ECONOMIC AND TECHNOLOGICAL PRIORITIES OF COMPETITIVE DEVELOPMENT OF RUSSIAN SYSTEMS OF ENERGY COGENERATION SOURCES

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ABSTRACT

The article studies the problem of evaluation of competitive advantages of energy cogeneration sources (ECS) included in centralised and decentralised systems of energy cogeneration. For this purpose, a methodological apparatus has been developed to evaluate the effectiveness of business processes, and competitive cogeneration plants adapted to the market exploitation conditions have been chosen.

The methodological framework for conducting a comprehensive economic assessment of business processes in development of competitive advantages of cogeneration energy has been developed, which ensures improvement of the capacities structure and optimisation of fuel consumption in territorial energy generating companies, and allows choosing the most competitive options for the development of cogeneration energy sources of various types and capacities with consideration of the competitive environment on the electric and thermal energy markets. The proposed methodological approach makes it possible to reveal the economic and technological priorities for the development of ECS in regional energy systems and can be spread to the developing economies within the BRICS.

In the course of the study, it was found out, that the development of competitive advantages of energy sources cogeneration may be based on implementing the following business processes: optimisation of generating capacities and fuel consumption structure, technical re-equipment, reconstruction, expansion of existing and construction of new cogeneration energy sources.

Keywords: cogeneration systems, competitive development, energy

1 INTRODUCTION

The current market development shows that the high-tech industries set the development and ensure the competitiveness of any economy. Power generation, as its part, remains the most important and life-supporting industry. It provides a multidimensional and profound impact on socio-economic development of society and environment. This is due to the high importance and uniqueness of the sector product – electric energy and heat, which ensures operation and development of the national economy, as well as the social life, in the harsh climate of Russia. Therefore, preservation and expansion of the capacity of electric power industry, modernisation of its production facilities, as well as solution of tasks, faced by the industry, requires investments. The difficulty of attracting private capital in the power-generation sector has been considered by the authors in several publications [1–5]. However, the methodological problems related to the high level of subjectivity in risk assessment and, in general, investment attractiveness of the companies in the industry are on another development stage. The solution of this problem, aimed to increase the level of estimations objectivity, lies in the methodological development of the mathematical apparatus, allowing minimisation of the experts' opinion significance [6–9].

WIT CONFERENCES
This paper is part of the Proceedings of the New Forest Conference on Complex Systems 2016 (Complex Systems 2016)
www.witconferences.com

ISSN: 1755-7437 (paper format), ISSN: 1755-7445 (online), http://www.witpress.com/journals
DOI: 10.2495/DNE-V11-N4-610-619

2 GENERAL LAWS OF ENERGY COGENERATION SYSTEMS DEVELOPMENT IN THE RUSSIAN CONTEXT

In the process of the Russian electric power industry development, the new conditions have formed, characterised primarily by a high degree of uncertainty in the development of a competitive environment. They have led to the change of former priorities to qualitative development of generation capacities due to improvement of their efficiency and reliability.

Modern trends of electric power industry development are characterised both by restructuring processes, which initiate commercial activity of energy companies, and by the increase of competitive tension in the markets of electric and heat energy, which leads to the appearance of specific forms of competitive struggle in the sphere of energy generation at the level of territories, related to the implementation of competitive advantages of generating energy sources.

A link between an electric power system and a consumer, and also the basis, providing at the territorial level such processes as electrification and district heating, are ECS, representing a joint production of electricity and thermal energy through cogeneration power plants. Depending on their type and capacity, ECSs form two system of energy cogeneration (SEC) – centralised and distributed.

2.1 Centralised system of energy

A centralised SEC includes a territorial generating company (TGC), which occupies some intermediate position between “system-wide” generation and consumption complex, formed as a result of the development of the Russian electric power industry in recent time. On the basis of the structure of TGC generating facilities, cogeneration steam turbine units (STU) are installed at combined heat-and-power stations (HPS). Combined heat-and-power plants (CHP) and gas turbine cogeneration plants (GTU) plants may be considered as the most advantageous ones.

