ELECTRIC POWER DEVELOPMENT IN THE USSR

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ABSTRACT. The generation of electric power in the USSR is based on the Unified Electric Power System (UEPS) whose networks cover most of the habitable territory of the country. Therefore, the development of UEPS governs the overall evolution of electric power generation in the country. At present, eleven out of the thirteen joint electric power systems, which supply electricity to most of the USSR, are operating within the UEPS. The total electric power generation in the country reached 1,728 billion kWh in 1990, of which the UEPS supplied approximately 90%. About 70% of installed capacity of the UEPS is fossil-fueled power plants, about 12% is nuclear power plants, and about 18% is hydroelectric power plants. The system-forming grid of the UEPS is made up of transmission lines of 220, 330, 500 and 750 kV. The on-line supervisory control of the UEPS is achieved by a four-level automated system of dispatch control (UEPS, joint electric power system, regional electric power system, electric power plants, substations, electric grid regions). The development and extension of the UEPS in the USSR ensure higher reliability and quality of electric power supply to end-users, combined with higher efficiency. The principal problems facing the UEPS are as follows:

- the need to ensure environmental protection and efficiency of steam power plants;
- the improved safety and efficiency of nuclear power plants.

The solution to these problems will define the conditions of the UEPS development, as well as electric power systems of other countries, at least for the coming two decades. This paper characterizes the peculiarities of the UEPS development over the last 20 years, including the installed capacity structure and systems-forming electric power grid. Special attention is paid to environmental problems related to functioning and development of the UEPS and to the means of their solution.

INTRODUCTION

The generation of electric power in the USSR is based on the Unified Electric Power System (UEPS) whose networks cover most of the habitable territory of the country. Therefore, the development of UEPS practically governs the overall evolution of electric power generation in the country.

It should be emphasized that the Unified Electric Power System is a single network, which must be developed according to a single plan allowing interchangeability of different types of fuel resources, means of production, conversion, transmission and distribution of electric power. The operation of the Unified Electric Power System is managed with the aid of a centralized automated control system, which operates according to designated priorities.

The current status, conditions and specific features of the development of the UEPS over the last 20 years are characterized below. Special attention is paid to the environmental problems associated with the functioning and development of the Unified Electric Power System and to the solution of those problems.[1]

STATUS OF THE UNIFIED ELECTRIC POWER SYSTEM

The basic structural unit in the country's system of electric power generation is a regional electric power grid covering, as a rule, one or two regions. Altogether, there are 106 regional power systems in the USSR. All the regional systems, with the exception of the Moldavian system, are incorporated in 13 joint electric power systems, as shown in Figure 1. The list of 13 joint electric power systems is as follows:

- Northwest (Baltic republics and adjoined Northwestern part of the Russian Soviet Federal Socialist Republic)
- Belorussia

