ISSN 0040-6015, Thermal Engineering, 2017, Vol. 64, No. 11, pp. 817–828. © Pleiades Publishing, Inc., 2017.
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GENERAL ISSUES OF POWER INDUSTRY

Strategic Prospects of the Electric Power Industry of Russia

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Received March 24, 2017; in final form, April 26, 2017

Abstract—The prospects for the development of the electric power industry of Russia adopted at a regular stage of working out the Energy Strategy and the General Plan of Distribution of the Electric Power Facilities are discussed. The monitoring of the progress in the implementation of the Energy Strategies for the periods until 2020 and 2030 adopted in 2003 and 2009 has, in general, validated the correctness of the estimated volumes of the energy resource production under overestimation of the expected domestic demand owing to an excessively optimistic forecast of the real development of the economy. The priority lines of the national energy policy in electric power and allied industries proposed in the Energy Strategy for the period until 2035 are considered. The tools for implementation of most of the proposals and the effectiveness of their implementation have yet to be defined more concretely. The development of the energy sector and the electric power industry under the conservative and optimistic scenarios of the development of the country's economy has been predicted using the SCANER modeling and information system, viz., the dynamics of the domestic consumption, export, and production of the primary energy and the electric power has been determined and the commissioning and structure of the required generating capacities and the consumption of the basic types of the energy resources by the electric power industry and the centralized heat supply systems has been optimized. Changes in the economic efficiency of the nuclear and thermal power plants under the expected improvements on their cost and performance characteristics and an increase in the domestic fuel prices are presented. The competitiveness of the wind and solar power production under Russian conditions has been evaluated considering the necessity of reservation and partial duplication of their capacities when operated in the power supply systems. When optimizing the electric power industry as a subsystem of the country's energy sector, the required amounts of capital investments in the industry have been assessed. Based on the obtained data and the predicted prices of fuel in the main pricing zones of Russia, the ranges of changes in the prices of the electric power in agreement with the macroeconomic restrictions on their dynamics have been calculated.

Keywords: energy strategy, energy sector, electric power industry, thermal power plants, nuclear power plants, nonconventional and renewable sources of energy, economic efficiency, prices of fuel and the electric power

DOI: 10.1134/S0040601517110064

For almost a decade, the electric power industry of Russia has been functioning under conditions of the market reform [1] that began in 2007 in the rising tide of the economic growth most successful in the post-Soviet period and the demand for electric power. At that time, the prospects of the reform were estimated based on the scenarios of the Energy Strategy of the Russian Federation for the Period until 2020 (ES-20) [2] adopted in 2003, although its forecasts were regarded as too conservative. Nevertheless, in 2010, the figures of 70% of key indicators of the Russian economy, energy sector, and electric power industry development were in agreement with the forecasts of ES-20 and, up to now, practically only the GDP and energy consumption figures are below the former (see Table 1). Despite the severe economic crisis of 2008–2009, when developing the General Plan of Distribution of the Electric Power Facilities for the Period until 2020 and the Energy Strategy of the Russian Federation for the Period until 2030 (ES-30) [3], the Ministry of the Economic Development of the Russian Federation made overestimated forecasts of the further development of the economy.

However, the economic recessions of 2008–2009 and 2014–2016 moderated the optimism of the long-term economic forecasts (see Fig. 1) and the national energy sector (see Fig. 2), including its integrating part, the electric power industry (Fig. 3).

The monitoring of the progress in the implementation of the ES-30 shows that the key parameters of the development of the industry—the production of the electric power on a whole and the basic generation types—are presently being hardly maintained at the lower bound of the prediction range of the first ES-30

Table 1. Progress in the implementation of the Energy Strategy of Russia for the Period until 2020 (ES-20)*

Index	2005		2010		2015		2020	
	ES-20	Actual	ES-20	Actual	ES-20	Actual	ES-20	Prediction according to ES-35
GDP, % of the 2000 figure	118–127	135	146–173	165	190–242	*170*	224–334	*181–183*
Consumption of:								
primary energy, million t of equiv. fuel	931–976	943	972–1097	982	1020–1181	*964*	1060–1267	*988–1002*
electric power, TWh	912–915	941	995–1035	1021	1085–1155	*1051*	1185–1290	*1096–1104*
Total energy resource export, m t of equiv. fuel	603–711	869	585–838	890	550–873	961	545–897	999–1065
Including								
oil, million t	182–241	254	183–277	248	154–296	245	153–308	288–290
gas, bn m^3	188–197	254	206–265	223	219–277	*200*	221–281	228–252
Total energy resource production, million tce	1503–1656	1738	1457–1822	1822	1463–1928	1873	1486–2031	1959–2043
Including								
oil and condensate, million t	373–447	470	358–489	505	325–506	533	315–520	548–555
natural gas, bn m^3	588–615	641	558–665	651	587–705	633	610–730	670–702
coal, million t	260–280	299	270–330	323	290–360	372	300–430	377–425
Total electric power production, TWh	902–937	953	940–1070	1038	1000–1205	1064	1070–1365	1106–1116
Including								
HPPs	179–183	*175*	182–190	*169*	186–200	*170*	190–215	193–199
NPPs	151–160	*149*	160–192	170	180–240	195	195–300	221
TPPs	572–594	629	598–688	699	634–765	689	685–850	687–690

Notation: 000—according to ES-20; 000 ---more than according to ES-20; *000*—less than according to ES-20.
* Sources: [2, 4].

stage (2014–2016), while the volumes of the electric power export are not reaching this bound at all. The main reason is that the postcrisis economic revival in Russia of 2010–2013 was retarded and then replaced by the recession with a fourfold drop in the world prices of oil and gas. In the electric power industry, the crisis caused the stagnation of domestic demand for electric power and reduction in the centralized heat consumption.

