DOI: 10.17747/2618-947X-2021-4-306-321

Prosumers: An overview of innovative models of interaction between subjects of the electric power industry and end consumers

P.S. Kuzmin[1]

[1] TENEX JSC (Moscow, Russia)

Abstract

Technological changes taking place in Russia and in the world have an impact on many sectors of the economy, including the electric power industry. There has been a tendency for consumers to withdraw from centralized power supply due to a wide range of factors: the spread and cheapening of generation technologies using renewable energy sources, energy storage systems, as well as the development of smart metering systems. The proliferation of digital technologies of Industry 4.0 allows innovative energy technologies to be integrated together.

The purpose of this work was to identify and verify the effects generated by the technologies of the fourth industrial revolution in the electric power industry, and the resulting new models of interaction between consumers and energy companies in the electricity market.

At the beginning of the study, the effects of the spread of distributed generation (including the use of renewable energy sources), energy storage systems, smart electricity metering systems, as well as digital technologies of industry 4.0 were identified, and the impact of these technologies on changing the nature of consumer interaction and energy companies.

Further, the analysis of the main approaches to organizing the interaction of energy companies with a new type of electricity consumers - an active consumer, is carried out, and the key effects from the spread of active consumer models are determined.

At the end of the work, industry experts were interviewed with subsequent questionnaires, which made it possible to assess the prospects for deploying active consumer models.

Keywords: smart metering systems, energy complex, digitalization, distributed generation, prosumer.

For citation:

Kuzmin P.S. (2021). Prosumers: An overview of innovative models of interaction between subjects of the electric power industry and end consumers. *Strategic Decisions and Risk Management*, 12(4): 306-321. DOI: 10.17747/2618-947X-2021-4-306-321. (In Russ.)

Acknowledgements

The article was prepared based on the results of research carried out at the expense of budgetary funds under the state assignment of the Financial University.

Introduction

The current market model of the Russian electric power industry is facing significant challenges such as rising electricity prices for end consumers stipulated by the outpacing inflation growth in prices for both electricity and capacity in the energy market, as well as growth in tariffs for transmission services electricity and sales allowances, the complexity and high cost of technological connection to power grids and increase in capacity, and in the volume of cross-subsidization[1].

The NTI EnergyNet roadmap highlights a number of internal problems of the Russian energy sector, such as relatively long distances and lower load density of the power grid complex, high capital and construction costs, low installed capacity utilization factor of the power system as a whole, as well as low labor productivity[2].

In addition to the challenges that have matured in the current market system, there are a number of technological changes taking place in Russia and in the world, including the trend to abandon centralized power supply due to a wide range of factors: the spread of energy generation by means of renewable energy sources, the growth in demand for electricity, changing consumer behavior [Trachuk, Linder, 2018]. The centralized energy supply is being replaced by decentralized (distributed generation), which includes not only low-power generators, but also price-dependent energy reduction programs, smart grids, and energy storage systems [Frankel, Wagner, 2017.

This trend is facilitated by the spread and cost-cutting of generation technologies using renewable energy sources [Digital transition.., 2017], technologies of energy storage systems [Application of energy storage systems.., 2019], including those using hydrogen[3], as well as the development of smart metering systems [Kuzmin, 2021]. The trend that allows to integrate innovative energy technologies, new energy sources and smart metering systems is the spread of industry 4.0 digital technologies [Ivanov et al., 2018].

The combination of these trends leads to the transformation of the Russian electric power complex, changes in current and the emergence of completely new models of interaction between end consumers and energy companies, such as smart grids [Khovalova, Zholnerchik, 2018], Internet energy [Nalbandyan, Khovalova, 2018][4], as well as models of active consumers – prosumers who no longer want to be in a price-taking position and seek to actively participate in electricity trade [Digital transition.., 2017; Kuzmin, 2019].

A number of researchers conclude that the impact of the digital transformation of the electric power industry will be the strongest on the side of electricity end consumers [Digital transition.., 2017; Khokhlov et al., 2018; Khovalova, Zholnerchik, 2018]. Moreover, the most significant changes will affect end consumers in the retail market and, as a result, territorial grid organizations and energy sales companies that directly interact with end consumers.

