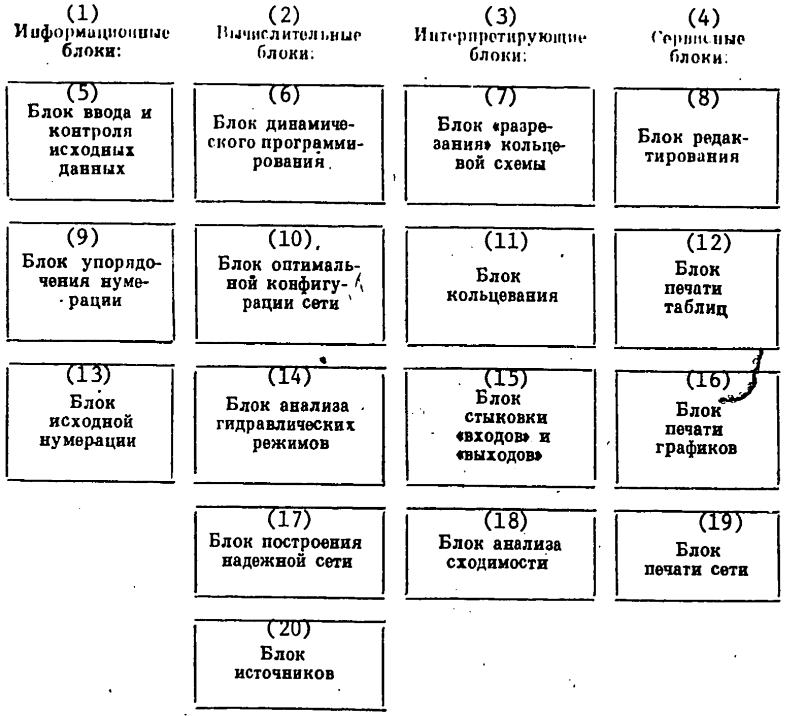

Fig. 6. Block diagram of the SOSNA computer program complex

KEY:
1--Information blocks
2--Computer blocks
3--Integrating blocks
4--Service blocks
5--Block for input and check of initial data
6--Dynamic programming block
7--Ring circuit "cutoff" block
8--Editing block
9--Block for ordering enumeration
10--Block for optimizing circuit configuration
11--Circuit completion block
12--Table printout block
13--Initial numbering block
14--Block for analysis of hydraulic conditions
15--Input and output interfacing block
16--Graph printout block
17--Reliable network design block
18--Convergence analysis block
19--Network printout block
20--Source block

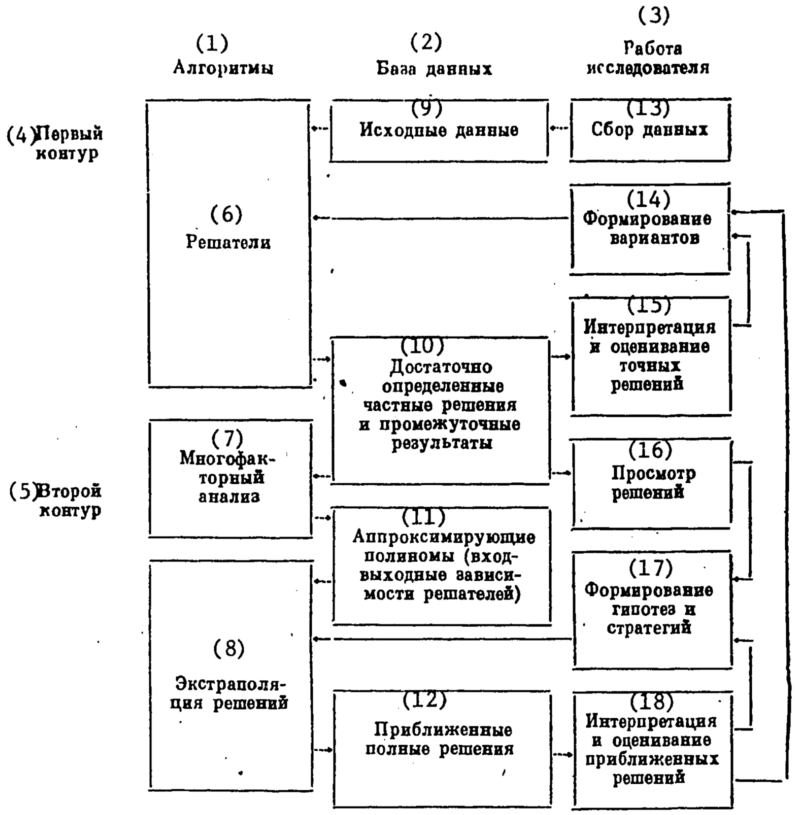

Fig. 7

KEY:
1--Algorithms
2--Data base
3--Researcher's work
4--First loop
5--Second loop
6--Resolvers
7--Multifactor analysis
8--Extrapolation of solutions
9--Raw data
10--Fairly definite partial solutions and intermediate results
11--Approximating polynomials (input/output dependences of resolvers)
12--Approximate complete solutions
13--Data gathering
14--Formation of variants
15--Interpretation and evaluation of exact solutions
16--Inspection of solutions
17--Formation of hypotheses and strategies
18--Interpretation and evaluation of approximate solutions

In the area of automating the design of power facilities, a system has been developed for computer design of research programs and programs for optimizing designs of thermopower plants. The system is developing in the direction of improvement of methods of interaction between the researcher and the system.

Research areas are determined by the fact that large power systems have been considered mainly in their technological aspect in setting up automated control systems up to the present. It is becoming apparent that greater consideration must be given to their man-machine nature. To do this we must study decision making procedures and take them into consideration in formulations of problems and mathematical models created for automated control systems. It is important to develop methods of interaction between researchers and decision makers on the one hand, and the hardware complexes of automated control systems on the other. This interaction must be implemented in the form of a dialog in languages that are close to natural languages, and efforts must be made to facilitate interpretation of the intermediate and final data obtained from the automated control system. Such an approach makes a number of demands on mathematical models and numerical methods. There is an increase in the significance of the simulation approach to research that is done in the control process.

For example the interactive mode is being used to study long-term trends in the development of the FEC (Fig. 7). The first loop of the system gives fairly definite partial solutions on all computational blocks of the FEC model. The set of these solutions is used in constructing the input/output characteristics of the blocks in the form of approximating polynomials. In the second loop the researcher gets approximate complete solutions corresponding to given hypotheses and strategies of development with a short waiting time for the result. The most interesting approximate solutions are again refined in the first loop.