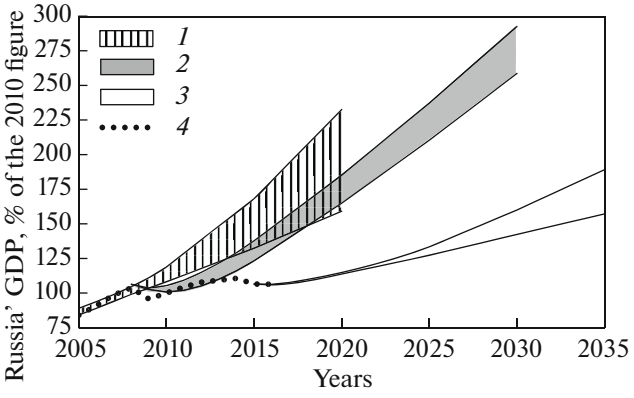

Fig. 1. Forecasts for the growth of Russia's GDP, % of the 2010 figure: *1*—ES-20; *2*—ES-30; *3*—ES-35; *4*—actual figures.

The Energy Strategy of the Russian Federation for the Period until 2030 prolonged until 2035 (below referred to as the Strategy) was actualized by the decision of the government for extremely moderate forecasts of the development of the Russian economy and the energy sector (see Figs. 1, 2). The first version of the Strategy was presented by the Russian Ministry of Energy to the government and the public in 2014; the second version was prepared in 2015 and finalized in 2016–2017 [4], and it was oriented towards the requirements of the new federal law on strategic planning "...to contain the evaluation of the state, the developmental Indicators according to several forecast variants of the long-term social and economic development of the Russian Federation, and priorities, goals, tasks, and figures of the state governance and

national security protection as well as the efficient means of their achievement and the medium-term plan of required measures" [5].

However, these requirements were not fulfilled when preparing the Strategy also because the Ministry of the Economic Development did not correct the long-term economic forecasts for the country after the sanctions had been made more stringent and especially after the 2015 slump in the world prices of hydrocarbons. Therefore, the developers of the Strategy had to actualize the previous scenarios of the social and economic development of Russia worked out by the ministry on their own using the SCANER modeling and information system [6, 7].

CONDITIONS FOR THE LONG-TERM DEVELOPMENT OF THE ECONOMY AND ENERGY SECTOR OF RUSSIA

The basic forecast of the socio-economic development of Russia for the period until 2030 adjusted by the Ministry of Economic Development as a matter of routine procedure underlies the conservative scenario of the Strategy; this forecast continued the established trends and preserved the structure of the Russian economy under moderate rates of its development. This forecast—adjusted by the authors and prolonged for another 5-year period—accounts for the sanctions imposed by the United States and the European Union against the banking and industrial sectors of Russia and the lower levels of equilibrium prices of oil and gas at the global markets (see Table 2). Under a conservative scenario, the gross domestic product (GDP) of Russia will increase by 46% in 2015–2035—annually by 1.9% on average (see Fig. 1)—with the modernized energy and raw-material sectors and the processing industry and the economy of the Central, Northwest, and Far-East federal districts developing at priority growth rates. In this scenario, Russia falls behind the development rates of the world economy and moves from the sixth to the eighth place in terms of GDP volume [8].

At moderate rates of economic restructuring and increase in the economy's energy efficiency, the consumption of the primary energy will increase under the conservative scenario by 13% and that of the electric power by 30%. The external demand for the Russian energy resources is determined by the world market conditions [8]: the total volumes of the Russian export will increase by 3–4% in 2020–2025 and then fall by 5% below the 2015 level. The export of oil, petroleum-based products, and coal will enhance the dynamics, while the export of gas will smooth by 2025 this trend by having stabilized the amounts after the growth (see Table 3). The net electric power export will stabilize with the increasing deliveries to China and other countries of Northeast Asia (see Table 4).

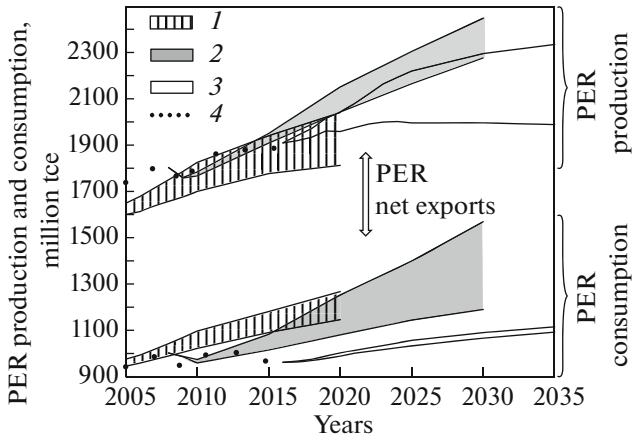

Fig. 2. Production and consumption of the primary energy resources (PER), million tce: *1*—ES-20; *2*—ES-30; *3*—ES-35; *4*—actual figures.

