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Forecast and Concept for the Transition to Distributed Generation in Russia

F. L. Byk[a], P. V. Ilyushin[b, *], and L. S. Myshkina[a]

[a] *Novosibirsk State Technical University, Novosibirsk, Russia*

[b] *Center for Intelligent Electric Power Systems and Distributed Generation, Energy Research Institute, Russian Academy of Sciences, Moscow, Russia*

**e-mail: ilyushin.pv@mail.ru*

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Abstract—The desire to increase the reliability of the Unified Energy System (UES) of Russia resulted in a decrease in the availability of electricity. At the same time, the cost of maintaining excess generation and network capacity was incumbent on electricity consumers. This led to the mass construction by consumers of their own distributed generation. The consideration of the volume of distributed generation will make it possible to reduce the nonmarket burden in pricing. The emergence of local public smart grids will reduce the negative impact of cross-subsidization. Changes in the institutional environment are required to make the transformation of the UES of Russia orderly and predictable.

Keywords: reliability and availability of electricity supply, local smart grid, distributed generation, decentralization, sustainable development

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Introduction. Strategies, schemes, and programs for the development of the Russian electric power industry mainly contain decisions aimed at improving the technical efficiency of the Unified Energy System (UES) of Russia and regional power systems. In generation companies (GCs) and territorial grid organizations (TGOs), when solving a set of technical and technological problems, insufficient attention is paid to the issues of increasing economic efficiency, removing restrictions on connection to grids, and, consequently, ensuring the availability of electricity to end users.

It is impossible to expect a decrease in the cost of electricity as long as the principle "The consumer pays for everything!" remains the main one, which reduces the competitiveness of enterprises forcing them to look for ways to reduce electricity costs in the cost structure of their products. They focus on generating units (GUs) of small capacity, which can be placed in close vicinity to power consumers and produce the necessary amount of electricity and heat at an acceptable cost [1, 2].

The process of energy transition in the domestic power industry is simultaneously "from above" and "from below," which generates contradictions and counteractions. If the processes of transformation of the UES of Russia are not put in order and taken under control, it will be difficult to ensure the predictability of its development.

The aim of the study is to substantiate the necessary changes in technical, economic, and social policy which determine the development of the electric power industry. The main tasks are the analysis and identification of deficiencies of the existing institutional environment in the Russian electric power industry which constrain its sustainable development. The results make it possible to reduce uncertainty and increase predictability of the transformation of the UES of Russia. Practical significance consists in the creation of favorable conditions for attracting private investment in the electric power industry of the subjects of the Russian Federation and thus contributing to its development.

Current state of electricity availability in the centralized power supply system. Large power plants dispersed over the territory of the country remain the technical and technological basis of the UES of Russia. At 67 thermal (TP), hydro, and nuclear power plants with a capacity of over 1 GW, there are about 150 GW of generating capacity. Concentrated power generation required the creation of the Unified National Electric Grid. Each constituent entity of the Russian Federation has a regional distribution grid complex that supplies power to consumers.

With the transition to a liberal market economy, the system of centralized management of the development and functioning of the UES of Russia remained almost the same. Changes occurred in the organiza-

Table 1. CC programs

Program name	Investments		Comparison of investments, RUB mln/GW	Returns from consumers, RUB trillion
	capacity, GW	cash equivalent, trillion rubles		
CC-1	30	1.3	43	2.6
CC RES	5.4	1.160	215	2.325
CC SMW	0.335	0.127	380	0.290

Source. Authors' calculations.

tional and economic subsystem. Economic relations between power industry entities are built within the framework of the wholesale (WPM) and retail (RPM) power and capacity markets with appropriate economic tools developed for each sector.

The imperfection of market tools in the electric power industry led to the strengthening of the seller market, although the supply of goods (electric power and capacity) significantly exceeds demand. At the end of 2020, the installed capacity of power plants in the UES of Russia was 245 GW with an annual maximum load of 150 GW [3]. In the power industry, there are preconditions for the formation of the buyer market, but it does not happen because of the unreasonably overestimated risk of a deficit of electric power. One of the reasons is the constant overestimation of the forecasted demand for electric capacity and energy.

