Development and research of structural and technological modernization scenarios of power engineering in power market conditions

E M Lisin

1 Department of Economics in Power Engineering and Industry, National Research University “Moscow Power Engineering Institute”, Krasnokazarmennaya 14, Moscow, 111250, Russia

E-mail: lisinym@mpei.ru

Abstract. The paper gives an analysis of the current state and development trends of the energy sector in a competitive electricity market. The most probable scenarios of the electricity innovative development and the electricity market structure changes have been outlined. A study of technology foresight methods that allow developing parametric models of the technological industry development has been undertaken.

1. Introduction

The feature of the Russian energy sector is the widespread use of electricity and heat combined production and the provision of the district heating from power plants. Heat has been produced by about 500 thermal power plants, including combined heat and power plants of general and industrial purpose. The total capacity and the amount of energy generated by thermal power plants account for about 70% of the capacity and generation by the country’s power plants [1, 2].

With the physical resources available capacity exhaustion and the loss of their further exploitation, there is a need for innovative technologies. Existing thermal power plants, mostly built in the 60-70s of the last century, and their equipment have been physically and morally outdated (low efficiency, at the level of 36-40% in comparison with the global rates: 42-55%, increased scope of repair work, a large number of maintenance staff, increased emissions into the environment). It is necessary to pull out of service the old and lower economic equipment and replace it with perspective one, providing a significant reduction in the cost of electricity and heat generation, decrease in fuel consumption and normal-mode ratio, environmental emissions and maintenance costs reduction [2, 3, 4].

For thermal power plants using natural gas, the transition to new energy-efficient technology shall mean a gradual decommissioning of all the condensing steam power units and replacing them with combined-cycle ones [5, 6]. It is reasonable to build combined-cycle power plants under unified projects, corresponding to modern standards. To implement such projects it is necessary to develop a new regulatory and technical basis, which shall take into account the technology solutions evolution in the energy and power engineering.

Coal-fired power plants improving will imply the turbines and boilers efficiency increase, reducing emissions into environment and losses decrease. Also, a significant increase in the efficiency of a coal-fired power plant would be possible after the industrial development of the combined cycle technology
with coal gasification. Combined-cycle units designed on its basis will significantly increase the plant efficiency [4, 6].

In the short and medium term it shall be also required to consider the development of new advanced energy technologies domestically produced. To do this, now it is advisable to perform a feasibility study of the solutions such as the development of hybrid power plants based on fuel cells, coal-fired power units under supercritical steam parameters, to develop pilot units with CO₂ decommissioning from the energy cycle and its disposal [7, 8, 9].

Table 1 lists the key technical and economic parameters of power generation technologies based on coal fuel with different efficiency levels.

| Technical parameter | State of technology |
|---------------------|---------------------|
|                     | Supercritical (SC)  | Ultra-supercritical parameters (USC) | Advanced ultra-supercritical parameters (A-USC) |
| Capacity level, MW  | 300                 | 660                             | 1000                               |
| Efficiency level, % | 40                   | 45.3                            | 50                                 |
| Superheated steam temperature, °C | 540 | 600                             | 720                                 |
| Superheated pressure, MPa | 24 | 30                              | 35                                 |
| Specific capital investments, U.S. dollars/kW | 1680 | 1900 | 2240 |

Due to the loss of a significant part of the industrial and scientific-technical capabilities the task of the industry innovative development is extremely complicated. To increase production capacities the Russian power equipment manufacturers need long-term agreements with energy companies which prefer more highly efficient foreign technologies. These agreements under market relations can be achieved by localization of the main power equipment and components production, thus increasing the technological level and industrial capacity of the country's power engineering. There is an actual task to assess the required level of the production localization.

It is also necessary to understand that the existing technology base of the energy industry, introduced in the planned economy period, in fact was not designed to be competitive. Power plants competition in consumers’ supply with electric power was not provided for, as it did not make sense to build several plants at the same time for the power supply of the same consumers at the expense of public funds. Due to this the formed wholesale electricity market to a great extent has the features of a natural monopoly that does not contribute to competitive pricing [12, 13]. It is necessary to seek technical and economic solutions that promote the concentration reducing in the industry, in other words, the appearance of small efficient power sources able to compete with large power plants. It is necessary to adhere to the country's energy development strategy, gradually implementing the transition from the predominant natural gas use to a significant use of solid fuels [2; 14].