The problem of a centralised SEC development under competitive conditions may be associated with a loss of competitive advantages and disturbance of system properties mainly due to high depreciation of equipment and due to the desire of the TGC leadership to maximise profits at the expense of intensive exploitation of its residual life. This may result in a reduced level of ECS competitiveness due to: (1) sub-optimal mode of operation of cogeneration plants; (2) increase of fuel consumption; (3) growth of production costs.

2.2 Distributed system of energy

Currently, along with the traditional centralised SEC, a new structural element appears in the regional energy sector – an independent producer, including small cogeneration units forming the basis of a distributed SEC.

ECS included in a distributed SEC can be installed in remote areas of a region, having no centralised power supply but having enough relatively cheap local fuel (e.g., biomass, coal), and are economically feasible at industrial enterprises and in housing and communal systems. Under certain circumstances, such cogeneration installations may be competitive compared to a centralised SEC. In technical terms, the development of distributed SEC is only possible at high energy and operational efficiencies of small cogeneration plants, resulting in the following: 1. Change of the structure of fuel and energy balance of the territory in favor of cheaper, than natural gas, solid fuels; 2. Restructuring of electricity supply towards distributed SEC, on the basis of energy markets liberalisation; 3. Change of the technology of biomass and solid fuels energy utilisation (with the use of modern gas technologies in cogeneration plants).

In general, the suggested directions are not contrary to the principles of competitive development of the entire SEC and do not reduce the system effects due to the spread of low-power ECS. This produces an additional link in the regional system of energy generation, which provides energy to small communities or industrial enterprises, where it is impractical for any reason to use the ECS included in a centralised SEC. Moreover, under certain circumstances, the ECS included in a distributed SEC can organically fit into the competitive environment, taking its market niche in energy generation in the region.

The rational combination of centralised and distributed systems can mutually complement each other and allow creating fairly flexible SECs on territories. Such SEC is able to reliably provide consumers with electric and thermal energy and to successfully compete with sources, conducting separate generation of energy through the implementation of competitive advantages of cogeneration.

From the point of view of system approach, SEC is an open system, providing a unity of interrelated parts – both centralised and distributed SECs, each of them can be divided into smaller elements – ECS and individual cogeneration units, altogether forming the SEC structure.

The existence and evolution of SEC as an open system, depends, on the one hand, on its internal structure, and on the other – on the interaction with the external environment. As a result, the level of ECS competitiveness may increase or decrease.

3 COMPETITIVE ADVANTAGES OF ENERGY COGENERATION SYSTEMS

The development of a competitive environment in energy generation on a certain territory requires the full realisation of competitive advantages of the SEC, revealed at comparison with alternative separate production of electricity and heat in condensing power plants (CPP) and in boiler houses. The main competitive advantages follow from: (1) fuel economy; (2) improvement of power supply reliability; (3) reduction of costs for the construction and operation of electric and heat networks; and (4) reduction of toxic emissions and greenhouse gases.

It is known that energy cogeneration is a highly efficient technology with a general EF of 60% to 80%, at that the more electric energy is produced in heat consumption (in heat extraction mode), the higher efficiency factor (EF) of the cogeneration plant is. It clearly shows the economic feasibility of cogeneration development and demonstrates its main competitive advantage, which consists in the saving of heat at energy production, and ultimately leads to a significant reduction of the largest fuel component in the cost of energy.

It should be noted, that the future development of centralised and distributed SEC largely depends on the state of the emerging competitive environment. The competition in the regional energy market forces the producers of energy, realising their competitive advantages, to improve the efficiency and reliability of ECS, which makes it possible to reduce tariffs for industrial and household consumers.

Taking into account the above, a scheme has been developed (Fig. 1), which shows that it is possible to build up competitive advantages of SEC.