The problems of investment in the development of the electric power industry are also important [4–7]. In order to encourage GCs to invest in new capacity, a capacity contracting (CC) tool was developed (Table 1) [4, 8–10].

In addition to the CC, the cost of electricity is influenced by social policy to protect the population from the negative effects of the market. The problem of cross-subsidization has led to an increase in the share of the grid component to 40–45% of the final price. In order to improve efficiency, PAO Rosseti is looking for ways to generate additional income and reduce operating expenses, which is the purpose of the ongoing RUB 1.3 trillion digitalization program for the power grid complex [11, 12].

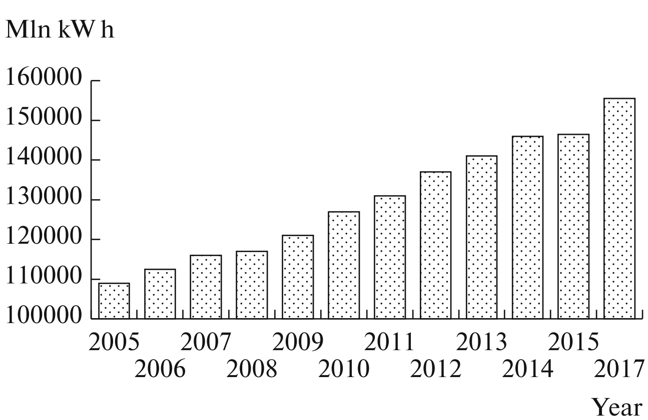

Fig. 1. Dynamics of the population electricity consumption growth in Russia.
Source. Authors' calculations.

The total volume of subsidy programs of the Russian electric power industry in 2020 was about 1.09 trillion rubles, including 615 billion rubles of additional burden on the WPM and 473 billion rubles in the form of redistribution of the tariff burden among consumers on the RPM [13]. Industrial and commercial enterprises, which had to bear the entire investment component of the adopted program of electric power industry development, had the hardest time. Although the tariffs for the population and equivalent consumer groups are on average by 30–50% lower than the electricity price for enterprises of the real sector of the economy, the size and dynamics of tariff growth for this consumer group becomes unbearable.

In the structure of electricity consumption of the UES of Russia, there is a growing demand for electricity from the population (Fig. 1) as well as from the companies providing public utilities and other services. They account for about 25% of electricity consumption [14, 15]. Obviously, with the growth of the share of municipal electricity consumption, the burden of cross-subsidization increases.

The degree of electricity availability should be considered in relation to the income of the population. The minimum availability is observed in the Republics of Kalmykia, Adygea, and Altai, as well as in Ivanovo and Pskov oblasts, in which an average monthly salary can buy 4880–5580 kWh. The highest level of availability is observed in the Irkutsk oblast, in which this figure is six times higher and amounts to 34440 kWh indicating significant differences between regions.

Each region sets not only tariffs for households but also the maximum level of unregulated prices (MLUP) for electricity for other consumers. Their ratio shows to what extent the social policy of regional authorities affects the conditions of economic activities of economic entities. Figure 2 shows a diagram comparing a single-rate tariff for households and the MLUP for electricity for consumers with a load of less than 670 kW. The choice of the Tambov oblast is due to the fact that in this region the tariff for households is close to the national average, and the choice of

