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INTELLIGENT POWER GRIDS (SMART GRID): INTRODUCING DIGITAL TECHNOLOGIES IN POWER INDUSTRY AS A FACTOR OF IMPROVING THE EFFICIENCY OF AGRICULTURAL AND INDUSTRIAL ENTERPRISES

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ABSTRACT

An urgent need to improve the efficiency of the power complex emerged in the context of establishment of new socio-economic requirements for the electric power industry. This article explores the power consumption by industrial and agricultural enterprises in the Russian Federation and compares the power efficiency of the Russian economy with some EU countries. The research allows to draw a conclusion that modern global challenges necessitate the shift of the power industry from traditional to digital intelligent solutions capable of helping to accomplish the tasks of collecting and analyzing a large amount of data. Smart grids allow power grid organizations to cut operating costs by combining several control and monitoring systems into a single network, to improve the reliability of energy supply to consumers, and to reduce the power consumption by agricultural and industrial production in Russia.

Keywords: Energy Efficiency, Power Consumption, Intelligent Grids, Smart Grid, Internet Of Power, Digital Technologies.

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1. INTRODUCTION

Improving energy efficiency is one of the most economically rational ways to improve security of supply, reduce emissions associated with power industry, ensure acceptable prices for energy carriers and increase the economic competitiveness of agricultural and industrial enterprises. Even despite the increase in energy efficiency, the Russian energy market currently experiences an increase in consumption, which, in turn, leads to an increase in peak loads. Securing this growth by traditional methods causes an increase in the annual costs of the grid maintenance.

At the same time, securing this growth by traditional methods causes an increase in the annual costs of maintaining the grid's operability. The existing electric grid infrastructure in Russia, which was actively designed and developed in the middle of the XXth century, has outlived its usefulness by today. Taking into account the level of technology (both primary equipment and information technologies) development at the time, the electric grid was built as a hierarchical system from generating sources, via mainline and distribution grids to an end user, focusing on a centralized one-way ideology of managing technological processes.

The principle of multiple redundancy at the level of schematic solutions of substations and grids was often used at the expense of the economic efficiency of the solutions being implemented, in order to solve the main task of securing a guaranteed and reliable power supply to the largest possible number of consumers and a power supply per production unit ratio for large industrial power-intensive industries.

The substations were connected under the projects that involved the use of equipment with insufficient reliability indicators. This connection was described by a surplus ratio of the number of switching devices and connections, under modern criteria, which led to a significant number of serious technological violations. The schemes for arranging the facilities' operation are focused on the 24/7 stay of operational personnel and, as a result, relatively high operating costs.

Over time, key drivers of the electric power industry development in Russia have undergone significant changes, which, given the excessive labor and capital intensity of the power system, has led to a disproportion between the real and nominal demand for modernization and technological reequipment of electric grid facilities [1]. Modernization of facilities for the proper economy functioning requires significant investment resources due to the critical nature of the power system. In the context of lack of financial resources related to the restriction in tariff increase, grid companies are forced to work on the equipment that has worked out its estimated service life.

Digital technologies are intended to make power systems more efficient, sustainable and reliable. Digital data and analytics can reduce the cost of the power system in at least four ways: by reducing operating and maintenance costs, increasing the efficiency of power plants and grids, reducing unscheduled downtime and theft, and extending the life of assets.

Digital technologies are already widely used in energy end-use sectors, with the most widespread use being in potentially transforming technologies, such as autonomous cars, smart home systems and additive production (3D printing).

The value of digitalization in increasing the power and materials' performance will further grow due to the expected expansion of Russian industrial and agricultural production. Further power savings can be achieved through advanced process control. Creation of smart grids of power supply is one of the innovative solutions for the power industry digitalization. Smart grids will increase the efficiency of the electricity end use through raising awareness of the system operation and more informed participation of electricity consumers. They will also secure efficient integration of variable renewable energy sources and electric vehicles, as well as new products and services. Smart grids coordinate the needs and capabilities of all generators, grid operators, end users and players of the electricity market. This enables electric power grids to work more efficiently, minimizing costs and environmental impacts, while increasing the reliability, flexibility and stability of the system. Intelligent grids perform this optimization using digital and other advanced technologies to monitor and manage electricity transportation from all sources to meet various needs of end users in electricity.

