Results of national generation reform and predictive information about power engineering market

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Abstract. The work presents the structure of generating capacities and fuel mix of territorial districts of Russia and shows the essential trends in development for the period from 2007 to 2017. Changing of utilization factor of territorial structure generation installed capacity is shown. Branch market of power engineering consists of a number of segments which can be divided in two large spheres: power equipment production and its maintenance. The particular features of Russian power engineering market are identified. The analysis of the state and trends of development of national power engineering market is performed. The market structure, growth dynamics, shares of production and of imported equipment, sales territory are outlined. The major players on the national power engineering market are characterised. The forecast for power-generating equipment development for the following six years including reliable statistic data for the period 2000-2016 is presented. Approximate reliance’s and correlation coefficients for each market fraction are defined. The paper shows that the type of regression equation for different fractions of market changes. The international cooperation and cooperation with world leaders via building in their production chains, creating alliances and localisation of leading foreign technologies in Russia will promote competition growth of Russian companies.

1. Introduction
Power engineering in Russia has been characterized recently by constant growth of installed capacities. For 10 years installed capacities in Russia increased from 200 GW in 2007 to 244 GW in 2017. Generation structure hasn’t changed very much indicating balanced development of each type facility market (figure 1). It should be noted that the growth of installed capacities on renewable energy sources, as well as the fact that the increase in the capacity of Thermal power plants (TPPs) is primarily ensured with the help of introduction of promising combined-cycle technologies (figure 2), which have an unachievable efficiency for other technical solutions.

The capacity of combined-cycle gas turbine (CCGT) unit and gas turbine unit (GTU) in 2017 was more than 22 GW, the increase in the capacity of non-renewable sources is the highest, figure 2. Nuclear power capacity grew from 23 to 28 GW and concentrated on 10 power stations. In the short term, the offshore structure as a floating electric station “Academician Lomonosov” will be launched (70 MWth capacity), in the meantime nuclear power station of Bilibinsk will be closed (48 MWth capacity). Therein a real launch of new generation is substantially greater, as in the period under review 6.4 GW of capacity of Sayano Shushenskoe HPP was compensated (after the accident in 2009) and more than 8 GW of outdated equipment were taken out of service in the last three years [1].
The line indicates the average growth in Russia for all types of assets.

**Figure 1.** Structure of Russia's generating capacity: NPP – Nuclear power plant, HPP - Hydroelectric power plant, TPP – Thermal power plant.

On the average in Russia, installed capacity growth rate (without isolated power systems) was approximately 15%, figure 3.

**Figure 2.** Absolute (a) and relative (b, d) increase in installed capacity in the Russian Federation and the structure of installed capacities of CCGT and GTU (c): CPP - condensing power plant, CHPP – combined heat power plant.

The increase in installed capacity by type of generation

| Year | HPP | TPP | NPP | Other |
|------|-----|-----|-----|-------|
| 2007 | 44  | 50  | 23  | 1     |
| 2017 | 50  | 131 | 28  | 2     |

The relative increase in installed capacity

| Type | HPP | TPP | NPP | Other |
|------|-----|-----|-----|-------|
| 2007 | 12.8| 13.9| 20.2| 132.2 |

The structure of installed CCGT and GTU capacities in 2017 for the Russian Federation

| Type  | CCGT CPP | CCGT CHPP | GTU CPP | GTU CHPP |
|-------|----------|-----------|---------|----------|
| MW    | 8 689    | 11 319    | 340     | 1558     |
It can be seen that territorial growth is not the same and three districts Ural Federal District, North Caucasian Federal District and Southern Federal District have the highest growth. The first paragraph after a heading is not indented.

