CHAPTER 5

The Soviet Electric Power Industry

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The Soviet Electric Power Industry

Ever since Lenin articulated the goal of electrification of the entire country, the electric power industry has been considered fundamental to the task of Soviet economic development. Although realization of this goal still belongs to the future, the use of electricity has been promoted throughout the Soviet economy, and the construction of generating stations and an integrated power transmission and distribution system have been given high priority in State plans. As a result, electricity consumption in all sectors of the Soviet economy has grown considerably.

Electric power is produced in the U.S.S.R. through the conversion of nuclear or hydropower, or through burning fossil fuels—coal and liquid hydrocarbons. The status of and prospects for the Soviet nuclear industry are treated separately in chapter 4; and OTA has not studied Soviet hydropower. This chapter, therefore, concentrates on the technological and other problems facing the U.S.S.R. in the conversion of coal, oil, and gas to electricity. These problems fall into three major categories: problems of electricity generation, problems relating to the construction of electricity transmission lines, and problems associated with the development of integrated electricity networks,

The chapter is concerned with the difficulties encountered in, and the prospects for, generation of electricity at powerplants fired by fossil fuels, with the ability of the U.S.S.R. to construct high voltage (HV) power transmission lines, and with the formations of power systems and the problems associated with managing these systems. It analyzes the present and prospective role of electric power in supplying energy to the Soviet economy, and the changes–in generating capacity and output, in location of generating stations, and in technology and equipment—which must take place for this role to expand. It goes on to describe present activities in, and plans for, electricity transmission lines and integrated networks, to discuss the present and potential contributions of the West in each of these areas, and to evaluate Soviet prospects for meeting growing electricity demands and for fulfilling existing plans for the addition of installed electricity capacity and growth in electricity production.

THE FUTURE FOR ELECTRICITY GENERATION IN THE U.S.S.R.

Table 33 shows that in 1980 the U.S.S.R. generated 1,295 billion kilowatt hours (kWh) of electricity, a 4.5 percent increase over 1979. Approximately 80 percent of this electricity came from fossil fuel or conventional plants, and about 5.5 percent from nuclear power. But the U.S.S.R, is planning a sharp shift from fossil-fired to nuclear and hydro generating capacity. In the next 5 years, the contribution of the nuclear industry will triple, while the amount of electricity provided by fossil-fuel stations is expected to grow only 5 to 9 percent for the entire period. This shift is further demonstrated in table 34, which shows that while installed fossil-fuel generating capacity is expected to grow about 15 percent by 1985, nuclear capacity is slated to nearly triple and hydropower to rise some 23 percent. This planned relative growth in hydropower's share of installed capacity is much higher than in previous years.

Table 33.—Soviet Electricity Production (billion kWh)

	1975	1979	1982	1985 (plan)
Total.	1,039[1]	1,238[1]	1,295	1,550-1,600[5]
Fossil-Fired . . .	893[4]	1,011[4]	1,038	1,100-1,135[6]
Nuclear	20.2[7]	54,8	[3] 73	220-225[5]
Hydro[a]	126.0[1]	172.0[1]	184	230-235[5]

[a]Includes production at pumped-storage stations

SOURCES [1]USSR Central Statistical Administration, *Narodnoye* khozyaystvo *SSSR v* 1979 g , (Moscow Izd "Statistika," 1980), p 168
[2]*.Ekorrorrr/ctreskaya gazeta, No* 12 (1981), p 2
[3]*Ekonomicheskaya gazeta*. No 7 (1980), p 1
[4]Residual
[5]*Izyestiya* (Dee **2, 1980),** p 3
[6]Fossil-Fi red generat ion to account for 71 percent of total generation in 1985 [*Ekonomicheskaya gazeta No* 12, (1981), p 2]
[7]L Dienes and T Shabad, *The Soviet Energy System* (Washington, D C V H Winston & Sons, 1979), p 153

Table 34.—installed Soviet Electrical Generating Capacity (thousand MW end of **year)**

	1975[10]	1978[1]	1979	1980	1985 (plan)
Total	217	246	255[2]	267[5]	332[6,8]
Fossil-Fired[a].	171	190	194[4]	201[4]	230[6,8]
Nuclear.	4.7	8.4	11,4[3]	13,4[6]	38[9]
Hydro[b].	41.5	47.5	50.0[2]	52.3[7]	64[5]

[a]Includes about 76000 MW at heat and power stations (TETs) in 1980[5]
[b]Includes pumped-storage stations

SOURCES [1]Elektricheskiye stantsii, No 8 (1979), p 6
[2]*Narodnoye khozyaystvo, SSSR b 1979 g* p 168
[3]See ch. 4
[4]Residual
[5]*Ekonomicheskaya gazeta, No. 12 (1981),* p 2
[6]*Teploenergetika, No* 1 (1981), p. 2.
[7]*Elektricheskiye stantsii, No* 1 (1981), p 3
[8]*Planovoye khozyaystvo, No* 1 (1981), p 7, reports a planned gross addition of 71,000 MW between 1981 and 1985 OTA has subtracted 6,000 MW to represent retirement of depreciated capacity in the period
[9]Izvestiya (Dec. 2, 1980), p 3, reports 24,00025,000 MW of new capacity to be added between 1981 and 1985
[10]*ACES Bulletin, No* 1 (spring 1978), p 41,

Despite this change in emphasis, however, fossil-fired plants still make up the bulk of Soviet generating capacity and will account for 44 percent of the new capacity called for in 1985. This section describes the present status of fossil-fired generating capacity, the ways in which the U.S.S.R. expects this capacity to change, and the demands that will be placed on the electric power and related industries if these plans are to be met.

One notable trend in fossil-fired electric power generation has been the substantial reduction in the relative importance of coal in power station supply over the past 15 years. Between 1960 and 1975, coal's share in the fuel structure of powerplants fell from 70.9 to 41.3 percent (see table 35). Coal was replaced largely by liquid fuels, the use of which has risen from 7.5 to 28.8 percent of the total; and by natural gas, which rose from 12.3 to 25.7 percent. The shift away from coal was due largely to the relatively low cost to the Soviets of petroleum in this period.

Now there are important incentives to return to coal for that increment to installed capacity that is not to come from nuclear or hydropower stations. Figure 10 shows the location of major sites for the construction of new fossil-fuel generating plants and of plants where plans exist to increase installed capacity. Table 36 summarizes the known characteristics of these new plants and additions. It is obvious that the Soviets hope that much of the increment in fossil-fired installed capacity and electricity production in the next Five Year Plan (FYP) period will come from coal produced in remote regions of the U.S.S.R. Seven of the nine new stations shown in figure 10 will be built in Kazakhstan, central and eastern Siberia, and

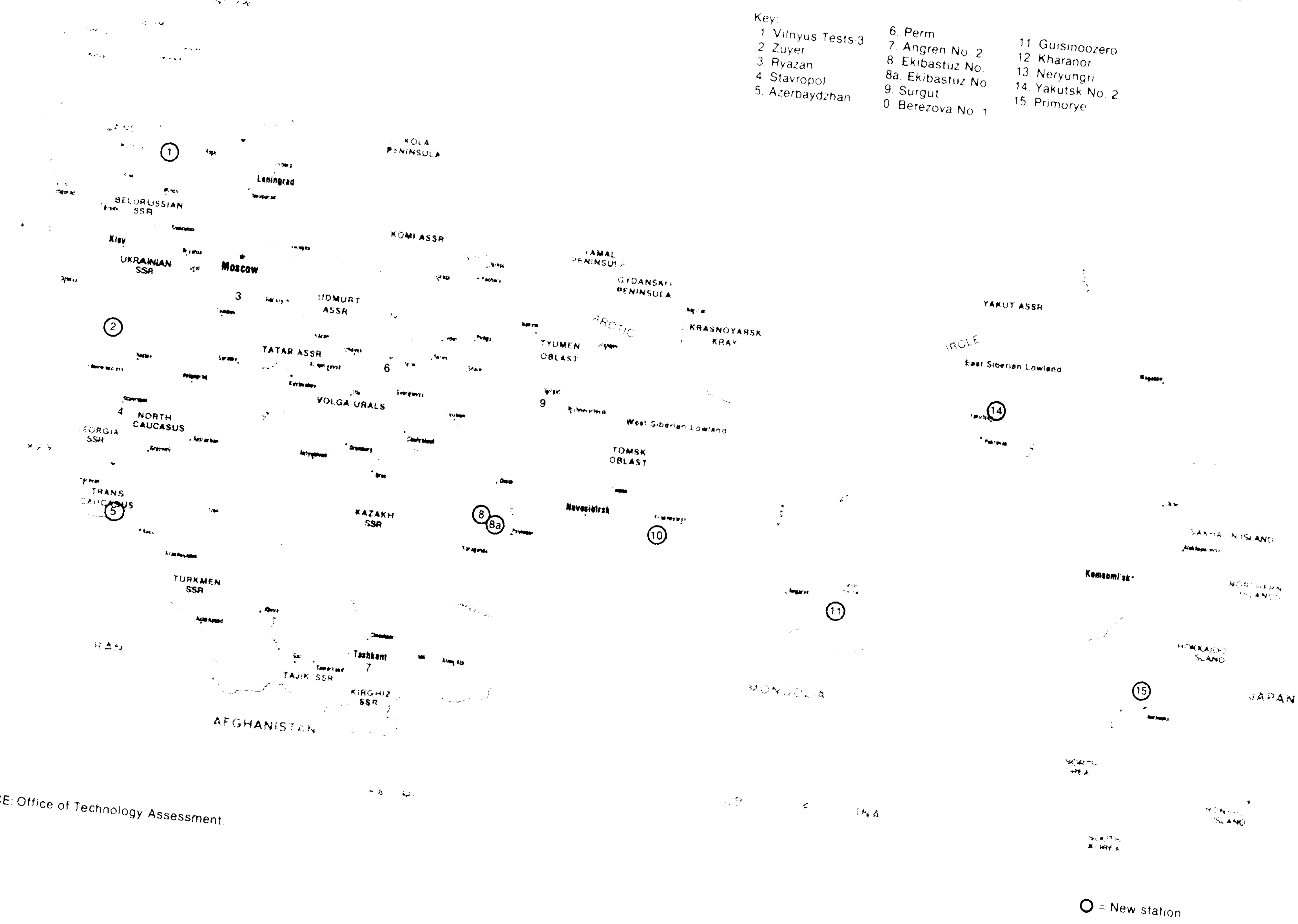
Table 35.—Structure of Fuel Use in Fossil-Fired Electrical Power Generation (percent)

