Prospects for development of Russia's power industry up to 2030

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ABSTRACT

The paper defines strategic priorities and directions in Russia's power industry development that require determination of energy demand scenarios and fuel price dynamics. The structure of power production within the fuel and energy complex (FEC) of the country, the rational structure of generation capacities of Russia's Unified power system (UPS), levels of distributed generation, measures on electric load control are optimized. Development of the main grid of UPS is forecasted. The adequacy and load flows of UPS of Russia are studied.

Key words: **Russia's power industry development, generation capacities, electric network, technologies of electricity production and distribution**

1. INTRODUCTION

In 2008-2009 the Ministry of Energy of the RF worked out the Energy Strategy of Russia for the period up to 2030 that was approved by the Government of the RF in August 2009. The section devoted to power industry in the Energy Strategy was elaborated by Krzhizhanovsky Energy Institute and Melentiev Energy Systems Institute, SB of RAS in cooperation with other institutions and some experts of the power industry. The principal concepts of power industry development in Russia that stem from the performed studies are described below. The work was done with participation of researchers from MESI: Prof. Yu.D.Kononov, Prof. A.M.Kler, Prof. B.G.Saneev, Prof. A.D.Sokolov, Dr. V.N.Khanaeva, Dr. I.Yu.Usov, Dr. V.V.Khanaev, Prof. G.F.Kovalev, Dr. L.M.Lebedeva, A.B.Osak et al.

2. MAIN PROBLEMS OF RUSSIA'S POWER INDUSTRY

For the years after disintegration of the USSR the economic indices of power industry operation have degraded. Since 1991 relative power losses in electric networks have increased by more than 1.5 times. Specific number of personnel in the industry has increased by more than 1.5 times. Efficiency of investment used has decreased by more than 2 times. Construction of generation capacities has declined substantially. From 1992 to 2008 construction of new generation capacities in Russia made up 24 GW (about 1.4 GW a year), which is approximately 5 times lower than that in the 60-80s of the past century.

Other problems of Russia's power industry are:

- acceleration of the process of energy equipment ageing. The share of obsolete equipment exceeds 40%;
- shortage of generation and network capacities in some regions of the country;
- sophistication of power system reliability problem and more heavy conditions for regulation of the variable part of daily load curves;
- high dependence of power industry on natural gas;
- sharp decrease in research-technological and building potential of the industry.

Therefore, the priority goal of the power industry of the country is to choose strategically proper decisions on power industry development, mechanisms and structure of its management that provide electric power security of the country, sustainable development and effective operation of power industry.

3. INITIAL CONDITIONS IN STRATEGY ELABORATION

The strategy of power industry development is based on the scenario of innovation economic development of the country (the base scenario) that was adopted in the Energy Strategy of Russia.

Dynamics of domestic energy demand for this scenario is characterized by the boundary values presented in Table 1.

TABLE 1. DYNAMICS OF ENERGY DEMAND

Indices	2005	2008	2015	2020	2030
Electricity demand, billion kWh	941	1021	1110 - 1220	1315 - 1518	1740 - 2164
Centralized heat demand, million Gcal	628	601	600 - 620	660 - 690	785 - 830
Export-import (balance), billion kWh	12	17	18 - 25	35 - 40	45 - 60

These boundary values underlie three variants considered: higher and lower levels of electricity demand that correspond to the bounds of the considered range and also an averaged variant with doubled electricity demand in 2030.

In the regional aspect the growth rates of electricity demand in East Siberia and the Far East were supposed to be above the average ones for the country.

Table 1 also presents possible volumes of Russian electricity export-import.

According to the fuel price forecast by 2030 the average gas prices will reach US$205-245/1000 m^3 (they will rise by 5.5-6.5 times as compared to 2005) in the European part of Russia and Ural, US$130-150/1000 m^3 (by 3.6-4.0 times) in Siberia and the Far East. The average coal prices will be US$80-100/tce (they will rise by 2.2-2.8 times) in the European part and Ural and US$55-80/tce (by 2.1-2.2 times) in Siberia and the Far East.

