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KEY FACTORS OF EFFICIENT USE OF DISTRIBUTED GENERATION TECHNOLOGIES IN THE INDUSTRY[1]

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ABSTRACT

Decline in technology value of distributed generation results in increasing decentralization of electricity production and large-scale development of distributed sources all over the world. This trend is significantly changing both electricity consumption characteristics so that the development gets more flexible and mobile, as well as models of consumer behavior in the electricity market. Electricity consumers during implementation of distributed generation projects in the meantime become its suppliers, and this does not comply with the electricity market regulation existing in our country.
Purpose of the article is to evaluate the effect of distributed generation on the economy of both enterprises in particular and the country in general.
To identify the introduction effects of distributed generation technologies the method of analysis of practical cases was used. The analysis was conducted on the basis of twelve Russian companies that use their own energy sources. The companies selected for research belong to the branches of industrial production, housing and communal services, retail trade, construction, food industry.
As a result of study, technological, economic and social effects were identified. The technological effects include increasing the reliability of energy supply to consumers; energy security through introduction of fuel technologies and the expansion of fuel variety, involvement of local energy resources, reduction of imported fuels dependence; optimization of load management and creation of necessary technological reserves taking into account the production cycles of a particular enterprise; provision of technological component of flexibility function of "smart networks" (in the part of generation); reducing impacts on the environment, including CO emissions. Economic and social effects are: energy efficiency due to a number of factors, optimization of the impact schedule in particular; cogeneration usage, combination of fuels, including products and wastes of the main production; providing consumers with electricity of a specified quality; reduction of technological losses in networks, corresponding to decrease in electricity value; increasing the energy availability for consumers, including those in isolated areas, outside the Unified Energy System of the country.
Effects of the introduction of distributed generation technologies identified during research process allow us to talk about the advantages of this generation. In conclusion, recommendations concerning a set of measures for the development of distributed generation in Russia are formulated.

KEYWORDS ELECTRIC POWER, DISTRIBUTED GENERATION, ENERGY EFFICIENCY, DECENTRALIZED ELECTRICITY, COGENERATION, TRIGENERATION

INTRODUCTION

Today, the key characteristic of the development of the electric power industry is a significant cost reduction of distributed generation sources installations, including renewable energy sources. Such sources allow decentralization of electric production and the large-scale development of distributed sources around the world [Trachuk A. V., Linder N.V. and others, 2017]. This significantly changes characteristics of electricity consumption, as well as and consumer behavior patterns in electricity market. Consumption is becoming more flexible and mobile. Consumers of electricity can in the same time become its suppliers, which requires, in turn, revision of the norms of the current system of electricity market regulation (EnergyDemocracy) [Faria P., Vale Z., 2011; Volkova I.O., Salnikova E.A., Shuvalova D.G., 2011; Trachuk A.V., Linder N. V., 2017]. Generating capacities of different categories have their advantages and disadvantages in certain economic conditions. In this study, the goal is:

- to analyze trends in the development of small (distributed) generation; to define the main categories of objects of small and medium generation, which belong not to electric companies, but to consumers;
- to study the effects of distributed generation projects;
- to estimate the effect of large-scale application of distributed generation for the country in general and recommend a number of measures and actions for development of industrial distributed generation in Russia.

[1] The article is based on results of “Problem analysis of maximizing benefits and losses of a unified energy supply system consumers when developing models of small (distributed) generation and intelligent energy systems” research, conducted with budgetary financing under governement assignement Finansial University 2017.

TECHNOLOGIES AND EFFICIENCY OF DISTRIBUTED GENERATION

The literature often contrasts the own generation of consumer companies and centralized power supply [Hansen c. J., Bower J., 2004; A. A., Hawkes A., 2004; Trachuk A.V., 2010a]. Capacities of different categories in certain economic conditions have their advantages and disadvantages. In most studies, distributed generation is understood as generation of electricity by a lot of local consumers that produce heat and electric energy for own needs and direct the surplus to the energy system through a common network infrastructure [Sellyakhova O., 2012; Trachuk AV, 2010 b]. The basic definitions of distributed generation in world practice are given in Table. 1.