4 PRACTICAL IMPLEMENTATION OF METHODICAL APPROACH

It is known that competitive advantages of ECS are represented by the price and quality characteristics of electrical and thermal energy, which favorably distinguish its manufacturer and provide him a stable position in the energy market [10].

The development of SEC competitive advantages is directly related to resolution of the following problems defining the further development of ECS:

1. Reduction of the cost of heat and electricity joint production by improving and increasing the efficiency of the structure of generating facilities in a centralised SEC;

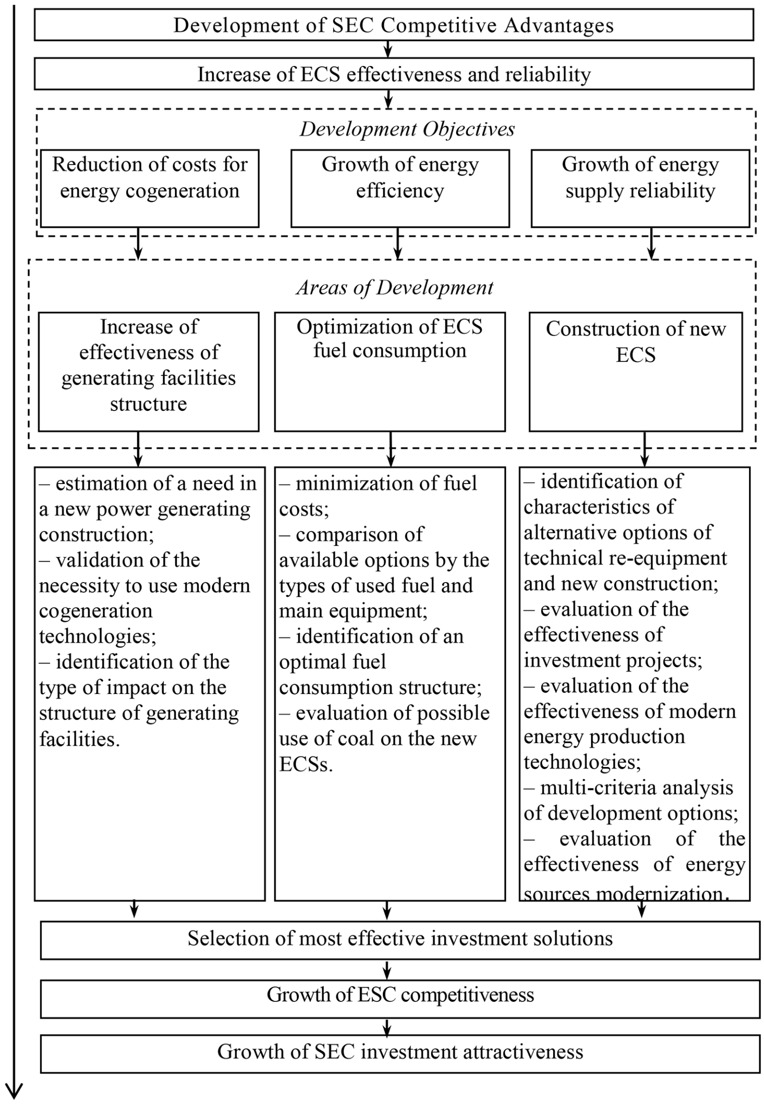

Figure 1: The scheme of building-up SEC competitive advantages.

2. Optimisation of ECS heat consumption in a centralised SEC;
3. Application of modern cogeneration plants with high reliability and efficiency.

4.1 Raising of centralised SEC competitive advantages

The structure of ECS included in the TGC has a significant impact on the realisation of competitive advantages of a centralised SEC. In this regard, the technical base of domestic cogeneration differs by an excessively large share of used inefficient steam turbine plants running on natural gas. Many of them have significant physical wear. Practical application of competitive and highly efficient cogeneration technology based on STU and gas turbines is still insignificant [11].