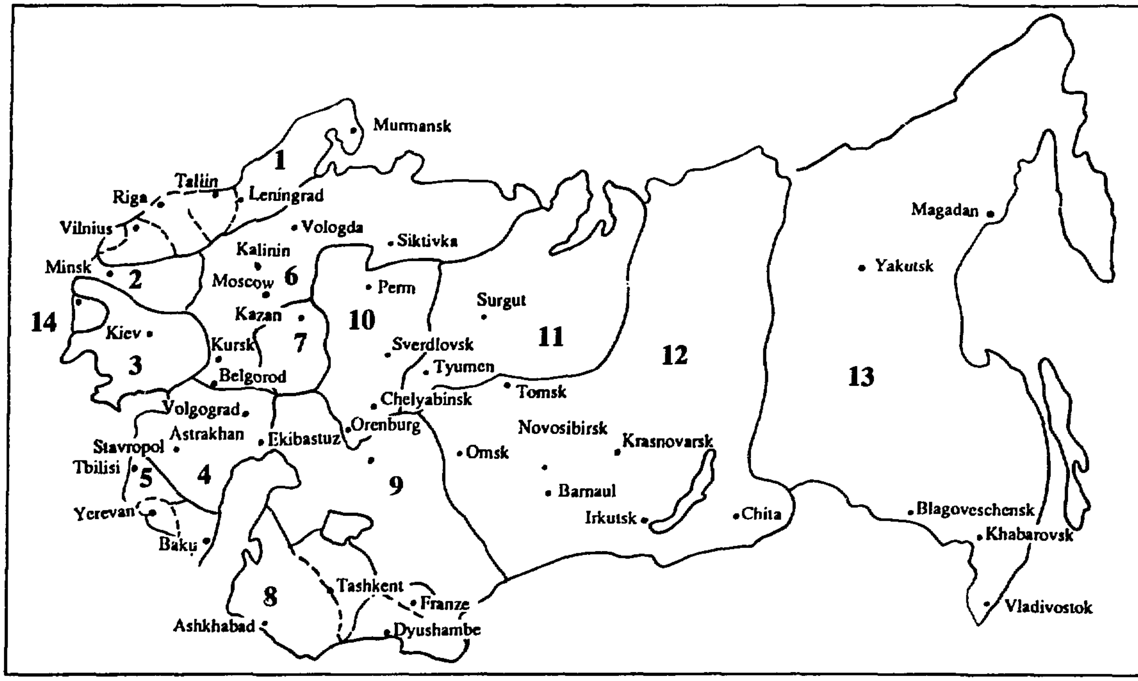

Fig. 1. *The borders of the USSR joint electric power systems*
1. North-West JEPS • 2. Byelorussia JEPS • 3. Ukraine JEPS • 4. North Caucassus JEPS • 5. Trans-Caucassus JEPS 6. Center JEPS • 7. Middle Volga JEPS • 8. Central Asia JEPS • 9. Kazakhstan JEPS • 10. Urals JEPS 11. Tyumen JEPS • 12. Siberia JEPS • 13. East JEPS • 14. Moldova REPS

- Ukraine
- North Caucasus
- Transcaucasia (Georgia, Armenia, Azerbaijan)
- Center
- Middle Volga
- Central Asia (Turkmenia, Uzbekistan, Tajikistan,Kirghizia)
- Kazakhstan
- Ural
- Tymen Region
- Siberia
- East

At present, eleven out of thirteen joint electric power systems and the Moldavian regional electric power system are operating within the Unified System. The UEPS networks cover the territory extending from the Transbaikal Region to the western borders of the country, an area of about 10 million km^2 with a population of about 240 million people. The joint electric power systems of Central Asia and the East are not integrated yet in UEPS.

The total electric power generation in the USSR reached 1,728 billion kWh in 1990, of which approximately 90% (1,529 billion kWh) was supplied by UEPS and 8% (161 billion kWh) was provided by separated regional power systems. Accordingly, decentralized electric power supply amounted to about 2%. The share of the USSR in the world generation of electric power over the last 20-25 years is 15-16%. The structure of electricity demand for domestic needs is characterized by the data of Table 1.[2]

Per capita generation of electricity in 1990 was about 6,000 kWh a year, which is approximately equal to per

Table 1. *USSR electricity demand for domestic needs*

Sector of demand	1985		1990	
	bln kWh	%	bln kWh	%
Industry & construction	823	54	900	53
Transport	120	8	140	8
Agriculture	109	7	150	9
Housing & communal services	229	15	280	17
Other	234	16	220	13
Total	1515	100	1690	100

capita demand in western Europe, but is half the demand in the USA.

The electric power systems of 6 East European countries are operating in parallel with UEPS in the western part of the country; and that of Mongolia — in the eastern part. UEPS is linked via a DC converter substation with the electric power system of Finland, which is incorporated in the joint electric power systems of Northern Europe (NORDEL).

The Unified Electric Power System of the USSR is one of the world's largest networks whose power is next after only two other such systems, namely, the combined network of the USA and Canada, and the West European system.