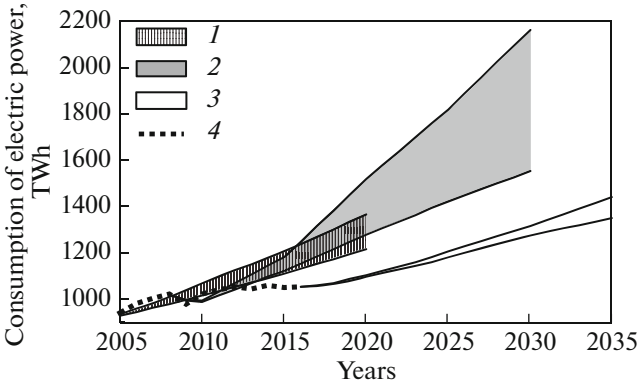

Fig. 3. Consumption of electric power, TWh: *1*—ES-20; *2*—ES-30; *3*—ES-35; *4*—actual consumption.

However, studies have found the possibilities of accelerating the development of the Russian economy under faster reflation of the world fuel prices (see Table 2) and an increase of the energy resource export by 1.3 times—a reduction in the export of oil and petroleum-based products only by 1% under an increase in the export of pipeline and liquefied gas of 1.8 times and coal sales by 1.5 times (see Table 3)—and nonenergy products and materials, predominantly to Asian markets. This will require increased investments (of approximately 30%) into the energy sector and industry, especially in Siberia and the Far East and will produce considerable multiplicative effects in the economy under intensifying of the import phase-out based on competitive domestic technologies. The optimistic scenario of the Strategy based on the above hypotheses provides for an increase in the GDP by 75% in the 2015–2035 period (see Fig. 1) at average annual growth rates of 2.9% with 3.5% in 2025–2035.

Table 2. Prices of exported Russian oil and gas*

Fuel type, scenario	2015	2020	2025	2030	2035
Urals oil, USD/barrel:					
conservative	52.4	60	81	88	94
optimistic	52.4	65	87	90	103
Gas, USD/ths m^3:					
Europe, conservative	245	306	357	366	380
China, conservative	–	319	373	392	419
Europe, optimistic	245	282	318	340	392
China, optimistic	–	333	375	411	465

Prices as of 2015.
* Source: [8].

Table 3. Basic parameters of the primary energy resource (PER) balance of Russia

Balance item	2015	2020		2025		2030		2035	
PER domestic consumption, million tce	964	988	1002	1033	1057	1066	1090	1092	1115
GDP energy intensity, %	100	96	92	89	85	81	75	74	66
Including									
gas	503	503	503	542	548	566	561	580	574
liquid fuels	187	191	191	197	194	201	195	204	194
coal and others	147	149	159	147	158	148	170	146	169
noncarbon resources	127	145	149	147	156	151	164	163	178
PER export, million tce	961	999	1065	995	1190	957	1228	916	1260
Including									
oil and refinery products, million t	415	434	443	406	416	392	409	365	404
gas, bn m^3	200	228	252	256	338	251	353	248	357
coal, million t	136	135	162	130	185	128	205	126	206
Total demand, million tce	1928	1990	2071	2031	2250	2027	2321	2012	2407
PER import, million tce	52	32	27	36	30	31	26	23	15
PER production, million tce	1873	1959	2043	1996	2220	1996	2295	1988	2363
Including									
oil, condensate, million t	533	548	555	530	555	512	555	490	555
gas, bn m^3	633	670	702	727	827	746	858	757	900
coal, million t	372	377	425	366	450	360	490	355	490
hydropower, TWh	170	193	199	195	204	199	215	207	230
nuclear power, TWh	195	221	221	223	227	229	238	250	269
NRESs, million tce	14	16	18	18	28	23	37	30	51

Here and below, the first columns refer to the conservative scenario and the second columns refer to the optimistic scenario.

This will allow the Russian economy to reassume the sixth place in the world at the end of the period.

It is stipulated in the optimistic scenario that the share of the low-energy-consuming industries, such as machine-building, light, food, and other industries, in the GDP will increase by a quarter under an adequate reduction in the share of energy-intensive primary industries. Along with such favorable changes in the structure of the economy resulting from the purposeful energy-saving policy, the energy intensity of the Russian economy will be reduced by 1.5 times and, with the GDP increase by 75%, the consumption of the primary energy will increase only by 16% (see Table 3). With the enhanced electrification of transport, industry, and households, the electric power intensity of the GDP will decrease by 1.3 times, while

Table 4. Basic parameters of the development of the electric power industry of Russia

