Roadmap for intelligent energy systems

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Abstract. The article is devoted to the prospects for the development of the energy complex of the Russian Federation within the framework of the concept “Industry 4.0”, the problems of integration of electricity, heat, cold and gas supply systems and energy security issues. A comparative analysis of the state and prospects of development of the fuel and energy complex of various regions of the world is given, and a forecast of the demand for integrated intelligent energy system is given.

1. Introduction
The modern markets of transport and supply energy, as well as the energy infrastructure, actively developed in the era of the second industrial revolution right up to the middle of the 20th century. Today, in the epoch of the third industrial revolution, the fuel and energy complex is the most conservative element hindering development of national economies [1, 2].

However, the next stage of development within the framework of the concept of the fourth industrial revolution “Industry 4.0” cannot exist without collaboration and deep integration of electricity, heat, cold and gas supply systems, which usually are differenced as in management and as in legislation [3, 4]. These systems must be ready to form the Integrated Intelligent Energy System (IIES) [5]. Energy sector requirements are changing, and these changes will inevitably require to energy to be more integration into the techno sphere. At the same time, as a result of the transition to “energy efficient thinking”, the role of a person changes from consumer to active object in the IIES [6, 7].

For the next 20 years, the energy sector in various regions and countries should solve the issues of ensuring energy security and become the guarantor of "sustainable development" as the basis for meeting their needs for future generations [8, 9]. The growing of population, increasing urbanization and exponentially increasing volumes of information will require an increase of 50% in electricity consumption, while tighten the requirements for efficiency, energy security, environmental friendliness, energy efficiency and adaptability of the energy infrastructure[10, 11]. Against the background of the growing limitation of the resource base of traditional energy, the role of intelligent energy is crucial for the whole world, a qualitative change in the nature of global and local energy systems based on digital and information technologies will allow the integration of electricity, heat, cold and gas supply systems.

The leading economies of the world clearly understand that collaboration in the framework of the IIES is critically necessary in Industry 4.0 in order to achieve the general goals of sustainable development for the benefit of future generations [12]. The technologies of the industrial Internet of things (IIoT) and artificial intelligence (AI) are among the most discussed trends in the world [13, 14].
In order to forecast the technological development of the fuel and energy complex of Russia in the context of global trends, it is necessary to single out and characterize the key global regions, whose activities depend on each other and influence the development of Russia's energy industry. In order to highlight the key parameters characterizing the problems and relevance of the transformation of energy systems in this study, the following regions are considered: the USA, the EU and Russia.

2. Analysis of the region «USA»

Territorial and demographic aspects. The United States of America occupy the 4th place in the world in terms of area: 9.5 million km², the country has a temperate climate. The population is 325 million people (3rd place in the world). The population density is 34 people/km². The unemployment rate is 4.1%. Fuel and energy complex. For 2016, investment in energy amounted to $ 276 billion (World Energy Investment). About $ 2.80 trillion per year potentially available from pension funds and insurance companies for new investments in clean energy [15]. The total installed capacity of traditional generation, including hydropower, is more than 980 GW. The share of small distributed energy in the country is about 10%. Ecological aspect. With regard to environmental safety, after reducing carbon dioxide emissions by 0.6% in 2017, EIA predicts that energy-related CO2 emissions will increase by 1.0% in 2018 and another 0.8% in 2019. In this regard, in 2018, together with the project The 2018 US Budget Bill, a tax credit “45Q” was introduced (to control the amount of CO2 emissions), which can lead to investments of about $ 1 billion over 6 years [16].