	1960	1965	1970	1975	1980[a]
Gas	12.3%	25 6%	26.0%	25.7°10	25.1%
Liquld fuel.	7.5	12.8	22.5	28.8	28.
Coal.	70.9	54.6	46.1	41.3	42.5
Peat	7.0	4.5	3.1	2.0	2.6
Shale	1.0	1.5	1.7	1.7	1.4
Other	1.3	1.0	0.6	0.5	0.4
Total	100 0%	100.0%	100.0%	100.0°0	100.0 %

[a]Planned structure

SOURCE A M Nekrasov and M G Pervukhin (eds.), *Energetika SSSR v* 1976-1980 *godakh, (Moscow* Izd. "Energiya,"' 1977), p 151

Figure 10.—Major Sites for the Construction of New Fossil-Fuel Burning Plants or Additions to Installed Capacity, 1981-85



SOURCE: Office of Technology Assessment.

Table 36.—Planned Expansion of Fossil-Fired Powerplant Capacity, 1981-85

Location	Fuel	Comments
New stations		
Azerbaydzhan	Unknown	
Berezovskoye No. 1	Lignite	Boiler system not developed
Gusinoozero	(Coal)	
Kharanor	(Coal)	
Neryungri	(Coal)	
Yakutsk No. 2	(Coal/gas)	
Primorye	(Coal)	
Ekibastuz No. 2	Coal	
Additions to exlsting stat/ens		
Zuyevka	(Coal)	300 MW in 1981
Stavropol	Gas/mazut	300 MW in 1981
Ryazan	Lignite	800 MW in 1981
Perm	(Coal)	
Surgut	(Gas)	
Ekibastuz No. 1	Coal	2500 MW generators installed as of 1980
Angren No. 2	(Coal)	

NOTE ( ) indicates probable fuel
SOURCES *Ekonomicheskaya gazeta, No* 1 (January 1981) p 11 and Izvestiya (December 2, 1980), p 6

the Far East. The plants will all be coal fired, although one at Yakutsk may also burn natural gas.

In fact, these plans not withstanding, it may be natural gas—not coal—which shows the most significant growth as a fuel for power generation in the 1980's. Recently published Soviet figures show that the planned structure of fuel use shown in table 35 was not fulfilled.[1] During the Tenth FYP there was a further jump in the share as well as the quantity of oil and gas used in power stations. Given the problems facing the Soviet coal industry (see ch. 3) and the enormous planned increases in gas output, it is not unreasonable to expect an appreciable surge in the share of gas as a power station fuel.

This outcome is made even more plausible by the nature of Soviet plans to utilize coal in power generation. Nearly all the increment in coal production will now come from Kazakhstan, Siberia, and the Far East.

[1]*Elektricheskiye stantsii. No. 5,* 1981.

Given the difficulties in coal transport, one way of utilizing this coal is to use it to generate electricity at the mine itself. Large electric power complexes intended to supply local and regional needs and fired by local coal are already under construction in both the Ekibastuz and Kansk-Achinsk basins. Indeed, one Soviet source claims that 77 percent of all the new fossil-fired capacity to be introduced in the present FYP will be mine-side plants at Ekibastuz and Kansk-Achinsk.[2] Eventually long-distance power transmission lines are expected to make this electricity available to the Urals and European U.S.S.R. These complexes, therefore, are central to known existing plans for electric power generation in the coming decade. The following sections describe the difficulties that are most likely to inhibit their completion and consequent growth in coal-fired power generation.

THE GENERATION OF ELECTRICITY IN MINE-MOUTH POWER COMPLEXES

The first Ekibastuz State Regional Power Station was to go online and construction of a second to begin during the Tenth FYP (1976-80). Eventually, four of these stations are to be built in the Ekibastuz region, each equipped with eight 500-MW generator blocks. Over 600 million rubles were to be invested in the Ekibastuz power and fuel complex between 1977 and 1980.[3]

Similarly, 8 to 10 power stations are to be built as part of the Kansk-Achinsk Fuel and Power Complex, development of which was formally called for in a 1979 decree.[4] Power stations erected near the eastern Kansk-

[2]*Planovoye khozyaystvo,* No. 1, 1981, p. 7.
[3]"The Pavlodar-Ekibastuz Complex," *Ekonomicheskaya gazeta,* No. 22, May 1978, p. 2; Ye. I. Borisov, "Energy in the Anniversary Year 1977 and Problems in 1978," *Teploenergetika,* No. 1, January 1978, p. 3; "A Giant at Power Engineering," *Izvestiya,* Feb. 25, 1978, p. 2; O. Mulkibayev, "Problems at Ekibastuz," *Narodnoye khozyaystvo Kazakhstana,* No. 12, December 1977, pp. 59-65, in JPRS 71,029, Apr. 28, 1978, pp. 44, 50.
[4]A. Sergeyev, "KATEK: The Forecasts and the Present," *Tekhnika i nauka,* No. 1, January 1977, pp. 4-6, 8; "A Constellation of Industry," *Izvestiya,* Apr. 7, 1979, p. 3.

Achinsk deposits are intended for local and regional power generation only, while those near the Western deposits are to supply power to the Urals and European U.S.S.R. Long-range plans envisage the investment of 13 billion to 14 billion rubles on development of mining, power generation, and coal treatment facilities.[5]

There are four major problems confronting these complexes. The first two—construction and supply of power equipment—are common to all forms of powerplant construction. The third—the development of boilers–relates to the intended use of low-grade coal from Siberia, especially Kansk-Achinsk lignites. The fourth factor is the development of appropriate electricity transmission technology and is discussed in a subsequent section of this chapter. Such technology is critical to the ability of the Ekibastuz and Kansk-Achinsk complexes to supply electricity to the Western U.S.S.R.

Construction

A major obstacle to the introduction of planned electrical generating capacity is the low quality of construction operations at many plant sites. Problems here are similar to those found in other sectors of the construction industry. They include labor shortages, supply problems, plant design errors, planning inefficiencies, and long construction times.

Like many other Soviet industries, the electrical powerplant construction industry faces labor shortages, resulting in part from a high degree of usage of manual labor (40 percent of the work in building powerplants).[6] This is caused largely by the low level of mechanization of auxiliary operations and insufficient use of prefabricated building elements. The situation is aggravated by the frequent need to "disassemble" completed work because of errors in construction or changes in plans. Such disassembly is not highly mechanized. In addition, labor shortages are exacerbated in Eastern regions where poor living conditions promote high labor turnover.

The Soviet press carries numerous articles on the problems of equipment and materials supply to powerplant construction sites. Producers of boilers or turbines often ship equipment in installments at their own convenience, and builders must store this machinery awaiting other needed parts. Often components arrive in insufficient quantities or in unsuitable grades or types. The supply system itself seems to be straining to maintain the flow of materials to a growing number of construction sites, It is increasingly common for materials to pile up at one site, while another runs short.

A frequent complaint is that the blueprints for powerplants contain errors, for which no one will take responsibility and which no one will correct. Often construction is well underway when the errors are discovered and it becomes necessary to rebuild part of the plant. Or, modifications are added to the initial designs during construction, and again, construction must be halted. Designers out of touch with construction problems may incorporate unobtainable parts or equipment in their designs. Problems of this sort are endemic to the Soviet system and are caused largely by the absence of a single point of responsibility for all phases of a project.

Attempts to fulfill construction plans often result in surges in new capacity start-ups during the fourth quarter of the year. This leads to a practice called "storming" in which intense efforts are made to finish work in a short time and projects of lower priority are abandoned in order to divert resources to others. Resources are increasingly dispersed among too many projects. This results in supply breakdowns, lower labor productivity, and increasing volumes of unfinished plant construction at the end of each year. Plant construction often consumes 1.5 to 2

[5]; S Ageyev, et al, "Basic Directions of Formation of the Kansk-Achinsk Fuel and Power Complex," *Teploenergetika*, No *4*, April 1974, pp. 31-34.