Index	2015	2020		2025		2030		2035	
Installed capacity, GW	254	257	262	266	273	280	288	295	312
Including									
HPPs	49	51	53	52	54	52	56	55	60
NPPs	28	35	35	33	33	34	34	36	38
Condensing TPPs	85	75	75	75	76	80	77	82	81
CHPs	91	93	94	101	101	107	111	112	119
NRESs	0.4	2.8	5.0	5	8.2	7	10	9	15
Electric power consumption, TWh	1051	1096	1104	1180	1205	1277	1305	1370	1420
GDP electricity intensity, %	100	101	97	97	91	95	83	92	77
Net exports, TWh	13	10	12	10	25	10	35	10	50
Electric power production, TWh	1064	1106	1116	1190	1230	1287	1340	1380	1470
Including									
HPPs	170	193	199	195	204	199	215	207	230
NPPs	195	221	221	223	227	229	238	250	269
Condensing TPPs	332	314	315	352	372	399	405	428	437
CHPs	365	367	369	405	407	438	451	466	488
NRESs	2	11	12	16	21	22	31	29	46
Heat supply, million GJ	2389	2473	2481	2732	2753	2958	3038	3146	3293
PER consumption, million tce	409	421	429	455	467	481	493	504	516
The same, % of the 2015 figure	100	103	105	111	114	118	121	123	126
Including fossil fuel, million tce:	289	286	289	317	324	342	345	357	358
gas	217	199	199	226	228	247	235	260	246
fuel oil	1	1	1	1	1	1	1	1	1
solid fuel	67	78	84	84	89	88	104	92	108

the demand for electric power will increase by 35% (see Table 4). However, owing to the technological renovation of the electric power industry, the primary energy consumption by the electric power plants and the district heating systems will be maintained at the half level of the total consumption by the country (see Tables 3–5). In the second energy-intensive sector—transport—the consumption of motor fuels will be increased by a quarter, while the power consumption by the public and industrial sectors will be behind the total domestic demand.

OBJECTIVES, MAIN PRIORITIES, AND EXPECTED RESULTS OF THE RUSSIAN ENERGY POLICY

In many respects, the Strategy is a compromise document that joins, sometimes not very effectively, contradictory tactical and strategic priorities and geopolitical, socio-economic, and commercial considerations. Its objectives are declared in a very general way as creation of an energy sector that effectively ensures a dynamic and sustainable socio-economic development of the country, i.e., capable of

(1) adequately, reliably, and safely satisfying the rational demand for fuel and energy at reasonable prices over the entire territory of the country;

(2) carrying out foreign trade activity in efficient volumes, forms, and directions considering the geopolitical interests of the country; and

(3) encouraging the development of the economy and improvement of the living standards of the people by expanding the scope and quality of the energy services, restraining simultaneously the growth of prices of energy carriers and increasing the investment demand for domestic products and tax revenues to budgets of all levels [4].

In the authors' opinion, the condition required to achieve the objectives stated in the Strategy is the adjustment of the institutional system of the energy sector, including the transition on the domestic market to the world ratios of energy carrier prices, although at naturally lower price levels than in the developed countries, harmonization of the taxes in the fuel industries on the basis of general principles, and a gradual decrease in the state's direct participation and encouragement of the competition on the energy markets. Not all these aspects of the energy policy are adequately reflected in the document.

The main priorities of the national energy policy stated in the Strategy include the following:

(1) In the sphere of governmental regulation of the markets, to develop of efficient forms of and condi-

Table 5. Basic parameters of the development of the centralized heat supply*

Parameter	2015	2020		2025		2030		2035	
Centralized heat, million GJ	5234	5234	5242	5296	5317	5359	5401	5401	5506
The same, % of the 2015 figure	100	100	100	101	102	102	103	103	105
Including									
thermal power plants	2370	2458	2466	2713	2734	2935	3014	3119	3266
central boiler plants	2495	2382	2378	2160	2144	1972	1926	1813	1758
Fuel consumption by boiler plants, million tce	101	96.5	95.4	87.5	86.2	79.3	77.5	72.6	70.4
The same, % of the 2015 figure	100	95.5	94.4	86.6	85.3	78.5	76.7	71.8	69.7
Including:									
gas	76	73.3	72.9	66.2	66.2	60.6	62.6	55.4	58.7
fuel oil	5	3.9	3.9	3.9	3.9	3	2.0	2.7	1.5
coal	15	13.1	12.4	11	9.0	9	5.3	7	1.7
biomass and waste	3	3.7	3.7	3.8	4.4	3.9	4.7	4.4	5.3

* Sources: 2015 Russian Statistical Yearbook, Moscow: Rosstat RF, 2016; [4]; calculations by ERI RAS.

Table 6. Characteristic of the comparative economic efficiency of the NPPs with respect to the gas- and coal-fired thermal power plants (the prices as of 2015)*

Index	Combined-cycle power plant		Coal-fired 24 MPa unit		NPP	
	2015	2035	2015	2035	2015	2035
Total plant cost (TPC) into the Central IPS, ths RUB/kW	50.1	45.1	85.7	85.7	132	101.6
Operating and maintenance (O&M) costs, % of TPC	3.0					
Construction period, yrs	2		4		6	
Heat rate, gce/kWh	0.225	0.205	0.315	0.30	–	–
Self-consumption factor, %	2.0		6.0		6.5	
Capacity factor, %	74		74		74	
Fuel cost component, RUB/(kWh)	0.95	1.42	0.69	0.91	0.19	0.21
Levelized cost of electricity (LCOE), RUB/(kWh)	2.15	2.50	2.94	3.16	3.68	2.58

Refer to [10] for the prices of the fuel for the TPPs. * Source: calculations by ERI RAS.

tions for the economic activity in the energy sector, including the measures of private–state partnership with businesses to ensure the growth of the value added created in the energy sector and the efficient capital influx to cover the investment demand of the sector by encouraging competition and improving the regulation of the rights of the market participants, the antimonopoly regulation, and the mechanisms of the exchange trade in basic fuel and energy types.