The man-machine nature of the power system also requires considerable attention to problems of business management. On the business management level, conditions are formulated that promote or block the use of automated control systems. It is necessary to study the mechanism of business management of the power system, which is much less formalized than in the case of process control. The interaction between levels of the hierarchy is also more complicated in business management. All this must find reflection in the job complex of the automated control system, mathematical models and software.

Working out Recommendations on Major Directions of Development and Optimizing the Operation of Power Systems. One of the directions of practical use of methods of optimization and control of power systems is the above-described creation of automated control systems in power engineering, and another is development of specific recommendations on growth and operation of the FEC and its component systems, including those that are arrived at with the aid of automated systems for solving planning, design and management problems.

As examples we can cite analysis of major trends and forecasting of the development of the FEC for the long-range future, and also optimization of scales and proportions of development of the power industry [Ref. 5, 49, 50][1]; elaboration of major areas of development of the UEPS, UGSS, local heat supply systems and some other systems with consideration of their interaction within the framework of the FEC (including variant determination of the structure, configuration and parameters of these systems [Ref. 17, 18, 31]); investigation of problems of development of the power industry in individual territories (Northwest, Urals, Siberia, Far East and so on) [Ref. 52]; determination of the part played in development of the power industry of the nation by certain territorial fuel-energy complexes such as the West Siberian petroleum and gas complex, the Kansk-Achinsk, Kuznetsk and Ekibastuz coal complexes; analysis of major areas of technical progress and determination of the optimum parameters of new equipment in power systems.

Among the problems that can be solved by improving efficiency in operation of power systems we might mention, for example, problems of setting up efficient reserves and stockpiles in the fuel supply systems of the nation and of individual regions, and optimum utilization of these reserves; problems of studying the regulatory capabilities of various specialized power systems and improving them [Ref. 22]; improvement of metrological support systems in operational control of functional power systems.

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SOME SCIENTIFIC, PROCEDURAL PROBLEMS OF SYSTEMS RESEARCH IN POWER ENGINEERING

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[Article by V. R. Okorokov, Leningrad]

[Text] An examination is made of major problems in the area of scientific and procedural aspects of systems research in power engineering. Directions of further research are formulated in the area of methodology of optimum control of large power systems, and methods and means of studying them.

Systems research in power engineering is taking on especially urgent significance under present-day conditions. As a scientific discipline for investigating developing systems of large dimensionality, systems research in power engineering is a logical continuation of the complex energy method developed by Soviet power engineers led by Academician G. M. Krzhizhanovskiy; it is the development of this method as applied to contemporary Soviet power engineering, which is an aggregate of large functional systems (electric power, nuclear power, petroleum supply, gas supply and the coal industry) and the general power system that unifies them [Ref. 1].

The object of systems research in power engineering is primarily the Unified State-Wide Power System (SPS) that unites large functional systems and covers the major elements and connections of the fuel-energy complex (FEC) of the nation.

The increasing topicality of systems research in power engineering is determined by the continuing quantitative development (increasing number of connections and components) and qualitative development (change in the structure of components and elements) of the SPS, and also by the increasing influence of the FEC on optimum functioning of the national economy as a whole. At the present time the scientific and technical potential of the FEC is essentially the determining factor of the scientific and technical potential of the national economy as a whole.

Like any scientific discipline, systems research in power engineering involves three interrelated areas: theoretical, procedural and applied. We feel that discussion of the first two areas is of the greatest interest since successful solution of these problems is the main thing that predetermines success in practical application of systems research to solution of specific power engineering problems.

Theoretical Problems of Systems Research in Power Engineering. According to Academician L. A. Melent'yev, the theoretical problems of systems research in power engineering should include investigation of the nature, objective developmental trends and properties of large power systems among other things [Ref. 1].

Theoretical problems in this area should also subsume research on the principal methods of matching working goals of individual components in the overall hierarchy of control of large power systems, as well as the socioeconomic conditions of their operation that are typical of a given social structure[1].

By socioeconomic conditions, the author means the totality of factors that determine the structure of the economy with respect to sectors and goods, working conditions, standard of living, technical and economic capabilities of the raw material base, the extent to which labor resources cover production, requirements of society for quality and comfort of the environment and so on.

Socioeconomic conditions are altered by development of the productive forces of society and by scientific and technical progress in power systems as well as elsewhere. And indeed the major properties of power systems are determined in large measure by this development.

The socioeconomic conditions of operation of large power systems undergo certain changes as they influence the purposes of these systems and major developmental trends. For example, orientation of the development of power in the nation toward preferential utilization of local forms of fuels as defined in the widely known plan of GOELRO [the State Commission for Electrification of Russia] was actually justified by the low level of development of the production forces of the early Soviet Republic as it began the work of peace after a destructive civil war, and especially by limited transportation capabilities. By the same token, the present-day development of Soviet power engineering in the direction of accelerated development of nuclear and hydroelectric (in the eastern territories of the nation) power plants is determined by the current level of development of productive forces and by the level of scientific and technical progress in power systems (in the broad sense of the power industry),

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[1] Hereafter our discussion refers to the socialist society.

We feel that there is still not enough attention being given to the influence that regular development of the productive forces of our nation is having on the development of the SPS, even though these studies are extremely urgent for determining present, and especially future areas of development of power systems. The lack of such fundamental theoretical research can apparently be attributed to the fact that no scientifically sound conception has as yet been formulated on the development, for example, of the Unified Electric Power Systems (UEPS) of the nation. There have been unjustified attempts to change certain principles that have been verified in practice on the development of the Soviet power industry (especially in the development of district heating, in the proportionality of development of power production and power consumers, concentration of power production and centralization of energy supply and so on). Nor is there a timely accounting for the complicated intersectoral problems of power engineering, which could be most productively solved by fundamental systems research.

Another aspect of theoretical systems research in power engineering that we feel has been underrated is the definition, and especially the matching of major goals of operation of both power systems as a whole, and their individual components. As we have said, certain goals of operation of power systems may change in connection with changing socioeconomic conditions of development of the national economy. For example, until recently it was assumed that the major goal of operation of electric power systems was to provide an economic and reliable supply of energy to consumers. However, a change in socioeconomic conditions, and especially a change in the ecological situation [Ref. 2] has brought about some new goals and constraints in operation and development of the SPS. For example, today much more attention must be given to eliminating or restricting the harmful effect of power facilities on the environment [Ref. 3]. Goals of operation and development are now changing in other power systems as well (and especially acutely for the petroleum supply system).