In view of the above, the urgency of the problem of introducing a smart grid in order to increase the competitiveness of national industrial and agricultural production is unmistakable.

2. LITERATURE REVIEW

Despite the fact that the term SMART GRID has been officially used since M.T. Burr's 2003 publication "Reliability demands drive automation investments" [2], there is still no single interpretation of this concept [3].

At the fundamental level, Smart Grid can be viewed as "updating the current electrical grid" [4]. Consequently, Smart Grid is expected to meet the current power needs by offering significantly higher capabilities designed to meet the constantly changing social demands of the XXIst century [5].

These social requirements are exaggerated by the need to create reliable, sustainable, scalable, manageable and environmentally safe power production, transmission and distribution systems that also include concepts of compatibility, cost-efficiency and intelligence [6].

Unfortunately, there is no consistent view of what a Smart Grid is. Table 1 illustrates various representative views on the prospects of intelligent grids.

Table 1 Representative set of prospects of intelligent grids

Author	Description of the selected prospect
Baumeister [4]	electric power infrastructure that makes reasonable decisions about the state of the electric power system to maintain a stable environment
McBride and McGee [7]	evolution of the power system entails infrastructure modernization to a Smart Grid in order to support the two-way communication among electric generation, transmission and distribution infrastructure and electricity consumers. It includes new intelligent grid applications, such as advanced measurement infrastructure (AMI), phasor measurement units, distribution automation (DA), automatic response to requests, electric vehicles, and microdrive control
Pearson [8]	... a grid that can intelligently integrate the actions of all connected users – generators, consumers – to efficiently provide sustainable, economical and secure sources of electricity ... merging the physical delivery grid with any number of individual ICTs (information and communication technologies) such as intelligent sensors, software, communications and distributed control technologies ... which provide multiple benefits to both power consumers and producers
Ray, Harnoor, Hentea [9]	... a paradigm shift in methods of the electrical energy production, trade and consumption. Most of the visions of the power industry infrastructure modernization involve integration of various interrelated, interdependent and adaptive functions and applications to increase the reliability of the grid, increase in the capital and operational efficiency and ensuring the security of electric grids..., including advanced methods for communication control and information processing, developed intelligence distributed among various segments of the power system that converts the grid into an interactive and adaptive system
European Union	... means an electric grid that is able to integrate the behavior and actions of all users connected to it, including generators, consumers and entities producing and consuming electricity, in a cost-effective manner, to ensure a cost-efficient and sustainable power system with low losses and high levels of quality, security and reliability of supply

Description of intelligent grids from the safety standpoint is the dominant topic in the literature [10]. It can be explained by the increasing importance of information in the energy sector, which creates new vulnerabilities [11]. These new vulnerabilities are, in particular, related to cyberspace threats [12].

An alternative approach to the description of intellectual grids is provided through the prism of architectural representations. Moslehi and Kumar proposed a hierarchical architecture model [13]. Their approach is based on the need of "using modern communication and information technologies that allow the IT infrastructure to provide opportunities for network monitoring and control" and is mainly focused on solving operational problems "in categories such as performance enhancement, operational limitations, systems of security and fast recovery" with an emphasis on the functional tasks of the Smart Grid elements.

Komninos has proposed another smart grid model [5] as a multilevel conceptual model that illustrates the three main sections of intelligent grids, as well as its parts and their interaction. These representations help view a typical intellectual grid as a collection of interconnected parts and elements [14].

The IEEE Standard 2030-2011 probably provides a more complete understanding of the Smart Grid [15]. This standard formulates the basic structure and functions of the "smart" network corresponding to the framework of the National Institute of Standards and Technologies.

Overall, it must be noted that the Smart Grid topic is still in its infancy, and therefore it is expected to have some degree of discrepancy, and sometimes even conflicting perspectives [16].

2. METHODS

The method of research includes qualitative and quantitative analysis of indicators of developing the power complex of the Russian Federation and some European countries. The information base of the research includes open sources, such as official statistics of Rosstat and Eurostat, the World Bank of Development, and the International Energy Agency, as well as analytical reports of the Center for Strategic Research of the Russian Federation, the European Commission, and the Analytical Center under the Government of the Russian Federation, and other publications, proceedings of round tables, etc.