4. EXPANSION OF GENERATION CAPACITIES

The studies underlying elaboration of power industry development strategy were carried out based on the methodological concepts described in [1, 2] by using the optimization mathematical model of the national FEC development [3].

The results of studies performed have revealed that the total construction volume of new, substituting and updating capacities for the considered variants of electricity and heat demand growth (higher, averaged, lower) for the period up to 2030 accounts for 297, 261 and 206 GW, respectively.

Generation capacities will be commissioned mainly at thermal power plants (TPP). In the averaged variant it will be needed to construct 155 GW of TPP, 67 GW of hydro power plants (HPP) including pumped storage plants (PSP), and renewable energy sources (RES) and 39 GW of nuclear power plants (NPP) by the year 2030.

As a result the structure of generation capacities and power production in Russia will change by 2030 towards wider use of NPP, HPP and coal-fired TPP and RES.

For the averaged variant the installed capacity of power plants in 2030 will amount to 410 GW, of which 239 GW of TPP, 57 GW of NPP, 114 GW HPP and RES. Power generation will make up 2045 billion kWh, of which 1265 billion kWh at TPP, 400 billion kWh at NPP, 380 billion kWh at HPP and RES.

The structure of fuel consumed at TPP will change towards decrease in the natural gas share from 70.3% in 2008 to 60-62% in 2030, towards increase in the coal share from 26% in 2008 to 34-36% in 2030. The ratio between the coal and gas shares will be determined therewith by the gas and coal price situation and the state policy of diversification of fuels used in power industry.

The total demand for fossil fuel in the averaged variant will amount in 2030 to 440 million tce, of which 266 million tce for natural gas, 161 million tce for solid fuel, 6 million tce for fuel oil.

Dynamics of generation capacity expansion and power production for the averaged variant is illustrated in Tables 2-5.

TABLE 2. INSTALLED CAPACITY OF POWER PLANTS IN RUSSIA, GW, %

Power plants	2008	2015	2020	2030
NPP	23.8 10.6%	32 12.8%	39 13%	57 13.9%
HPP and RES	47.2 21%	57 22.8%	71 23.7%	114 27.8%
TPP	153.9 68.4%	161 64.4%	190 63.3%	239 58.3%
Total	**224.9**	**250**	**300**	**410**

TABLE 3. CONSTRUCTION/DISMANTLING OF POWER PLANTS IN RUSSIA, GW

Power plants	2009-2015	2016-2020	2021-2030	**2009-2030**
NPP	8 / 0	7 / 0	24 / 7	**39 / 7**
HPP and RES	10 / 0	14 / 0	43 / 0	**67 / 0**
TPP	16 / 9	42 / 13	97 / 48	**155 / 70**
Total	**34 / 9**	**63 / 13**	**164 / 55**	**261 / 77**

TABLE 4. POWER PRODUCTION BY POWER PLANTS IN RUSSIA, BILLION KWH

Power plants	2008	2015	2020	2030
NPP	163	205	268	400
HPP and RES	167	190	233	380
TPP	705	755	969	1265
Total	**1037**	**1150**	**1470**	**2045**

TABLE 5. POWER PRODUCTION STRUCTURE IN RUSSIA, %

Power plants	2008	2015	2020	2030
NPP	15.7	17.8	18.2	19.6
HPP and RES	16.1	16.5	15.9	18.6
TPP	68.2	65.7	65.9	61.8
Total	**100.0**	**100.0**	**100.0**	**100.0**

The optimal structure of generation capacities with detailed description of operating conditions of electric power systems (EPS) was calculated on the sectoral mathematical model SOYUZ [4]. The calculations aim to control admissibility of the above variants in terms of technical requirements for operation of Interconnected power systems (IPSs) and UPS of Russia.