The challenges facing the current market electric power industry in Russia, global technological trends, as well as changes in end-user behavior patterns contribute to the transformation of the electricity market in general and the retail market in particular.

The purpose of this work is to identify the effects generated by the technologies of the fourth industrial revolution in the electric power industry, and the resulting new models of interaction between consumers and energy companies in the electricity market.

1. Technical and economic features of the key technologies of the energy transition

In order to describe promising models of interaction between consumers and energy companies, it is necessary to consider in more detail a number of digital energy technologies that actively involve consumers in the processes of generation and consumption of electricity. Research suggests that traditional centralized energy systems will undergo significant changes due to the growing competitiveness of distributed, decentralized generation relative to centralized models built on fossil fuels as a primary energy resource [Wegner et al., 2017][5]. According to the reports of the International Energy Agency (IEA), there is a significant trend in reducing the cost of distributed generation using renewable energy sources (RES). For example, the price of wind turbines from 1980 to 2013 decreased by 10 times, while by 2014 the fall in prices for photovoltaics was 75% compared to the price of 2009[6].

1.1. Distributed generation

One of the main trends in the transformation of the electric power industry is the spread of distributed generation. According to a study [Trachuk, Linder, 2018], about 12.5% of industrial enterprises around the world use distributed generation (the share of such enterprises in Russia is 6%). At the same time, a study by the Energy

[1] Electricity costs for small and medium-sized businesses in Russia: a growing burden (2021). Moscow: Center for Strategic Research. https://www.csr.ru/upload/iblock/282/am06ifly4c3oq2xz2xsrzvisr3hl84ah.pdf.

[2] Action plan (roadmap) "EnergyNet" of the National Technology Initiative (2016). National Technology Initiative. https://nti2035.ru/markets/docs/DK_energynet.pdf.

[3] Prospects for Russia in the global hydrogen fuel market (2019). Moscow: Infrastructural Center EnergyNet. https://drive.google.com/file/d/1MvV2_kV2j4WUOUeoaZ1M6JObrQD-qy75N/view.

[4] See also: Active energy complexes - the first step towards industrial microgrids in Russia (2020). M.: Infrastructural Center Energinet. https://drive.google.com/file/d/1PwyNYskwbaES_5oE3utFDDOnbucosZ0q/view.

[5] See Subject: Lazard's Levelized Cost of Energy Analysis (2021). https://www.lazard.com/perspective/levelized-cost-of-energy-levelized-cost-of-storage-and-levelized-cost-of-hydrogen/.

[6] Perspectives for the energy investment needs for a low-carbon energy system about the IEA (2017). International Energy Agency. https://www.iea.org/reports/investment-needs-for-a-low-carbon-energy-system.

Center, Skolkovo School of management [Khokhlov et al., 2018] predicts that among the total increase in the installed capacity of the energy system by 2035, about 12 GW will be covered by generators with an installed capacity of less than 25 MW.

Distributed generation technologies can include gas turbine generators, low-capacity combined cycle gas and gas piston units [Hansen, Bower, 2004], renewable energy-based power plants (including wind and solar generators) installed end-use. Distributed generation facilities can refer to installations operating in a cogeneration cycle (including those for power and heat supply to isolated energy regions), as well as low-capacity nuclear power plants [Sellyakhova et al., 2016].

Despite the fact that today the share of RES in the installed capacity of the Unified Energy System of Russia (UES) is relatively small and amounts to 1.12%, its further growth is predicted. One of the main drivers of the growth in the prevalence of RES is their cheapening.

However, in Russia the rates of RES distribution are significantly lower than the global ones. This is mainly due to the historical structure of the energy system, climatic and geographical features and, as a result, the relatively low cost of electricity consumed from a centralized energy system using traditional energy sources [Linder, Trachuk, 2017]. On the side of the population, the development of RES is slowed down by cross-subsidization, which provides a lower cost of electricity for the population, covering the gap with the cost price at the expense of industrial consumers [Trachuk, Linder, 2017].