Distributed generation technologies. Distributed generation technologies, as usual, are designed for low-power plants (up to 25 MW), including renewable electricity sources (RES). The most complete classification of distributed generation technologies is provided in [Stennikova VA, Voropai NI, 2014] (Fig. 1).

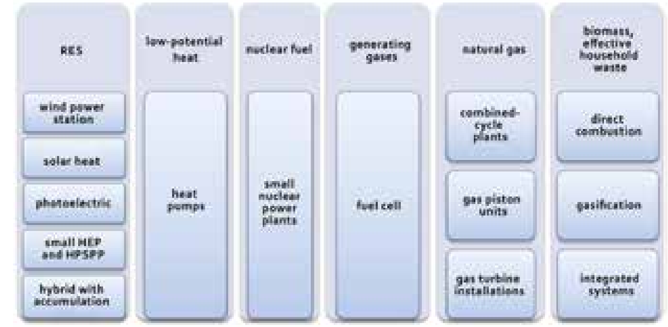
Analysis shows that most of the technologies that are used for distributed generation plants are based on direct burning of solid fuel (coal, biomass and solid household waste). Combustion of natural gas is used in gas turbine plants, gas piston units, combined-cycle and other installations. Wind power stations, small hydroelectric power stations, solar power plants and photovoltaic installations, solar heating stations, as well as hybrid plants use relevant renewable energy sources. Heat pumps use low-potential heat both for heat supply and for cold supply. Nuclear power plants of low power as autonomous sources of electric and thermal energy are used in isolated energy areas.

Fuel cells including gas piston aggregates, microturbines, Stirling engines, energy storage devices (chemical, inertial, gravitational and others), rotor-blade engines, chillers (devices for air cooling) are promising.

The main sources of distributed generation have different technical characteristics (Table 2) and different economic efficiency as technological directions, as follows:

- gas powered engines (gas turbine installations, microturbines, low-power combined-cycle plants, gas piston internal combustion engines) are of high quality and ensure the efficiency of energy supply;
- rotary-lobe engines of external combustion with other types of fuel, as well as technologies for obtaining gas fuel at the place of electricity production, provide a reduction in fuel risks and costs relative to tariffed types of electricity;
- small cogeneration plants make it possible to increase the efficiency of fuel use up to 80-90 percent;
- fuel cells of a new generation (in particular, such field of development as hydrogen energy) are effective in supplying isolated territories and mobile consumers.

Fig. 1. Composition of technologies of distributed generation [Stennikova V.A., Voropai N.I., 2014].



Distributed generation is most often used:

- as autonomous sources of electricity, heat (in cogeneration mode) and cold (in tri-generation mode);
- to remove peak loads in parallel operation modes with the centralized power supply system;
- in cogeneration and trigeneration projects based on the use of alternative fuels: biogas, associated petroleum gas, coal mine methane and other types;
- in projects with specific requirements for energy quality, reliability, start-up times, ecology, which under specific conditions cannot be provided by centralized power systems [McDonald, 2005; Trachuk, 2011 a].

Autonomous sources. Distributed generation on the basis of autonomous sources is used by industrial enterprises, office centers, and social infrastructure facilities if the centralized technological connection is not available for some reason. Such reasons include, in particular: territorial remoteness of facilities, a shortage of installed capacity in the region, limited bandwidth of the network infrastructure. In addition, centralized power supply can be economically inefficient (high connection price, high tariffs, other reasons) or may not meet the requirements of the consumer by the terms of connection taking into account reconstruction and development plans for networks and generation. This is why new or reconstructed medium and small enterprises of various industries increasingly choose distributed generation as an alternative to joining the country's energy systems.