From the results of calculations it follows that all the assessed variants are admissible in terms of technological capabilities to cover daily operating conditions of EPS on a winter and summer working day. Maneuvering capabilities of generation capacities are sufficient to cover the minimums of daily loads curves. Loads at the hour of maximum of the coincident load curve in UPS on a working day in December are covered in all variants with a considerable surplus. The actual value of capacity reserve increases in this case to 21-22% in 2030 at the rated demand of 15%.

The strategy of generation capacity expansion is based on the following **basic principles.**

The formed situation in power industry with regard for its high inertia can be overcome by accelerated development of electric power potential of the country.

In the short run it can be achieved by extensive construction of highly effective power plants with combined cycle (CCI) and gas turbine (GTI) installations, first of all at operating power plants, accelerated completion of started electric power facilities and also network construction to eliminate “bottlenecks” in the system of power transmission. The outpacing growth of generation capacities even at the beginning of the studied period will make it possible to start radical updating of thermal power plants on the basis of CCI and GTI and bring the average efficiency of gas-fired power plants to 50% and to 55-60% of new power plants by 2030. It is necessary to update district gas-fired boiler plants by installation of GTI with waste-heat boilers.

In parallel more capital-intensive power plants – coal-fired and nuclear – should be built at accelerated paces.

The main directions in heat power industry development for the period up to 2030 are the re-equipping and upgrading of thermal power plants and also construction of new capacities by using new advanced technologies of power production. CCI should be installed at gas-fired TPP. For coal-fired TPP these are installations with supercritical steam parameters, installations with fuel combustion in circulating fluidized bed, installations with coal gasification or its combustion in pressurized fluidized bed boilers.

New technologies for NPP include pressurized water reactors (PWR) of higher security, large fast reactors in the closed nuclear fuel cycle, modular gas cooled reactors for industrial heat production.

In the European part of the country the power industry will develop mainly on the basis of construction of combined cycle power plants and nuclear power plants in combination with PSP to meet a variable part of load, maximum utilization of the hydro power potential of North Caucasus and North-West, local fuels, potential of small-scale hydro power industry.

In Ural the power industry will develop primarily on the basis of construction of gas- and coal-fired and nuclear power plants.

In Siberia and the Far East the power industry will develop chiefly owing to construction of new HPP and coal- and gas-fired power plants (as gas fields in this region of the country are developed to mitigate environmental situation first of all in large cities). Besides, in some regions of Siberia and the Far East expensive fossil fuel and heavy environmental situation will necessitate construction of NPP.

On the whole, generation capacity expansion will lead to the following situation.

By 2030 all currently available generation capacities on gas will be represented mainly by 70-450 MW CCI with the efficiency 52-53%. Among new combined cycle installations there are installations with a unit capacity of 325-800 MW with the efficiency 55-60% and CCI of lower capacity at cogeneration plants (CP). GTI and a combination of GTI with waste-heat boilers will be extensively used for electricity and heat production.

Generation capacities on coal will be represented by installations with supercritical steam parameters of the efficiency 46-55%, installations with circulating fluidized bed boilers, boilers with low-temperature swirling-type furnaces as well as pioneering installations with coal gasification and for combined production of synthetic fuels and electricity. The total average efficiency of power production at coal-fired installations will be about 41%.

By 2030 the commercial power units of NPP with PWR of higher security and large capacity (1000-1500 MW) with the efficiency up to 36% will dominate in the nuclear power industry in the European part of Russia. Commercial power units with large fast reactors with the efficiency above 40% on the uranium and uranium-plutonium fuel in the closed nuclear fuel cycle will be introduced in Ural. Nuclear power plants and nuclear cogeneration plants with PWR of the average capacity (up to 600 MW) of higher security will be used in the peripheral parts of UPS of Russia and in the isolated power systems. The floating nuclear power plants of small capacity (up to 70 MW) will be utilized in the coastal areas of the Extreme North and the Far East. High-temperature modular nuclear reactors with gas cooling are designed for industrial heat supply, production of hydrogen, synthetic liquid fuel, etc.