The problem of defining and matching major goals of both the development and operation of power systems on different time levels has still not been adequately studied. And associated with this problem are methods of solving a number of procedural and practical energy problems. Among the procedural problems, mention may be made of choosing a sound criterion functional[1] in the construction of various mathematical economics models, and among the practical problems mention could be made of choice of the optimum unit power for the generating facilities in thermal electric power plants. Solution of this problem for different priorities of various goals leads to options of optimum strategies of development of thermopower equipment that are not at all alike. Obviously it would not be wise to maximize unit powers (1200 MW or more) of equipment with

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[1] This problem is discussed in greater detail in the following section of our article.

supercritical steam parameters when the main goal of using steam turbine units today in the European section of the UEPS is to provide a reliable electrical supply with high rates of change in loading, which we know is achieved with subcritical steam parameters (and let us note that giant generators with supercritical steam parameters are practically unheard of in the power industry outside of the Soviet Union).

No less important is the problem of matching the major goals of operation of different power systems as well as their separate components on different time intervals. A set of different components and connections can be treated as a system only when their particular goals of operation are coordinated so as to form an entity and a unit. Unfortunately this obvious principle is not always taken into consideration, for example in the practice of business management of the power industry where the individual structural agencies of management in their practical action are ruled by unmatched goals (in our opinion the well known conflict of action in the unified dispatcher administrations and regional power systems can be attributed to violation of the condition of coordination between the particular goals of the components and the overall goals).

Among theoretical problems of systems research in power engineering, perhaps the most attention is now being given to the nature, objective developmental trends and major properties of power systems [Ref. 1, 4-7]. Research in these areas has already led to important scientific, procedural and practical conclusions: the concept of objective trends in development of power engineering and properties of power systems has been developed; methods have been worked out for optimization calculations under conditions of ambiguous raw data; particulars of designing and studying a hierarchical structure for systems have been studied; the part played by closing expenditures in optimization calculations has been defined, and the mechanism of formation of these expenditures has been determined; the theory and methods of optimizing the FEC of the nation and of territories have been worked out and so on [Ref. 1, 5, 8, 9]. However, the positive results that have been attained still cannot meet the demands of practice. In particular, there are still not enough scientific principles formulated on setting up the SPS of the USSR as a higher form of integration of functional power systems corresponding to the state of development of the productive forces of the nation in the period of developed socialism. Studies have not been done in sufficient depth on objective trends of development of the power industry of the USSR in the future, or on the stability of these trends in the face of random variations of many environmental factors (change in values of resources, indeterminacy of certain specific manifestations of scientific and technical progress and so forth).

Insufficient study has been done on the major properties of power systems both in the existing structure of the SPS of the nation and in possible variants of its future structure, particularly with possible changes in technological parameters of power systems. For example, properties of the SPS of the USSR and its individual subsystems such as rising inertness and rigidity and decreasing elasticity that have been noted by many researchers [Ref. 1, 7] are not, in our opinion, absolute. To a certain extent they can be considered as a mere consequence of inadequate investigation of the objective conditions of development of the national economy as a whole and of the power industry in particular, as well as poor use of such a lever as the feedback principle in the control of complex systems. Nor have in-depth studies been done on the major trends of proportionality of development of power systems in the national economy of the nation that determine the optimum levels of electrification and energy supply [Ref. 10], or on a number of other important problems of systems research in power engineering.

Procedural Problems of Systems Research in Power Engineering. This division of systems research in power engineering is generally taken to include problems aimed at improving:

methods and means of studying large power systems;

criteria of optimizing the development and operation of power systems on different hierarchical levels;

decision making methods on different time intervals of operation of power systems;

special methods of selecting optimum parameters of individual components of large power systems.

Intense research aimed at perfecting methods and means of studying large power systems has been in progress in our nation for nearly 20 years. The major result of this research is the creation of a large arsenal of formalized methods (mathematical models) for solving individual problems of optimum control of power systems that are being put to wide practical use. At the same time, proposed mathematical models in many instances cannot meet their own main purposes: as a means of studying the power industry, and as a tool for "playing out" the consequences of management decisions. Despite the great number and variety of proposed models, they are mainly uncoordinated since they are aimed primarily at solving isolated, though important, problems of optimum control. Therefore at the present time we can see more and more the need of setting up a *system of mathematical models* (as an interconnected aggregate) that reflect on the whole the process of control in actual hierarchically structured large power systems [Ref. 1]. Besides, many mathematical models are excessively formalized and do not account adequately for the physical and technological particulars of the systems to be modeled, or the active role of man in the working process. Most of the proposed models enable determination only of conditionally optimum states of the investigated system rather than the optimum process of its development and operation.

The present-day power industry has a complex hierarchical structure and numerous internal and external interconnections. Therefore, scientifically sound management of power systems and the SPS that unifies them requires development and utilization of research methods that are equivalent to the actual nature of the power industry. In our opinion, mathematical models for studying large power systems should be able to account for major relations, including the aftereffects that exist in complicated dynamic systems; to investigate the dynamic behavior of the system being modeled; to reflect its nonlinear characteristics and partly undefined nature of many parameters and factors; and also to account for the consequences of possible changes in parameters and characteristics of the environment. Of promise in this respect are dynamic simulating computer complexes realized by man-machine interactive techniques as well as an effective combination of physical and mathematical models. Obviously physico-tekhnical principles must in the first instance be studied by using physical (material) models, while their reflections in the set of systems properties should be studied on mathematical (informational) models. In principle the investigation process should be iterative, with sequential use of both physical and mathematical models.

Investigation of the problem of optimization criteria for development and operation of power systems has an even longer history. Despite this, the urgency of this problem has not abated. A qualitatively new stage in development of the power industry of the nation (the formation of large power systems and the SPS that unifies them) necessitates the further investigation of this problem in the direction of finding optimization criteria that most fully reflect the goals of optimum control of power systems on different levels of their hierarchical structure and on different time intervals of their operation.

It is quite obvious that in addition to the hierarchy of goals and the hierarchy of tasks in the operation of power systems, there should be a hierarchy of optimization criteria as a system of interrelated partial optimization criteria that ensures satisfaction of requirements of the overall criterion for the national economy as a whole. The essentials of the hierarchy and the forms of the optimization criteria for control of power systems have not yet been adequately studied. The only thing that we can take as well studied is the essence of the optimization criterion for solution of individual optimization problems on intermediate and higher levels of the hierarchy. For example, on a certain level of the hierarchy of control tasks, the optimization criterion is taken as the minimum adjusted expenditures commensurable in monetary terms for one-time and annual expenditures with consideration of the time factor [Ref. 1, 3, 11, 12]. If we abstract ourselves from controversial questions of strictly economic nature (substantiation of the norm of effectiveness of additional capital investments, the norm of adjustments, methods of calculating capital investments and annual expenditures), we can state that the "adjusted expenditures" optimization criterion in the deterministic formulation also presupposes adherence to the rule of "identity of effect" [Ref. 13], and besides, complete accounting in monetary terms for all expenditures of the national economy due to development of power systems. However, these requirements are not always realizable for complicated power systems. Therefore it would be wise to continue looking for a solution that would improve the accord between the monetary criterion and the overall national economic criterion.