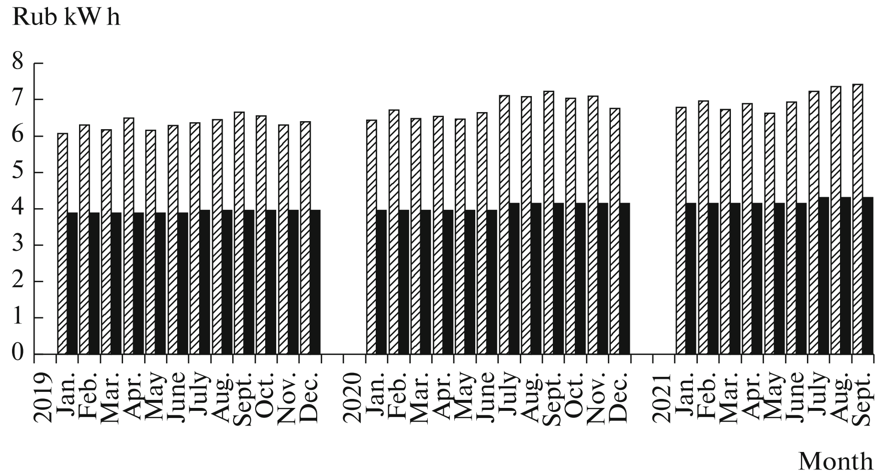

Fig. 2. Single-rate tariffs (■) and MLUP (▨) for electricity for consumers under 670 kWh in the Tambov oblast. Source. Authors' calculations.

capacity corresponds to the load of small and medium enterprises (SMEs) in various sectors of the economy.

The logical result of the technical, economic, and social policy in the electric power industry of Russia was a decrease in the availability of electric power for the subjects of the real sector of the economy and low-income strata of the population. The problem of increasing the economic efficiency of centralized power supply systems has become critically important and urgent. In the existing institutional environment, there are not many options to solve this problem. One of them is to increase the tariff for the population, which will inevitably lead to an increase in nonpayments and an increase in social tension in society. Another option is associated with further increase in the load on large energy-intensive enterprises, e.g., powered from the networks of OAO FGC UES, which also causes the resistance of economic entities.

Distributed generation as a natural response "from below". While the problem of electricity price reduction has not been solved "from above," the entities of the real economy found a way to reduce electricity costs by creating their own generation facilities connected to the internal power supply networks. This triggered the mass development of distributed generation with power plants of different installed capacities based on modern cogeneration technologies [16–19].

Large enterprises of metallurgical, chemical, and other energy-intensive industries that use secondary energy resources were the first to take this path. Metallurgical plants began to use GUs based on blast furnace, coke oven, and converter gas to produce electricity and heat. A number of enterprises plan to increase the share of their own electricity production to 95% [1, 2].

In contrast to metallurgists, oil companies use the associated petroleum gas as fuel for gas turbine (GTU) and gas piston (GPU) units of domestic and foreign production. In this case, the in-house generation is located at the fields and refineries. At PAO Lukoil, the in-house generation in 2020 covered up to 35–40% of the total electricity consumption [1].

In accordance with the current order, power plants with a capacity of up to 25 MW and using secondary energy resources, regardless of the installed capacity, are not required to participate in the WPM. At the same time, these power plants belong to the objects of operational and supervisory control. The reports of AO System Operator of the United Power System show that against the background of a general decrease in electricity consumption in 2020, power plants of industrial enterprises generated 3.1% more electricity than in 2019. The share of in-house electricity generation by industrial enterprises in 2020 was 6.2% of the total [3]. It is important to note that the reports do not include power plants of less than 5 MW and power plants of any capacity not connected to the UES of Russia.

The market has a sufficient number of competing companies offering services for design, construction, and commissioning of small distributed generation (SDG) facilities, including the organization of their subsequent operation.

According to estimates of the expert community, the in-house generation at the enterprises in the area of the UES of Russia is about 20 GW, including SDG of at least 6 GW [17, 20]. A significant number of consumers with SDG are forced to choose the option of combined power supply, i.e., with a partial supply of electricity from the centralized system. There are enterprises which have chosen full energy independence, i.e., power supply systems are isolated. They are not on the radar of AO System Operator of the United Power System, territorial grid organizations (TGOs), and guaranteeing suppliers at all.

SDG-based isolated power supply systems emerge due to three reasons:

1. High cost of technological connection to TGO power grids and unpredictable growth of cost of electric power received from the centralized power supply system.

2. Limitation on the in-house generation capacity. For the in-house generation with a capacity exceeding 25 MW connected to the internal power supply networks of the enterprise, except for individual cases, there is an obligation to supply cheap electric power to the WPM while receiving it at a high price established at the RPM.