Hydro power plants of different capacities with their concentration in the regions of East Siberia and the Far East will be extensively used, performing the backbone functions and covering a peak part of the load curve..

Increase in power generation by HPP in Siberia and the Far East will depend on their competitiveness with coal-fired TPP.

An important factor will be the possibility to gain multiplicative effects of development of these regions owing to construction of new HPP and creation of clusters of industrial enterprises on their base – consumers of HPP power. Construction of large hydro power complexes: Nizhne-Angarsk, South-Yakutia, Vitim and Lower-Yenisei can be the main direction in achieving these effects.

Electric power of these complexes can be used for development of sizable local natural resources and transmitted by AC and DC transmission lines of superhigh voltage to other regions.

Unconventional energy will be represented by wind turbines, power units using energy of sun, biomass, biogas, gas emitted by production and consumption waste, gas formed at coal mines, geothermal energy and tidal energy of seas and oceans.

Heat production will be concentrated at large cogeneration plants with decrease in their share in heat supply due to development of small cogeneration systems (GTI with waste-heat boilers) and autonomous heat supply plants.

The trends in the world power industry are stipulated by both the growing scales of power production at traditional large power plants and by the increasing share of distributed power generation. These trends depend on the necessity to adapt consumers and EPS expansion to the market uncertainty, emergence of new highly effective energy technologies, the increasing share of high-grade fuels, the toughening of environmental requirements that encourage RES utilization.

Table 6 presents the forecast of distributed power generation development up to 2030 based on the analysis of available resources, demand for electric and heat energy, capabilities of equipment manufacture. By the obtained estimates in 2030 the share of distributed power generation sources in the total electricity production can amount to about 16 %, in heat production – above 20 %.

Measures on electric load control (energy saving, load-controlled consumers) are an alternative to generation capacity expansion. The potential and optimal scales in using different load-controlled consumers by 2030 are determined based on the expert analysis and calculations on the mathematical model [5] (see Table 7). The potential of all types of such consumers in Russia totals 173-192 GW for the considered range of power demand. Most of this potential is concentrated in the Central Federal District (50-55 GW), the South Federal District (25-28 GW) and the Volga Federal District (36-39 GW). The main load-controlled consumers are residential consumers, facilities for electric heating with heat storage and electrified transport (electric vehicles).

TABLE 6. FORECAST OF DISTRIBUTED POWER GENERATION DEVELOPMENT

Source	2005	2015	2020	2030
Gas turbine, combined cycle and steam turbine CP				
Power generation, billion kWh	1.2	35-40	80-110	220-280
Electric capacity, million kW	0.45	6-8	15-20	40-50
Renewable energy sources				
Power generation. billion kWh	7.0	15-20	20-25	50-70
Electric capacity, million kW	2.2	5-6	7-8	17-23
Distributed heat sources				
Heat production, million Gcal	4.2	50-70	130-170	340-420
Thermal capacity, thousand Gcal/h	1.5	18-24	45-60	120-150

The calculations of optimal scales for using load-controlled consumers have shown that industrial and agricultural consumers, facilities for electric heating with heat storage, electric vehicles and refrigerators are the most effective. The total optimal capacity of all types of load-controlled consumers in Russia makes up 11 GW.

Thus, in 2030 generation capacities will include energy facilities operating on advanced technologies of the world level. The average specific consumption of equivalent fuel per kilowatt hour will decrease at thermal power plants to 270 gce in 2030 in comparison with the existing level of 333 gce.

TABLE 7. POTENTIAL AND CAPACITIES OF LOAD-CONTROLLED CONSUMERS, 2030, GW

Consumer	Potential	Opt. capacity
Transport		
Electric vehicles	70-80	2.0
Hydrogen vehicles, hydrogen production	1.5-1.7	0
Climatic facilities		
Refrigerators	8-10	0.1
Electric heating with heat storage	56-62	1.7
Ordinary consumers		
Residential	28-29	0
Industrial	9-10	7.3
Agricultural	0.2-0.2	0.2
Total	173-193	11.3

5. DEVELOPMENT OF ELECTRIC NETWORKS

The main grid of UPS of Russia up to 2030 should develop primarily by reinforcing the AC grid. DC transmission lines can be used for power transport over long distances and also for power export.