The total power generated in the USSR was 298 GW in 1985 and 329 GW in 1990, respectively: UEPS supplied 265 GW in 1985 and 292 GW in 1990.

The distribution of generating capacities is given in Table 2. In the steam power plants (SPP) the share of gas and liquid fuel is approximately two-thirds; this is true for both condensing plants (CPP), and heat-and-electricity cogeneration plants (HEPP). Well over 65% of the installed capacity in the UEPS belongs to large-scale power plants with a power of over 1 GW (more than 60 steam power plants, 13 nuclear power plants and 12 hydroelectric power plants).

Table 2. *UEPS power generation distribution (in % of total power generated)*

Plant Type	1985	1990
CPP	40.2	39.3
HEPP	30.2	29.9
Total Steam Power Plants (SPP)	70.4	69.2
Nuclear Power Plants (NPP)	10.6	12.9
Hydroelectric Power Plants (HPP and HPSPP)	19.0	17.9

The UEPS system grid is based on transmission lines of 220, 330, 500, and 750 kV. In Ekibastuz-Kokchetav-Kustanai-Chelyabinsk and Ekibastuz-Barnaul 1,150-kV AC transmission lines were put into operation.

Construction of the Ekibastuz-Center a 1,500-kV DC transmission line is under way. The extent of high-voltage electric grids exceeded 215 thousand km by the end of 1990, including 184 thousand km in the Unified Electric Power System.

UEPS on-line supervision and control is achieved by a four-level automated system (Unified Electric Power System, joint electrical power system, regional electric power system, and individual components, such as electric power plants, substations and electric grid regions).

EFFICIENCY OF THE USSR SYSTEM

The development and extension of UEPS ensure increasing reliability and quality of electric power supply to end users, combined with high efficiency. This is achieved mainly by mutual assistance between individual regions in cases of imbalance between electricity production and demand.

The increase in the efficiency of electricity supply is achieved due to:

- the reduction of required installed capacity by lowering the designed reserve capacity (for emergencies and general overhaul) and by lowering the combined peak load, due to the time difference in peak demand between regional electric power systems located in *different time zones;*
- the use of cheaper energy resources from the centers of electric power consumption;
- an increase in the efficiency of individual power-generating units, transformers and power plants;
- an increase in the efficiency of steam power plants by reducing the amount of fuel required for power generation and by improving the operation of hydroelectric power plants within the system;
- raising the transmission capacity of main transmission lines;
- reducing the number of operation personnel, and so on.

Some examples: The required reserve capacity of UEPS was reduced by approximately 5 GW. The reduction of UEPS's annual load peak was estimated as about the same compared with the sum of peak loads of regional electric power systems. This yields a savings of 3-5 billion Rbl in power plants operation, at the electricity cost of 300-500 Rbl/kW. However, such a reduction is conditional on the construction of additional inter-system transmission lines with a cost of approximately one billion roubles. Therefore, every rouble invested in the construction of inter-system transmission lines yielded a saving of two-four roubles.[a]

The increase of power plant efficiency by improving electric power generation in a steam condensing mode is estimated at 0.26 g/kWh; this corresponds to combined fuel savings of 277 thousand roubles.[a]

Additional reduction in fuel consumption can be attained by:

a. optimization of the combined system

[a]*As estimated by I.M. Volkenau.*

operation. This can be achieved by increasing electricity production in hydroelectric plants using water from storage basins and by reducing electric power generation in steam power plants.
According to the the data submitted by the Central Administration of Supervisory Control of the UEPS, the annual savings could amount to 12-15 million Rbl.

b. optimizing the distribution of electric power, which results in the reduction of transmission losses.
Increased utilization of main transmission lines is attained by ensuring reliable electricity supply to end users under the condition of minimum (much lower than the rated values) reserve capacity. In this case, the annual savings are estimated by the Central Administration of Supervisory Control of UEPS at about 15 million Rbl.