(2) In the taxation sphere, to ensure stable and predictable tax and customs regulations, harmonization of taxes for different energy industries, and correct and effective withdrawal of the natural rent for the development of the national economy without damaging the financial soundness and investment attractiveness of the industries and efficient companies of the Russian energy sector.

(3) In the pricing policy, arrangement of conditions for inter-fuel competition inside the country by reducing the disproportion among domestic prices of different kinds of fuel with the domestic prices of gas approaching equilibrium with the export prices.

(4) With respect to enhancing the energy efficiency, the maximum use of the existing potential of technological energy savings and enhancement of the quality and expansion of the range of energy services in all industries.

(5) In the sphere of science and engineering, creation of a sustainable innovation system in the energy sector and related sectors to provide all stages of pro-

duction, distribution, and consumption of energy with highly efficient domestic technologies and equipment, and breakthrough engineering solutions necessary for the efficient development of the energy industries and ensuring the stimulating role of the energy sector in the economy.

(6) In the regional policy, the balanced and economically efficient development of the energy sector and the infrastructure of the regions of Russia to ensure the regional energy security, to increase the self-reliance of the territories, and to effectively use the local energy sources.

(7) In environmental and climatic policy, ensuring of environmental security and sustainable development of the energy sector restraining in every possible way the growth in energy consumption and decrease in the adverse impacts of extraction, production, transportation, and consumption of energy resources on the environment, climate, and human health.

(8) In the social policy and the development of the human capital in the energy sector, guaranteed provision of the energy services for the population, expansion of the range and enhancement of the quality of these services, ensuring of the affordable prices of the energy for the socially significant users, improvement of the partnership of the energy business, society, and state, and supply of qualified specialists in the energy sector [4].

These general provisions of the Strategy are to be qualitatively specified and supported by the target figures, drawn up in the form of normative requirements for the development of the energy sector, and fitted with mechanisms of commercially incentivizing the energy-producing companies to implement the goals and tasks of the Strategy.

The systematic studies of the development prospects of the Russian energy sector conducted by specialists of the Energy Research Institute of the Russian Academy of Sciences (ERI RAS) show that, in order to achieve the goals and priorities of the energy policy stated in the optimistic scenario, the following is to be done by 2035:

(1) to increase the efficiency of utilization the energy resources in the end-user sectors, electric power industry, and district heating system to such an extent that the growth rate of the domestic energy consumption is sixfold behind the GDP growth;

(2) to ensure a structural shift in the energy consumption in favor of low-carbon resources—a growth from 13 to 16%—maintaining the share of natural gas at a level of 52–53% and decreasing the share of petroleum-based products from 19.4 to 17% and of fossil fuel from 15.3 to 13% of the total primary energy consumption;

(3) to encourage the inter-fuel competition increasing the electric power production by 35–38% by increasing the use of natural gas by the power plants by 13% and of noncarbon nuclear and renewable energy resources by 30%;

(4) to increase the significance of nonconventional and renewable energy sources (NRESs) in the energy balance of the country increasing their share in the primary energy consumption from 1.5 to 4–5% by a wide use of biomass, predominantly firewood and domestic and agricultural waste, wind, and solar energies in the electric power industry and the centralized heat supply;

(5) to restrict by 2035 the greenhouse gas emissions resulting from the energy use of fuels to a level 25% lower than the level of 1990 by taking the all mentioned above measures strengthening the latter after 2020 by economic incentives;

(6) to stabilize the energy component of the expenses in the energy-intensive industries and to reduce by one-third the share of the energy payments in the incomes of the population despite the growth in the domestic prices of gas, coal, and the electric energy for the industry by 1–2% higher than the inflation rate;

(7) to double the value added produced by the energy sector decreasing its contribution to the GDP from 27 to 23% owing to the advanced growth of other kinds of economic activity;

(8) to stabilize tax payments—calculated in real terms—effected by the energy-producing enterprises to the consolidated budget, i.e., to increase the nominal tax revenues according to the inflation rates, reducing the tax payment share from 32 to 21%; and

(9) to reduce the share of the energy sector in the total capital investments of the country from 24 to 15%, which will double, considering the import phase-out, the orders to machine-building and construction enterprises.

MAIN PROVISIONS OF THE STRATEGY CONCERNING THE DEVELOPMENT OF THE ELECTRIC POWER INDUSTRY AND THE CENTRALIZED HEAT SUPPLY

The main results of the implementation of the Strategy will be the effective use of the energy potential of Russia in order to maximally facilitate the recovery from the economic recession and the further sustainable development of the country in the first third of the 21st century. The document sets the task of a deep structural reconstruction and renovation of the electric power industry based on new technologies in consumption, development of centralized and distributed power generation under the condition of the advanced use of noncarbon energy resources, and transition to the smart power systems. For this purpose, the following measures are intended to be taken in the electric power industry and the centralized heat supply:

(1) intensive decommissioning of worn-out and outdated power equipment, replacing it by plants with better energy and environmental performance based predominantly on domestic equipment;

(2) modernization and development of the Unified Power System (UPS) successively connecting to it the Far East Integrated Power System and the isolated power systems, intensification of the interstate integration within the framework of the common energy market of the Eurasian Economic Union, and the increase in the electric power energy and capacity export, especially in the east of the country [9];

(3) development of new-generation power supply systems based on the combination of centralized and distributed generation, demand response, and new algorithms for smart controlling the grid and the operating conditions of the power systems, from local to national levels;

(4) radical modernization of the centralized heat supply systems overcoming the decline in the heat consumption (increasing it by 3–5% by 2035) and creating a competitive environment based on the development of small-scale cogeneration, including the use of nonconventional energy resources; and

(5) encouragement of the competition and development of the methods for the governmental regulation of the operation and development of the electric power industry and centralized heat supply to curb the growth in the prices of electric energy and heat near the inflation rates.