(3) The expected imposition of a grid reserve fee for businesses with in-house generation will require a choice:

— Close down temporarily the in-house generation and move away from the combined power supply, because this method of power supply becomes economically inefficient under the proposed conditions.

— Increase the capacity of the in-house generation to a value sufficient for the self-balanced operation with the necessary level of reliability of power supply and switch to an isolated mode of operation.

It is obvious that the larger the enterprises' in-house generation capacity, the smaller the volume of their power consumption from the centralized power supply system. Therefore, the decrease in the growth rate of power consumption in the UES of Russia is probably due to the growth of the number and capacity of SDGs. The lack of order and control in the process of transformation of the energy system "from below" reduces the validity of decisions made when making plans and programs for the development of the electric power industry of the subjects of the Russian Federation and the UES of Russia.

It is proposed to change the attitude to SDG through changes in the institutional environment aiming not only to improve energy efficiency and energy conservation in electricity generation but also its availability to consumers. An important element should be the coordination of schemes and programs for the long-term development of the electric power industry of the subjects of the Russian Federation and the Heat Supply Schemes of Municipalities, in which there are already sections related to SDG and the use of cogeneration technologies.

Local smart energy systems. It is known that the efficiency of heat and electricity production in a cogeneration cycle is at least 1.4 times higher than in a separate cycle. Therefore, mini-CHPs based on GTUs and GPUs, taking into account the cost of transmission of these types of energy, can compete with large TPs operating in condensing mode as well as with heating plants.

The potential for improving energy efficiency and energy saving in Russia is quite high due to a large number of heating plants. At present, they account for about half of the total heat production in the country. The country's gasification program encourages large scale construction of heating plants with a capacity of 20–100 Gcal/hour in medium and large cities and more powerful heating plants in medium and large cities. It is necessary to support the reforms "from below" aimed at the transfer of heating plants to the cogeneration technology [21, 22]. The current regulatory framework is insufficient for the creation of mini-CHPs, because their connection to power grids is expensive, and the status of a participant in the wholesale or retail market makes it impossible to receive income sufficient to recoup investments.

The increase in the number and capacity of mini-CHPs, as well as the reduction in the cost of connecting them to the power grid, will reduce the nonmarket load if they are taken into account when selecting generating capacity for the conclusion of a CC. The systemic effect is important, because it reduces the power grid constraints from the in-house generation of consumers powered by closed power centers (PCs). Unloading of PCs without the expenses on the part of TGOs will reduce the investment component in the tariff for electricity transmission and increase the availability of power supply systems and electricity [23, 24].

The cost of power generation at mini-CHPs largely depends on the prices of generating equipment and natural gas. At the current price level, the cost is 1.5–3 RUB/kWh, and the higher the installed capacity utilization factor (ICUF), the lower it is. The use of SDG as a source of electricity for industrial enterprises leads to a decrease in the ICUF, which can be increased by the supply of electricity to the RPM. At the same time, in addition to increasing the availability of electric power, the reliability of electric power supply to consumers in the area of the PC increases.

The transition of enterprises to SDG due to the need to maintain competitiveness leads to an increase in the price of electricity for industrial and commercial consumers remaining in the system of centralized power supply. The burden of nonmarket surcharges from cross-subsidies will increase, and the reduction in the volume of electricity transmission through TGO grids leads to an increase in the transmission tariff. Therefore, while gaining local effects, companies with in-house generation aggravate contradictions on the WPM and RPM [23].

There is reason to believe that economic interests will prevail and the number of enterprises with SDG, including those operating in isolated mode, will only increase. However, with the growing number of consumers who have created self-balanced power supply systems, new positive system effects can be obtained, if this process is given the right direction.

Such system effects can be obtained with the creation of balanced local intelligent power grids (LIPGs) based on SDG (mini-CHPs), medium- and low-voltage distribution networks, as well as electrical receivers of consumers. LIPGs can operate both in parallel with the UES of Russia and in an island mode with the required reliability of power supply for consumers. The LIPG is based the decentralized intelligent control system, which provides its reliable operation in normal, emergency, and postemergency modes and makes it possible to optimize consumption of energy resources and losses in networks, rationally use the fleet life of generating equipment of mini-CHPs, etc.