Improving the structure of generating facilities of TGC through its optimisation is a very important step towards the realisation of competitive advantages of a centralised SEC, since the existing steam turbine cogeneration units located at the CHP plant, in some cases, find themselves unable to compete with producers of thermal energy, mainly due to low total efficiency and reliability.

Optimisation of the structure of TGC generating facilities will help to reveal low-efficient cogeneration plants and to propose the best possible development options from the point of view of economic criteria, for which the following can be used: (a) integral costs; (b) integral effect.

The proposed criteria allow taking into account different economic interests of subjects of management of the centralised SEC. Such interests can be divided into two groups. The first group reflects the desire to define the necessary costs of production and distribution of electric and thermal energy, based on the desire to minimise them, to enhance the competitiveness of the ECS. The second group reflects the desire of power producers, as independent entities, to achieve the most favorable financial results in their activities, often to the detriment of the reliability of cogeneration plants.

The improvement of the ECS structure in TGC is achieved with the help of an optimisation object-structural model, specially developed for this purpose. This model shows the possibility of adaptation of a centralised SEC to the competitive environment, taking into account the development of ECS competitive advantages [12].

4.1.1 Analysis of estimates according to the criteria of the integral cost and integral effect

The analysis of the results of calculations, presented in Figs 2 and 3, shows the following. The optimisation of the generating facilities of TGC-9 has revealed some weaknesses in its composition and structure, which are characterised by a significant lag in the development of the energy generating company, and in the near future, they will inevitably become an obstacle to the development of industry and social sphere of the region.

By the criterion of integral costs, certain measures are required for most CHP plants on replacement of equipment with a total capacity of 2 255 MW (56%). Partial or complete dismantling of the equipment must be carried out in the amount of 520 MW (13%) due to its low technical and economic indicators, mainly due to high fuel consumption for energy production. It should be noted, that a

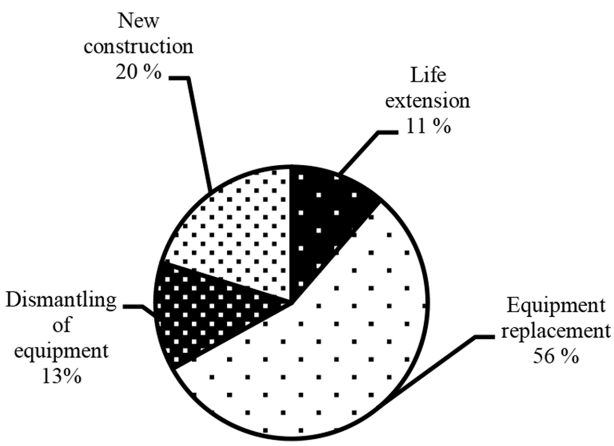

Figure 2: Optimised structure of measures at TGC-9 according to the integral costs criterion.

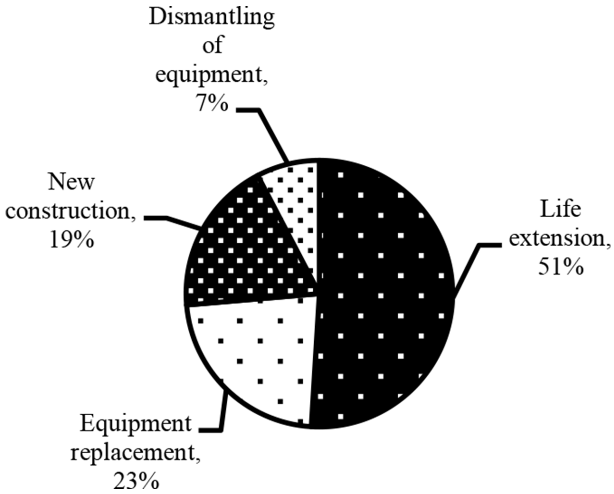

Figure 3: Optimised structure of measures at TGC-9 according to the integral effect criterion.

number of power plants of TGC-9 will need to extend the life of their equipment by upgrading (11%), with a total installed capacity of power plants of the power company increasing by 240 MW and thus comprising 3,535 MW in 2018.