The optimistic scenario of the development of the electric power industry provides for a 38% increase in the electric power production and an 18% increase in the installed capacities of the power plants by 2035 (see Table 4). The predominance of the thermal power plants (TPPs) in production of electric power will be preserved, with their portion being reduced from 65% in 2015 to 63% in 2035. The basic strategic tasks of the development of the TPPs are:

(1) the renewal of the equipment presently in operation; the effective methods of the renewal considered in [10] provide for reconstruction and replacement of 80% of the capacity of the existing TPPs and

(2) the development of central heating, including distributed cogeneration, applying the ways considered in [11] with the portion of the TPPs in the centralized heat balance exceeding 50% among others by intensive development of the industrial and public distributed generation.

Under the optimistic scenario, the solution of the above tasks and other measures aimed at the enhancement of the efficiency of the thermal plants will reduce the average heat rate for generation of electric energy by 12% and slow down the growth of the consumption of fossil fuel to 24% (see Table 4), with the portion of gas in the primary energy consumption by the electric power plants reduced from 53.1 to 47–48%. Under the conservative scenario, the heat rate will decrease by 7%, while the portion of gas in the energy consumption by the electric power plants will be reduced by only 1.5%. The accelerated reconstruction of the industry under the optimistic scenario will ensure an absolute gas consumption rate 6% lower than that in the conservative scenario.

One of the controversial problems that arose in the course of working out the Strategy was the scale of the development of the nuclear power plants (NPPs) determined by the requirements for the economic efficiency of the latter, the improvement of the energy balance structure, and the preservation of Russia's technological leadership in this field.

The rates of the increase in the capacities—considering the decommissioning of the existing units that have exhausted their design service life—and the nuclear power generation adopted by the Strategy are determined by the optimization of the electric power industry as an integral part of the country's energy sector and are caused by the following noneconomic considerations:

(1) diversification of the energy sector of the country in behalf of the energy security;

(2) restraint of the growth in the greenhouse gas emissions; and

(3) support and development of the "infrastructure" of the country's most high-technology nuclear power sector that involves training of personnel, research and development, development of special enterprises and competences, production of equipment prototypes for the subsequent export, etc.

The increase in the portion of the NPPs will also be facilitated by the increase in the competitiveness of the latter against the combined-cycle and coal-fired TPPs over the period in question owing to:

(1) improvements of new nuclear units under design and reduction in the costs of construction— by 10–15% [12, 13] for the domestic new-generation VVER-TOI reactors—and operation;

(2) an increase in the price of gas for electric power plants by 1.5 times (in real terms) envisaged by the Strategy [10]; given a long-term decrease in the gas export margin, such an increase in price is necessary for maintaining the gas recovery in the gas fields that are becoming increasingly expensive as well as for encouraging the end users to save energy, especially in the electric power industry under large-scale renewal of the TPPs; and

(3) the effect of devaluation of the ruble, which is beneficial for the NPPs compared with the large CCGT units competing with the former, since the portion of the imported equipment in the CCGT is still large; the effect of this factor, however, will gradually become weaker as the import is successfully phased out and the production of the domestic gas turbines is mastered.

The LCOE calculations according to methods adopted by the IEA [14] and IAEA [15] show that, under the existing ratio of the capital investments in the thermal and nuclear plants and the current prices of gas, the levelized cost of electricity generated by new

Table 7. Comparative economic efficiency of the gas-fired and renewable power plants, incl. the "system effects" for RES integration (prices as of 2015)*

Index	Combined-cycle power plant		Wind power plant		Solar power plant		Gas turbine	Storage (batteries)
	2015	2035	2015	2035	2015	2035		
Total plant cost (TPC) into the Central IPS, ths RUB/kW	50.1	45.1	110.0	95.7	114.1	57.1	20.1	64.0–32.0
Operating and maintenance (O&M) costs, % of TPC	3.0		1.5		2.1		5.6	3.0
Construction period, yrs	2		2		2		1	1
Heat rate, gce/kWh	0.225	0.205	–	–	–	–	0.324	–
Self-consumption factor, %	2.0		0.3		0.3		2.0	10.0
Capacity factor, %	74		23		17		–	–
Fuel cost component, RUB/(kWh)	0.95	1.42	–	–	–	–	–	–
Levelized cost of electricity (LCOE), RUB/(kWh)	2.15	2.50	7.03	4.98	10.77	6.19	–	–
Same considering the "system" effect (partial duplication of the gas turbine)	–	–	8.86	6.45	13.22	8.64	–	–
Same using the energy storage systems (power output control)	–	–	13.00	8.04	18.90	11.06	–	–

* Source: calculations by ERI RAS.