The power consumption of agricultural and industrial production in the Russian Federation is used to estimate the current index of energy efficiency of industries, calculated using the following formula:

EI = CE/VP (1),

where CE is th consumption of energy resources, mln. toe;

VP is the volume of shipped production goods, bln rub.

The total energy consumption per GDP (power consumption of GDP) indicator was used for a comparative assessment of the energy efficiency of national economies.

3. RESULTS

Withdrawal of the Russian economy from the recession and the growth of industrial production have led to an increase in the consumption of energy resources in recent years. Positive dynamics of the decrease in the power consumption of agricultural and industrial production must be noted. For instance, power consumption increased by 4.2% in agriculture and by 1.8% in industry in 2013-2016.

It must be noted that power consumption of the agricultural and industrial production sectors decreased by 30.2% and 22.4%, respectively, during this period (Table 2).

Table 2 Consumption of energy resources and power consumption of agricultural and industrial production of the Russian Federation in 2013-2016

Indicator	2013	2014	2015	2016	Change	
					+/-	%
Consumption of energy resources in agriculture, mln. toe	15.45	17.5	16.1	16.1	0.65	15.45
Consumption of energy resources by industrial production, mln. toe	415.4	419.4	414.9	423	7.6	415.4
Output of agricultural products, bln. rub.	3,687.1	4,319.1	5,164.9	5,505.7	1,818.6	3,687.1
Volume of shipped goods of industrial production, bln. rub.	40,545.1	44,064.24	51,267.65	53,228.9	12,683.8	40,545.1
Power consumption of agricultural products, toe/thous. rub.	4.19	4.05	3.12	2.92	-1.27	4.19
Power consumption of industrial production, toe/thous. rub.	10.25	9.52	8.09	7.95	-2.30	10.25

Despite the positive dynamics of energy resource efficiency, the Russian Federation is currently among the countries with high power consumption – much higher than that of developed European countries (Figure 1).

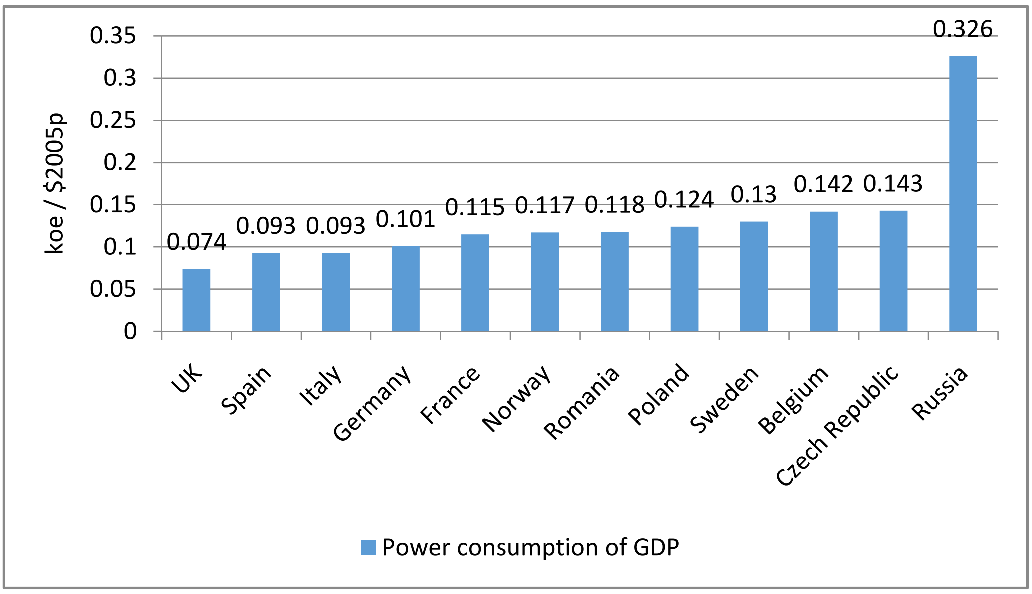

Figure 1 Total energy consumption per unit of GDP (power consumption) of GDP in Russia and European countries in 2016 [17]

High power consumption in Russia and other developing countries is mainly due to the predominance of energy-intensive industries, high levels of commodity exports, and low prices for energy carriers, which do not contribute to energy efficiency.