The presence of the above issues and major tasks of public significance facing the industry in terms of the state commitment to ensure a competitive energy market and the localization of power engineering industries, determines the relevance of the predictive scenarios design for the innovative development of energy industry.

2. Scenario analysis of the innovative development of the energy sector
The increasing aging of the power plants’ main equipment leads to a reduction in the operating reliability of the sector, sub-optimal loading of generating capacities in the power system, the presence of “pent-up capacities”, as well as reduction of the equipment performance, environmental and energy efficiency. The uncertainty of the long-term rules of the wholesale and retail electricity markets functioning, and the lack of effective mechanisms to ensure the effectiveness of investments in new construction and modernization of power facilities, impede the long-term private investment attraction to the industry, moreover, result in private investors’ willingness to sell business assets acquired in the course of the reform [2, 12].

The assets redistribution arising in the industry results in the establishment of large vertically integrated companies which operate with public participation, and in gradual monopolization of the industry. The lack of effective price regulation for fossil fuels (coal, oil) contributes to this factor, which in independent power producers result in a significant increase in the fuel component costs and has a significant impact on profitability due to high operating costs and fixed assets depreciation.

The structure of the industry has been gradually changing. In particular, due to the heat business operating at a loss, the displacement by regional boiler CHP from heat load schedule occurs and, as a consequence, a significant reduction in the heating cycle production, thereby reducing the technical and economic efficiency of cogeneration capacities [13, 14]. Efficient highly maneuverable plants operating in a purely condensation cycle have preference in the electric power market. CHP, being the basic generation facilities for many years, due to the low maneuverability in connection with the heat load bearing in the market economy environment are also in the lost position.

The ongoing integration of the energy sector with the extractive industry leads to large-scale investment programs in the energy sector and the distributed generation development. To a large extent, this phenomenon causes a steady increase of fuel component costs and high potential for increase in the operational efficiency of enterprises.

Integration of certain energy systems and energy markets results in the gradual basic prices equalization and a shift of financial and economic policy of the energy sector companies towards the energy system optimization. Optimizing technologies of energy supply and energy consumption modes have been developed, such as the electricity supply smart grid and smart metering, electricity storage technology, energy power transmission over long distances, highly economical and environmentally friendly energy-efficient equipment production, as well as the development of electric transport (vehicle-to-grid (V2G), grid-to-vehicle (G2V technologies)) [15, 16].

The ways of the old inefficient generation decommissioning and preservation remain another priority issue as well as their payment with the minimum price load on consumers and preserving the reliability of the power system operating.

The innovative industry development in the market economy environment has been significantly determined by the competitive environment. Such a competitive environment for the electric power sector, in the first place, is the Wholesale market for electricity and power (WMEP).

WMEP is characterized by a structural division of generation, transmission and distribution of electric energy, as well as by the specific nature of the electric power production and consumption, caused by the lack of opportunities of electricity storage in significant volumes and maintaining a balance between its production and consumption at any given time.

In addition to the structural division the wholesale market is also characterized by the geographical separation caused by technological reasons. WMEP is divided into separate little or not communicating with each other geographic zones: the first price zone (European Russia and the Urals territories), the second price zone (Siberia), non-price zones (regions of the Far East, the Arkhangelsk Region, the Kaliningrad Region, the Republic of Komi).

The price zones are characterized by a large number of suppliers and buyers of electricity, as well as well-developed network infrastructure availability that allows operating of a competitive electricity market. On the territories of non-price zones it is impossible at the moment to create a competitive market for technical reasons, electricity and capacity sales is performed at regulated prices.
The performed analysis of the market shares composition of economic entities and grouping them to price zones has revealed a high level of concentration on the wholesale market in terms of production volumes, established and available capacity [12, 14]. The concentration growth leads to the competition reduction in the industry, small energy enterprises have been absorbed by large holding companies that are not interested to the full extent in the competition development among their companies.