In the author's opinion, a progressive trend is development of a system of interrelated optimization criteria that reflect the goals of optimum control in actual hierarchically structured large power systems. Perhaps equal among these will be multicriterial systems that correspond to the nature of large power systems; it is also possible to use criteria that are based on natural (rather than adjusted) indicators, and so forth. However, it is important that none of them must be subjective, but rather that they must be based on complete measurement of socially necessary labor expenditures, while the form of accounting (direct or indirect) is ultimately determined by the capabilities and convenience of computation. The optimization criteria used on stages of controlling the development and operation of power systems must also be matched and mutually coordinated. At the present time, a certain breach of these criteria is observed in practice.

Studies of decision making methods on different time intervals of the development of power systems have also yielded some positive results. In our opinion, the main result of these studies can be briefly summarized in two major conclusions: that the possibilities of using deterministic methods are limited, and that decision making methods with incomplete information must be used [Ref. 1]. At present, a large number of methods of decision making with incomplete information have been proposed [Ref. 1, 5, 6, 14, 15]. However, in our view, the main problem is to find better methods of discovering incomplete initial information rather than to develop the "best" method of decision making. There are a variety of ways to solve this main problem. The following methods deserve serious attention. First of all to set up an information base that is founded on the corresponding automated systems for gathering, processing and storing data, and that is accessible to all users, and secondly, to set up a sequential (iterative) decision making process. Such a procedure must ensure matched actions on different levels of the hierarchy and in different time intervals.

The tool for such matched actions on lower levels of the hierarchy of control might be normative requirements or limitations that should be justified on the basis of conditions of optimum operation of the higher-level system (the national economy as a whole or the SPS). Because of the objectively existing indeterminacy of information of future conditions of operation of the higher-level system, it is obviously advisable to set these as the minimum admissible normatives (based on the condition of fulfillment of formulated goals with a certain fairly high degree of reliability that is guaranteed, even if only the minimum admissible fulfillment). The corresponding final optimization of decisions should be done on lower levels of the hierarchy of control on subsequent time intervals, which in our opinion better corresponds to the methodology of decision making in management of large power systems under conditions of information indeterminacy.

It would seem that methods of decision making with incomplete information should provide not only conditionally optimum plans of development of power systems, but also critical (turning) points, i. e. those at which the system may leave the steady state or go into another qualitative state. In other words, in controlling complex power systems it is important to know not only the best directions of development, but also the worst, in order to be able to take appropriate corrective steps.

Special methods of choosing optimum parameters of the components of large power systems should be taken as the best covered problems in the procedural aspect of systems research in power engineering. Numerous serious papers on this problem are known, both fundamental [Ref. 11, 12, 16] and applied [Ref. 17-20], which is completely natural since the theory and methods of systems research have developed from the "particular" to the "general." Because of this peculiarity, not all the special methods of choosing optimum parameters of the components of power systems can be considered sufficiently sound from the systems standpoint (in the broad methodological sense). Many of them are characterized by extremely detailed analysis of peculiarities inherent in the given object, and a comparatively sketchy representation of its relations to other components, even though the latter are frequently decisive from the standpoint of optimum control. Perhaps the formation of a systems approach to optimization of parameters from the "general" to the "particular" should be taken as the major task of systems research in power engineering for developing special methods of choosing optimum parameters of the components of large power systems at the present time. However, this method of optimization, which is natural from the standpoint of the methodology of systems research, requires serious preparatory work in the area of formation of systems thinking when training the corresponding specialists, organizing the work of research, design and planning organizations, providing for gathering and processing of data, and also setting up automated systems for development and optimum planning of power facilities and so on.

At the present time one can see a certain breach between the theoretical research on large power systems and the solution of specific practical problems in the process of operation of these systems. Therefore, serious research is also needed on functional tasks that ensure realization of the solutions found in optimization calculations.

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ELECTRIC POWER AND POWER EQUIPMENT

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SYSTEMS APPROACH TO SELECTING PARAMETERS OF POWER EQUIPMENT

Moscow IZVESTIYA AKADEMII NAUK SSSR: ENERGETIKA I TRANSPORT in Russian No 3, May/Jun 80 pp 54-62

[Article by L. S. Popyrin, Moscow]

[Text] The author considers the specifics of the systems approach as applied to solution of problems of technical-economic analysis and optimization of power facilities. An analysis is made of the state of research on major systems properties (hierarchism, incompleteness of information, reliability), and of practice in using the method of mathematical modeling to choose the parameters of power equipment.

The problems of optimum planning and development of power facilities and their components is an important one for development of the power industry of our nation. Facilities of this kind include fossil-fuel and nuclear power plants, boiler installations, oil refineries, power transmission lines, power-using enterprises and others that are part of the lower hierarchical level of the fuel-energy complex of the nation.

Modern large producers and consumers of electric and thermal energy in the aggregate are a most important part of the interlacing of the fuel-energy, material-resource, labor and financial balances of the nation. And these in turn are complicated systems.

The systems approach to optimizing power facilities is based on the general principles of systems research in power engineering since many complicated procedural questions of finding optimum decisions are common to different power systems [Ref. 1]. At the same time, it would seem that the technique of finding optimum solutions for power facilities has quite specific distinguishing features. Some of the principles of this technique are not yet sufficiently clear, and require serious revision. Besides, there are also certain differences in approaches to systems analysis of power facilities. All this dictates the advisability of a separate examination of procedural aspects of systems research on power facilities for the purpose of determining the major directions of further studies in this area and the possibilities of their practical use.

In this article an attempt is made to give a generalized idea of the present state of research on this problem. In doing this, with consideration of the considerable number of papers that have dealt with the problem [Ref. 2-14], major emphasis is given to examining such decisive aspects of systems research as: 1) accounting for the properties of hierarchism of power facilities; 2) decision making under conditions of incompleteness of initial information; 3) accounting for the reliability factor; 4) improving methods of mathematical modeling of power facilities.