The price for electricity is a sensitive factor for enterprises in energy-intensive industries. The cost of electricity purchased by industrial and agricultural enterprises grew by 16.7% and 40% respectively over 2012-2016 (Figure 2).

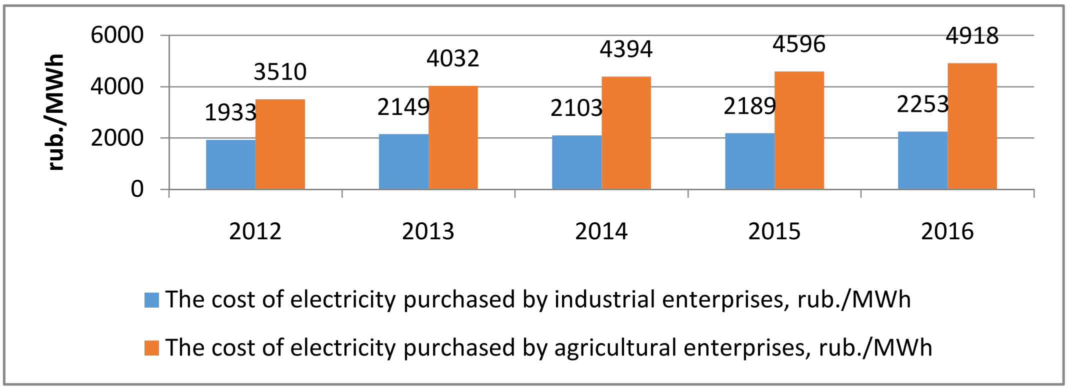

Figure 2 Dynamics of the cost of electricity purchased by industrial and agricultural enterprises in Russia in 2012-2016

High price for capacity, including the price for generating capacity and the tariff for grid usage, is determined by several reasons in the Russian Federation, such as:

- considerable distances and low density of load. Compared with most other countries, Russia requires 1.5-3 times more grid assets per 1 kW of power consumption;
- cost of capital is 2-3 times higher than in Europe. Cost of construction is 20-40% higher than that of European countries;

- low load on the grid and generating capacities. The average load on grid assets of the mainline grid complex is 26%, and the load on distribution grid complex is 32%. The average annual capacity utilization factor [CUF] is about 50%.
- low labor productivity. There are 10 times more workers in the industry at 1 MW of installed capacity in Russia, than in the US. Even with the adjustment for the presence of combined output in Russia, this gap remains at the level of 5-7 times.

Growth of tariffs and prices for electricity for industrial and commercial consumers is negatively affected by the low performance of the electricity energy sector. For example, the efficiency of most thermal power plants, which make up 68% of the generating capacity of the Russian Federation, does not exceed 40%, and few TPPs operating in the combined cycle have an efficiency of 50%-60%.

Outdated infrastructure in the power industry causes a growth in the costs of its maintenance in the working condition. The inclusion of the cost of generating and grid capacities in power tariffs can lead to the fact that the final price for industrial enterprises will match the average price in European countries, which can negatively affect the competitiveness of Russian products in the foreign market [18, 19].

Based on traditional technologies, the Russian power industry finds it hard to improve its efficiency without noticeable growth in tariffs and prices. At the moment, there is an urgent need to move from analogue to digital methods of managing the power industry that can support transformation of business practices of power supply and service companies.

Digital and information technologies, including the development and introduction of “smart” grids and the required infrastructure, have been actively used in the power sector since the early XXIst century [20]. The need to introduce the newest technologies has become more acute due to the development of renewable energy and the spread of distributed generation.

Digitalization of the grid infrastructure is most intensive in Europe, where the share of renewable energy sources (RES) in electricity generation is 34.2[21]. RES also gain market share in the US and Australia, where the RES cost reduction plus the availability of land allow to implement large-scale projects quickly and cost-efficiently.

Growth in investments in the last few years indicates the increased attention of energy companies to digital technologies. For example, global investments in digital infrastructure and software have grown by more than 20% per year since 2014, reaching $47 bln in 2016 (Figure 3) [22].