According to the integral effect criterion, the largest share in the structure of measures takes the measure of generating capacity life extension by 50%, which is 1,690 MW. The activities associated with the replacement of equipment will be needed in the amount of 752 MW (23%). The dismantling of obsolete equipment having low technical and economic indicators will make 254 MW (8%), the new construction based on modern technologies will make 620 MW (19%), a large proportion of which should lie within the STU-CHP mainly because of their high efficiency that would be especially true at the increase of price for natural gas [13]. The total installed capacity of company will increase by 417 MW and will reach 3,712 MW.

In general, the optimisation results show that, depending on a selected criterion, a different structure of the types of impact on generating capacities of TGC-9 is observed. So, by the criterion of integral costs, the largest share will fall on the replacement of major equipment – 56%, and by the integral effect, only 25% will be effected by this type of impact.

According to the integral effect criterion, a large proportion of 50% falls on life extension of power equipment, whereas this type of impact makes only 11% according to the criterion of integral cost. For other types of impact, no significant change will take place according to both criteria. As it is shown by the calculations, new power-generation construction will take 20% and 19%, and dismantling – 13% and 8%, respectively, according to the criteria of integrated costs and effect. It should be noted, that if the management of TGC-9 in their decisions will adhere to the criterion of integral costs while improving the structure of its capacity, it will lead to a more rapid transition to sustainable development of the regional economy, because such a strategy focuses primarily on decommissioning of equipment with expired service life and thus has relatively low technical and economic indicators. However, it is not possible to obtain maximum revenue in the long term, primarily due to significant investments in the development of generating facilities.

In accordance with the second criterion, the commercial interest of the company management is associated with their focus on the biggest income, due to intensive exploitation of the equipment residual life and extension of its service life. However, a focus on higher yield will increase the installed capacity of TGC-9 power plants at 177 MW compared to the alternative strategy. It should be noted, that the inputs of new energy capacity in the energy company by the criterion of the integral effect will be 260 MW less, than by the criterion of integral costs [14].

In the future, the focus on maximising revenue-generating that brings rather big profits at the first stages of development to the detriment of the implementation of large-scale technical re-equipment and modernisation, is likely to cause a decrease of yield due to more frequent repairs and low-cost effectiveness of the generating facilities of the power company, and to become a serious threat to sustainable development of the economy of the region.

It is obvious, that TGC-9 leadership, in the process of decision making for further development, must proceed from the priority of sustainable and long-term development and not of quick income. The strategy developed in accordance with the criterion of integral costs fully meets this approach.

The revealed contradictions in possible developments of a centralised SEC can be resolved by using three groups of criteria. An energy group is characterised by: specific fuel consumption, availability factor, and electricity and thermal energy generation volume. An environmental group is determined by: emissions of nitrogen oxides, the cost emissions, and fee for land resources. Finally, the third group of economic criteria is formed by: specific investment costs, energy production costs, integral effect and integral costs. These groups of criteria allow the study of the development directions based on specific characteristics and development status of a certain ECS, as well as the opportunities of building-up the competitive advantages.

In the course of preliminary analysis of the effectiveness of possible ECS development options, four out of all possible options have been identified as the most promising from the point of view of efficiency increase: 1. Extension of the service life of a cogeneration unit due to modernisation of the auxiliary and main power equipment with replacement of physically worn-out elements, mainly operating in areas of high temperatures and pressures; 2. Replacement of an existing cogeneration plant to a new one preserving the former type sizes; 3. Expansion of an existing ECS due to installation of a cogeneration unit – combined-cycle gas turbine (CCGT) UNIT unit in the new main building; 4. Construction of a new CCGT UNIT-based ECS with gasification of solid fuel.