![Figure 3. Installed capacity growth in territorial district: CFD – Central Federal District; NWFD – North-West Federal District; SFD – Southern Federal District; NCFD – North Caucasian Federal District; PFD – Privolzhsky Federal District; UFD – Ural Federal District; SFD – Siberian Federal District; FEFD – Far Eastern Federal District.](image)

2. Modern features and the forecast of the domestic market of power mechanical engineering

Fuel balance structure has changed in favor of gas by means of a carbon share reduction. One of the forecast of RAO Unified Energy System of Russia by 2015 assumed a decrease in the share of gas to 60% due to an increase in the share of coal to 37%. This tendency fell through.

One of important indices characterizing power engineering development is a utilization factor of installed capacity (UFIC). Outlining in terms of UFIC its theoretically possible value considering routine maintenance of the equipment during the year and comparing it with an actual utilization factor in 2007, it is obvious that in Southern Federal District and Ural Federal District actual UFIC is higher than the theoretical one, figure 4. This is possible only if the time limits for the withdrawal of equipment in planned repairs are not observed, which is fraught with increased accident rates. As power system has to have operating margin to provide accident-free operation and frequency maintenance on the level of 12-13 %, the power system of Central Federal District had also insufficient installed capacity in 2007.

![Figure 4. Utilization factor of installed capacity for different district of Russian Federation](image)
By 2017 the referred problem of regional generation was solved due to launching new capacity. Almost all major world players such as General Electric, Siemens & Westinghouse, Mitsubishi & Hitachi Power System are involved in the market of power engineering in Russia. At the same time, according to the Federal Customs Service (FTS), the share of imports depends on the type of product and for the ten years is 20% of the total investment. The share of imports in gas turbine construction exceeds 36% during the same period, which is due to the backlog of national production in this field of technology.

Consolidated market of own production for ten years is 1306 billion rubles or $ 37.4 billion when calculating at the average annual exchange rate (in annual terms it is 5.2% of the world market volume without services). Consolidated import market for ten years is $ 9.46 billion.

The structure of the exporting countries for each type of product shows the expansion of the energy equipment supply geography to Russia in 2016 compared to 2012 [2]. It is important to note that the equipment import also includes the supply of blades, impellers for hydraulic units, component and spare parts. The share of gas turbines for the energy purpose in the total supply of gas turbine equipment does not exceed 30%, the rest is for turbines driven, fleet, air, gas-pumping.

The program of import substitution in the field of power engineering is solved by creating joint ventures, table 1. It is expected that by 2020 in Russia a significant part of the generating capacities envisaged by the energy development program will have been produced within the framework of joint ventures [3-6].

| Company               | Head structure       | Beneficiary party | Partner | Subject of agreement                             |
|-----------------------|----------------------|-------------------|---------|--------------------------------------------------|
| Atomenergomash        | Rosatom              | State             | Alstom  | Powerful steam turbines for nuclear power plants |
| Leningrad Metal Plant | Russian Technologies | Siemens, Siloviye Mashiny | GE      | Gas turbines                                     |
| the Ural Turbine Works | Siloviye Mashiny    | Siemenes          | Siemens | Heavy-duty gas turbine                           |
| RusHydro              | RusHydro             | State             | Alstom Power | Hydropower equipment for small hydropower plants |
|                       |                      |                   | Voith Hydro | Small and medium power hydro turbines            |

Further in the article, we propose the results of the medium-term forecasting of the development of the Russian power engineering market for six years, that is, until 2022 inclusive. The forecast was made for each market segment taking into account its actual data for the previous period from 2000 to 2016 inclusive using approximating dependencies of different kinds. This approach is used quite widely in the problems of forecasting economic development [8-10]. In the present work, the choice of approximating dependence is determined from four possible versions (logarithmic, exponential, exponential, polynomial) for each market segment individually basing on the accuracy of the forecast estimates, which can be established according to reliable statistical data for the period 2000-2016.