[6]1'. P Falaleyev, "Basic Directions of Increasing the Effectiveness of Power Engineering Construction, *Energetiche ~},() vestroitelstto*, No.6, June 1979, pp. 2-6.

times as long as called for in plan norms.[7] The situation is aggravated by increasing downtime of construction equipment, due in large part to the poor quality of maintenance work.

Supply and Quality of Power Machinery

Important problems here are the apparent difficulties of the power machine building and electrical equipment industries in meeting delivery schedules, and the unreliability of equipment. The power machine building industry produces, among other things, boilers, turbines, and generators for hydroelectric, fossil-fired, and nuclear powerplants. The performance of this industry generally reflects the high priority accorded electrification. Production of electrical equipment grew by over 21 percent between 1975 and 1978, and industry labor productivity grew by over 14 percent. Its share of products in the highest product quality category nearly doubled between 1975 and 1978, rising from 12 to 22 percent.[8] The Soviets claim that the latest products of this industry are on a par with the best Western equipment. Indeed, Soviet hydroelectric turbines have found a market in the West where few other Soviet industrial products are competitive, and the efficiency of Soviet oil- and gas-fired boilers is said to be 0.5 to 1 percent higher than that of foreign analogs.[9]

Yet the performance of the industry is uneven, and not all its power machinery is up to the technical level of the export-worthy models. The industry as a whole seems not to have an integrated plan for solution of its quality problems and only faces those which can no longer be ignored.[10] Low quality here can be traced directly to the economic incentive system where, output being the prime goal, much may be sacrificed to achieve it. In the power machinery industry, such sacrifices can take the form of inadequate testing of new equipment before the start of serial production. In addition, finished equipment is not "debugged" before delivery; rather it is left to the engineers of the powerplants to correct the defects. A turbogenerator destined for the Nazarovo regional power station, for example, was not tested before delivery. Vibration problems surfaced in operation and over a 5-year period resulted in 62 shutdowns—equivalent to nearly 3 years of idle time.[11] Such problems will persist until the incentive system is reoriented toward rewarding producers for production of "quality equipment" instead of merely "equipment.

Boiler Development

A major problem of coal-fired power stations is declining coal quality. The Soviet Ministry of the Coal Industry (Minugleprom) is required to monitor coal quality and to deliver suitable supplies to power stations. Minugleprom's plan targets, however, are expressed in terms of the quantity, rather than the quality of the coal shipped. Indeed, it has been known to falsify records to hide the low quality of its coal.[12] The Ministry of Power and Electrification (Minenergo) frequently complains about the coal it receives, and promotes the idea of either moving quality control outside the coal industry or of setting up an independent agency to perform this function. Meanwhile, poor quality coal–particularly coal with high ash content—poses serious problems for electricity generation.

Both Kansk-Achinsk and Ekibastuz coal tend to form sediment on the convective surfaces of boilers. The Soviets have reportedly succeeded in designing a boiler which suits the particular properties of coal from Ekibastuz, and this is now being burned at

[7] Ibid., p. 35.

[8] *Ekonomicheskaya gazeta No. 22,* May 1979, pp. 1-2, in JPRS 73,859, July 18, 1979, pp. 9, 11.

[9] V. P. Goloviznin, "Soviet Power Machine Building-Base of Development of Power of Engineering of the Country," *Energomash-inostroyeniye, No. 4,* April 1980, p. 3.

[10] V. Krotov, "Complex Approach to Management, " *Trud,* Mar. 15, 1979, p. 2, in JPRS 73,380, May 4, 1979, p. 62.

[11] Sidanov and A. Zarnadze, "Effectiveness of Introducing New Technology, " *Voprosy ekonomiki, No.* 2, February 1980, p. 128.

[12] V. Levin, "Padding the Load, " *Sotsialisti cheskaya industriya,* May 11, 1980, p. 2.

15 thermal power stations. Kansk-Achinsk coal has proved less tractable. The Soviets claim to have modified a large boiler system so that it can burn some types of Kansk-Achinsk coal; however, coal from at least one of the basin's large deposits has not yet been sufficiently studied to permit development of boilers which can be fired by it.[13] Until this problem is solved, Kansk-Achinsk coal will be of limited utility in electricity generation.

[13] "The Problem of the Combustion of Kansk-Alchinsk Coal," Teploenergetika. No. 7, July 1975, p. 92.

ELECTRIC TRANSMISSION

A major purpose in creating the Kansk-Achinsk and Ekibastuz complexes is to provide electricity to the Urals and the European U.S.S.R. Development of appropriate ultrahigh voltage (UHV) transmission technology is necessary if this goal is to be realized. (Lines at voltages between 250 and 1,000 kilovolt (kV) are considered extra-high voltage (EHV) and voltages above this are UHV.) The Ekibastuz complex is to be linked to the Urals by an 1,150-kV alternating current (AC) line and to the central regions by a ±750-kV direct current (DC) line. The Kansk-Achinsk complex is to be linked to the Urals or the central regions by a ±1,100 to ±1,200-kV DC line. This section examines the current status of UHV technology and prospects for its development by 1990.

Transmission of large amounts of power over very long distances is expensive. The amount of power that an electrical transmission line can carry increases as the square of the voltage, i.e., if the voltage of a line is doubled, it carries four times the original power. Thus, HV transmission lines mean that power can be more economically transmitted over longer distances than lower voltage lines. But the task of bringing electricity from the East to the European part of the country requires the construction and operation of UHV lines at unprecedented voltages. In this respect, the U.S.S.R. will be entering relatively uncharted territory.

In the Soviet Union, as in the United States, AC is the most common method of transmitting electric power, allowing high voltages to be transmitted and then easily reduced to lower voltages at the point of utilization. On the other hand, HV DC transmission requires less insulation, and when the same size cables and insulation are used, a DC circuit will carry considerably more power than an AC circuit. In addition, because no alternating magnetic field exists inside the wires carrying DC, energy losses and the problem of synchronizing systems are reduced. But the cost of DC wires is raised by the necessity of placing converters at both ends of the line. For this reason, DC transmission is not economical over short distances. The U.S.S.R. considers DC more economic than AC for transmitting power over distances in excess of 1,500 to 2,000 km,[14] and it is pioneering the use of direct current in UHV from power stations in Kazakhstan and Siberia to the European part of the country.

The U.S.S.R. has thus far built only two DC transmission lines. The newer and larger of these is a ±400-kV line between Volgograd and the Donets basin. Commissioned in stages between 1962 and 1965, this line is scheduled to be overhauled within the next 5 years in order to upgrade its equipment.[15] Experience gained in the construction and operation of the ±400-kV line is being used to develop DC lines of higher voltages.

[14] Zhinlerin, op. cit., p. 82. For more on AC v. DC power transmission, see Ronald Amann, Julian Cooper, and R.W. Davies (eds.), *The Technological Level of Soviet Industry* (New Haven and London: Yale University Press, 1977), pp. 202-204 and 23.

[15] "On Reconstruction of the Volgograd-Donbass Direct-Current Power Transmission Lines," *Energetik*, No. 1, January 1981, p. 37. The first DC line, with a voltage of ± 200 kV, runs from the Kashira Power Station to Moscow. See D. G. Zhimerin, *Energetika: nastoyashcheye i buduschcheye (Moscow: Izd. "Znaniye," 1978), p. 82.*

Increasing line voltages has been a basic trend in the development of Soviet power engineering. At present, the voltage in Soviet trunklines has reached 500-to 750-kV AC and ±400-kV DC, and there have been plans for lines of 1,150-kV AC and ±750-kV and higher DC. The attainment of these voltage levels is based on many years' experience with powerline development and construction, which in the past has earned the U.S.S.R. a leading position worldwide in high-voltage transmission.[16]

The construction of UHV powerlines of 1,150-kV AC and ±750-kV DC signifies a qualitatively new level in Soviet power engineering-a transition to what is still largely an experimental technology, both in Soviet and world practice. In the case of the ±750-kV DC line, all equipment reportedly has been developed in the U.S.S.R. and will be produced at Soviet plants.[17] Nevertheless, some technical problems apparently remain. For example, at least one Soviet expert sees the need to hasten the development of new reactive-power compensation devices to maintain voltage levels and reduce energy losses in AC lines of 1,150 kV (and also 750 kV).[18] In the development of UHV DC transmission, the major problems have centered around circuit breakers and, especially, converter equipment.[19] While Soviet experts seem to be confident that these problems have been or will be solved,[20] Western experts are less certain.

"K. D. Lavrenenko, ''.Soviet Electric Power in the Past 60 Years, " *Teploenergetika*, No. 11, November 1977, pp. 2-8; P. S. Neporozhniy (cd.), *Elektrifikaysiya SSSR (1967-1977 Kg, }* (Moscow: Izd. "Energiya," 1977), pp. 260-26 1; Amann, Cooper, and Davies, op. cit., pp. 222-224.

[17]M. Pchelin, "A River of Energy Will Start to Flow, " *Stroitelnaya gazeta*, Jan. 23, 1980, p. 3.

[18]Peterson, op. cit., p. 66.

[19]Amann, Cooper, and Davies (eds.), op. cit., pp. 215-220.