The main AC highest-voltage grid in UPS of Russia should be reinforced by using voltages 220(330)-500(750) kV. The voltage 1150 kV can be valid only for transit transmission lines and requires special substantiation.

The 750 kV AC network will be expanded in the European part of Russia for increase of intersystem ties of IPS North-West with IPS Center, power output by NPP and potential increase of electric ties with Belarus and Ukraine.

The 500 kV AC transmission lines are needed to reinforce main grids in IPSs South, Center, Middle Volga, Ural, Siberia and East and increase ties among them.

The 330 kV AC network will continue to perform backbone functions in some power systems of the European part of Russia (IPSs South, North-West, Center, Kaliningrad power system) and provide power output from power plants.

The 220 kV transmission lines in the majority of power systems will perform distribution functions and deliver power to nearby consumers. They can also be used for interconnection of isolated power systems of Sakha Republic (Yakutia) and their connection to IPS Siberia, reinforcement of electric ties in Arkhangelsk power system, power system of Komi Republic and in isolated power systems of Siberia and the Far East.

In the future the new breakthrough technologies will be used in systems of power transmission and distribution. The “ideal” conductor will have conductivity of high-clean copper, weight of aluminum, strength and service life of high-grade steel.

Controlled devices and new highly effective systems of electric network control will find extensive application. Among the controlled devices there are controlled shunt reactors, thyristor-controlled static compensators, series capacitive compensators, unified power flow controllers, phase shifters, STATCOM; facilities of asynchronous link – HVDC transmission lines and back-to-back DC links, electromechanical converters; electricity storage facilities. Besides, superconductors, first of all cables, SMES, current limiters will also be used.

The studies performed on expansion of the transfer corridor East – West have shown a relatively high cost of increasing transfer capability of electric networks that is comparable with the cost of power plant construction. The analysis of joint power output from power plants of West (Tyumen power system) and East Siberia to Ural and the European regions of Russia has revealed essential dependence of two power flows on each other. Such dependence necessitates a detailed consideration of all main ties in the transfer corridor Siberia – European part of Russia and joint studies on the prospects for power industry development in the regions of East and West Siberia, Ural and European part of the country.

Table 8 presents the maximum calculated values of required transfer capability of electric ties between IPSs for the time horizon to 2030. The highest increase in transfer capability of ties is seen to be needed in the cutset Ural – Siberia (by 5.7 GW by 2030). It is economically efficient to integrate IPS East into UPS, providing the power flow of at least 1000 MW from IPS Siberia to IPS East. It is also expedient to connect power systems of West and Central Yakutia to UPS of Russia.

TABLE 8. TRANSFER CAPABILITY OF INTERSYSTEM TIES, MW

Cutset	Current	2030
North-West – Center	1500	2800
Center – Middle Volga	3500	6100
Center – South	2400	3500
Middle Volga – Ural	3000	4500
Ural – Siberia	3300	9000
Siberia – East	0	1000

The priority directions in reinforcement of electric ties are:

- Construction of the second 750 kV transfer corridor IPS North-West – IPS Center to reinforce the ties and improve reliability of parallel operation of these IPSs.

- Contruction of the 750 kV transmission line Kalininskaya NPP – Kaluzhskaya NPP to improve power output from Kalininskaya NPP.

- Construction of the 330 kV transmission line Kirishskaya condensing power plant (CPP) – Syas substation (SS) – Petrozavodsk SS – Onda SS – Putkinskaya HPP – Kolskaya NPP (the second circuit of the transfer corridor) to improve transfer capability of the 330 kV corridor Kolskaya EPS – Karelskaya EPS – Leningradskaya EPS to cover deficit of Karelskaya power system.