Distributed systems, including those integrated in a local area network, can be used to supply energy to complex built-up micro-district and even cities built under the national program "Affordable and Comfortable Housing" [Energy Efficient Megapolis

Table 1. Definitions of the concept of distributed generation

Source	Definition
World Union of Distributed Energy	Distributed Generation is often used along with the term Decentralized Energy. Whereby the term "distributed generation" is understood only as electricity generation, while "decentralized energy" includes the production of both thermal energy and electricity. [McDonald, 2005]
International Energy Agency	"Distributed generation is a generating object, generating electricity at the customer's location or providing support for the distribution network, connected to the network with a voltage distribution level" [IEA, 2002].
Union of Distributed Energy in America	"Distributed generation is a low-power generating object using any type of technology, generating electricity closer to the consumer in comparison with generating objects of the centralized power supply" [Rújula et al., 2005].
US Department of Energy	"Distributed generation - modular generating objects of low power, located close to the consumer, allows to avoid expensive investments in transmission and distribution systems, also provides a reliable supply of electricity of better quality »[Rújula, 2005.]

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- Smart city "Novaja Moskva", 2015]. Such construction can be planned in the territories not provided with the corresponding infrastructure. Distributed generation allows the introduction of power capacity in stages, as electricity consumption increases, for example, for mechanization of construction work or in accordance with the order of commissioning of residential and infrastructural facilities [Decentralised generation, 2002].

Parallel operation with the power system. If the production volume is changed or the facility is redesigned, especially with an uneven daily energy consumption profile, both a deficit and a surplus of electricity supplies from the central power system are possible. During peak loads, a distributed system can transmit excess power when connected to a central power system. And vice versa, it may be economically efficient to design the capacities of distributed systems, based on the amount of constant consumption, while the peak loads are covered by the central power system.

Cogeneration and trigeneration. Cogeneration is a process of joint generation of electricity and heat with the use of a single source of primary energy (n the case of trigeneration, the production of cold is added). Cogeneration is the most effective solution for reconstruction of boiler houses that are switching to gas or re-profiling into mini-CHP. Cogeneration and trigeneration is one of the most economical solutions for office buildings, shopping malls, sports facilities power supply [Ackermann T., Anderson G., Soeder L., 2001].

When implementing these technologies, alternative fuels can be used. As a rule, they are used to solve a complex problem: improve the environmental situation and meet the company's own needs for heat and electricity. For example, associated petroleum gas - with the arrangement of new oil fields, mine methane - with the creation of effective systems of explosion safety, biogas - with the improvement of the ecological situation in the areas of urban landfills and treatment facilities.

Specialized solutions. Specialized solutions for design of distributed generation systems can be applied depending on the industry and territory features where the enterprise is located. Thus, in of greenhouse energy supply, carbon dioxide released during generation can be used; livestock farms use biogas; Economical trieneration is effective in the energy supply of swimming pools and water parks.

The need to comply with strict environmental requirements for emissions of harmful substances, noise, vibrations at ski resorts and in hunting facilities leads to the usage in design of a distributed generation system for special equipment. The same applies to mobile power sources, power supply features of remote unattended power systems, such as radio relay stations on long-distance communication lines, pipelines chemical protection systems, weather stations.

Technical solutions – microturbines and low-power turbines. For a long time, from the 60s to the 90s of the 20th century, large-scale construction of distributed power systems was restrained, in particular, because of the lack of an adequate technological base. The practical realization of the concept of distributed generation systems was facilitated by the commercial production of a completely new class of power equipment – microturbines (15 kW – 1 MW) and radial turbines of low power (2 MW). Nowadays, some international companies have managed to establish a mass production of reliable, simple and relatively inexpensive gas small and microturbines [Massel A., Massel L., 2015]. The design of such generation is carried out in accordance with the specific requirements of specific consumers, power units are completed depending on the purposes, tasks and use cases, including for the production of heat and cooling. Compactness, compliance with environmental requirements, low noise and vibration level, technical possibility of an operational load change without a significant reduction in efficiency, high reliability, and also greater efficiency in cogeneration and trigeneration modes in comparison with equipment of other classes are the main advantages of small and microturbines [Hovalova T.V., 2017]. These and other characteristics have influenced the increase in the spread of small and medium generation in the world [European Smart Grid, 2006]. For example, in the EU countries, distributed generation makes about 10% of the total electricity production.