DIFFICULTIES ENCOUNTERED IN THE DEVELOPMENT OF THE UEPS

The two principal problems, whose solution greatly influences the development of the Unified Electric Power System, much like electric power systems of many other countries, at least for the next two decades, are:

- the need to ensure environmental protection and proper efficiency of steam power plants;
- the improved safety and efficiency of nuclear power plants.

The development of environmentally acceptable coal-fired steam power plants calls for:

- the use of new and improved boiler units (with fluidized-bed combustion of fuel and so on);
- maximum possible cleaning of flue gas and waste water from harmful materials;
- preparation of various sulfur products and standard fertilizers using sulfur and nitrogen oxides recovered from flue gas; utilization of ash and slag.

In all coal-fired steam power plants with conventional steam-power equipment, the cleaning of flue gas from ash must be at an efficiency of no less than 99.5-99.8%; sulfur and nitrogen oxides must be eliminated at an efficiency of 80-90%. Additional investment in a "clean" steam power plant utilizing low-grade solid fuel is estimated at 70-100 Rbl/kW (approximately 25% of principal capital cost).

In new and retrofired power plants utilizing gas fuel, steam-gas plants (SGP) of various types can be used to great advantage, as well as combined cycles with upstream gas turbines.[3] This can increase the plant efficiency from 35-40% to 45-50% (and more). It is also accompanied by reduction of NO_x emissions by a factor of 1.5-2 and of capital cost by approximately 30%.

Since natural gas is ecologically a much cleaner fuel than coal, all power plants in urban areas (where stable gas supply can be provided) must be converted from coal to gas, starting with areas of most unfavorable environmental conditions. The available gas resources make such a program feasible.[2]

An even more serious problem is the necessity of improving the safety of nuclear power plants, which depends primarily on the nuclear reactor safety. In spite of the measures taken after Chernobyl, the safety level of the currently employed channel-type (RBMK) and shell-type (VVER) nuclear power reactors appears to be clearly inadequate. Therefore, a series of consistently improving nuclear reactor designs, which are expected to have a safety level several orders higher than that of the reactors currently in use, are under development.[4] It appears that a significant increase of the safety level, i.e. the development of practically safe nuclear reactors, can only be attained if inherent safety features (self-protection) are developed.

Since safety of nuclear power generation depends on the safety level of both the nuclear reactor and overall plant, the design of the so-called out-of-reactor part must also be appreciably improved.

Besides the two main problems discussed above, a number of local, practical problems of UEPS development need to be solved:

1. Prospects for hydroelectric power development, considering their environmental effect. The program must include the development of design standards, codes and procedure for evaluation of their economic efficiency.
2. The development of reserve generating capacities for periods when the annual peak load exceeds 10-15% (at present, only about 3-5%).
3. The technical equipment improvement, including an increased capacity of reactive power compensation devices (by a factor of 2.5-3), higher capacity of on-load tap-changing transformers, larger number of factory-assembled switch-gears, etc. This will provide an increased reliability of electricity supply to consumers, higher quality of electric power and lower losses in electric power grids.
4. The reduction of labor expenditure by improving the technical equipment and better operation of UEPS units.
5. Improvement of automatic supervisory control systems by developing, on a broader scale,

interactive control systems supporting the Operator-Computer dialog, simulators and intellectual hierarchic systems for automatic accident-prevention.

DEVELOPMENT OF THE UEPS

1. Possible scenarios for future development of the UEPS

The development of UEPS suffers from the uncertainty of the economic situation in the country and its separate regions; this problem is aggravated by peculiarities associated with the shaping of economic independence of Union republics. As a result, it is difficult to predict power demand, which is defined by both the rate of economic growth and technological improvements. Considerable uncertainty also is related to progress in branches of industry which are associated with energy, such as power generation, as well as in primarily fuel producing branches of the national economy.