Hydrocarbon resources. Electricity production in the United States in 2017 decreased by 1.5%. Despite the decline in coal-fired power production, the US resource storage is one of the largest in the world. Coal production is 569 million tons per year, according to calculations made it is determined that there will be enough coal for the next 400 years, recoverable reserves amount to 237 billion tons. EIA predicts that coal production will decline by almost 5% in 2018 and then increase by 1% in 2019. US natural gas reserves are 9.6 trillion. cc m, which are designed for 70 years with production of 137 billion cubic meters. m per year. The production of traditional crude oil in the United States, including condensate, amounted to 567 million tons in 2017, reserves are estimated at about 11 years (10th place in the world). As of 2017, the United States imported approximately 39% of total oil consumption and 61% extracted independently. The cost of the resource (crude oil) on 03/16/2018 is $ 64 / barrel. Also, the United States is the world's largest producer of nuclear energy (more than 30% of world nuclear energy). Uranium reserves amount to 138 thousand tons, with a production of 1.88 thousand tons of reserves a year will be enough for almost 74 years.

Renewable energy sources. The share of RES for 2017 in total generation was 19.5%. Wind accounted for almost 8% of the total net generation, and solar energy about 1.3% - record shares for both fuels. It is expected that in 2019, the wind will become the predominant source of renewable electricity, because in 2017 another 6.3 GW of wind turbines were added. The number of jobs in the solar and wind power industry is increasing by 20% annually, and also RES create jobs 12 times faster than other sectors of the economy. Forecast for the fuel and energy complex in the long term. EIA forecasts, by 2030, the growth of electricity generation from renewable sources by an average of 3.9% per year. In general, by 2030, the share of renewable energy will increase to 25% of the total generation. But natural gas is the leading fuel in the power industry and by 2050 its share may be 35% of the total production. Electricity production from coal and nuclear fuel will decline, yielding a share of natural gas and renewable energy sources. By 2020, renewable energy sources will surpass nuclear sources, and by 2030, sources on coal fuel [17].

Long-term forecast of economic growth. The US GDP will steadily grow over the next decade by 3.3% per year, from $ 19.2 trillion. in 2017 to $ 27.99 trillion in the year 2027. Reflecting the slow transition to renewable energy, it is expected that only 10% of global energy consumption will be in renewable energy, because China consumes twice as much renewable energy as the United States. Economic growth remains modest: about 2.0% by 2018, and then 1.9% per year. The production of electricity based on nuclear energy is declining, since about half of the existing nuclear power plants will be decommissioned by 2050. Regardless of the goals of the use of augmented reality, an
important part of the augmented reality system is the script. Since augmented reality is a combination of real and virtual reality, the script is very similar to the virtual reality scenario, but there are some unique features.

3. Analysis of the region "European Union"
Territorial and demographic aspects. The European Union occupies an area of 4,324,782 km² (7th place). The European Union includes 28 states. The prevailing temperate climate. The population is 511,522,671 people. The population density is 115.8 persons/km². The level of urbanization 70-90%. The unemployment rate is 7.3%. In the EU, there is a low birth rate and a low level of natural growth. According to analyst’s prediction, by 2050, 50% of the European Union’s population will be over 50 years old. According to the Organization for Economic Cooperation and Development, the standard of living in the EU countries without a large-scale organization will decrease by 18% [18].

Fuel and energy complex. The package of measures on energy and climate change until 2020 aims to reduce greenhouse gas production by 40% compared with the 1990 level, to achieve a share of energy obtained from renewable sources to 27%, and also to increase energy efficiency to 27% by 2030. The EU has adopted guidelines for countries on developing and reforming support schemes for the use of renewable energy sources and investments in this sector [19].

Hydrocarbon resources. In the global consumer market Europe is on the 2nd place. Oil imports in 2015 amounted to 66% of energy imports to the EU, followed by gas (23%) and solid fuel (10%). In 2015, almost two thirds of crude oil imports came from Russia (29%), Norway (12%), Nigeria (8%), Saudi Arabia (8%) and Iraq (8%). Renewable energy sources. The total installed capacity of renewable energy facilities in the European Union was 421 GW in 2016. EU countries plan to generate about 70% of electricity from renewable sources by 2040, compared with 32% in 2015.

Long-term forecast of economic growth. Stronger demographic restrictions due to the aging trend in the Eurozone population will restrain the growth of the European economy: the average annual growth rate for the period 2013–2030 will not exceed 1.5%. The average annual growth rate of the economically active population will significantly decrease: from 0.8% on average over the period 1991-2010 up to 0.1% for the period 2013-2030.