In the United States, about 12 million small distributed power plants are operated (the capacity of individual installations is up to 60 MW, the total installed capacity is over 220 G, increase is about 5 GW per year). A part of the distributed generation objects is used as an emergency reserve (about 84 GW), the rest are used as the main source of electricity. The Distributed Power Coalition of America predicts that in the next two decades 20% of new generation capacity will be from distributed generation objects [Grid 2030, 2003].

RESEARCH METHODOLOGY

Proceeding from all above, we have formulated a research question: "What effects from the introduction of distributed generation have an impact on the activities of companies in various industries and how can they affect the Russian economy?"

The empirical analysis was conducted on the basis of 12 Russian companies, which work in different sectors (industrial production, housing and communal services, retail trade, construction, food industry) and each of them uses its own generation.

RESEARCH RESULTS: EFFECTS OF INTRODUCING DISTRIBUTED GENERATION

The initial data for the study are given in Table. 3.

Effects of using distributed generation for enterprises.

Using the analysis of the data presented, a number of effects of the introduction of distributed generation for enterprises of various industries have been drawn up. The study did not attempt to assess the impact of large-scale introduction of distributed generation on the electricity (capacity) market. The revealed effects can be generalized and divided into two large groups.

The technological effects include:

- Increasing the reliability of energy supply to consumers (in case when distributed generation is connected to a centralized power supply, than in emergency situations such system maintains reliability of power supply, reduces or prevents damage);
- energy security through introduction of fuel free technologies and expansion of the range of fuels, involvement of local energy resources, reduction of dependence on imported fuels;
- optimization of load management and creation of necessary technological reserves taking into account the production cycles of a particular enterprise;
- providing the technological component of the flexibility function of smart networks (in terms of generation);
- reducing the load on the environment, including CO emissions (especially reducing carbon dioxide and other pollutants (CO, SO ...) emissions into the atmosphere, in particular for the sanatorium and resort industry in general and the oil and gas industry when flaring associated petroleum gas is burned).

Economic and social effects include:

- energy efficiency due to the following factors: optimization of the load graph, reduction of technological losses in the process of energy distribution, (the location of distributed generation facilities in the territorial proximity to the consumer makes it possible to dispense with the construction of regional power stations and the reconstruction or construction of a network infrastructure;

Table 2. The main technical characteristics of distributed generation sources

Characteristics	Diesel generator	Gas turbine installation	Combined-cycle plant	Small hydropower plants	Solar installation	Wind generator
Fuel	Products of oil refining	Natural and biogas	Natural and biogas	Water energy	Sunlight energy	Wind energy
Ability to work on schedule	Possible	Possible	Possible	Possible	Limited	Limited
The possibility of regulation	High	High	High	Low	Low	Low
Available capacity, MW	From 6	0,1–30 and more	0.3–10	0.1–30	Up to 3	0.1–2.5
Efficiency,%	30–45	30–45	20–40	30–50	6–30	1–35