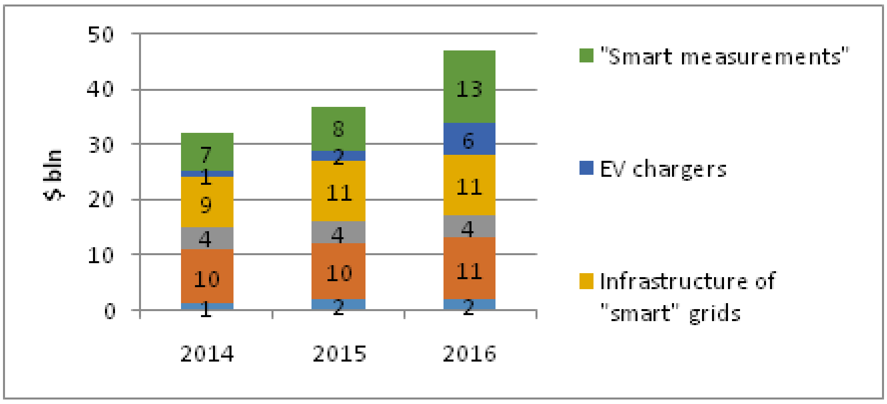

Figure 3 Global investments in digital power industry in 2014-2016

According to the report of the Joint Research Center of the European Commission's Directorate-General for 2016 [23], 950 projects to create "smart" infrastructure were implemented only in 50 countries, with 4.97 bln euro invested. Investments are concentrated in several countries (Denmark, Germany, Spain, France and the UK). Some member states became initiators of major investments earlier than others (for example, France, the UK), while other member states started investing later (for example, Belgium, Sweden).

642 projects worth a total of 2.82 bln euros have been completed by 2017 (an average of 5 mln euros per project). The largest number of introduced grids was in Germany (140), Denmark (105) and the UK (73).

The results of the research reveal that countries with intensive state support for "smart grids" and large investments in their development have a higher efficiency of electric grids. For example, there is a decrease in electricity energy transmission and distribution losses in China, Germany, Sweden, and the US to a lesser degree.

Despite the intensive promotion of the new technology policy in the power sector (profile startups, approval of the Forecast of Scientific and Technological Development of the Fuel and Energy Sector of the Russian Federation for the period through to 2035, adoption of the EnergyNet Roadmap of the National Technology Initiative), the digitalization of the power economy is not going at such high rates in Russia as in the developed countries.

4. DISCUSSION

The task of developing "reliable and flexible grids", along with the development of distributed generation and consumer services in the power industry of the Russian Federation, has become one of the tasks of the National Technology Initiative EnergyNet, which aims to create competitive technological solutions in the world by 2035. According to experts, it is possible to solve the main problems of the country's power sector fundamentally through the creation of an alternative power system – intellectual power industry – arranged on the basis of the "Internet of power" model.

Technologies used for the intellectualization of power supply include smart grids. The international experience of implementing “smart grids” reveals that Smart Grid technologies can solve a number of problems related to obsolescence of the power industry infrastructure, a continuing increase in demand for energy resources, a need to improve the security of supply, and also contribute to the development of cleaner power supply, which is more power-efficient, affordable and stable.

Experts estimate that, compared to prices set in the inertial forecast for the development of the Russian electric power industry, the shift to smart grids will allow to cut prices for electricity by 30-40%. Besides, it will expand the domestic market for domestic producers to $10 bln per year. Conducting a planned reconstruction of TPPs based on the units with increased efficiency will secure the growth of the efficiency of the Russian economy as a whole.

Results of pilot projects implemented in Russia indicate the efficiency of smart grids. For example, the first stage of the project of a digital distribution grid in Kaliningrad, whose members are Rossetti JSC (Yantarenergo JSC) and Tavrida Electric, was launched in 2014 and has already been implemented. The results of the first stage of the project confirmed the positive impact of Smart grid technology on the key reliability indicators of the power grid: the average time of power supply recovery was reduced by 5 times, the number of residents left without power in the pilot areas of the project decreased by more than 3 times.

A project to modernize the city's electricity grid using Smart Grid elements was launched in Ufa in 2013, implemented by BESK JSC and Siemens LLC. The project is currently under implementation. The power losses are expected to decrease from 15.6% to 8.7%, after the completion of the design work, the level of the grid automation (700 medium voltage distribution devices) is expected to increase; operating costs are expected to decrease by 20%.