Hierarchism of Power Facilities. Hierarchism is one of the major properties of large technical systems, which include modern power plants. The validity of formulation of the problem of optimum design of any power facility is determined in large measure by the completeness of accounting for this factor. The concept of the hierarchical structure of power facilities is a complex one, and takes consideration of the unity of a number of hierarchies: the actual technological structure of the object, technological and informational relations, decision-making agencies, goals of development of power facilities, methods and means of realizing these goals.

At the present time, the hierarchy of the technological structure of actual power facilities is fairly obvious, as is the hierarchy of the decision-making agencies involved in the development of power facilities [Ref. 2, 3]. Much less study has been done on the structure of vertical and horizontal controlling ties, and on the relative strength of manifestation of these ties. Their investigation is one of the major problems in developing an effective hierarchical structure for power facilities.

It should especially be emphasized that any hierarchy of goals of optimization of power facilities takes on a constructive form and real utility only under condition that the initial data needed for reaching these goals has been prepared, and the makeup of the controlling (exchange) information that ensures mutual coordination of optimum solutions has been elucidated. In other words, the given hierarchy of goals of optimization of the energy facility should have a corresponding analogously structured hierarchy of initial and exchange information.

The property of hierarchism of power facilities is considered in most detail in Ref. 2-6. A system of mathematical models organized in accord with the hierarchical principle and its corresponding system of data exchange are presented in Ref. 2 and 3 as applied to the problem of choosing the parameters of a power facility. Here an examination is made of: the sources of the initial external and internal information; the designation of reverse external and internal information; the designation of so-called intermediate information that circulates within the given system of mathematical models.

In Ref. 4, 5 the problem of choosing the parameters of conventional and nuclear heat and power stations [TETs] is formulated as a hierarchical problem with respect to technological and territorial levels. Here a list of the jobs to be handled is formulated for each hierarchical level, the specifications of the jobs are given, and lists of initial and sought information are defined. In solving the problem of studying nuclear electric plants, Ref. 6 uses a three-level technological system of mathematical models in which information flows by hierarchical levels are fairly well defined.

Particularly important for successful solution of problems of optimizing power facilities is the stepwise process of their planning and development. The process of planning and development of power facilities has a number of stages: feasibility studies, rough, engineering and working drafts, and in each of these stages it is advisable to differentiate optimization problems with respect to the depth and detail of working up various points.

Thus a joint study is needed on a two-dimensional hierarchy (with respect to features of technology and time) of problems of optimization of a power facility (see the Table) that will reveal the overall characteristics of the makeup of major jobs. These must be matched to make the resultant hierarchy of goals fairly complete without duplication, and at the same time ensure that each problem can be handled separately and in the aggregate within an acceptable time limit by available computer facilities.

Such matching presupposes: establishment of the sequence and periodicity of solving individual problems; determination of content and forms of representation of information transferred from one job to another; distribution of jobs by executive organizations. In fact, construction of an intercoordinated job hierarchy can be treated as simultaneous formulation of a set of interrelated problems. This circumstance increases the requirements for clarity in formulating each of them [Ref. 3].

Decision Making Under Conditions of Incomplete Initial Information. Interrelated problems on the nature of initial information and decision making methods are exceptionally important. The currently accepted position is that a complex aggregate of random factors has a considerable effect on the force of action of objective laws of development of the productive forces of the nation, and especially on trends in development of the power industry [Ref. 1]. This effect precludes strictly defined and exact information on such development in the future. Accordingly, a large part of the information used in the development and planning of power facilities may be given with an error whose precise magnitude and

Job hierarchy in thermopower plant optimization

Plan and development stage	Technological planning levels			
	Facility as a whole	Aggregates	Groups of equipment components	Equipment components
Feasibility studies	Optimizing fundamental solutions by variants of technological layout	Optimizing fundamental solutions by type and design of mojor aggregates		
Rough draft	Optimizing major structural, thermodynamic and flow parameters	Optimizing major configurational design parameters	Optimizing fundamental solutions by new groups of equipment components	Optimizing solutions by type and design of new kinds of equipment components
Engineering draft	Refined optimization of structural, thermodynamic and flow parameters	Optimizing configurational design, thermodynamic and flow parameters	Optimizing configurational design, thermodynamic and flow parameters of all groups of equipment components	Optimizing configurational design decisions for all equipment components
Working draft	Final optimization of individual solutions	Final optimization of individual solutions	Refined optimization of all parameters and solutions	Refined optimization of all decisions

nature of variation are unknown. The insufficient definition of information that is used precludes an unambiguous optimum solution.

These principles have found reflection in almost all recent research dealing with technical-economic studies of power facilities. Unfortunately most of this research covers different aspects and proposes different approaches to formalization of the decision making method proper under conditions of incompleteness of initial information, and only a few papers have been aimed at getting initial information with minimum possible indeterminacy. At the same time, the principal means of overcoming ambiguity of initial information is always investigation of the actual conditions of development of power systems and the facilities that make them up. Formalized methods of decision making must be used in cases where, despite all efforts, the ambiguity of initial information has a considerable effect on decisions.

As to research in the second area, we could mention Ref. 7-10. A considerable part of the initial information could be classified as probabilistically indeterminate, i. e. information for which no statistical patterns have yet been established with availability of certain statistical material. The establishment of such patterns is one of the important ways of reducing indeterminacy of optimum solutions. This problem can be resolved on the basis of recommendations made in Ref. 7, where it is shown in application to conditions of preparation of initial information in the optimization of sources of centralized heat supply, that the use of statistical methods enables evaluation of the nature and possible range of fluctuations of initial indices, determination of the correlations between them and so on.

In Ref. 8, 9, considerable attention was given to investigating sources of initial information under difficult conditions, and to methods and means of gathering, processing and preparing all factors of predicting reliability. Simplified methods have been checked out for evaluating the reliability indices of components of power equipment as a function of the nature and properties of the available initial information: methods of expert evaluation and correction of statistical extrapolation from limited data beyond the incomplete period of observation, analysis of random processes of thermomechanical loading and change in the carrying capacity of the structure as a whole.

Fairly effective methods of acquiring and processing information, methods of accounting for indeterminacy of information used in constructing mathematical models of power facilities and certain other questions associated with the optimization of power facilities under conditions of incomplete determinacy are considered in Ref. 10.

For cases where, despite all efforts, the ambiguity of the initial information has a considerable influence on the decision, resort must be taken to the method of doing technical-economic calculations in power engineering developed by the commission of the Science Council of the Soviet Academy of Sciences on Complex Problems of Power Engineering [Ref. 11, 12]. Experience in using this method to solve practical problems in planning and design of power facilities and equipment will enable us to determine further areas for improving the method.