4.1.2 Additionally conducted multi-criteria analysis

The results of additionally conducted multi-criteria analysis (applying the fuzzy set theory) have shown that the most effective is an option of ECS technical re-equipment based on the new technology of electrical energy production - option 3, which provides the construction of a cogeneration CCGT UNIT. This option has the greatest degree of non-dominatedness in comparison with other alternatives, by energy and environmental criteria (with their weights equal to one). In the said conditions, the second most preferable option is installation of a new cogeneration CCGT UNIT (option 4). A lower grade of the latter, as the analysis shows, is explained: according to the energy criterion – by significantly smaller volumes of electricity generation at the initial stage (due to longer terms of the power-generation construction) and according to the environmental criterion – by a need for additional land acquisition for the new ECS. With the increased weight of the economic criterion (0.75–1.0), an option of life extension of an existing cogeneration unit (option 1) with more favorable investment characteristics becomes more effective. As a result, options 1 and 3 get into the zone of the highest efficiency. So, for a short term ECS development, it is most preferable to extend the residual life of main equipment, and for a long-term development – to expand the existing ECS with an CCGT UNIT installation [15].

An important problem in the realisation of competitive advantages of a centralised SEC is the fuel consumption, which largely determines the efficiency of ECS. It requires a development of a methodological approach to the study of the problem of diversification of types of fuel used in a centralised

SEC, which needs coordination among investors and the linking of the rate of fuel production, its transportation and consumption by a centralised SEC.

As an example, a forward-looking assessment of ECS energy efficiency in TGC-9 for 2018 was conducted according to the following two variants: the first variant – preservation of the existing level of energy efficiency; the second variant – raising the energy efficiency, by conducting of measures related to the use of modern technologies: Gas and oil-fired ECS – construction of a CCGT UNIT; pulverised coal-fired cogeneration energy sources, using circulating fluidised bed (CFB) technology.

By the results of the fuel component forecast for 2018, one can make the following conclusions. With the projected growth in gas prices, the performance of the fuel component for gas-fired ECS will increase to a much greater extent than coal, even with the broad use of modern technologies.

According to the first variant of the forecast, assuming that the current levels of efficiency at ECS will stay the same, while the fuel component indices for gas and oil will increase at 265.4%, and for coal – at 157.8% by 2018.

According to the second variant of the forecast providing for the ECS reconstruction and increase of their efficiency, the indices of the fuel component in the oil-gas units will increase at 203.3%, and on coal ones to 120.4% by 2018.

As a result, each forecast option predicts that by 2018, the fuel component indices for oil and gas ECS will be higher than for coal ones. It should be also mentioned that fuel costs for coal ECS in TGC-9 according to the second forecast variant (at transition to modern technologies of fuel combustion in CFB boilers) will be 23.4% lower than the corresponding costs according to the first forecast variant addressing the ECS work at the existing values of efficiency. Thus, the gas and oil ECS, using cogeneration CCGT UNIT, in 2018, may save 23.7% of fuel costs as compared to the costs of fuel when working on the existing steam power equipment.

4.2 Raising of distributed SEC competitive advantages

In the conditions of growing prices for certified energy resources, of deteriorating quality of fossil solid fuels and of increasing negative manmade burden on the environment, the issues of a reasonable decentralization of power supply with the use of the distributed SEC potential, as well as the issues of improvement of reliability and continuity of energy supply, when the main part of power equipment is significantly worn out, become very important. The problem of supplying electricity to remote areas can be solved through the use of distributed SEC capacity.

One of the main directions of distributed SEC development on remote territories having no central heating, taking into account the climatic features and provision with a sufficient amount of suitable fuel, is the use of biomass for production of heat and electricity in cogeneration on gas-fueled power plants with closed cycle gasification. It should be noted that under certain conditions, the gasification of biomass represents a competitive alternative to direct fuel combustion for energy generation. Therefore, autonomous ECS, operating on the basis of gas piston cogeneration units, should be recognised as a perspective direction of distributed SEC technical development. Such plants represent a quite competitive option in the field of 'mini-energy', due to the fact that they have high technical and economic indicators. Since such plants are especially useful in the presence of various solid fuels, including organic wastes (e.g. wood and agricultural waste, etc.), which increases the efficiency of distributed energy system. One of the competitive advantages of using such cogeneration plants is that they can be as close to energy consumers as possible, which does not require construction of a large network infrastructure and significantly reduces the payback period of investment projects on construction of gas generating ECS.