Table 2. The main technical characteristics of distributed generation sources

Company	Distributed generation	
	Equipment and / or technology	Industry / main effects
Housing and utilities		
OJSC "Mytishchinskaya Heat Supply Network", Mytishchi	Cogeneration	Creation of the municipal communal market of power supply; development and economical use of decentralized sources; access of consumers to cheaper thermal and electric energy; ensuring the city's need for additional capacity; emergency supply of vital infrastructure of urban infrastructure; solution of environmental problems; optimization of the load curve, reduction of process losses in the process of energy distribution; application of cogeneration, combination of fuels.
Retail		
ZAO "Apteki 36.6" Moscow	12 microterbines capstone, trigeneration	Maintenance of needs of a new office building and storage facilities: established emergency supply of electricity costs; optimization of the load graph, reduction of process losses in the process of energy distribution
Large-scale construction		
Moscow International Business Center "Moskva-City", Moscow	Gas-turbine unit OPRA, the second stage of mini-CHP (the second gas-turbine unit OPRA with a capacity of 1.8 MW)	Power supply for construction`s mechanization; stable supply of high-quality electricity from microturbines; monitoring of the electrical network condition; the possibility of working microturbines in an autonomous mode; power supply of a system of uninterrupted power supply
Oil and gas industry		
PJSC "Orenburgneft" (Vakhitovskoe field)	6 power units OPRA, autonomous mode	Use of associated petroleum gas; providing the infrastructure of the field with cheap energy; no need to build gas collection facilities, pipelines, compressor stations; low emissions level into the atmosphere, compliance with environmental requirements
"Lukoil-sever" LLC (Tedinskoye field)	2 gas-turbine units OPAP cogeneration	Use of associated petroleum gas — involvement of local energy resources, provision of cheap energy infrastructure of the field; no need to build gas gathering facilities, pipelines, compressor stations; low level of emissions into the atmosphere, compliance with environmental requirements, reducing impacts on the environment
"Naryanmarneftegaz" LLC (Toboyskoye field)	Mobile power station based on 2 microturbines capstone C60 with a total capacity of 120 kW, parallel mode (diesel generator)	Autonomous energy supply of the infrastructure of the field; relatively simple installation and operation of the power unit; optimal number of approvals in controlling bodies; economic maintenance and repair in an open area; reducing impacts on the environment
Food industry		
"AMA" LLC (confectionery factory), Moscow region, Dolgoprudny	Power plant based on 6 capstone microturbines, trigeneration	Well-established emergency supply; ensuring predictable energy costs; reduction of energy costs; optimization of the load schedule depending on the production cycle; reduction of process losses in the process of energy distribution
Sanitary and Resort Services		
Mountain-ski resort "Igora", Leningrad region	Power plant based on 30 capstone c60 microturbines and 8 capstone c65 microturbines, under capstone server cPS-100	Ensuring environmental standards: low emissions, low noise generation equipment; use of energy turbines exhaust gas to produce heat, as a result — reducing the impacts on the environment; saving energy costs due to a number of factors
Mountain ski resort "Krasnaya Polyana", Adler region, Esto-sadok village	6 gas turbine power plants with a capacity of 1.8 MW	Permanent, uninterrupted power supply. Ensuring environmental standards: low emissions, low noise. Provision of seismic resistance up to 9 (MSK-64)
Production		
OOO "Eka-97" (nonwoven fabric plant), Ryazan	Distributed power plant based on 6 microturbines capstone C60 with a total power of 360 kW	Possibility of gradual increase of power capacities; quality and reliability of electricity supply; reduction of production costs and costs for electricity and heat; optimization of the load curve, reduction of process losses in the process of energy distribution; optimization of load management and creation of necessary technological reserves
Communication		
LLC "Uralsvyazinform" (radio relay communication station), Khanty-Mansiysk	Microturbines capstone C30 with a capacity of 30 kW, cogeneration, trigeneration	Effective power supply, heat and cold supply for consumers not podluchennyh to the central electrical network; complementaccording to the needs of the enterprise; convenient transportation and maintenance; reduction in the cost of electricity

Table 3.
Effects of distributed generation introduction in enterprises of various industries

Results of distributed generation use	Evaluation of distributed generation effect for the country
Energy Efficiency	Energy saving at the state level, ensuring competitiveness of the country's economy
Use of local energy resources	Increasing the country's competitiveness, optimizing energy consumption, maintaining the country's energy security
Increase of energy supply reliability	Increase of work efficiency of enterprises and corresponding tax base, reduction of government spending on eliminating the consequences of accidents in electricity, social stability increase
Use of high-tech equipment	Growth of investments in innovative research and production in the country's power engineering and electrical engineering industry
Reducing the amount of investment needed to maintain and develop the network infrastructure	Reducing the rate load on consumers, maintaining social stability