The greatest difficulties in decision making with insufficiently complete information arise at present in coordinating decisions in the hierarchical job system. It is shown in Ref. 3 that the procedure of complete iterative refinement of solutions found on different hierarchical levels is cumbersome even in the case of deterministic assignment of the initial information; for the more realistic case of matching solutions under conditions of incomplete information this procedure is almost unusable. Accordingly, another decision-making procedure is described that is more realistic in the sense of its execution, and more importantly is closer to the essence of decision making under conditions of indeterminacy. It includes the following stages: 1) selection of a small number (3-5) of combinations of ambiguous factors that cover the entire range of indeterminacy of utilized information; 2) solution of the problem of optimizing the upper hierarchical level for the selected combination of information, analysis of the results to set apart a small number of variants of the solutions that cover the entire range of resultant solutions; 3) formation of a small number of combinations of conditions of solution of problems on the lower hierarchical level that cover the entire range of variation in ambiguous information obtained from higher-level systems and inherent in lower-level systems; 4) solution of optimization problems for lower-level systems with the given combinations of initial conditions, analysis of the results to get generalizing relations for optimum solutions with respect to systems of the lower hierarchical level as a function of the solutions coming from higher-level systems.

Such an approach precludes laborious procedures of repeated optimization of systems with a set of combinations of raw data. The discreteness of the change in many parameters, the form of plan and a number of technological characteristics facilitates selection of a small number of optimum decisions on individual systems and subsystems. Complete solution of the problem of optimum design of a power facility is usually realized in one or two iterations.

An optimality principle that is realizable in developed mathematical models is used in Ref. 4, 5 to coordinate the solutions found for individual problems on different hierarchical levels. Information is transmitted to higher levels in aggretized form -- by constructing generalized power-economy characteristics of optimized lower-level systems.

Reliability Factor. A rather important and complicated procedural problem is prediction of the reliability of new energy facilities, and accounting for this factor on stages of their development and optimum planning. Over the last decade, a number of organizations have done procedural and applied research aimed at developing a complex of methods and computer research programs that give a rough (interval or probabilistic) estimate of the indices of reliability of power facilities as complex technical systems [Ref. 2, 13-16].

In Ref. 2, 13, 15 the problem of ensuring optimum reliability of power facilities on the stage of their planning and development is formulated as a complex intersectoral problem. An important part in the solution of this problem should be played by the development of computational methods of forecasting, optimizing and normalizing reliability indices as a function of major technical and economic factors. On the stage of design calculations, account is taken of the following conditions of ensuring an optimum or normative level of reliability of power facilities: 1) optimization of technological layout (structure) and optimum redundancy of aggregates and auxiliary systems of the facility and their components; 2) selecting preventive maintenance schedules for the facility; 3) optimizing reserves of strength and reliability indices, reserves of productivity and other characteristics of components of the power facility that influence their reliability.

As of now, algorithms have been developed for evaluating the reliability and adjusted computational expenditures that account for the reliability of the installation, loading conditions, redundancy and substitution of capacities in the electric power system as a function of choice of the fundamental thermal (technological) layout, structural and load redundancy [Ref. 2, 14]. The first stage of design research has been completed, demonstrating the feasibility of economically justified selection of the plan and methods of redundancy based on the example of large power units in a nuclear electric plant. It has been demonstrated that optimum solutions can be fairly stable with incomplete initial information on reliability.

Ref. 16 is based in large measure on operational statistics with respect to reliability of existing kinds of equipment. While this is a quite valuable source of information, the statistical data obtained on existing equipment can be only indirectly and partly utilized on stages of planning and development of new equipment for power facilities. Hence the need for further research in this area.

Interesting results have been attained in the process of developing methods for evaluating and optimizing the reliability of the components and parts of power facilities [Ref. 3, 9]. Quite promising is a procedural approach that provides for consideration and optimization of the overhaul schedule for power facilities on the design stage [Ref. 14]. The unification of these two approaches enables simultaneous solution of two problems in a unified interative calculation: substantiation of the reliability of components and parts of the power facility, and substantiation of the repair schedule for the facility on the design stage.

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On the whole, only the first steps have been taken in solving the problem of creating effective methods of ensuring reliability of power facilities on the developmental and planning stage as well as the corresponding engineering information complexes. Many important and complicated problems await their solution.

Perfecting Methods of Mathematical Modeling of Power Facilities. Mathematical modeling as a formalized means of doing systems research plays an exceptionally important part in the given problem.

As of now, considerable advances have been made in this area: theoretical principles have been worked out for the design of mathematical models of different kinds of power facilities; practical techniques have been developed for application of the method of mathematical modeling to the determination of ways to improve the economy of power facilities; numerous studies have been done on power facilities of various types, their technological layouts and equipment components.

It should be noted that in contrast to the mathematical models of power systems on a higher hierarchical level (fuel-energy complex, electric power systems), those for power facilities in most cases have been constructed as simulation models in a certain sense. In order to do optimization studies, they have been combined with programs that realize nonlinear programming methods.

The fundamental advantages of mathematical models have dictated their extensive use in planning and development of power facilities. At the present time the mathematical models realized on computers are the most efficient tool for finding optimum layouts and parameters of power facilities. However, the potential possibilities of the method of mathematical modeling of power facilities have not been completely used by any means. A transition is needed from the solution of isolated individual problems to the creation and use of intercoordinated systems of mathematical models that describe all levels of technological, territorial and temporal hierarchies of the system of optimum design of power facilities of various types. Such a system for the power facilities of each type should be realized as a unified complex of algorithms and programs that account for participation in the process of planning and development of facilities by research institutes, design offices and planning institutes of different agencies.

In addition to this, when developing a system of mathematical models for a given type of power facility considerable attention should be given to the formulation of requirements for individual mathematical models of the system as to accuracy of their design and flexibility of the algorithms that implement them to ensure the feasibility of using each mathematical model (or its modification) for solving problems on different hierarchical levels and in any combinations with other models.

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The requirements for accuracy of mathematical modeling of any object or process are determined mainly by the formulated goal, volumes and error of the initial information; they differ appreciably in the consideration of this object or process on various levels of the technological and termporal hierarchy. These requirements can be met by using a number of procedural techniques for construction of mathematical models: 1) methods of differentiating the factors that are essential and nonessential for the investigated object or process (this determines the optimum volume of the mathematical model); 2) methods of equivalentizing, i. e. conversion of one mathematical model to another that is equivalent to a degree to the former, but simpler; 3) methods of aggregated representation of data; 4) methods of decomposition, i. e. breaking down the problem into a number of subproblems and studying each subproblem independently, followed by their coordination.