In the work G.G. Nalbandyan and S.S. Zholnerchik distinguishes the areas of distributed generation use that are characteristic of the Russian energy system [Nalbandyan, Zholnerchik, 2018]. Distributed generation can be applied:

1) for the autonomous production of electrical, thermal energy (in the case of work in a cogeneration cycle), as well as cold (in the case of trigeneration);
2) when operating in parallel with the unified energy system to generate electricity during the hours of high peak prices in the UES and reduce the resulting electricity costs;
3) in the power supply of facilities that require a high level of quality, reliability and uninterrupted power supply, which cannot be provided with supplies from the unified energy system;

Table 1
Comparison of the effects created by distributed generation with participants in the electricity and capacity market

Direction of influence	Potential effect from the spread of distributed generation
End users: industry, business and households	1. The possibility of autonomous production of electrical, thermal energy, as well as cold 2. Reducing the resulting costs for electricity during the hours of high peak prices in the UES in parallel operation with a unified energy system 3. Increasing the level of quality, reliability and uninterrupted power supply 4. Improve sustainability and reduce CO_2 emissions 5. Use of alternative fuels such as biogas, pyrolysis oil, associated gases, etc. 6. A source of additional agility both to participate in smart grid models and for active consumer
Generating companies	1. The ability to introduce additional generating capacities in smaller volumes, more accurately adjusting to the dynamics of energy consumption growth 2. Improving the efficiency of investments in additional generating capacity
Electric grid companies	1. Reducing the need for construction of additional power grid capacities 2. Reducing losses in distribution networks 3. Reducing the number of outages and accidents in the power grid complex
Organizational structure of the electricity and capacity market	The emergence of new models of interaction between consumers and energy companies, including smart grids and models of active consumers
State Administration and regulators	Improving the quality and accuracy of decisions made on the strategic development of the electric power industry

Source: compiled by the author.

4) in the power supply of facilities with more stringent requirements for environmental friendliness and CO_2 emissions;
5) in projects involving the use of alternative fuels such as biogas, pyrolysis oil, associated gases, etc.

Another important effect from the spread of distributed generation is the ability to introduce additional generating capacities in smaller volumes, thereby more accurately adjusting to the dynamics of energy consumption growth and hedging the risks of irrational investments [Khokhlov et al., 2018]. In addition, distributed generation can reduce the need for the construction of additional power grid capacities [Trachuk, Linder, 2018].

Also, distributed energy is comparable in its energy efficiency (performance factor) with large power plants, but due to its proximity to the consumer, it is characterized by a lower level of network losses in the distribution of electricity. In addition to reducing losses, some studies note a decrease in the number of outages and accidents in the power grid complex [Nalbandyan, Khovalova, 2018][7].

In addition to technological effects, the spread of distributed generation can affect the commercial structure of the market and the mechanisms of interaction between energy companies and consumers. Thus, distributed generation is one of the key elements of smart grids that integrate the generation, distribution and consumption of electricity with the help of digital solutions and provide a bidirectional power flow [Khokhlov et al., 2018][8].

At the same time, the opportunity for consumers (including households) to sell surplus electricity produced on their own generation, both on traditional fuels and using renewable energy sources, can involve consumers in active participation in the electricity markets, thereby forming a new type of consumer – an active consumer [Klimovets, Zubakin, 2016].

A comparison of the effects created by the spread of distributed generation with the directions of influence are presented in Table 1.

1.2. Energy storage systems

The next significant trend is the spread of electricity storage systems (ESS).

The main factor in the spread of electricity storage systems is the peculiarity of electricity as a commodity: the volume of electricity production must equal the volume of consumption at any given time. Due to the fact that the daily consumption schedule is uneven and has pronounced consumption peaks, the power system must contain reserve capacities that can cover these peaks[9].

Storage systems are a technological solution that organically complements distributed generation technologies based on renewable energy sources. The stochastic nature of renewable energy generation due to dependence on weather conditions can be supplemented by accumulation systems that will smooth out uneven generation. In this case, ESS will act as storage when electricity generation exceeds the demand of the power system, and as a source when energy generation is not enough[10].