[20]A major reason for the planned overhaul of the ±400-kV Volgograd-Donets line is to replace less efficient mercury-arc converter equipment with more advanced thyristor devices. See "On Reconstruction ., .," op. cit. Similar devices reportedly by have been developed in the U.S.S.R. for the ±750-kV Ekibastuz-Tambov line. See V. P. Fotin, "Development of a Complex of Equipment for the 1,500-kV Ekibastuz-Center Direct-Current Power Transmission Line, " *Elektrotekhnika*, No. 6, June 1978, pp. 1-6.

SYSTEM INTEGRATION

Soviet efforts to extend electricity supply to all sectors of the economy have aggravated the problem of "maneuverability," i.e., meeting widely varying demands for electricity, increasing the need for reserve capacity and maneuverable equipment at power generating stations. This section describes the ways in which the Soviet load pattern is changing, and Soviet problems and plans for responding to these changes. It deals first with peaking problems–including programs for creating equipment for this purpose and the difficulties associated with introducing large amounts of baseload nuclear capacity—and then with plans for integrating the electricity system through a nationwide power grid.

PROSPECTS FOR COPING WITH DEMAND VARIATIONS

Table 37 illustrates the growth in electricity generation and consumption in the U.S.S.R. from 1960 to 1980. From this table, it can be calculated that total electricity consumption increased from 292 billion kWh in 1960 to about 736 billion kWh in 1970 and about 1,276 billion in 1980. (The difference between total production and total consumption in the latter 2 years is due to exported electricity.) Electricity consumption is clearly growing rapidly and demand must be met by the construction of adequate amounts of generating capacity. The table also shows dramatic changes in electricity consumption

Table 37.— Electricity Generation and Consumption in the U.S.S.R. (billion kWh)

	1960	1970	1980a
Generation of electricity	292	740.9	1293
Consumption of electricity			
Industry	188.7	438	696.2
Construction	89	15	23.3
Transportation	17.6	54.4	102.5
Agriculture	9.9	38.5	109
Municipal services and households	30.5	81.1	155
Electricity generation and transport.	36.4	108.7	189.7

[a] 1980 figures are preliminary

[b] Includes electricity consumed at power stations (approximately 6 percent of the total) and grid losses (between 85 and 9 percent of the total)

SOURCE Elekfricheskiye stantsii No 12 (December 1980) p 44 and No 1 (January 1981) p 2

by economic sector. The relative share of consumption by industry–the heaviest user—has decreased, while shares of agriculture and municipal services and households have increased.

As demand has grown in the agricultural, urban services, and household sectors, the power system has been confronted with increasingly irregular load curves, with more pronounced periods of moderate to high demand–so-called semipeakloads and peakloads—during certain hours of the day. These alternate with periods of sharply reduced demand.[21] (The maximum continuous demand throughout all periods is called the baseload).

The Soviet power industry continues to have difficulty covering semipeak and peak loads, primarily because of a lack of generating equipment designed for this purpose. Soviet convention distinguishes three types of generating capacity: 1) baseload units, 2) semibaseload (or semipeakload) units, and 3) peakload units.[22] The equipment stock now consists mainly of the baseload type, in both fossil-fired units and nuclear units.

The U.S.S.R. lacks adequate gas-turbine technology, pumped-storage facilities, and hydro units for handling sharp, short-time peaks. Moreover, the problem of coping with semipeak fluctuations is aggravated by the increasing importance of large (300 MW or more) generating units which are technologically unsuited for this purpose.[23] The power machine building industry is aware of these deficiencies and is being called on to step up the development and construction of peak and semipeak equipment, including 150- to 200-MW gas-turbine units and hydroturbines for pumped-storage plants.[24]

The Soviets have tended to build generating stations and units with larger and larger capacities in order to reap benefits of economies of scale in power generation. This has created a problem, because the market for electricity from baseload capacity is limited. Even with the growing overall demand for electricity, particularly in the European part of the country, there may even now be a surplus of available baseload capacity. The lack of highly maneuverable equipment has already forced power stations to use ill-suited baseload equipment to cover peak and semipeak periods.[25]

The installation of more baseload equipment will increasingly raise both technical and economic problems. Both fossil-fuel and nuclear units are slow to start up and to reach rated capacity. They, therefore, cannot respond to sudden sharp load fluctuations. Indeed, such fluctuations can even damage the equipment.[26] The equipment may be used to cover moderate load fluctuations, but this practice is economically inadvisable, especially in the case of nuclear units.

Loads also vary on other bases, including weekly, monthly, and seasonally; however, the shorter and more frequent daily variations seem to pose the greatest difficulties for power stations.

V N, Gusev and V. 1. Rozova, "On the Possibility of Operating Nuclear Power Stations Under Variable Loads," *Elektricheskiye stantsii*, No. 9, September I 977, pp. 9- 11.

[23] Leslie Dienes and Theodore Shabad, *The Soviet Energy System* (Washington, D.C.: V. H. Winston & Sons, 1979), p. 19 i

[24] Goloviznin, op. cit.; Ye. Borisov, "High Tension." *Sotsialisticheskaya Industriya*, Dec 21, 1980, p. 1; and V Boldyrev, "For the Needs of Heat Supply," *Sotsialisticheskaya Industriya*, Jan. 30, 1981, p. 2,

[25] Dienes and Shabad, op. cit, pp. I 89- 192.

[26] Neporozhniy, op. cit, p 215.

Besides being technically suited to baseload operation, nuclear stations must be operated for a large number of hours per year. This is because nuclear stations have low operating costs but high fixed costs (e.g., high construction costs per kW of capacity). Only by producing large volumes of electricity per year can the fixed cost per kW be brought low enough to make the average cost of nuclear electricity competitive. Soviet planners are well aware of the need to balance the advantages of nuclear power stations (NPSs) in conserving fossil fuels against their high investment costs.[27]

Soviet experts recognize the importance of using nonnuclear capacity wherever possible to compensate for load fluctuations. It is now recommended that fuel-intensive fossil-fuel stations be unloaded before nuclear ones.[28] In such a case, nuclear capacity is used as a substitute for less economical fossil-fuel capacity. As the proportion of nuclear capacity increases, it will eventually become necessary to operate both fossil-fuel and nuclear units under variable loads.[29] OTA's information does not permit it to determine the point at which this problem will become acute in the U. S. S. R., but the evidence does allow some observations on this subject.

Much has been written about the maneuverability of nuclear generating units.[30] Until recently, nuclear plants were designed to operate only under baseloads. An all-union conference was held in 1977 to discuss results of research on this problem, and trials have been conducted to determine the feasibility of running nuclear stations under variable loads. In order for them to perform well under such conditions, several technical problems must be solved, including removal of limitations on the number of start-stop cycles for the equipment; choice of the best fuel, fuel cladding, and designs of fuel elements; and optimization of reactor control and protection systems. Moreover, operating conditions themselves will have to be improved. Stations presently operating under variable loads are very inefficient.

According to one Soviet source, baseloading of nuclear capacity will be possible as long as the following conditions pertain: 1) NPSs account for no more than 22 to 24 percent of total generating capacity; 2) other types of capacity are unloaded to the degree possible, as needed, including complete weekly shutdowns of one or two units at regional fossil-fuel stations; and 3) maneuverable equipment (hydraulic, pumped-storage, and gas-turbine units) accounts for at least 18 to 19 percent of total capacity (in the European part of the U.S.S.R.).[31]

OTA has estimated that Soviet NPSs will account for approximately 11 percent of total installed capacity by 1985, and for no more than 18.5 percent by 1990 (see below). This suggests that baseloading of Soviet NPSs should present no problems until after 1990. However, if NPSs account for as much as 18.5 percent of installed capacity nationwide by 1990, their proportion could exceed 24 percent in the European U.S.S.R. This would force NPSs there to operate under variable loads. In fact, the Soviet source cited above anticipates some unloading of nuclear capacity, mainly on weekends, even before the 24-percent level is exceeded.[32] The likelihood that this will happen depends, in part, on how successfully the U.S.S.R. exercises its options for coping with load fluctuations.

One such option is building new, flexible heat and power (cogeneration) stations, designed to operate under either base or varying loads. This would obviate the construc-

[27] I. M. Volkenau and Ye. A. Volkova, "operating Conditions of Nuclear Power Stations in Power Systems, " *Elektricheskiye stantsii, No.* 3, March 1978, pp. 7-9.

[28] S. Ye. Shitsman, "The Effectiveness of N PS'S Under Daily (Unloading, " *Elektricheskiye stantsii, No.* 8, August 1980, p. 11.

[29] Ibid.

[30] "N. A. Dollezhal, "Nuclear Power and Scientific-Technical Tasks of Its Advancement, " *Atomnaya energiya, vol. 44, No. 3,* March 1978, pp. 203-212.

[31] Volkenau and Volkova, op. cit., pp. 8 and 9, According to this source, in 1975 the share of maneuverable equipment in the European part of the Unified Power System was approximately 22 percent, but this share is expected to decrease to 18 to 19 percent in the future.

[32] I bid., p. 9.

tion of specialized semipeak condensing stations, which would generate only electricity and consume fuel at a higher rate than would cogeneration stations operating under variable loads. Proponents of this option contend that the expansion of cogeneration capacity in the European U.S.S.R. will be necessary despite the growth of nuclear capacity in that region.[33]

This position is controversial, however. A 1979 article by A. Troitskiy, Deputy Head of the Department of Power and Electrification of Gosplan U.S.S.R., argues that construction of cogeneration stations should be "drastically limited" so that these stations will not displace generating capacity at NPSs.[34] Troitskiy recommends: 1) the retention of obsolete units which are not physically worn out to serve as reserve capacity for short-term peakloading, 2) the improvement of the load-following characteristics of large fossil-fuel units, and 3) the construction of pumped-storage stations. Pumped-storage stations (PSSs) are a form of hydroelectric capacity.