Two indicators determine the accuracy of forecasting in this approach. First, the deviation of the mathematical expectation of the approximating function from the actual value on the forecast horizon to 6 years. In this case, the actual is a reliably known value of the indicator (market volume) based on the statistical data of the industry work over the past years. Secondly, the variance or deviation of the
actual values from the mathematical expectation on the forecast horizon. Approximating functions and correlation coefficients for each market segment are determined, table 2. It is worthy of note that the dynamics of different market segments are best described by different dependencies, while the accuracy of forecasting does not depend on the form of the equation, table 3.

Table 2. Approximating dependencies and correlation coefficients

| Segment of the market          | The form of equation | Coefficients of approximation |
|-------------------------------|----------------------|-------------------------------|
| Steam turbines                | $y = Ae^{ax}$        | $a$ = 15,12, $b$ = 0,09      |
| Gas turbines                  | $y = Ax^b$           | $a$ = 6,43, $b$ = 0,8        |
| Hydroturbines                 | $y = A \ln(x) + B$   | $a$ = 6,05, $b$ = 0,24       |
| Steam-generating units        | $y = Ae^{ax}$        | $a$ = 9,71, $b$ = 0,02       |
| Generators and transformers   | $y = Ae^{ax}$        | $a$ = 2,12, $b$ = 0,89       |
| Gas reciprocating unit and Diesels | $y = A \ln(x) + B$   | $a$ = 4,69, $b$ = 2,7        |

The worst indicators $\Delta$ are market segments in steam generating, gas reciprocating unit and diesel engines. The root-mean-square deviation for them is 96 and 112%, respectively. At the same time, for the consolidated market, the indicator defined as the rms forecast for the years, taking into account the share of each segment, is 68%, table 3.

Table 3. Factors characterizing the accuracy of forecasting

| Segment of the market          | Deviation of the mathematical expectation on the forecast horizon,% | Dispersion ($\delta$), % | Standard deviation of the forecast,% |
|-------------------------------|------------------------------------------------------------------|--------------------------|-------------------------------------|
| Steam turbines                | $0.28$                                                           | $0.7$                    | $0.15$                              |
| Gas turbines                  | $0.36$                                                           | $0.14$                   | $0.15$                              |
| Hydroturbines                 | $0.08$                                                           | $0.06$                   | $0.08$                              |
| Steam-generating units        | $0.06$                                                           | $0.06$                   | $0.15$                              |
| Generators and transformers   | $0.15$                                                           | $0.15$                   | $0.15$                              |
| Gas reciprocating unit and Diesels | $0.07$                                                           | $0.07$                   | $0.15$                              |
| Consolidated market           | $1.0$                                                            | $1.4$                    | $1.4$                               |

The result of the forecast is to determine the prospects for the development of the market of power engineering in Russia for the next six years. After the growth of 2014-2016, we can expect some decline in 2017 (possibly 2018), with a further stable growth of 7% per year. Consolidated market in 2022 will be about 350 billion rubles. However, taking into account the deviation of the mathematical expectation and its variance, the market volume can be 1.9 times larger. For comparison, in [11] the indicator of 317 billion rubles is expected to be reached only by 2030.

3. Conclusions
Nowadays a certain “excess” of capacity characterizes the power industry of Russia. This surplus has been created in recent years of active investing in generating capacities in the electric power industry, according to various estimates it ranges from 30 to 40 GW of installed capacity and it is some
necessary reserve for the development of the country's production base. The energy of Russia has grown by more than 20% from 2007 to 2016. The generation structure remained, in general, unchanged, with a doubling of unconventional generation, which in the total balance rose to 2%. The increase in the installed capacity of CCGT in the TPP structure more than 20 times has reduced the specific fuel consumption for electricity generation by 7%. The power industry of Russia is characterized by a steady growth of installed capacities with the proportional development of the markets for installations of each type (TPP, HPP, NPP). In the structure of generation, there is an increase in installed capacity on renewable energy sources. The forecast for the development of the market of power engineering until 2022 shows that in the coming years we should expect some decline with the subsequent growth of 7% per year.

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