The uncertainty suggests the use of an alternative approach trying to understand and select the principal guidelines of the development of UEPS. Note that it is the existence and development of a unified electric power system which helps to compensate for some imbalances between supply and demand of electricity in different parts of the country. These conditions are caused by deviations from plans and forecasts of economic development.

Projections of energy demand, based on different scenarios of economic development and energy conservation, are shown in Table 3.[2]

Table 3. *Projections of domestic energy demand, USSR, (in bln kWh)*

Scenario	Years		
	1990	2000	2010
maximum	1,690	2,100	2,700
high	1,690	2,015	2,625
low	1,690	1,935	2,460
minimum	1,690	1,840	2,280

The analysis[b] shows that the development of UEPS requires a study of four alternatives (scenarios) covering the most complex and limiting (within the assumptions made) cases. Qualitatively, these alternatives are characterized in Table 4, and quantitatively in Table 5.

Table 4. *Qualitative characteristic of alternative developments of UEPS*

№	Level of electricity demand	Development of nuclear	Development of hydroelectric	Emphasis on particular feedstock
1	high	maximum	maximum	medium
2	high	low	maximum	maximum emphasis on natural gas
3	low	medium	minimum	medium
4	minimum	minimum	minimum	high

Table 5. *Quantitative characteristic of alternative development of UEPS (in bln kWh)*

Alternative	Years		
	1990	2000	2010
1	1530	1970	2570
2	1530	1970	2570
3	1530	1890	2400
4	1530	1800	2230

2. Structure of generating capacities

The conditions of UEPS's development until the year 2010 were studied according to every one of the four alternatives divided into 11 regions by five-year periods.

The structure of generating capacities for the years 1990, 2000 and 2010, obtained by calculations, is given in Tables 6 and 7.[c] The data on total generating capacity for the entire country (i.e., including the regions operating in isolation from the Unified Electric Power System) also are given for the comparison.

Analysis of various power generation alternatives leads to the following conclusions:

- UEPS should begin a large-scale utilization of gas turbine and combined steam-gas plants using both low (16-25 MW), and high (115-150 MW) power units. It is desirable to erect combined steam-gas (SGP) and gas turbine (GTP) plants at the maximum power level (Table 7). This level should be ensured both by the construction of new power plants and by the provision of gas turbine topping in the existing heat-and-electric power plants (and boiler houses);

[b] *The analysis was performed by a working group on electric power generation and heat supply of the USSR Academy of Sciences, Commission for the Development of Alternative USSR Energy Development Scenarios, under V.V. Yershevich.*
[c] *The calculations were performed by the working group under V.V. Yershevich (see previous footnote).*

Table 6. *Prospective structure of installed generating capacities, UEPS (in GW)*

Types of power plants \ Years	1990	2000				2010			
		Alternatives							
		1	2	3	4	1	2	3	4
SPP, total	202	250	270	245	260	345	380	325	345
NPP	38	50	25	40		65	25	45	
HPP and HPSPP	52	90	90	80	80	105	105	90	90
UEPS, total	292	390	385	365	340	515	510	460	435
USSR, total	329	405	405	385	365	540	535	485	460

two joint electric power systems, namely the Central Asian and the Eastern networks. In the future, only small, isolated and newly formed regional electric power systems of the extreme North and Northeast of the country will not be combined within UEPS.

Table 7. *Prospective structure of steam powered plants, UPES* (in GW)

Types of power plants \ Years	1990	2000				2010			
		Alternatives				Alternatives			
		1	2	3	4	1	2	3	4
CPP	115	135	140	130	140	160	170	160	175
from which SGP and GTP	2	5	10	7	40	20	35	20	60
HEPP	87	115	130	115	120	185	210	165	190
from which SGP	-	10	35	2	35	40	115	30	85
SPP, total	202	250	270	245	260	345	380	325	345

- The construction of nuclear power plants must continue, provided by required safety levels. Conservatively, an increase in the capacity of nuclear power plants would reach approximately 50 GW by 2000 and 60-80 GW by 2010;
- The need to meet electric power demand calls for annual commissioning of 8-15 GW generating capacities; this depends on system development and the rate of dismantling or radical modernization of equipment;
- The structure of generating capacities in individual regions (and Union republics), in which fuel supply is economical, could be shifted toward self-balancing electricity generation.