Other pilot projects on digitalization of grids are also being implemented – for example, in Sevastopol and St. Petersburg, which should be paid off through the reduction of the network power losses, reduction of operating costs and investment needs for grid upgrades.

At the same time, building a power system using the smart grid technology requires a proactive public policy. By now, the state has already developed a number of documents aimed at forming a new technological paradigm in the power sector based on the "smart" infrastructure, the market ecosystem of active consumers, prosumers and other agents of distributed power industry.

In particular, the draft of the Energy Strategy of Russia for the period through to 2035 was developed [24], as well as the concept of the national project "Intellectual Power System of Russia" (NP "IPSR"). A Roadmap of the National Energy Initiative, aimed at developing intellectual energy, which was designed through to 2030, was also developed to solve the industry's problems.

At the same time, experts note a number of obstacles to the transition to intellectual power industry in Russia [25]:

- major market players and infrastructure organizations are not interested in moving to a new model in the current institutional environment, while retail consumers and actors of the distributed power industry face some regulatory barriers in the industry;
- infrastructure organizations and regulators are not fully ready for the liberalization of the power market and the massive emergence of a new class of market actors – active consumers and prosumers;
- the Russian power system is technologically not prepared for the emergence of multilateral flows and multidirectional flows of electricity;
- obsolescence of the technological and production base of enterprises of power equipment and machine building;
- obsolete technological standards and rules of technical regulation and design in the power complex;
- lack of interest of the power market players in improving the efficiency of the power system.
- Market players have formulated a set of organizational and institutional measures to solve the main problems of the power sector, including:
- Creation of a strategic investment and technology partnership with suppliers of technology solutions, consumers and regulators, whose functions will include the development of standards for new technologies and reference architecture for infrastructure digitalization; creation and promotion of new provisions of regulatory and legal regulation, as well as participation in international collaborations.
- It is required to form regulatory conditions, making appropriate adjustments to the regulatory legal acts on the electric power industry in order to develop and implement flexible forms of participation of new agents of the power market in energy exchange.
- It is required to develop incentive mechanisms for enterprises in the industry to apply contemporary innovative solutions by changing the norms of technical regulation and design based on new technologies, providing support for the infrastructure of organizations when implementing innovative solutions and smart grid pilot projects.
- It is required to reconsider the practice of cross-subsidization in order to generate incentive signals for technological modernization and increase energy efficiency in the most promising sectors of the electric power industry. The main types of cross-subsidization in the electricity sector are cross-subsidies among regions, among the fields of activity (electric and thermal energy, between electricity and power produced by nuclear power plants, hydroelectric power

stations and thermal stations, in a certain sense), and among consumer groups (population, industry).

The Department of Energy of Russia estimates the actual amount of cross-subsidization in the electric power industry at 368 bln rub. for 2017 . Cross-subsidization is one of the most serious problems for the Russian electric power industry. It distorts not only the economy of the industry, but the entire Russian economy, making the structure of the electricity price formation virtually nontransparent and being a serious impediment to the transition of the power industry to a competitive development model. The key task is to find the maximum permissible level of cross-subsidization in the wholesale and retail electricity power markets and reduce its volumes to this level. However, the ways of implementing this task cause lively discussions among representatives of the state, industry, expert community and are a subject of further study.

It can be stated with a high degree of confidence that the presented set of measures will secure the quickest and the most rational distribution of efforts to overcome the problems of transition to intellectual power industry in the Russian Federation.

CONCLUSION

The current situation and trends in the power complex development in the Russian Federation and in the world necessitate the transition to an innovative scenario for the industry development.

Given the forecasts of a range of analytical agencies on the significant growth in demand for electricity in the long term, the state should pursue a balanced policy that anticipates the building up of the scientific, technological and industrial potential for the creation of intellectual power industry.

The experience of developed European countries and the first results of the Smart Grid pilot projects in Russia reveal that “smart grids” will increase the level of electricity continuity and quality, optimize operating costs, and have positive impact on the formation of a selling price for power resources for enterprises. This will ultimately allow to reduce the power consumption of agricultural and industrial production and to increase the competitiveness of Russian products on the foreign market.

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