4. Analysis of the region "Russian Federation"
Territorial and demographic aspects. The Russian Federation occupies the first place in the world in terms of area - 17.125 million km². Most of the territory of Russia lies in the temperatecontinental climate zone. Permafrost (areas of the north of the European part, Siberia and the Far East) covers 65% of the territory of Russia. Population - 146, 880 million people. (9th place). The population density of Russia is 8.57 people. As of January 2018, the unemployment rate was 5.5%.

Trends in the use of various fuel and energy resources: Gas generation is the main production structure of the electric power industry. Over the past decade, the share of gas in the fuel balance of UES of Russia power plants continued to grow from 63% to 72%. The power system of the Russian Federation. More than 90% of the production potential of the energy sector of Russia is integrated into the Unified Energy System of Russia (UES of Russia), which covers the entire inhabited territory of the country and is one of the world's largest centrally controlled energy associations. Seven United Energy Systems (ECO) operate in the UES of Russia. The UES of Russia electric power complex includes 748 power plants with a capacity of over 5 MW. As of January 1, 2018, the total installed capacity of UES of Russia power plants was 239.812 GW. The structure of the installed capacity of UES of Russia power plants includes: TPPs - 68.24%, hydropower plants - 20.6%, NPPs - 11.16%, SES - 0.22%, WPPs - 0.06%. The size of technological and commercial losses is networks and averages 9.22% [20, 21].

The total capacity of distributed generation facilities in Russia as of 2017 is 23.5 GW: 8.5 GW of stations up to 25 MW operating outside the UES, 15 GW of the more powerful stations in the UES. The share of distributed generation power in the country's energy system is estimated at 9-9.5%. Depreciation of power equipment of power plants of all types and systems of transport, transmission
and distribution of electric and thermal energy is 56%, and on equipment of electrical and heating networks - up to 80%. Dismantling of generating capacity for the period 2011-2030 will be 82.1 GW, which will create the need for new capacity.

Financing. The share of the fuel and energy complex in the Russian GDP is 22.6%. The share of the fuel and energy complex in exports is 56.9%. To increase energy efficiency in industry, almost 31 billion rubles were allocated from the federal budget in 2018–2020 for the program “Energy Efficiency and Energy Development”.

The development of the hydrocarbon potential of the continental shelf of the Arctic seas and the northern territories of Russia will play a stabilizing role in the dynamics of oil and gas production in the country, offsetting the possible decline in the level of production in traditional oil and gas producing areas. The share of the shelf of the Arctic seas in oil production can be up to 5%, and gas - up to 10% by 2035. By 2024, the Government of the Russian Federation plans to increase the installed capacity of generation facilities based on renewable energy sources to 5.9 GW.

In the EEC for the period 2025-2035, a shortage of generating capacity is predicted, however, distributed generation can fill up half of the current deficit (about 36 GW by 2035). At the same time, the maximum potential has distributed cogeneration - about 17 GW. Own generation will provide an additional about 13 GW, demand management - up to 4 GW, energy efficiency - 1.5 GW and microgeneration on renewable energy sources - 0.6 GW. The growth of the energy efficiency of the economy and changes in the structure of the energy balance up to 2035 will help curb the growth of greenhouse gas (GHG) emissions associated with fuel at + 2.6% from 2012.

The implementation of the Energy Strategy for the period up to 2035 will lead to a decrease in depreciation of production assets by 25% from the 2010 level. Maintaining a steady reserve of electricity and heat-generating facilities, including maintaining the reserve capacity of power plants at 17% of the total installed capacity of the UES of Russia, will reduce the dependence from external volatile energy markets. With an increase in the share of the countries of the Asia-Pacific region in the total export of fuel and energy resources of Russia to at least 31% by 2035, a new alternative to the European market will open, which seeks independence from Russian supplies of fuel and energy resources and increases the share of renewable energy sources in its own energy balance. By 2035, by reducing the specific fuel consumption for electricity generation by 48%, the economic efficiency of the TPPs and, consequently, the entire UES of the Russian Federation will be ensured (the share of the TPPs in the energy mix will be 65.5% of production). The trend towards increasing energy efficiency and tightening environmental requirements dictates the need to ensure an appropriate level of GHG emissions by 2035: no more than 120% of the 2010 level [22]. Achieving all of these parameters in the economy and energy of the country will be the result of the transition to a resource-innovative way of development of the fuel and energy complex [23].