Major monopolists - suppliers of fuel for power plants, such as PJSC “Gazprom” and PJSC “SUEK” which have come to the market through the creation of vertically integrated structures, have an increasing impact on the industry. In the medium term, the vertically integrated generating companies will play a crucial role in the market structure formation and innovative development of the energy industry. In this regard, the following predictive scenarios are possible (see Table 2).

| The energy market development scenarios | Features of the industry innovative development |
|----------------------------------------|------------------------------------------------|
| Scenario 1: There is no competition. Vertically integrated generating companies are under the state control. (Closed monopoly) | The manufacturers’ competition is absent and replaced by the manufacturer’s ability to protect its price before the regulatory body. For a consumer, tariff shall be imposed by the regulatory body on the basis of the average price for all power plants. Funds for innovation development are included in the tariff. |
| Scenario 2: There is competition of vertically integrated companies on the wholesale power market before the state-controlled buyer. (Monopsony, Oligopsony) | Manufacturers compete on the wholesale market. For consumers, the tariff shall be imposed by the state controlled buyer at the level of the average price for all the plants. Funds for innovation development are included in the tariff. It is possible to reduce the tariff by the use of a competitive mechanism in manufacturers. |
| Scenario 3. Competition of vertically integrated companies to the sales companies. (Oligopoly) | Manufacturers compete on the wholesale market. The price of electricity is set based on the marginal auction of price bids. Sales company sets the tariff for the consumer on the basis of a market price and sales premium regulated by the state. Funds for innovative development shall be not included in the tariff. The tariff increases due to the increase in prices of the wholesale market. |
| Scenario 4. Full competition in the wholesale and retail power markets. (Oligopoly, monopolistic competition) | Manufacturers compete on the wholesale market. The price of electricity is set based on the marginal auction of price bids at the maximum price of price-accepting application of the power plant. In the retail market, the sales premium is added to the price of the wholesale market. Funds for innovative development shall be not included in the tariff. The tariff slightly decreases due to the competition between retail companies. |

Depending on the energy market development scenario, the direction of the industry innovative development will change, including the production technology selection, electric power transmission and distribution and capacity structure optimization. In a competitive energy market environment the long-term competitiveness ensuring through the introduction of cost-based innovative solutions becomes a key factor for the energy sector. One of the fundamental feasibility tools are methods of technology foresight.

3. The technology foresight methods analysis
To describe the innovative development of the industry in the medium and long term the methods of technology foresight shall be applied, which allow designing parametric models of the industry technological development. In a competitive energy market such models should be complemented by predicting the value of capital expenditures for modernization and commissioning of the new power equipment, electric energy cost for consumers and conducting study of the energy market participants’ behavior on agent models. Also, to describe sustainable innovative development of the industry it is necessary at the level of the model to solve the issue of alignment of the natural resources exploitation, environmental requirements, areas of investment and scientific and technological development, institutional changes in the energy market and the society needs with each other.

The scientific literature study [17, 18, 19] shows that the problem of technology foresight is far from being solved. Currently, different methods are used in the practice of foresight that is explained by the continuing theory development due to the changing economic conditions and increased opportunities of researchers.

There are three main methods of technology foresight:

1. Quantitative methods - based on the use of mathematical statistics methods (time-series analysis, regression analysis, econometric models, and stochastic modeling methods). They allow making forecast by extrapolation for a very limited period of time. The variance of the random variable will inevitably increase then, which greatly affects the accuracy of predictive estimates. Also statistical methods do not allow taking into account rapidly occurring changes of the studied system, caused, for example, by the implementation of technological innovations.

2. Qualitative methods - based on the use of qualitative assessments, with underlying analysis of highly qualified experts’ judgments. The methods are universal and applicable without significant restrictions to address objectives of short-term, medium and long-term forecasting. The methods provide only a general idea of the development direction of the phenomenon studied; therefore they are mainly used to predict new scientific and technological developments and the formation of scientific and technological policy of countries (for example, the method of long-term forecasting of scientific and technological development Foresight).

3. Evolutionary methods - based on the analysis of the existing technology growth. It is believed that this process is not of a random nature, and develops in a certain trajectory. Therefore, in case of the information availability on the composed partly technological path it can be assumed that the technology will be further developed according to this curve, and hence, to obtain predicted values by extrapolation. The complexity of the methods lies in the analysis and the selection of a reliable model of technological path. In this regard, it should be taken into account that technology shall develop at the expense of the market, and one of its main driving forces is an investment.

The most promising modern direction in terms of applied research conducting in the field of forecasting is the development and analysis of nonlinear deterministic systems with chaotic behavior. Thus, today there is no mathematically precise machine of chaos theory application to address objectives of the technological forecasting.