Hydropower is highly maneuverable. The Soviet power industry is well aware of this option and is striving to maximize its value.[35] Unfortunately, the availability of hydraulic capacity is affected by water levels in the rivers and reservoirs that feed hydroelectric stations. In the European part of the U.S.S.R., where the load-variation problem is at its worst and where most NPSs are being built, suitable water resources are much more limited than in remote regions such as Siberia.[36] Since as much as 70 percent of the suitable hydraulic resources in the European U.S.S.R. have already been developed,[37] the construction of conventional hydrostations alone will not satisfy the growing need for maneuverable capacity in areas where it is most needed. Therefore, the U.S.S.R. is turning more and more to the construction of PSSs for peakload coverage.[38] The specially designed reversible hydraulic turbines of pumped-storage units serve a dual purpose: during offpeak hours, excess generating capacity from other units is used to run the turbines to pump water up into a reservoir; in peak hours, this water is released to generate electricity by turning the turbines in the opposite direction. The use of pumped-storage capacity, consequently, can help to maintain baseload operation of nuclear or other stations by providing coverage of peakloads and also additional consumption during offpeak hours. For this reason, the construction of PSSs is considered an inseparable part of Soviet plans for growth in nuclear power production.[39]

Despite such plans and the expressed need for pumped-storage capacity, progress with the design and construction of PSSs in the U.S.S.R. is said to be slow, mainly because Soviet designers have neglected these stations, which are expensive to build. Only one small PSS near Kiev is presently in operation.

The first PSS to be built in conjunction with an NPS is, however, underway. This is the Southern Ukrainian Power Complex, which includes the Southern Ukrainian NPS, the Tashlyk Hydroelectric Station, and the Konstantinovka Hydroelectric and Pumped-Storage Station. When completed, the complex will have a total capacity of more than 6,000 MW, nearly two-thirds of which will be nuclear.[40] Another PSS has been under construction at Zagorsk, near Moscow, since 1976, but its completion is apparently not yet in sight.[41] The Kayshyadoris PSS in

[33] P. P. Korytnikov, "Basic Tasks for Heightening the Effectiveness and Reliability of Heat Supply to the Country's Economy," *Teploenergetika*, No. 8, August 1980, pp. 2-5.

[34] Troitskiy, op. cit., p. 22. Both Troitskiy's and Korytnikov arguments are aimed at lowering fuel costs and conserving fossil fuel. To cover growing heat demand, which would ordinarily be met with cogeneration capacity, Troitskiy calls for construction of large boiler houses, presumably in conjunction with conventional fossil-fired and nuclear electric stations. Korytnikov, op. cit., p. 3, points out, however, that this arrangement would result in greater fuel expenditures than those incurred at cogeneration stations.

[35] Dienes and Shabad, op. cit., pp. 133-136.

[36] Peterson, op. cit., p. 65.

[37] Dienes and Shabad, op. cit., p. 133.

[38] Neporozhniy, *Elektrifikatsiya...*, op. cit., p. 216.

[39] Peterson, op. cit., p. 65.

[40] P. S. Neporozhniy, "Lenin's GOELRO Plan Is 60 Years old, *Elektricheskiye stantsii*, No. 12, December 1980, pp. 2-8, especially p. 6.

[41] V. Vennikov, 'contemplating the Future, " *Sotsialisticheskaya industriya*, Jan. 30, 1981, p. 2.

Lithuania is to be commissioned during the Eleventh FYP, and plans have been drafted for at least two other stations—the Dnestrovsk and the Leningrad PSSs.[42]

But even the timely construction of PSSs will not completely solve the problem of covering sharp load fluctuations in the European U.S.S.R. Pumped-storage capacity must be augmented with other highly maneuverable equipment, particularly gas-turbine units, which may be used alone or as part of combined "steam-and-gas" units.[43] The U.S.S.R. is reported to be working on the practical use of gas-turbine units with a capacity of 100-MW and also of 250-MW steam and gas units.[44] However, there is no evidence that these units are being used extensively in the Soviet power industry.[45]

A final option for coping with load fluctuation is capacity substitution through the creation of large-scale, interconnected power systems or grids. Such systems permit generating capacities to be shared by shifting their output from one grid to another. This is particularly advantageous to the U.S.S.R., with territory that spans 11 time zones. When a grid in one time zone is experiencing peak demand for electricity, it can borrow power from an interconnected grid in another time zone. The supplier also benefits by utilizing capacity that would otherwise be idle. Predictable load variations allow capacity exchange schedules to be worked out in advance, and this has reportedly been done for Soviet power systems. On the other hand, unplanned variations require more immediate response. This situation is said to be covered through the intervention of dispatcher personnel and the operation of the automatic frequency and power regulating system.[46] The effectiveness of response to unplanned loads by many power stations probably is reduced, however, by the shortage of maneuverable generating equipment.

In sum, if the U.S.S.R. carries out its plans: 1) for building peakload capacity, including hydroelectric and pumped-storage stations as well as gas-turbine and steam-and-gas units, 2) for improving the maneuverability of fossil-fuel stations, and 3) for expanding its unified power grid to facilitate capacity sharing and substitution, the baseloading of NPSs should be feasible until 1990. Delays in these plans could force some unloading of nuclear capacity during offpeak hours. This situation could present technical problems for the Soviet nuclear industry; as recently as 1978, the ability of conventional reactors to withstand repeated load variations was still in question.[47]

THE UNIFIED POWER SYSTEM

The Soviet Union is attempting to take full advantage of large-scale grids by the formation of a nationwide Unified Power System (UPS). When complete, UPS will incorporate 11 smaller joint power systems ranging across the entire U.S.S.R. In addition, UPS will be tied into the unified system of the East European countries.

The core of the unified system was formed in the 1950's in the European U.S.S.R. The "European" UPS presently takes in eight joint systems in the Northwest, the Center, the South, the Middle Volga region, the North Caucasus, Transcaucasus, the Urals, and North Kazakhstan. In 1978, a 500-kV line was strung linking the European UPS with the Joint Power System (JPS) of Siberia. Other joint systems are in Central Asia and the Far East,[48] and plans exist for

[42] *Ekonomicheskaya gazeta*, 1981 :2, p , 2; Neporozhniy, *Elektrifikatsiya* . . . op. cit., p. 217; Borisov, 4 High Tension," op. cit.

[43] Peterson, op. cit., p. 65.

[44] Neporozhniy, "I, .enin's GOELRO ., ,"' op. cit., p. 8, uses the passive form *osvaivayutsya*, which literally means that the new types of equipment "are being mastered.

[45] "W'orkers of the " Kharkov Turbine Plant"' Production Association reportedly have begun work on adjusting and putting into operation a gas turbine designated the GT-35. The turbine is part of the U.S.S.R. first steam-and-gas unit, the PG U-250, which is installed at the Moldavian Thermal Power Station, See V. M. Velichko, "I'he Labor Contribution of Power Machine Builders," *Energomashinostroyeniye*, No. 1, January 1981, pp. 2-5.

[46] L. G. Mamikoyants, et. al., "The Development of Power Engineering in the U.S.S.R. and the Control of Electrical Power (Generation and Distribution," presented at the Control Data Corp. Seminar on Power Industry Development, Washington, 1).('., Dec. 6 and 7, 1979.

[47] Volkenau and Volkova, op. cit., p. 9.

[48] Fotin, op. cit., pp. 1 /14 and 18,5.

these to be linked to the European UPS in the 1980's, thus completing the formation of the nationwide system.[49] The smallest units of the unified system are the so-called Regional Power Systems, which can cover several administrative regions or *oblasts*.[50]

To form the unified system, JPSs and regional systems are tied together with HV transmission lines of 220- to 750-kV AC and ±4000-kV DC. In the future, higher **voltages** are to be used—1,150-kV AC and ±750- to ±1,125-kV DC and above.[51] The main AC voltage level for system interties in the UPS is 500 kV. In the South and Northwest JPSs, 330-kV interties have been used in the past, but a network of 750-kV lines is being developed. At present, a 750-kV system intertie connects Leningrad and Moscow, and a second line of this voltage runs from the Donets basin to the Western Ukrainian substation and on into Hungary. Plans also call for the construction of a ring of 750-kV lines around the Moscow region to transmit and distribute power from nuclear stations, and 1,150-kV lines linking Ekibastuz to the Urals. Construction of the first of the latter lines, which will be nearly 1,500-km long, reportedly is already underway.[52]

The Soviet Union claims that the JPSs presently tied into the UPS encompass an area of 10 million km^2 with a population of nearly 220 million people; that UPS unites 88 of the 97 power systems in the U.S.S.R.; that only two JPSs and several power systems "in remote regions' remain isolated from UPS; and that in 1979, power stations of UPS accounted for 82 percent of the installed capacity and 88 percent of the electricity generated in the U.S.S.R.[53]

It is difficult to evaluate these claims, however. While the Soviet literature stresses the achievements of UPS in providing connections between grids and tends to convey the impression of a sophisticated system, Western electrical engineers who have visited the U.S.S.R. report that these connections are tenuous and that the entire system is run from a single, underequipped dispatching office in Moscow.[54]

The latter point is particularly important. The coordination and management of a power system covering a large territory requires a well-organized system of control centers and effective control equipment. In theory, overall management of the Soviet UPS is assigned to the system's central dispatching department (CDD), which oversees the work of dispatching departments of the 11 joint systems. The latter departments, in turn, supervise the work of regional control centers and power stations.[55] The CDD's primary responsibility is to ensure the stable, efficient operation of UPS and its components and, thus, the delivery of reliable, quality electric power to consumers. In addition, the CDD takes part or assists in research, development, and planning aimed at maintaining and improving UPS.