5. Analysis results
To assess the impact of technological trends on the acquired properties of IES, 70 key technologies were analyzed, which were divided into 8 areas: digital, information, accumulation, renewable energy sources (RES), transport technologies; Materials Science; technologies of distributed and centralized non-renewable energy (non-renewable energy); energy saving technologies. For each of the technologies, an estimated relationship has been established with the corresponding IESI property and, based on expert opinions, weighting factors are distributed: strong; significant; moderate; weak; lack of influence. Accordingly, the proposed model allows, taking into account the analysis of regional issues, to make a predictive assessment of the demand of those technological areas that will prevail over the next decade in terms of eliminating the growing problems in the energy systems of individual regions. The impact of key technologies currently in use and which will be successfully developed up to 2030 on 5 key parameters of the IESE - flexibility, environmental friendliness, energy efficiency, reliability, economy, characterizing the power systems in general for 2018 and 2030, based on statistical data and data of regional development forecasts.
The need to create IIES in the United States. Despite the high level of technical equipment and economic support, US energy policy requires a long-term plan for energy security. Thus, over the past 10 years, more than 27 highly dangerous natural disasters (2 place in the world after China) occurred in the country, which caused damage to the economy and the fuel and energy complex of the country. America’s deteriorating energy system is an increasing danger to the public. Of course, outages occur quite often and, as a rule, they are completely manageable and are resolved within a few minutes or less than an hour. However, there are other cases where this is not possible. All this leads to the need to create an intelligent power grid, which will increase the stability and quality of the power supply, while a significant shift in the transformation should be made in the direction of environmental friendliness.

Forecast of demand: the main - digital, informational, accumulation; moderate - RES, transport; Materials Science; not priority - not renewable energy; energy saving.

The need to create an IIES in the European Union. The creation of the IIES system is due to the formation of the concept for the development of the power industry in the European Union, due to the territorial dispersion of renewable energy sources, the lack of its own oil and gas mineral deposits, and the environmental situation in the region. The development of the infrastructure of charging stations and the improvement of electric vehicles will contribute to the high growth rate of this market segment. The improvement of the system is aimed at the massive introduction of cyber technologies into the energy sector and into production as a whole - the fourth industrial revolution (Industry 4.0).

Forecast demand: the main - renewable energy, digital, informational; moderate - accumulation, energy saving; not priority - not renewable energy, materials science, transport.

The need to create IIES in Russia. The main internal challenge is the need for deep and comprehensive modernization of the fuel and energy complex of Russia, overcoming the high wear and tear of a significant part of the infrastructure and production assets, and increasing the production of high value-added energy (light petroleum products, gas engine fuel, oil and gas chemistry products). The main problem is the significant unrealized potential of organizational and technological energy saving, exceeding 1/3 of the total consumption of fuel and energy resources in the country.

Forecast of demand: the main - digital, informational, energy saving; moderate - renewable energy, materials science, accumulation; not priority - not renewable energy, transport.

6. Conclusion

The analysis showed that, despite the difference in the problem areas in the energy systems of the regions examined, the transition to the IIES is impossible without large-scale digitalization and informatization. It is these technologies that will be the basis for solving the main problem characteristic of all energy systems - the acquisition of greater flexibility in the integration of various energy resources. It is worth noting that the characteristic problems of Europe related to energy security will determine the demand for renewable energy sources and energy storage, but an excessive increase in these areas according to the simulation leads to a threat to economy, which will affect the final consumer and the competitiveness of products. At the next stage, the tasks of integrating the system with decentralized facilities should be solved, this will significantly increase the adaptability and energy security.

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