In general, based on the analysis of technological forecasting methods, we can conclude that for purposes of the study of the energy sector innovative development it is necessary to solve a number of problems associated with both the choice and the improvement of the prediction method, and a prediction error estimate and determination of the degree of confidence of the results obtained.

4. Conclusion
At present time, modernization of equipment and assimilation of new manufacturing technologies may enhance competitiveness of the Russian power engineering enterprises and provide security of energy supply in the country. At achieving these purposes under current economic conditions, it is necessary to manage costs of new power equipment manufacturing. Cost forecast for new power equipment during research and development stage is of prime importance. This could allow for attracting investments in power engineering sector from generating companies at early stages.
The results of the analysis performed indicate inefficiency and uncontrollability of the existing market model of energy sector in the medium and long term, non-compliance of technical and economic development of the sector with the energy strategy selected.

It is necessary to develop predictive models to manage innovative development of the industry in a competitive energy market.

The basic approach to achieve this goal is solving the problem on the methodology development for assessing the technological and economic potential of the technologies that determine the innovative development of the industry and included in the technology platforms.

References

[1] Ministry of Energy of the Russian Federation. (2010). Energy Strategy of Russia for the Period up to 2030. Institute of Energy Strategy, Moscow, Russia, 172.

[2] Lisin, E., Rogalev, A., Strielkowski, W., & Komarov, I. (2015). Sustainable modernization of the Russian Power Utilities Industry, Sustainability, 7(9), 11378-11400.

[3] International Energy Statistics. Available online: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm (accessed: 2017, June 1).

[4] Breeze, P. (2014). Power generation technologies, Newnes, 408.

[5] Smil, V. (2015). Natural Gas: Fuel for the 21st Century, John Wiley & Sons, 264.

[6] Lisin, E., Strielkowski, W., Komarov, I., & Garanin, I. (2016). Improving the methodology of main power equipment choice for the gas turbine plants. Electronics, 19(2), 80-87.

[7] Bugge, J., Kjær, S., & Blum, R. (2006). High-efficiency coal-fired power plants development and perspectives. Energy, 31, 1437-1445.

[8] Tola, V., & Pettinua, A. (2014). Power generation plants with carbon capture and storage: a techno-economic comparison between coal combustion and gasification technologies. Applied Energy, 113, 1461-1474.

[9] Zhang, D. (2013). Ultra-Supercritical Coal Power Plants: Materials, Technologies and Optimization. Woodhead Publishing, Cambridge, 273.

[10] New Coal-Fired Power Plant Performance and Cost Estimates. Report No SL-009808, Sargent & Lundy, L.L.C: Chicago, IL, USA, 2009, 82.

[11] Coal-Fired Power Plant Capital Cost Estimates. Report No PE-1865, Bechtel Power Corporation: San Francisco, CA, USA, 1981, 182.

[12] Lisin, E., & Strielkowski, W. (2014). Modelling new economic approaches for the wholesale energy markets in Russia and the EU. Transformation in Business & Economics, 13, 566-580.

[13] Lisin, E., Sobolev, A., Strielkowski, W., Garanin, I. (2016). Thermal efficiency of cogeneration units with multi-stage reheating for Russian municipal heating systems, Energies, 9(4), 269-288.

[14] Lisin, E., Garanin, I., Strielkowski, W., & Kritkova, S. (2015). Economic and business aspects of Russian energy market: development of combined heat and power technologies. Transformations in Business & Economics,14(1), 251-267.

[15] Tan, K. M., Ramachandaramurthy, V. K., & Yong, J. Y. (2016). Integration of electric vehicles in smart grid: A review on vehicle to grid technologies and optimization techniques. Renewable and Sustainable Energy Reviews, 53, 720-732.

[16] Gangale, F., Mengolini, A., & Onyewu, I. (2013). Consumer engagement: An insight from smart grid projects in Europe. Energy Policy, 60, 621-628.

[17] Meissner, D., Gokhberg, L., & Sokolov, A. (2013). Science, technology and innovation policy for the future: potentials and limits of foresight studies. Springer Science & Business Media, 292.

[18] Magruk, A. (2011). Innovative classification of technology foresight methods. Technological and Economic Development of Economy, 4, 700-715.

[19] Salo, A., Gustafsson, T., & Ramanathan, R. (2003). Multicriteria methods for technology foresight. Journal of Forecasting, 22(2-3), 235-255.