To accomplish all of this would require constant upgrading of control facilities and equipment, including the introduction of new communication and data transmission techniques. The rapid transmission and processing of information on all aspects of grid performance and operating conditions are necessary to effect timely shifts of power from one system to another. It is not clear that the U.S.S.R. has as yet acquired these capabilities.

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[49] Mamikoyants, op. cit.

[50] W. G. Allinson, "High Voltage Electric Power Transmission," ch. 5 in Amann, Cooper, Davies, op. cit., pp. 199-224. It should be noted **that** not all sectors of the Soviet economy are served by the Unified System and joint systems. Until recently, agriculture and certain other sectors were excluded, giving rise to the spread of small, unconnected electric power stations. This problem of a "dual economy" in the electric power industry is discussed by Dienes and Shabad, op. cit., pp. 185-187.

[51] A. Pivenko, "High-Capacity Transformers," *Izvestiya* June 1, 1980, p. 1; and V. Ganzha, [title **unknown**], *Sotsialisticheskaya industriya*, June 14, 1980, p. 2.

[52] L. L. Peterson, "The Development of Power Systems," *Elektricheskiye stantsii*, No. 12, December 1980, pp. 63-66.

[53] Ibid.

[54] Discussion with Val Lava and Frank Young, members of the Joint American-Soviet Committee on Cooperation in the Field of Energy.

[55] Mamikoyants, et al., op. cit.

Computer technology is also important to UPS management, and there is evidence that the Soviet Union recognizes a need to use computers more extensively for this purpose.[56] For example, the automatic monitoring of frequency (which is supposed to be the same throughout UPS) and of active power, is reportedly done using minicomputers at all levels of control, from the CDD down to local power systems. Voltage levels in basic networks will also eventually be placed under centralized automatic control, which likely will require the use of computers, but this work is said to be only at the preliminary development stage. Such control equipment is the basis for the formation of a hierarchical computerized system for managing UPS—a goal which is still to be achieved.

[56] Ibid. See also the section below on Western *Technology in the Soviet Electric Power Industry.*

WESTERN TECHNOLOGY AND THE SOVIET ELECTRIC POWER INDUSTRY

The Soviet Union has so far been successful in the development and implementation of HV (up to 750-kV AC and ± 400-kV DC) transmission, apparently with little or no assistance from the West.[57] Moreover, at least on the evidence of Soviet literature, there seems no reason to doubt the U.S.S.R.'s ability to continue to progress and to make the transition to UHV transmission. Certainly given the great distances over which electric power is to be transported in the U.S.S.R., it probably has greater economic motivation than any other country in the world to employ UHV.

But, from a technical standpoint, the fact remains that UHV is still a relatively new and experimental technology. There is evidence that the U.S.S.R., which in the 1960's emerged as a world leader in HV power transmission, has since lagged behind the West in some aspects of UHV, particularly in the development of thyristor converters for DC lines.[58] These observations cast some doubt on Soviet claims about UHV powerline construction and suggest that the Soviet program might benefit from foreign experience and equipment.

OTA found no direct evidence that the U.S.S.R. is purchasing or intends to purchase UHV equipment and technology from the West, yet the possibility of future purchases cannot be ruled out. In the case of thyristor converters, for example, the U.S.S.R. has developed its own equipment. But this may be inferior to that available from Western countries; Sweden has at least one firm that is actively engaged in commercial applications of this technology.[59] While the U.S.S.R. can and does achieve the same effect as one foreign thryistor by using several of its own, it is possible that a decision could be made to purchase foreign models if large numbers were required. Soviet industry may also be unable to manufacture enough cable for power distribution. A 1976 source reported that the U.S.S.R. had been placing large orders for cable for small (10-kV) powerlines with suppliers in West Germany and Finland, and that even larger orders could be expected in the future.[60] Conceivably, the U.S.S.R. could also turn to the West for assistance with the development or supply of compensation devices for UHV AC lines.

Finally, despite its gains in the automation and computerization of UPS, the Soviets have a long way to go before they can possibly realize centralized control of the whole system. A considerable amount of computerization has been applied at the

[57] "Amann, Cooper, and Davies, op. cit.
[58] Ibid., p. 220.

[59] Ibid.
[60] "Power Lines, "*Soviet Busine.s.s and Trade, No. 9, 1976,* pp. 5-6.

regional and power-system levels for economic and grid management. But very little closed-loop control has been implemented and the software lags that of Western systems. Only limited computerization exists at regional control points and powerplants. These functions tend to be limited to accounting, monitoring, and short-term planning. Some form of closed-loop control is not planned until the early 1980's, and the Soviet goal of automating the whole system over the next 10 years does not seem realistic,

The power industry has had access to and made use of most of the major computers produced in the U.S.S.R. over the last 15 years. Conversely, it has not relied extensively on the West for computer equipment although, as has generally been the case with economic management, the indirect influence of U.S. computing has been great.

The addition of inflexible nuclear powerplants, the need for more power generating capacity, and more reliance on Siberian plants now make management tasks considerably more difficult, increasing the need for more sophisticated control of the whole power system. The more the Soviets try to tie the network together, the greater will be their requirements for real-time control systems which can model a wide variety of situations and optimize operational economics.

In addition, very large computers may allow the Soviets to do more extensive modeling, as opposed to field testing, of various network configurations. The U.S.S.R. has spent millions of dollars on test generators and other testing equipment. In the United States, such testing is performed by simulations on computers. Soviet facilities for computer modeling are only now being created. As the grid becomes more complex, substantial savings could be realized here.

Building a multilevel hierarchical process control system of the magnitude of UPS raises enormous software engineering problems. The Soviets lack sophisticated software design tools and experience. Their usual practice is to farm out the development of separate pieces of large systems to various institutes. Without rigorous specifications of interfaces and frequent communications, the overall system is unlikely to work correctly. Consequently, the U.S.S.R. will probably have to settle for considerably less during the eighties than UPS envisaged: greater manual intervention at each level, slower system response, greater cost, and less reliability.

The West could supply integrated software tools, data base management systems, and other software which would help the Soviet software industry and trickle down to this application. Joint ventures, long-term contacts, training, and other transfer mechanisms would also help to build up overall software engineering capabilities. It is unlikely that the Soviets would seek to purchase a large computer for modeling. The new large Soviet-made computers are sufficient for this purpose, provided they are available to the power industry over the next few years. This is another area in which general help in software would play the most decisive role. The same can be said for software for management of construction.

In sum, the Soviets have introduced a large number of computers at various levels of the electric power generation hierarchy. Most of these are concerned with economic management tasks and the overall level of closed-loop control of the power grid is not great. As new atomic and peakload capacities are added and more electricity is generated in Siberia, the management problems will become even more complex. Building this system requires software abilities that the Soviets probably do not yet possess. The U.S.S.R. may also encourage technology transfer from the West in this area. This would be a departure from past experience, for the electric power industry has not previously made extensive purchases of hardware and software. Despite Soviet claims about domestic developments in power transmission technology, the

U.S.S.R.'S apparent loss of supremacy in this field in recent years suggests the potential for Western assistance, particularly in the areas of UHV transmission and computer equipment, software, and software engineering tools and techniques for power system management and control.

THE FUTURE OF THE SOVIET ELECTRIC POWER INDUSTRY

ALTERNATIVES FOR MEETING INCREASED ELECTRICITY DEMAND

This chapter has discussed two ways in which the U.S.S.R. can generate and transmit more electricity to meet a still growing demand in the European part of the country. It can build power stations in the European U.S.S.R. itself, or it can transmit power there over long-distance lines which originate at remote coal basins. Soviet planners are pursuing both approaches, but it seems that some preference is being accorded the first, which is based mainly on the construction of nuclear power stations and the curtailment of fossil-fuel generation in this region. The second approach involves the construction of UHV power transmission lines from coal-fired stations in Kazakhstan and Siberia. As noted above, this project has begun, although the ultimate fate of the program may be delayed, pending the outcome of the nuclear program.