3. System-forming electric power grid

As mentioned above, the UEPS grid is the principal means to compensate for the imbalances between electric power generation and consumption in individual regions of the country. This is due to the ability to make decisions regarding construction of inter-system transmission lines within a relatively short time before their actual installation, compared to construction of a power plant. The rate of construction of the former is also much faster.

It is expected that in the next decade the territorial formation of UEPS will be completed by merging two joint electric power systems, namely the Central Asian and the Eastern networks. In the future, only small, isolated and newly formed regional electric power systems of the extreme North and Northeast of the country will not be combined within UEPS.

The main direction of capacity flow in the Unified Electric Power System is that of Siberia-Kazakhstan-Ural-Middle-Volga-Center. This is due to the fact that the Eastern zone of UEPS has a surplus of fuel supply (which will remain true even after 2010). The reason for this is the concentration of organic fuel and water resources in the eastern regions of the country. As a result, the electric power transmission proves more efficient than the transport of low grade coal from east to west. An additional flow of electric power in this direction is provided by the available Siberian hydroelectric power plants. They cover the variable part of the daily load in the European zone of the system at a lower cost than the construction of new hydroelectric pumped storage power plants. Under conditions of unbalanced development of UEPS, the maximum power transferred from east to west may reach 10-15 GW before the year 2000 and 20-25 GW in 2005-2010.

The basic power grid of UEPS must be developed using the existing rated voltages of power transmission, and the development of 1,150 kV grid. It is planned to use 1,150 kV transmission lines in the direction of Ural-Middle Volga-Center, Kazakhstan-Central Asia and within the Siberian power system (in the zones of Kansko-Achinskii fuel-and power complex and zones of large hydroelectric power plants). For long-range power

Table 8. *Impact of power industry on the environment (1987-1988)*

Source of impact	Greenhouse Gases (mln ton of carbon ann.)	Toxic Gases and Ash (mln tons annually)	Alienated Land (mln hectares)	Intake of Fresh Water (cubic km annually)	Ejection of Stagnant Water (cubic km annually)
USSR, total	1700*	64	71	327	164
Organic fuel combustion	1250	50	no data	no data	no data
Fuel energy industries, total	610	28	7,5	83,5	59
(from which electric power industry)	570	18	6,7	80	55

*Estimate

transmission to distances of 3-4 thousand kilometers it is practical to use 1,500-kV DC transmission lines capable of carrying 6-9 GW.

4. Environmental aspects of development

As noted in the section titled Difficulties Encountered in the Development of the UEPS, the principal problems in the development of the Unified Electric Power System are environmental (including the safety guarantees of nuclear power plants).

A sharp rise in the production of energy resources in the USSR (doubling over the last 20 years) and, in particular, of electric power has drastically increased their environmental impact. The combustion of fossil fuel yields about 75% of all greenhouse gas emissions (which creates the problem of global warming) and up to 80% of aggregated harmful emissions due to anthropogenic activities in the territory of the USSR. The environmental impact of the power industry, including electric power generation in the USSR, is characterized by the data listed in Table 8.[d]

During the current five-year period, capital investment in the environmental protection was doubled. This led to a reduction in the rate of harmful emissions to the atmosphere, and a slower growth in the disturbed land area. Nevertheless, the ecological situation in many cities and entire regions of the country should be improved.

The development of the USSR Unified Electric Power System in accordance with the recommendations which was discussed above must lead to a substantial improvement in the ecological situation.

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[d]*Report on the "Alternative Scenarios of USSR Energy Development. Forecasting Estimates," Commission of the USSR Academy of Sciences, Moscow, May 1990.*