- for owners of distributed generation, the cost of energy is usually lower than the regulated electricity tariffs for enterprises, the operating costs of the units are stable and well-predicted, which allows for long-term production planning; the connection to the centralized power supply system is carried out on the basis of calculations that take into account both the payment for technological connection and the assessment of the risks of reducing the reliability of the electric power supply);
- usage of cogeneration, combination of fuels (the overall efficiency of a modern combined electric and thermal power plant is 85-90%, whereas with the traditional use of only a condensing power plant, more than half of the energy released from the combustion of fuel is lost due to the removal of surplus heat into the environment;
- due to cogeneration, the efficiency of energy and heat production increases by 30%, which is especially attractive in cases when the enterprise has by-products that serve as fuel for generation; efficient and proven technologies of combined production of electric energy and heat energy can be used in objects of any scale);
- providing consumers with electricity of specified quality;
- reduction of technological losses in networks, corresponding to a decrease in the cost of electricity;
- optimization, in some cases, significant savings, electricity costs due to a number of factors (lack of payment for technological connection, optimization of the fuel component, minimization of investments in the network infrastructure, application of innovative technologies, application of specialized technological solutions for a particular enterprise; There is no electricity component in the electricity tariff, that is, the tariff load in terms of the investment programs of the grid complex on all consumers of the region is decreasing);
- increasing the availability of energy supply for consumers, including those located in isolated areas, outside the Unified Energy System of the country.

It should be noted that distributed generation projects can be economically feasible at any scale [Trachuk, 2011b], but at present generation of energy at distributed generation facilities that have the status of a participant in the wholesale market, is unprofitable for consumers, because the current rules oblige to sell generated electricity to the wholesale market, buying it for consumption, that is infrastructure services. As a result, the profitability of distributed generation objects is ensured in the isolated mode of operation. Distributed generation projects with electric power less than 25 MW are generally recognized as economically viable (taking into account regional differences).So, the development of distributed generation requires adjusting the regulatory environment, which will be noted in the conclusions.

INFLUENCE OF TECHNOLOGICAL, ECONOMIC AND SOCIAL EFFECTS OF THE DISTRIBUTED GENERATION USAGE ON THE ECONOMY OF THE RUSSIAN FEDERATION

The effects of distributed generation for enterprises, identified in the course of the study, can affect the economy of the country as a whole, both now and in the future. As the scale of distributed generation increases, the effects will also increase. Some of the effects are transmitted directly from the level of the enterprise, some occur on a national scale.

At the same time, the database for research does not allow quantifying all possible scale effects and risks of such influence, but allows us to point out certain trends that are presented below.

Thus, the country effects achieved as a result of the introduction of distributed generation allow us to conclude that the reorganization of the Russian electric power industry as an organizational and business system into a network of localized clusters of energy producers and consumers integrated in the Unified Energy System that can use a common infrastructure and maintain a reliable electricity supply throughout the country. The basis of such a paradigm in the electric power industry is distributed generation. Of course, a corresponding change in the regulatory environment requires a preliminary quantitative and qualitative assessment of the cost and consequences of such a transformation.

PRACTICAL APPLICATION OF THE RESEARCH RESULTS

Based on the research results, a number of measures can be recommended for the development of industrial distributed generation in Russia.

In the medium term:

- development of a strategy for the development of distributed generation in the Russian Federation, including taking into account the implementation of projects for combined generation of electric power and thermal energy.

In the short term:

- adjustment of the regulatory environment, in particular the rules according to which power stations connected to the grid with a capacity of 25 MW or more are obliged to sell electricity in the wholesale market, which hinders the development of distributed generation, an increase in the power level threshold of such stations;
- simplification of the procedure for obtaining permits for the implementation of distributed generation projects;
- creation of legislative conditions allowing the entry into force of contracts for the supply of natural gas and electric power before the facility is put into operation;
- carrying out information campaigns and developing motivation programs, raising the level of awareness of interested persons;
- ensuring the stability of the regulatory environment after its formation for the maintenance and development of distributed generation, which will help reduce investment risks for individual projects and improve the stability of energy markets in general.

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