- Construction of the 500 kV transmission line Pomary SS – Udmurtskaya SS to reinforce the transfer corridor Ural – Middle Volga – Center, improve reliability of Tatarskaya, Chuvashskaya and Mariiskaya power systems.

- Construction of the 500 kV transmission line Gazovaya SS – Krasnoarmeiskaya SS to reinforce the transfer corridor Center – Middle Volga.

- Construction of the 500 кВ transmission line Kostromskaya CPP – Nizhegorodskaya SS (the second circuit) to reinforce the transfer corridor Center – Middle Volga.

- Construction of the 500 kV transmission line Balakovskaya NPP – Klyuchiki SS (the second circuit) and Klyuchiki SS – Penza-2 SS to remove limitations on power output from Balakovskaya NPP and Saratovskaya HPP and reinforce the ties with IPS Center.

- Shift of the 500 kV transfer corridor Irkutsk – Buryatia – Chita to the nominal voltage to improve reliability of power supply of the Trans-Baikal part of IPS Siberia.

- Construction of the 500 kV transmission line Omsk SS – Ishim SS – Kurgan SS and Tobolsk SS – Ishim SS to reinforce the ties between IPSs Siberia and Ural.

- Construction of the second 500 kV circuit Alyuminievaya SS – Abakanskaya SS – Itatskaya SS to provide guaranteed power supply of the Abakan-Minusinsk area.

- Construction of the 500 kV transmission line Severnaya SS – Vyatka SS to increase transfer capability of the 500 kV network of IPS Ural.

- Construction of the 500 kV transmission line Severnaya SS – BAZ SS to improve reliability of power supply of the Berezniki-Solikamsk and Serovo-Bogoslovsk areas, increase power output from Permskaya CPP.

- Construction of the 500 kV transmission line Troitskaya CPP – Privalovo SS to improve reliability of power supply of the Kropachevo – Miass area of Chelyabinsk power system and increase power output from Troitskaya CPP.

- Construction of the 500 kV transmission line Surgutskaya CPP-2 – Magistralnaya SS to increase transfer capability of the 500 kV ties between Surgutskaya CPP and the southern part of Tymen power system.

- Construction of the 500 kV transmission line Stavropolskaya CPP – Nevinnomysskaya SS to improve operation reliability of Stavropolskaya CPP.

- Construction of the 500 kV transmission line Balakovskaya NPP – Kurdyum SS – Frolovskaya SS to reinforce the ties between IPS South and IPS Middle Volga.

- Construction of the 500 kV transmission line Frolovskaya SS – Rostov SS – Shakhty SS to improve operation reliability of UPS of Russia, reinforce the cutest Volgograd – Rostov.

- Construction of the 500 kV transmission line Volgodonskaya NPP – Nevinnomyssk SS to increase transfer capability of the 500 kV network of IPS South and provide reliable power ouput from Volgodonskaya NPP.

- Construction of the 500 kV transmission line Tikhoretsk SS – Krymskaya SS to provide reliable power supply to consumers in the Central and South-Western parts of Krasnodar Territory.

- Construction of the 500 kV transmission line Tsentralnaya SS – Krymskaya SS to provide reliable power supply to consumers of Krasnodar Territory.

- Construction of the 330 kV transmission line Nalchik SS – Alagir SS – Vladikavkaz SS to improve reliability of Severo-Osetinskaya, Ingushskaya and Chechenskaya power systems.

- Construction of the 330 kV transmission line Mozdok SS – Artem SS to improve reliability of the interstate transfer corridor IPS South (Dagestan power system) – Azerbaijan power system.

- Construction of the 500 kV transmission line Dalnevostochnaya SS – Vladivostok SS to increase transfer capability of the cutest from Primorskaya CPP to the south of Primorye Territory, improve reliability of power supply to Vladivostok and Nakhodka cities.

- Construction of the 500 kV transmission line Neryungrinskaya CPP – Tynda SS to remove limitations on power output from Neryungrinskaya CPP in IPS East.