NPPs in the Center Interconnected Power System (IPS) is almost 1.7 times higher than that of CCGT. However, the predicted increase in the prices of gas and reduction in the construction costs of the new-generation NPPs decrease the LCOE value of the latter making the nuclear generation economically commensurate with the gas generation (see Table 6). Additional factors that make the electric power generated by the NPPs cheaper are an increase in the use of the NPP capacity to 90% with the LCOE decreasing by 15% or a reduction in the cost of capital, which is reduced LCOE by 17% with the discount decreasing by two percent points (pp).

For all the above reasons, including noneconomic considerations, under the scenarios of the Strategy, the installed capacity of the NPPs will have increased by 28–36% by 2035 and the power generation will have increased by 30–38%, which will allow stabilization of the portion of the NPPs in the total electric power production at a level of 18% (see Table 4). In that period, a new technology platform will be created for the nuclear power production equipped with advanced water-moderated and fast-neutron reactors with a closed nuclear fuel cycle.

The power plants based on renewable energy resources will be developed intensively with the electric power generated by large-scale hydroelectric power plants (HPPs) increasing by 20–35% and NRES-based power plants increasing by 15–23 times (see Table 4). In connection with this, the main tasks of the development of the NRESs are:

(1) acquisition of practical experience in the exploitation of the NRESs under the natural and climatic conditions of Russia considering the specific features of the country's energy sector;

(2) certain restraints on the growth of the fossil fuel consumption accompanied by diversification of the energy balance of the regions and reduction in the greenhouse gas emissions; and

(3) mastering of foreign and development of domestic methods, equipment, and materials for the renewable energy production and training of qualified domestic specialists.

A fundamental problem of using the NRESs under the conditions of Russia is their economic uncompetitiveness in the zones of the centralized power and gas supply. Under the current level of capital costs [16], the electric power generated by new wind and solar power plants (WPPs and SPPs, respectively) is 3.3–5.0 times more expensive than that of the power generated by a new CCGT plant (see Table 7). The expected reduction [17] in the capital costs of NRES-generation—by 15% for the WPPs and a 50% reduction for the SPPs—and the expected increase in the prices of gas will decrease this ratio in Russia by approximately 2.0–2.5 times. The reduction in the cost of the capital for the projects of the renewable power production by 2 pp will decrease this ratio to 1.7–2.2. However, for energy supply of the most end-

Table 8. Capital investments into the development of the electric power and heat supply, bn USD (prices as of 2014)*

Electricity and heat sources	2011–2015	2016–2020	2021–2025	2026–2030	2031–2035	2016–2035
Power systems, total	115	97–118	135–170	163–169	138–173	520–621
Including						
HPPs and NRESs	12	10–17	7–11	8–17	12–20	37–65
TPPs	38	29–25	61–70	69–75	63–67	222–237
electric power grids	40	19–27	31–41	39–40	35–38	124–147
NPPs	25	39–49	37–48	33–37	28–38	137–172
Decentralized electric power generation	5	7–8	10–12	14–19	17–22	48–61
Centralized heat supply	29	29–30	30–32	28–31	29–33	116–126
Renewable heat sources	2	4–6	4–10	7–14	10–19	26–49
Total for electric power and heat supply sources	151	137–162	179–224	212–226	194–237	710–857

* Source: calculations by ERI RAS.

users of Russia, the NRES-power will remain much more expensive than that generated using the conventional sources. The main reason for this are worse natural conditions in the most-developed areas of the country and lower prices of fuel compared with the countries that extensively switch over to the noncarbon energy sources.

The competitiveness of the NRES-generation is reduced by the accompanying expenses on its integration into the power supply systems (the system effect). Even if we do not consider the construction of additional electric grids, large-scale development of WPPs and SPPs, which do not regularly generate the electric power, will necessitate either partial duplication of the capacities, e.g., increasing the gas turbines, or installation of energy storage systems that control the electricity output of the former. Calculations show that the system effect, in particular, the necessity of partial duplication of the capacity, increases the price of the WPP energy by 30% and that of the SPP energy by 40% eliminating the basic part of the cost reduction effect of the wind and solar power technologies. The use of energy storage systems—even doubly cheapened—proves to be an even costlier solution, since the price of wind and solar power will increase in 2035 by 60–80%, i.e., it will reach the current level or even exceed it (see Table 7).

Considering the technological and structural reconstruction of the Russian electric power industry, the share of noncarbon resources in the total primary energy consumption by the country's power plants will increase from 29% in 2015 to 31% in 2035 with the share of the fossil fuel decreasing accordingly; the share of natural and associated gas will reduce from 53 to 51–48% while the share of the solid fuel will increase from 16 to 18–21%.

The implementation of the scenarios of the development of the electric power industry and centralized heat supply considered in the Strategy will require the capital investments presented in Table 8. Under the conservative scenario, the capital investments in the development of the centralized electric power generation, upon reduction by 16% in the current 5-year period compared with the 2011–2015 period, will increase over the next three 5-year periods by 25% on average and will be allocated predominantly in the development of the TPPs (43%), NPPs (26%), and electric grids (24%). Under the optimistic scenario, the capital investments will be slightly increased as early as in the current 5-year period and then will exceed the level of 2011–2015 by 45% on average with the share of the TPPS (38%) decreasing in favor of HPPs + NRESs (11%) and NPPs (28%) compared with the conservative scenario with the share of the capital investments in the development of the electric grids being preserved.