The analysis of feasibility of construction of gas generating ECS shows a significant economic efficiency of own cogeneration. As an option for solution of the problem of distributed SEC competitive advantages development, gas cogeneration plants, running on wastes of wood processing and agriculture, can be suggested. Another very promising option for the development of competitive advantages of distributed SEC is the modernisation of outdated energy equipment in boiler houses. As a result of such modernisation, a boiler house is transformed into ECS due to implementation of the scheme of cogeneration add-in boiler house with the gas turbine, operating with a "reset" of flue gases in the furnace of a hot water boiler. In this scheme, the functions of heat recovery, post-combustion and peak heating are combined. Before the gas is supplied into the turbine, its pressure is increased with the help of a pressurising compressor. The passing gases are cooled in an economiser before on-blast feeding to the hot water furnace. The waste gases are fed into the burner of the hot water boiler in an amount necessary for combustion with the design excess air ratio. A year-round work of the relief scheme is provided by the transfer of make-up water heating from steam boilers to hot water ones. It should be noted that the capacity of such cogeneration gas turbine must cover the year-round domestic hot water load of the city and work as much as possible in an economical mode during the inter-heating period.

The analysis of the results of calculations has confirmed the economic efficiency of cogeneration gas turbine construction, with the capacity of 58 MW at OJSC UralATI, as it provides: a relatively low-cost price of electricity (by 76%); thermal energy to the housing and utilities sector and manufacturing; fuel cost savings due to high thermal efficiency of the installation; receipt of additional income from external sales of energy. An important factor for the development of distributed SEC is an additional effect of ECS on the intensity of competition in the regional generation and appearance (under certain circumstances) of a true competition with centralised SEC. As a result, some energy consumers can shift from the category of a buyer to the category of a seller (when there are sufficient electrical power and flexibility) and supply excess electricity to the regional energy market. As shown by the economic assessment of competitive advantages of distributed SEC, its development must follow the path of increased use of modern high-performance clean solid fuel technologies, e.g. based on liquid-fueled and gas-fueled cogeneration plants, with quite high technical-economic and environmental indicators.

5 CONCLUSIONS

The assessment of SEC economic and technological development priorities showed that the ratio between its both parts may be different, depending on the state of the competitive environment. Thus, in addition to traditional STU, the priority in a centralised SEC should be given to cogeneration CCGT UNITs as the most competitive, from the point of view of load management; and in a distributed SEC, the priority should be given to cogeneration gas turbines, basically built on the basis of boilers. With this structure, the cogeneration STUs and CCGT UNITs will work in the basic part of electrical load, and the individual STUs - in semi-peak and peak zones, which will significantly improve the ECS efficiency and reliability.

The studies have shown that SEC competitive development is a process, associated with the creation of rapidly developing, cost-effective and reliable ECS, included in the centralised and distributed SEC, which are actively involved in the formation of a stable regional market of electric and thermal energy and are in permanent search of new directions and ways of realisation of their competitive advantages.

LIST OF ACRONYMS

ECS – energy cogeneration sources;
SEC – system of energy cogeneration;
TGC – territorial generating company;

STU – steam turbine units;
HPS – heat-and-power stations;
CHP – combined heat-and-power plants;
GTU – gas turbine cogeneration plants;
CPP – condensing power plants;
CCGT unit – combined-cycle gas turbine;
CFB – circulating fluidised bed;
EF – efficiency factor.

ACKNOWLEDGEMENT

The work was supported by Act 211 Government of the Russian Federation, contract № 02. A03.21.0006.

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