- Construction of the 500 kV transmission line Chuguyevka-2 SS - Lozovaya SS – Vladivostok SS with the 500 kV Vladivostok substation to improve reliability of power supply of Primorye Territory.

By the year 2030 the length of constructed transmission lines of 110 kV and higher in the averaged variant of power demand is estimated at 415 thousand km, of which transmission lines of 330 kV and higher – 50 thousand km.

6. POWER SUPPLY RELIABILITY AND ANALYSIS OF LOAD FLOWS

The regulatory documents in Russia provide for less strict requirements to reliability than in power pools of the US and Europe. The adequacy criterion that is characterized in the most general form by the probability of deficit-free operation of power systems, is by an order of magnitude higher as a rule in the West than in Russia. The criterion *N*–1 and in some cases the criteria of higher orders are usually applied in the West as a criterion of security. At the same time the Russian power systems are provided with emergency control systems to a great extent.

At the transition to market relations reliability becomes an economic category determined by the price to be paid by consumers for the claimed reliability level. This calls for specification of normative criteria of the adequacy and security towards their toughening, in particular increase of probability for deficit-free operation of power systems to the value 0.9997 by the end of the considered period, and also obligatory fulfillment of the criterion *N*-1 and in some cases the criterion *N*-2 for especially important objects. In doing so it is necessary to specify the totality of associated reliability criteria including capacity reserves of UPS of Russia, IPSs, regional power systems, transfer capabilities of intersystem ties, rated disturbances, at which dynamic stability should be provided, etc. Comprehensive studies have been carried out to analyze adequacy of UPS up to 2030. The results of calculations on the software package YANTAR [6] have shown that the operating active power reserves in UPS of Russia as a whole increase in the absolute value during the whole considered period for the accepted reliability to 0.9990 in 2015, 0.9991 – in 2020 and 0.9997 – in 2030 in the variants of its development.

Load flows were calculated and analyzed on the software package ANARES [7]. The analysis was based on the results of a series of calculations, when the load or generation values at individual nodes were changed by using the preset algorithm or the scheme topology was changed by the *N*-1 criterion and for some groups of elements by the *N*-2 criterion. In this case existence of the load flow and admissibility of the controlled operating parameters are analyzed for each variant.

The results have shown that the calculated scheme for all variants of power demand in the base normal load flow satisfies the criterion *N*-1 in static stability at the single failure of a transmission line, transformer or power plant unit. Further increase of load with supervision of active power limits for generators is impossible. The UPS stability at alternate nulling of the calculated nodes was also analyzed. At some disconnections the load flow was transient and modeling the work of emergency control systems and subsequent generation redistribution normalized UPS operation.

7. ASSESSMENT OF POWER INDUSTRY ENVIRONMENTAL IMPACT

The environmental assessment of the variants for implementing the Strategy of power industry development was done for the following components of natural environment: atmospheric air, hydrosphere, land resources (slag and ash waste). The calculations were made on the assumption that all new and updated facilities satisfy standard requirements.

The results of environmental assessment show that for the period up to 2030 the power industry will face increase in the volumes of water use, formation of ash and slag waste and also volumes of gross emissions of pollutants (except flue ash) and greenhouse gases in all considered variants. At the same time construction of more environmentally friendly facilities will improve specific emissions of flue ash, sulfurous anhydride and nitrogen oxides. Thus, for the averaged variant enhancement of the specific environmental efficiency of TPP operation from 2009 to 2030 is characterized by the following data: specific emissions of flue ash will decrease from 15.67 to 6.54 kg/tce, sulfur dioxide – from 15.32 to 11.46 kg/tce, nitrogen oxides – from 3.69 kg/tce to 2.79 kg/tce.

In all variants greenhouse gas emissions by enterprises of the industry for the period up to 2020 will not exceed the 1990 level taken as the base one in accordance with the obligations of the Russian Federation by the Kyoto Protocol. At the 2030 level the expected emissions of greenhouse gases will exceed the 1990 level in all variants.