A number of such procedural techniques that have been developed for application to the specifics of construction of mathematical models of power plants are outlined in Ref. 2, 4, 10, 17, 18. On the whole, however, this important procedural problem has not yet been adequately investigated. Accordingly one of the problems that requires solution is the development of design algorithms for choosing essential factors, equivalentizing, aggretizing and decomposition.

Extensive introduction of mathematical modeling in engineering practice has revealed a bottleneck in this process: large inputs of labor by skilled programmers to prepare computational programs. Therefore it is urgent to increase the efficiency of putting together the mathematical models by such means as developing nonalgorithmic problem-oriented languages for describing and formulating complex models, algorithms and goals on the conceptual level without describing the mass of details that are unassociated with the fundamental aspect of the algorithm. It is quite important to set up automated programming systems that translate these descriptions into algorithmic or machine languages.

As applied to thermal power problems, two areas can be differentiated in the development of promising systems of programming: 1) creation of a method of machine generation of programs for design of thermopower plants [Ref. 2, 19, 20]; 2) development of the modular principle to improve efficiency in interfacing and unifying different algorithms and programs [Ref. 21].

Rather complicated problems remain to be solved in automating the process of mathematical modeling of the structural elements of equipment components. The specific nature of these problems is due to difficulties in representation of data on the geometry of equipment components. Many design problems of an informal nature are not easily algorithmized. Intensive research is being done in this area both as applied to the general problems of machine building and with consideration of the specifics of power units [Ref. 22].

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Research on conceptual analysis of power facilities as objects of systems research is still in its infancy; the physical and engineering properties of these facilities are not adequately accounted for. Considerable work is ahead on development of mathematical models that best reflect all properties of power facilities. For example the important problem arises of accounting for the way that power units now being designed will influence the indices of electric power systems of the more distant future. Perhaps the problem could be properly handled by examining and modeling the entire life cycle of the power facility, beginning with the period of installation and adjustment of equipment and ending with the period of dismantling due to age or obsolescence.

Consideration of potential types and parameters of power facilities must without fail include consideration of the influence of this facility (or set of facilities) on the environment. Often it is environmental consequences that determine the applicability of a given power facility. A number of interesting studies have been done recently in this area, e. g. Ref. 23, but they should be considered as the first steps in solution of this complicated problem.

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ENERGY CONSERVATION

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DECREASING LOSS OF ELECTRICITY IN SUBWAYS

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[Article by F. Ye. Ovchinnikov, candidate of economic sciences, All-Union Scientific Research Institute of Railway Transportation, and M. A. Lebedev, engineer, Moscow Subway imeni V. I. Lenin: "Decreasing Loss of Electricity in Subways"]

[Text] Subways are large consumers of electricity. In 1979 alone, they expended about 1.6 billion kilowatt hours of electricity at a cost of 22.6 million rubles (over 12.8 percent of all operational expenditures). In connection with the construction of subways in Minsk, Gor'kiy, Sverdlovsk, Novosibirsk, Yerevan and other cities, as well as with the increase in the length of existing subway lines, subway electric power requirements over the next few years will increase significantly. Great attention, therefore, is constantly devoted to the question of improving the effectiveness of electric power utilization by subways.

Effectiveness of the utilization of expenditures for electricity, defined as the relationship between the fulfilled volume of passengers hauled expressed in passenger-kilometers and the cost of the electric power expended expressed in rubles over the period 1976-1979 is shown in Table 1. As is evident, basically over the past 4 years an improvement in the use by all subways of operational expenditures for electricity can be seen, including money spent for subway train tractive force. Being reduced is the difference in the effectiveness of electric power utilization for the operational needs of recently constructed subway lines and those which have long been in operation.

The basic consumers of subway power resources are the electric train rolling stock service, escalators, the electromechanical, signal and communications as well as the traffic flow services. The overwhelming portion (78-80 percent) of the electricity required by subways goes for the electric train rolling stock service and is expended for pulling subway trains. A definite proportion of those power resources is utilized by various electrotechnical devices for the repair of rolling stock at depots. About 9-10 percent of subway electric power consumption goes

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Table 1

Subway System	Effectiveness of Utilization of Expenditures for Electric Power (by years)								Increase in Effectiveness in 1979 as Compared with 1976 (in percent)	
	1976		1977		1978		1979			
	Total	For Train Traction	Total	For Train Traction	Total	For Train Traction	Total	For Train Traction	Total	For Train Traction
Moscow	1467	1865	1527	1981	1538	1996	1545	1994	105.3	106.9
Leningrad	1331	1753	1317	1753	1333	1766	1275	1669	95.8	95.2
Kiev	1365	1724	1421	1898	1540	2056	1555	2083	103.9	120.8
Tbilisi	1097	1568	1169	1647	1118	1549	1056	1497	96.3	95.5
Baku	745	994	965	1337	1043	1421	1174	1607	157.6	161.7
Khar-kov	1232	1340	1320	1871	1086	1474	1177	1618	95.6	120.8
Tashkent	--	--	499	822	549	987	727	1296	--	--
Average For All Subway Systems	1397	1801	1443	1898	1435	1893	1438	1887	103.0	104.8

for sanitary-technical devices: ventilation and air conditioning installations which maintain required air temperatures at subway stations, tunnels and underground production facilities, pumping facilities which remove technological and ground water from tunnels and stations, as well as by fecal sewage facilities, plumbing equipment, shower and drying units, small heating devices, and so forth.

Of the overall subway electric power requirement, approximately 9-10 percent of the electricity is used for illumination devices and the cleaning machinery of the traffic division; 3.5-4 percent is used for escalators, with most of that used by escalator electric drives; 0.4-0.5 percent is used by the signal and and communications service. In addition to this, electricity is required by auxiliary electric motors and braking devices as well as by the apparatus belonging to traffic operation, signal and electric protection systems. A portion of that electricity is required by various electrotechnical devices in various repair shops, by electrified repair machinery, and by devices of various sorts at substations.

We shall review in greater detail the loss of electric power by the Moscow Subway. Loss in the electric power feed system is about 0.89 percent of the required electric power, while in the 10 kv power distribution system there is an 0.48 percent loss in the transmission of electricity from traction substations to the subway. In addition, about 0.2 percent of electric power is expended for the needs of traction, step-down and combined traction-step-down power substations. There are definite losses of power at the traction substations themselves. Thus, power losses in silicon rectifiers and traction transformers (1.5 and 2 percent) consist of power lost in current rectification and within transformers and resistors. In addition, there are losses (0.45 percent) in major power feed and lead off cables. There is a considerable loss of electric power in the traction system from the busbars of traction substations and rolling stock.