Soviet preference for localized power generation at NPSs can be understood by comparing the costs of electricity supplied by each approach. Troitskiy has compared the costs of electricity y generated at a baseloaded NPS in the European U.S.S.R. and electricity transmitted there over a 1,500-kV DC line from a coal-fired station in Ekibastuz in Kazakhstan.[61] According to his figures, the total cost of 1 kWh of electricity, including the costs of extracting, producing, and transporting fuel (coal or uranium) and electricity, is 6 percent higher at the point of consumption for electricity from an Ekibastuz power station than for electricity from a local NPS (1.22 kopecks/kWh v. 1.15 kopecks/kWh, respectively).[62] Given the possibility of error in the calculations, actual costs could be roughly the same, or nuclear electricity could be even less expensive than indicated. In either case, one may question the U.S.S.R.'S decision to build long-distance transmission lines at all if nuclear electricity costs about the same or is cheaper to produce locally. Indeed, Troitskiy himself argues that power transmission westward from Ekibastuz and Kansk-Achinsk is advisable only if the demand for baseload capacity in the European U.S.S.R. cannot be covered with nuclear stations.[63]

One answer may be to substitute fossil-fired generation for nuclear, particularly if nuclear growth falls short of planned targets. In such a case, a shortfall in nuclear generating capacity might be covered with coal-fired capacity in Ekibastuz. Troitskiy also gives figures for capital investment costs per kilowatt of capacity required to deliver electricity to the European U.S.S.R. (including transmission lines) via either

[61] A. Troitskiy, ''Electric Power: Problems and Prespects, *Planovoye khozyaystvo, No. 2,* February 1979, pp. 18-25. OTA believes that Troitskiy's figures for the center are indicative of the European U.S.S.R. as a whole.

[62] Ibid., p. 20. Troitskiy also considers the option of building gas-fired condenser stations in the Center and supplying them with natural gas from the Tyumen region. Although this option is cheaper (1.08 kopecks/kWh) than the other two options described, Troitskiy points out that gas-fired stations "cannot be recommended" for the Center for two reasons: 1) possibilities for long-distance transport of natural gas in the future are still limited, and 2) additional gas resources are necessary, first of all, in order to replace residual fuel oil *(mazut)* as a fuel at power stations.

[63] Ibid., p. 21. Troitskiy's estimate of the cost of electricity from Kansk-Achinsk is based on transmission over a 2,250-kV DC line. Because this voltage level is not likely to he reached before 1990, if at all, the Ekibastuz-Center option is considered in the present discussion.

nuclear capacity there or coal-fired capacity in Ekibastuz.[64] To cover a shortfall in nuclear capacity of, for example, 5,000 MW with an equivalent amount of coal capacity in Ekibastuz would require only about 25 million rubles of capital investment less than the investment in the equivalent nuclear capacity, a difference of about 1 percent.[65] Again, given the likely margin for error in Troitskiy's estimates and the magnitude of the investment costs (billions of rubles), this difference is insignificant.

In terms of capital investment, then, using low-grade Ekibastuz coal to generate electricity for the European U.S.S.R. appears to be at least as good as, and maybe slightly better than, building nuclear stations near consumers. Nevertheless, the fact remains that the estimated total cost per kilowatt-hour of electricity (as opposed to capacity) is lower for the nuclear than for the Ekibastuz coal option.

Furthermore, from a technical standpoint, there are at least two major risks associated with coal-generated electric power from Kazakhstan or Siberia. First, Soviet equipment for burning low-grade coal at power stations, particularly boilers for burning Kansk-Achinsk coal, remains to be perfected. Second, as noted above, technology for transmitting coal-generated electricity, especially UHV DC technology, is unproven in practice. Although the first ±750-kV DC line from Ekibastuz apparently is under construction, the U.S.S.R. has not demonstrated practical mastery of this voltage level. Even more uncertain is the possibility of practical application of ±1,125-kV DC, which is the minimum voltage planned for use in UHV lines from Kansk-Achinsk.

Nor are the economics of using AC lines entirely clear. Troitskiy views 1,150-kV AC lines as an effective means of supplying power to the Urals from Ekibastuz, but he does not mention the possibility of further extending such lines.[66] Conceivably, announced plans to do this could be questioned, since UHV AC lines from Ekibastuz to the area around Moscow presumably would create problems similar to those discussed above in connection with UHV DC transmission v. nuclear power generation. In any case, as with UHV DC, Soviet success with UHV AC will depend on the solution to whatever technical problems exist. Here, again, Soviet plans reflect a confidence that such problems have been or can be solved.

Nuclear technology, on the other hand, is proven. NPSs have been operating successfully in the European U.S.S.R. for years, and the voltage level for transmission lines from these stations–750-kV AC–apparently has been mastered. Moreover, the cost of building these lines is lower than that for UHV lines. If Troitskiy's estimates of capital investment costs are accurate, the share of powerlines in total investment costs is greater for coal-fired stations in Ekibastuz than for NPSs around Moscow.[67]

In sum, while the option of supplying electricity by building NPSs in the western part of the country requires slightly higher capital investment than building coal-fired stations in Ekibastuz for the same purpose, the delivered cost of electricity from NPSs is slightly lower than for coal-generated electricity from Ekibastuz. Moreover, a large portion of the investment costs for the coal-fired stations, and the higher cost of Ekibastuz electricity, can be attributed to the

[64] Ibid., p. 20. The figures are 380 rubles/kW of nuclear capacity and nearly 375 rubles/kW of fossil-fired capacity—a difference of only about 1 percent.

[65] OTA's projection in chapter 4 on the "base case" scenario for the Soviet nuclear power industry included an estimated shortfall in nuclear capacity of 5,000 MW by 1990, relative to the assumed target for that year. Using Troitskiy's investment figures, this amount of nuclear capacity in the European U.S.S.R. would cost about 1.90 billion rubles, while the same amount of coal-fired capacity in Ekibastuz would cost about 1.88 billion rubles.

[66] Troitskiy, op. cit., p. 21.

[67] Based on figures in Troitskiy, op. cit., p. 20, OTA estimates that UHV powerlines account for roughly one-fourth of the cost of building a coal-fired power station in Ekibastuz to supply power to the Center. This estimate was derived by comparing the cost per kW of Ekibastuz capacity serving the European U.S.S.R. (374.8 rubles) to the difference between this figure and the cost per kW of Ekibastuz capacity serving Siberia (278.2 rubles). Presumably, this difference (96.6 rubles/kW) can be largely attributed to the cost of UHV lines to the Center.

cost of UHV DC transmission lines-technology which is unproven in practice. These factors, plus unsolved problems of burning low-grade coal at power stations and successful experience with nuclear power, make the nuclear option seem more desirable than the coal option. Technological advancements in UHV and coal power generation, together with practical experience, may make coal use more viable in the future. At least for the present, however, OTA believes that Soviet planners will downplay coal, particularly plans to use Kansk-Achinsk coal to generate electricity, and place more emphasis on nuclear power.[68]

PROSPECTS FOR MEETING PLAN TARGETS

1981-85

Tables 33 and 34 above showed Soviet plans for commissioning of new generating capacity and for electricity production between 1981 and 1985. Achievement of this program could be jeopardized in at least two important ways. First, Soviet plans call for the commissioning of only 10,000 MW of new capacity in 1981,[69] leaving over 15,200 MW to be added each year from 1982 through 1985. In the past, introductions of new capacity have averaged about 10,000 MW per year (in 1980, however, the increment was some 13,000 MW), although production of turbines and generators has been running at 18,000 to 20,000 MW per year.[70] Construction must be expanded in the last 4 years of the FYP if the goal of installing 71,000 MW of new capacity is to be met. Second a substantial share of this new capacity is to be built at Kansk-Achinsk (the Berezovskoye No. 1 Plant) (see table 35), but there is no evidence that a suitable boiler has yet been developed. It is known that trials using a 2,650 tons of steam/hour boiler have failed to solve the problems.

Taking these factors into account, OTA estimates that lags in construction at fossil-fired plants make it likely that the projected growth of 29,000 MW will not be attained and that net growth might more probably be around only 24,000 MW. If the estimated "best-case" shortfalls projected in chapter 4 (2,000 MW) and the plan targets for hydropower are factored in, the result is the achievement of 325,000 MW by 1985, 7,000 MW short of the plan. These projections are summarized in table 38.

The Eleventh FYP calls for the generation of 1,550 billion to 1,600 billion kWh of electricity by 1985.[71] As table 39 demonstrates, OTA estimates that actual generation will be

[68] Besides greater technical risks, the option of using Siberian coal to supply electric power to the European U.S.S.R. involves higher costs than the Ekibastuz option. According to Troitskiy (Ibid.), supply of the Center from generating capacity in Kansk-Achinsk would cost nearly 390 rubles/kW, presumably because of the greater distance from the European U.S.S.R. and the use of higher voltage (2,250-kV DC v. 1,500-kV DC) in transmission lines. Overall, electricity from Kansk-Achinsk would cost an estimated 1.28 kopecks/kWh.

[69] Result.s of Development of Elctric Power Engineering in 1980 and Tasks for 1981, *Elektricheskiye .stantsii, No.* 1, ,January 1981, p. 181.

[70] U.S.S.R. Central Statistical Administration, *Narodnoye khozyaystvo SSSR v 1979g.* (Moscow: Izd. "Statistika," 1980), p. 181.

[71] Draft of the Main Directions of Economic and Social Development of the U.S.S.R. for 19/41 -1985 and for the Period to 1990," *Izvestiya*, Dec. 2, 1980, p. 2.