Sustainable power industry development and achievement of environmental target indices in the studied period call for elaboration of a complex of legal and regulatory-methodological documents as well as sizable increase of funds for development of advanced energy technologies.

8. INVESTMENT AND ELECTRICITY PRICE FORECAST

On the whole the required investment of power industry for the period up to 2030 is estimated at USD890 billion for the averaged variant of power demand.

The calculations have shown that the cost of power generation will appreciably rise because of the necessity to considerably increase investment in replacement of obsolete facilities and new construction, as well as rise of fuel cost.

Table 9 illustrates dynamics of increase in the average cost of power production in IPSs and UPS of Russia and the average electricity tariff for all categories of consumers for the averaged variant of power demand growth subject to minimization of costs for power industry operation and development.

TABLE 9. POWER PRODUCTION COST, CENT/KWH (IN 2007 PRICES)

IPS	2008	2015	2020	2025	2030
UPS of Russia*	$\frac{2.2}{3.3-3.5}$	$\frac{3.6}{5.4-5.8}$	$\frac{4.4}{6.6-7.1}$	$\frac{5.1}{7.6-8.1}$	$\frac{5.5}{8.3-8.8}$
European part and Ural	2.5	4.0	4.8	5.3	5.9
North-West	2.5	3.5	4.8	5.7	6.2
Center	3.0	4.3	5.0	5.5	6.1
Middle Volga	2.1	2.5	3.7	4.6	5.2
South	2.0	3.7	4.6	5.0	5.4
Ural	2.5	4.4	5.1	5.5	5.9
Siberia	1.1	2.5	3.1	4.0	4.4
East	1.7	3.8	4.6	5.6	6.7

*) For UPS the average electricity tariff for all categories of consumers is given in denominator.

For UPS of Russia the average cost of power production for the averaged variant will rise from 2.2 cent/kWh in 2008 to 5.5 cent /kWh in 2030.

The average tariff for all categories of consumers in UPS of Russia is estimated to be 5.5 cent/kWh at 2015 level, 6.8 cent/kWh at 2020 level and 8.5 cent/kWh at 2030 level for the averaged variant.

At present the electricity tariffs in Russia are sizably overstated in comparison with the tariffs, in case the optimal operation and development of power industry in the country were provided. In 2006 the average tariff for consumers in UPS as a whole was 3.6 cent/kWh, in 2007 – 4.0 cent/kWh, in 2008 – 4.4 cent/kWh, in 2009 – 5.2 cent/kWh. At these rates of electricity tariff increase the level of average electricity prices in Russia will reach those of the US already in 2011. Note that the electricity tariffs there remain practically invariable for 50 years and according to forecasts they will be at the same level in 2030.

9. INDICATORS OF POWER INDUSTRY DEVELOPMENT

Table 10 presents main strategic indicators of the described variant of power industry development in Russia.

TABLE 10. STRATEGIC INDICATORS OF POWER INDUSTRY DEVELOPMENT IN RUSSIA

indicators/ directions	2008 (fact.)	2015	2020	2030
Power production				
Share of non-fuel energy sources in structure of power production, %	32.5	34	35	38
Fueling of thermal power plants				
Share of gas in structure of fueling, %	70.3	70-71	65-66	60-62
Share of coal in structure of fueling, %	26	25-26	29-30	34-36
Energy security and reliability of power supply				
Probability of deficit-free operation of power systems in Russia	0.996	0,.990	0.9991	0.9997
Power industry efficiency				
Efficiency of coal-fired TPP, %	34	35	38	41
Efficiency of gas-fired TPP, %	38	45	50	53
Efficiency of NPP, %	32	32	34	36
Specific fuel consumption for power production by TPP, gce/kWh (% of 2005)	333 (99%)	315 (94%)	300 (90%)	270 (81 %)
Network losses, % of power supply to network	13	12	10	8

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