Calculations prove that there is a 5.88 percent loss in power in contact and track rails, this substantially influenced by the size of the cable, the design of the contact rail, and by a number of other factors. In the illumination system as well as in systems utilized for heating devices. the loss of electric power reaches 2.85 percent. Lowering this percentage is accomplished by replacement of old light sources with luminescent fixtures as well as through the use of more up-to-date heating devices, electric stoves, heating systems and the like. Losses in systems which feed power to escalator motors, to sanitation-technical devices, to signal and communication devices, as well as to other subway equipment are equal to 4.92 percent.

For the purpose of decreasing the loss of power by subways, an effort is being made to strengthen power cable and contact systems so as to increase the amount of power transmitted through them; at traction substations, oiled switches are being replaced by electromagnetic switches, while traction and transformers filled with oil are being replaced by more reliable and explosion-proof transformers with organosilicon insulation. In addition to this, condensers used in the shunting circuits of substation traction sections are having their resistors replaced by rectifiers.

At the Moscow Subway in 1978, 12 oil-filled power transformers used in underground traction-step substations were replaced by transformers with organosilicon insulation; 12 silicon rectifiers with induced ventilation were replaced by rectifiers with natural ventilation; and 8 old type booster units were replaced with new ZPU-1 and ZPU-2 units. Introduction of this more improved electrical equipment helped conserve more than 300,000 kilowatt hours of electricity for the year. To decrease the loss of electric power in traction motors of the electric rolling stock, the Mytishchi Machinebuilding Plant and the "Dinamo" Plant imeni S.M. Kirov have now mastered the production of "E" type subway cars with more powerful traction motors and improved traction-power characteristics. In addition to this, these cars have been equipped with more economical luminescent lights and forced ventilation.

In order to decrease the loss of electricity and to improve the technical-economic indicators of subway cars in operation, they are now being modernized: their undercarriages and traction motors are being replaced, static transformers are being introduced, as are new automatic, anti-skid and antislippage devices. The measures indicated will allow us to improve the acceleration and deceleration of rolling stock. Now being developed and placed into use are more improved automatic performance devices which assist in the regulation of current being fed to traction motors while trains are being started or when their brakes are being applied and over the entire range of charging those motors with electricity.

These "E" type subway cars with all their built-in modifications will be equipped with devices for pulse thyristor nonrheostat starting and for follow-up braking, this for the purpose of recouping electric energy. Of great significance also will be the work now being done on raising the level of insulation of contact and track rails. Preliminary calculations and test results have shown us that carrying out these measures will allow us to lower the expenditure of electricity for train traction by approximately 12-15 percent, while at the same time increasing the technical and operational speed of rolling stock by 6-8 percent.

Work on curtailing the loss of electric power in illumination networks is also being conducted. Thus, the question of the further shift from lighting subway stations with incandescent lamps to the use of luminescent illumination is being reviewed. Loss of electric power being used along subway routes and in production installations is being reduced through improvement in the operational efficiency of the electric motors used in escalators and ventilation shafts by shifting over to compensating reactive capacity, as well as through application of the thyristor starting of escalators.

The basic methods for conserving electric power in subways consist of the following:

Automation of Production Processes. Its application on a broader scale is possible as regards escalators, traction substations, in the operation of sanitation-technical devices, heating instruments, and in turning on and turning off lights. The transfer of escalators to remote control will also enable us to reduce the expenditure of electricity thanks to changing lighting schedules during the period in which repair-and-inspection brigades are absent, as well as through the introduction of remote control at combined traction substations--by shutting off the lights there when personnel are absent. The automatic and programmed management of ventilation at battery-equipped traction and step-down substations will make possible, depending upon the temperature, the rational turning on of cooling devices. Introduction of a system for the automatic maintenance of the microclimate at subway stations will permit the strict observance of air temperature parameters (within the limits of sanitary standard requirements), which will reduce the duration of operation of the basic air-exchange ventilation system. Automatic control of lighting at subway stations and vestibules is to be accomplished in keeping with natural illumination and train schedules. Remote control of the illumination in open-line subway tunnels is to be widely applied.

Replacement of Electric Equipment. Being utilized in subways at the present time is electric equipment which is patently and physically out-dated, equipment which requires considerably more electricity than new gear. Its timely replacement will allow subways to conserve additional electric power.

Changing Equipment Work Schedules. This method is achieved through introduction of a step-by-step schedule for the work of ventilation shafts, depending upon the temperature of the outside air, the correction of subway train schedules, the observance of established schedules for the operation of electrical equipment, plus the rationalization of schedules for the work of escalators, sanitary-technical equipment, and other devices.

Introduction of Leading Experience. Of great significance in the lowering of electric power consumption is the wide-scale dissemination of leading work experience, the organization of schools for the study of operating subway trains, plus the constant conduct of machinist-instructor training together with locomotive brigades for facilitating rational operating procedures.

Fulfillment of Organizational Measures. Belonging to this category are: conducting regular checks on the use of electricity at subway stations and at surface installations with the aid of initiative groups and public inspectors; having subway central commissions and local commissions for conserving electric power make surprise inspections of subway subdepartments; the organization of public inspections, competitions and conferences on the conservation of power resources, the uncovering and utilization of further conservation reserves; the periodic analysis (monthly, quarterly, semi-annual and annual) of power resource utilization; execution of complex checks as to the fulfillment of subway train schedules and as to driver operational procedure of locomotive brigades (by both directors of subunits and by machinists-instructors). In conserving power resources, of important significance is the maintenance of constant control over the adjustment of electrical apparatus, pneumatic devices and main circuits, mechanical devices which are supposed to operate within specific allowable standards. The dissemination of visual aids material on the conservation of electric power and fuel, plus publicity in the local and industrial press on conservation work being conducted will definitely influence lowering electric power resource expenditure.

Every year, subway workers are successful in lowering electric energy expenditures for operational needs, as is testified to by the data in Table 2.

Table 2.

Conservation of Electricity (in thousands of kwh)	Year			
	1976	1977	1978	1979
For the Moscow Subway:				
Overall	19,849	21,837	31,593	33,585
For subway train traction	17,145	16,334	24,041	27,862
Total for subways	36,725	42,163	52,900	63,775

Realization of plans for organizational-technical measures for the rational expenditure of energy resources will allow us to lower electric power consumption, curtail operational expenditures, and increase the effectiveness of the use of power expenditures for subways.

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