Under both scenarios, the capital outlays on the centralized heat supply will remain at the level of the last 5-year period and will be increased by 9–12 times on the decentralized electric power generation and by 13–25 times on the renewable heat sources; however, altogether, they will account for only 12–13% of the total capital outlays on power and heat supply of the country.

Under the conservative scenario, the level of prices of the electric power necessary for financing the required capital investments and the reliable functioning of the industry are to increase and outpace the inflation by 18–20% in the first 5 years and then practically stabilize, while, under the optimistic scenario, they are to outpace the inflation by 0.5 pp on average having increased almost by 30% by 2035 (see Table 9). The current ratios between the zonal prices of the electric power will be preserved in general. In the European zone, the prices increase in the same way as do the average prices in Russia remaining 3–5% higher, while the hydro and coal-based electric power indus-

Table 9. Dynamics of the prices of the electric power in the main market zones, kopeck/(kW h) (prices as of 2015)*

Market zone	2015	2020	2025	2030	2035
Russia, total	346	409–416	404–424	397–430	409–446
European zone	357	423–430	419–439	411–445	425–465
Siberian zone	271	330–336	327–343	328–356	341–372
IPS of the Far East	364	546–557	498–524	477–504	449–468

* Source: calculations by ERI RAS.

try of Siberia will ensure the price levels 20–22% lower than the average prices in Russia.

The greatest uncertainty of prices is characteristic of the electric power produced in the Far East. By 2020–2022, the implementation of relatively large-scale investment projects and the increase in the consumption of the country's most expensive gas will have caused an increase in the electricity price in the Far-East IPS by more than 30%. However, under both scenarios, the infrastructural work-in-progress will allow a reduction in the electricity price by 2025 and further stabilization of it approaching the price level in the European zone. To implement the scenario of a faster equalization of the energy prices for the users in the Far East with the all-Russia prices, the sizes of the inter-regional financing should be increased, redistributing part of the required gross returns between the price zones of the European part of the country and Siberia, which will result in a further growth of the price pressure on the users of these zones.

To achieve the predicted price parameters of the development of the electric power industry, large amounts of work will be required to improve the existing system of tariff and competitive pricing mechanisms in order to create adequate incentives for further effective investment of the industry under minimization of the price pressure on the users.

CONCLUSIONS

(1) The Energy Strategy of the Russian Federation for the period until 2035 [4] is less ambitious compared with the previous documents [2, 3] with regard to the tasks in the energy policy, forecasts of the domestic energy demand, and the development of the electric power industry of Russia; therefore, it is more viable, especially during the first 5 years[1]. However, the volumes of the energy export stated under the optimistic scenario of the Strategy and the development of the fuel industries of Russia caused thereby are considerably higher than the predictions of the world energy markets [4], which is a serious risk factor.

(2) The demand for energy and fuel in Russia will overcome the stagnation and have restored a moderate growth—3–4 times slower than the economy—by 2020 and the electric power will continue to displace other energy resources outstripping the growth of the total energy consumption by more than two times.

(3) Fossil fuel will remain the base of the energy balance of Russia accounting, under a regular reduction in its share, for at least 85% of the total energy consumption. The prevailing demand for gas will be preserved with the consumption of the liquid and solid fuels decreasing under an increase in the share of the noncarbon energy resources. The inter-fuel competition will be facilitated by growth in the gas prices outstripping the inflation, which is necessary for ensuring the domestic consumption and energy export under an inevitable increase in the gas production and transportation costs; by approximately 2030, such growth will ensure a yield level of the prices equal to that on foreign markets. The increase in the gas prices is a significant factor in enhancing the energy efficiency, primarily, in the electric power industry—the largest user of gas on the domestic market—including both an increase in the economic efficiency of replacing the equipment by CCGT and the development of central heating based on the CHP plants.

(4) The electric power industry will remain the key field of the inter-fuel competition, which will become more intense with noncarbon energy production and energy storage technologies becoming cheaper. The thermal power plants will hold their leadership in the electric power production; their portion, however, will decrease by 1.0–1.5 pp with the portion of the NPPs being preserved and the common portion of HPPs and NRESs increasing accordingly. The growth in the prices of the fuel for the TPPs and advancements in the projects for the nuclear power industry will increase the market competitiveness of the NPPs; however, concerning the NRESs in Russia, considering the costs of their integration into the power system, the renewable sources in the centralized power supply zone will have remained noticeably more expensive by the end of the period than that produced by the TPPs.

(5) Owing to the intensive development of the noncarbon power plants and renovation of the thermal plants, the portion of consumption of the fossil fuel in the total primary energy consumption by the power industry of Russia will be reduced by 1.0–1.5 pp. A more intensive increase in the energy efficiency of the gas generation, along with a considerable increase—of 1.5 times compared with the prices of 2015—in the

[1] The legally established interval of upgrading the strategic planning documents [5].

domestic gas prices, will decrease the portion of gas in the primary energy consumption by the power plants by 3–5 pp owing to the increased role of coal.

(6) Despite the expected increase—in terms of the fixed 2015 prices—in the price of the fuel for the power plants by 40–50% and in the capital investments in the development of the power systems by 25–45%, the prices of the electric energy will have increased by 2035 only by 20–30% owing to reduced specific fuel and operating costs upon renovation of the power plants and power grids and to the increased investment resources of the industry at the expense of the increasing depreciation deductions from the accumulated capital investments.

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Translated by O. Lotova