The main difference of the LIPG is the operator responsible for generation, transmission, and sales of electric power to consumers of the LIPG. LIPGs can differ in purpose, type of used technologies, voltage class of the main network, and type of used energy resources.

The majority of the existing LIPGs are created based on multimachine mini-CHPs with a capacity of 5–25 MW with the generator switchgear of 10(6) kV and the main distribution network of 10(6) kV. The power grid complex of the LIPG includes 10(6) kV switchgears, 10(6)/0.4 kV transformer substations, and 0.4 kV network.

It is proposed to give the LIPG operator the status of an RPM subject and not to extend to it the norms that prevent it from being a vertically integrated electric power entity with a decentralized management system. The LIPG operator should be able to solve the problems of technological connection of new power consumers, to perform dispatching, accounting, and control of mutual payments, to ensure the functioning of relay protection and automation devices, as well as to implement other necessary functions [25]. According to expert estimates, in the short term, the volume of commissioned SDG in LIPGs will reach 1.2 GW/year [20]. For these purposes, not less than 180 billion rubles/year of private investments will be allocated, the payback period of which at the current price level will be 5–7 years, which will increase the availability of electrical energy for consumers.

According to their purpose, LIPGs can be divided into the following types:

— Industrial, which are dominated by enterprises of various industries engaged in the processing of raw materials or the development of subsoil.

— Agricultural, with a high proportion of agro-industrial enterprises engaged in the processing of agricultural raw materials and/or the production of products from them.

— Public, in which the main consumers are the population and categories of consumers equivalent to it, as well as small and medium enterprises rendering services to the population.

Of the above types of LIPGs, from the perspective of increasing the availability of electricity, priority should be given to public ones. This is justified by the fact that by withdrawing the population and equivalent consumers from centralized power supply systems, the negative impact of cross-subsidization is mitigated. When forming and managing demand, the LIPG operator is interested in using a customer-oriented pricing mechanism, in which the final price of electricity for the consumer is determined taking into account the profile and nature of the load, reliability requirements, availability of reactive power compensation, active or passive harmonic filters, etc.

The public LIPG operator can solve a set of technical, economic, and social problems on the basis of market relations making the LIPG attractive to investors. An energy ecosystem is created for consumers which makes it possible to provide for the livelihood of the population and become attractive for SMEs. In essence, the areas of the public LIPG become territories of rapid development in the subjects of the Russian Federation.

Obviously, any LIPG is redundant, because it has a reserve of active power necessary to ensure the reliability of its operation, which creates the potential that can be realized if it is connected to the centralized power supply system. The efficiency of integrating the LIPG into the UES of Russia depends on the cost of building the electrical connection, through which the excess power will be delivered to the power system, and the cost of the corresponding system automatic equipment, which ensures the stable parallel operation of the LIPG with the UES of Russia [26, 27].

The LIPG system automatic equipment ensures the operation of the LIPG in two operating states without interruption of power supply to consumers: the parallel synchronous operation mode within the UES of Russia and the island operation mode, to which the LIPG switches during any emergency disturbances in the external network. This makes it possible to increase uninterrupted power supply to consumers connected to LIPG networks. The permissible power flow over 10(6) kV power lines between the LIPG and the PC in accordance with the current technological regulations is limited to 5 MW. This makes it possible to increase the ICUF of mini-CHPs, reduce the specific gas consumption, as well as receive additional income from power supply to the RPM and the provision of system services (e.g., leveling the load schedule of the PC, maintaining the normative values of node voltages, etc.) [23, 24, 26].

The creation of public LIPGs and their integration into the UES of Russia is the most effective way to increase the availability of electricity for consumers, to reduce the negative impact on the cost of electricity from cross-subsidization and nonmarket markups.