Table 38.— Estimated Soviet Electrical Generating Capacity, 1985 and 1990 (thousand MW)

	1985		
	Planned (from table 34)	Projected	1990
Total	332	325[a]	405[a]
Fossil-Fired	230	255[b]	255[e]
Nuclear	38	36[c]	75[c]
Hydro , ...	64	64	75[d]

[a] Sum of fossil - fired, nuclear, and hydro capacities

[b] Estimated Of 71,000 MW to be added in the period, 35,000 MW are assumed to be fossil.fired This figure has been adjusted downward by 11,000 MW to ac. count for retirements and underfulfillment of plan targets

[c] Estimated

[d] Extrapolated trend. V S. Serkov (ed), *Ekspluatatsiya gidroelektrostantsiy*, (Moscow Izd. "Energiya," 1977), p 18, indicates that hydroelectric capacity in 1990 is to be 82,000 MW. This appears ambitious, but indicates that sites for new capacity are not exhausted

[e] Represents a net addition of 30,000 MW (A gross increase of 35,000 MW, less 5,000 MW of retirements)

SOURCE Off Ice of Technology Assessment

Table 39.— Estimated Soviet Electricity Production, 1985 and 1990 (billion kWh)

	1985		
	Planned (from table 33)	Projected	1990
Total	1,550-1,600	1 ,515-1 ,625	1,900-2,040[a]
Fossil-Fired	1,100-1,135	1,095-1,180[b]	1,235-1,330[d]
Nuclear	220-225	190-210[c]	400-445
Hydro	230-235	230-235	265[e]

[a]Sum of fess i l fired nuclear and hydro capacities

[b]Mid 1985 capacity of 223,000 MW times operating rate range of 4,900 to 5,291 hr/yr The latter is the 1980 rate

[c]Estimated

[d]Mid 1990 capacity of 252,000 MW times operating rate range of 4,900-5,291 hr/yr The latter is the 1980 rate

[e]Estimated mid-1990 capacity of 73,900 MW used at a rate of 3600 hr/yr, that is at roughly the 1979 rate of utilization. See Narodnoye *khozyaystvo* op. cit. (1980) p 169

SOURCE: Office of Technology Assessment

1,515 billion to 1,625 billion kWh in 1985, well within the scope of the plan. This estimate too uses the optimistic nuclear projections in chapter 4 and adopts the goal set for hydroelectric generation; OTA estimates that fossil-fired electricity generation will reach 1,095 billion to 1,180 billion kWh in 1985. Combining these three components yields a result that should equal the plan target even if capacity introductions fall short of the goal. This outcome depends on the assumed rate of utilization of installed capacity. If the 1980 rate is maintained, fossil-fired generation could reach 1,180 billion kWh, but if rates continue to decline—say to 4,900 hr/yr—then generation will reach only 1,095 billion kWh, still within the plan target range.

It must be noted that opportunities to increase the amount of electricity produced from coal may be limited by the availability of coal. Although *planned* coal growth is commensurate with *planned* growth in fossil-fired electricity generation over the FYP (8 to 12 percent v. 5 to 9 percent, respectively), chapter 3 estimates that at most coal output will actually increase by only 7 percent, and even this is a highly optimistic projection. Given probable growth of demand for coal in other industrial sectors, notably in ferrous metallurgy, even a 7-percent growth in coal production is insufficient to achieve the upper end of the range for electricity growth. In addition, if growth in Kansk-Achinsk output is excluded owing to boiler problems, growth in coal production to 1985 falls to 5 to 6 percent, When likely declines in the average calorific value of other coals are taken into account, there is a possibility that coal production on a Btu-basis will fall from the 1980 level. There is, then, a substantial probability that coal's contribution to total fuel consumption in electrical power generation will decline. As a consequence, some plans for adding new coal-burning capacity may have to be scrapped or at least postponed until after 1985.

In sum, present rates of power machinery production suggest that the Soviets are capable of producing the 35,000 MW of power generating equipment needed to achieve the planned gross addition of fossil-fired capacity by 1985. But unless greater resources are allocated to construction of powerplants, there will be insufficient finished plant to house much of this equipment at the end of 1985. In addition, it is possible that growth in coal production will not be sufficient to support a 5- to 9-percent growth of fossil-fired electricity production. As a consequence, it is difficult to see how coal's share of the fuel balance in electricity generation can be expanded between 1981 and 1985.

1986-90

Estimates for Soviet electricity generating capacity in the Twelfth FYP are highly speculative. The figures shown in table 38 indicated that this capacity could exceed 400,000 MW by 1990, possibly amounting to 405,000 to 415,000 MW. Fossil-fired capacity will grow between 1986 and 1990, although the extent of the growth is hard to judge. During this period, additional plants will be built at the Ekibastuz and Kansk-Achinsk basins and probably at the South Yakutian basin. Other plants may be built in the Far East and in the Urals, In all, OTA has assumed a net addition of 30,000 MW of capacity between 1986 and 1990. If so, fossil-fired capacity in 1990 could reach 255,000 MW (see table 38). Total electricity production could reach 1,900 billion to 2,040 billion kWh by 1990, with 1,235 billion to 1,330 billion kWh being generated by fossil-fired stations (see table 39).

SUMMARY AND CONCLUSIONS

The U.S.S.R. has amassed great experience in power transmission, including long-distance HV transmission. This experience has proved valuable in and has been enhanced by the formation of the nationwide Unified Power System. At the same time, Soviet power engineering is moving into a qualitatively new field—UHV transmission. The move to UHV, at least initially, will involve substantially higher investment and operating costs; but the Soviets are confident that these costs will be offset by the great savings to be gained from long-distance UHV transmission. The success of this move may determine the outcome of Soviet plans to complete the UPS. The chances for success will depend, in large part, on the applicability to UHV of past Soviet experience in power transmission and, perhaps, the availability of assistance from the West.

Plans for UHV DC transmission of coal-generated electricity to the center of the European U.S.S.R. from Kazakhstan and West Siberia seem to be viewed as a way to supplement nuclear power, particularly in the event of a shortfall in planned nuclear capacity. However, the technical risks involved in UHV transmission and power generation using low-grade coal support the conclusion that Soviet planners may be downplaying coal in favor of nuclear power, at least for the present. This may mean that construction of UHV DC lines other than the ±750-kV line now being built will be delayed, pending success of the nuclear program and the solution of technical problems connected with developing a boiler to burn Kansk-Achinsk coal and technology for DC transmission at voltages of ±1,125-kV and more. Gas may also come to play a more important role in power generation.

There are no economic constraints to building the planned 1,150-kV AC lines to supply power to the Urals, assuming that technical problems are or can be solved. Presumably, however, plans to extend these lines to the Western U.S.S.R. would raise economic questions similar to those entailed in proposed UHV DC transmission vis a vis nuclear power.

To some extent, the generation of electricity by fossil-fired plants in the 1980's will be tied to the fate of the nuclear electrification program. But if nuclear power falls behind schedule, fossil-fired equipment will be called on to cover the shortfall.

On the face of it, there would appear to be a substantial amount of flexibility in the system, at least in handling the baseload. Fossil-fired capacity at the end of 1980 (201,000 M W) would satisfy and even exceed the 1985 generation targets of 1,100 billion to 1,135 billion kWh if utilization rates of 5,475 to 5,650 hr/yr could be achieved. If the 1985 goal for fossil-fired capacity (230,000 MW) were met, operation of this capacity at the 1979 utilization rate (5,651 hr/yr) would permit the generation of 1,300 billion kWh in 1985–almost enough to cover the 1985 targets for both fossil-fired and nuclear plants.

There is sufficient evidence to suggest that the U.S.S.R. will have substantial reserve capacity in its power generation system in the 1980's and will be able to compensate to some degree for shortfalls in the nuclear program by increasing the rate of utilization of fossil-fired capacity, provided that the needed fossil fuel supplies are available. Nor does the availability of generating equipment appear to be a problem. Present annual production of turbines and generators seems more than sufficient to support a gross addition of 65,000 MW of fossil-fired capacity by 1990 (54,000 MW net).

Examination of the available literature, both Soviet and Western, revealed virtually no imports of Western technology and equipment in nonnuclear power generation. In fact, the Soviets have opted for domestic development of this industry and have largely succeeded in achieving a high technological level in their equipment, comparable in some cases with the best available in the West.

One equipment problem–the development of large boilers for Kansk-Achinsk coal—probably must be solved domestically. Boilers are custom designed for specific types of coal and suitable boilers would not be available from the West. The Soviets have been working on the development of such boilers for years, but to date appear to have had little success. This is not unusual, however. Boiler development can take decades, and there is no assurance that an efficient boiler can be developed for a given type of coal. In any event, Soviet capabilities in boiler design are comparable with Western capabilities. In short, Soviet reliance on domestically produced power generating equipment will probably continue into the foreseeable future and the availability of Western technology and credits should be of small concern in this area.

Similarly, the U.S.S.R. appears to be largely self-reliant in the construction of power transmission lines. This self-reliance may be reduced if Soviet plans for UHV transmission are carried out; the U.S.S.R. may be forced to turn to the West to help it supply the large body of technology and equipment which would be required. At the same time, the need for the U.S.S.R, to move ahead at full speed with plans for UHV development, particularly UHV DC, is questionable, given past success with and future plans for nuclear power. Postponement or abandonment of Soviet UHV plans would limit the potential impact of Western technology in this field.

Although reliance on the West for computer technology for UPS has been very limited, the U.S.S.R. could profit substantially from using U.S. software engineering techniques to build the network's computer control system. Continued indirect acquisition of these techniques is at least as likely, however, as direct acquisition.