A technical and economic policy aimed at stimulating the creation of LIPGs, especially public ones, will change the image of the UES of Russia. If at present the processes of electricity generation, transmission, and distribution resemble a “multilevel cascade,” with the emergence of LIPGs the power system will have a cellular structure. A large number of energy cells will be united around the main core, the UES of Russia, within which major power producers and consumers will interact.

In this case, the main task of the regulators will be to preserve and strengthen the core as the basis of the country's electric power industry. LIPG operators will be interested in the existence of the core as a means of improving the reliability and availability of electricity supply in the LIPG. The energy cells will improve the economic efficiency of the UES of Russia and the availability of electricity from the centralized power supply system. When an economically feasible electricity price is achieved, the need for businesses to switch to SDGs will be reduced. The TGO grids will serve as interconnections between LIPGs while generating the corresponding revenues.

It is important to note that the inclusion of RES-based generating facilities in the LIPG will reduce the negative impact of stochastic generation on the operation modes of the UES of Russia manyfold. In addition, it will increase the investment attractiveness of LIPGs due to compliance with ESG criteria and will help accelerate the transition to carbon neutrality [28, 29].

The primary steps for the development of LIPGs are proposed:

— Remove restrictions on SDG capacity as the main source of electricity in the LIPG but set a limit on the amount of power transfer from the UES of Russia to 25 MW.

— Supplement technological regulations with the procedure for the technological connection of LIPGs to the UES of Russia, which should be fundamentally different from the procedure for the development and approval of SDG power delivery schemes.

— Take into account the status and prospects of SDG commissioning in subjects of the Russian Federation when selecting generation to conclude a CC, which will reduce the need for additional capacity commissioning at traditional power plants and, consequently, nonmarket markups in the WPM pricing mechanism.

— Provide state support for LIPGs that improve the energy efficiency of electricity and heat generation, remove grid constraints, promote openness of electricity supply systems, affordability of electricity, and carbon neutrality.

— Supplement the list of RPM participants with a new entity, the LIPG operator, while not subjecting it to the requirement to separate types of activities in the electric power industry, which will ensure its functioning as a vertically integrated company with full legal responsibility for the reliability and uninterrupted supply of electricity as well as the quality of electricity before consumers connected to the LIPG networks.

— Supplement schemes and programs of development of the electric power industry of subjects of the Russian Federation with new tasks and sections securing the priorities of the LIPG creation, which will make it possible to lower the need for investments in construction and reconstruction of electric network objects and direct them to the program of digitalization of the network.

Conclusions. Creating artificial barriers and obstacles on the part of regulators will reduce the investment attractiveness of the construction of SDGs by companies from various industries. However, it will lead to the growth of isolated power systems, in which the cost of electricity will be lower than in the centralized power supply system. Holding back transition to the distributed power industry can destroy integrity and unity of the UES of Russia.

The development of in-house generation by companies is a response to the lack of a buyer market in the Russian power industry. It is obvious that reducing and even more so abandoning centralized power supply systems contradicts the interests of large generation companies and PAO Rosseti forcing them to seek support from regulators. The position of the regulators is due to the ownership structure of electric power industry entities, where the state dominates. It is difficult to estimate the exact consequences of such a development of events, but the probability of the loss of predictability of the development of the Russian electric power industry, even in the short term, is high.

It is necessary to make the process of transformation of the UES of Russia manageable by coordinating changes "from above" and "from below" and subordinating them to a common goal, which is the generation of cheap and clean electric power as well as the increase of reliability and openness of power supply systems. In order to achieve this goal, an important role is assigned to LIPGs, which are integrated into the UES of Russia, which makes it possible to obtain significant system effects. Priority should be given to public LIPGs, because this makes it possible to reduce the negative impact of cross-subsidies and nonmarket markups in WPM and RPM pricing.

In order to achieve the goals of sustainable development and compliance with ESG standards, changes in the institutional environment determining technical, economic, and social policies in the electric power industry are necessary. The transformation of the UES of Russia should occur in accordance with the energy trilemma, which would allow us to raise the index of Russia adopted by the World Energy Council.

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