For a long time, such systems were not seriously considered due to weak economic indicators, however, the gradual industrial development and reduction in their cost makes it possible to consider the introduction of ESS and the creation of new network and system services[11].

The rapid growth in demand for solar energy is due to a decrease in prices for Li-ion storage, as well as the trend towards the development of distributed generation, including the predicted decrease in the cost of solar and wind generation [Use of energy storage systems.., 2019]. An additional incentive is the spread of electric transport, which, once connected to the grid, can act as a storage facility and participate in demand management mechanisms and active consumer models[12].

The Ministry of Energy in the "Concept on storage" suggests that ESS can be used as:

1) an autonomous source of energy, which allows to ensure a long term power supply of the facility without being connected to a unified power system;
2) an energy source in case of accidents, partially or fully providing electricity for the period of repair of the main source of electricity supply;
3) a way to control the energy consumption schedule - control of the consumed power due to the return or accumulation of electricity, depending on different periods of time;
4) a regulator of system parameters - a method for controlling the operating mode of an electrical system, maintaining frequency and voltage at the required intervals, as well as a method for reducing electricity losses in networks[13].

[Application of energy storage systems.., 2019], the list of possibilities of systems for accumulating their effects is expanded. In addition, the authors proposed grouping of ways to use ESS into four categories.

[7] See also: Distribution automation. Results from the Smart Grid investment grant program (2016). U. S. Department of Energy. https://www.energy.gov/sites/prod/files/2016/11/f34/Distribution%20Automation%20Summary%20Report_09-29–16.pdf.
[8] See also: Smart Grid 101 (s.a.). Berkeley Lab. Electricity Markets and Policy Group. https://emp.lbl.gov/sites/default/files/chapter1–3.pdf.
[9] Batrakov A., Shaposhnikov D. (2017). How energy storage technologies will change the world. RBC, 008 (2505). https://www.rbc.ru/newspaper/2017/01/19/587e404e9a7947208a047c9d.
[10] Concept for the development of the market for electricity storage systems in the Russian Federation. https://minenergo.gov.ru/node/9013.
[11] Energy storage for grid and ancillary services (2016). Navigant Research. https://www.navigantresearch.com/research/energy-storage-for-the-grid-and-ancillary-services.
[12] The impact of electric vehicles on the grid: Customer adoption, grid load and outlook (2016). Wood Mackenzie. https://www.woodmac.com/reports/power-markets-the-impact-of-electric-vehicles-on-the-grid-customer-adoption-grid-load-and-outlook-58120591.
[13] Concept for the development of the market for electricity storage systems in the Russian Federation. https://minenergo.gov.ru/node/9013.

1. System storage devices - ESS of relatively high power, used within the UES of Russia, connected to backbone networks or high voltage networks, with the possibility of issuing power to the network or its accumulation, can:

- participate in the system services market, namely in primary and secondary frequency regulation;
- to optimize the loading of sections of the main transmission lines by smoothing the peaks, as well as to participate in ensuring static and dynamic stability;
- serve as RES integrators. For systems and energy interconnections with a large amount of generation from renewable sources, ESS can smooth out the stochastic nature of renewable energy generation and ensure the required quality of electricity supplied to the grid.

These features make system ESS similar to peak generators and, accordingly, the cost-effectiveness of such ESS will determine the ability to compete with them. Despite the fact that ESS have restrictions on the time of issuing stored energy, they have a number of advantages, including a high rate of power output (or accumulation).

2. ESS applied at the level of distribution networks, in addition to the above listed ones, are capable of:

- unloading distribution network power centers;
- increasing the reliability of power supply by acting as a backup power source in case of accidents in higher voltage networks or other interruptions in power supply;
- improving the quality of electricity, stabilizing voltage and frequency.

3. Saving systems located end-use "behind the counter" have an even greater range of possibilities - they can:

- be used as an uninterruptible power supply end-use in case of accidents in networks;
- be used for equipment that is sensitive to power quality or equipment that requires continuity of the process. Thus, they ensure the required level of quality and continuity;
- reduce the cost of technological connection to networks, covering the difference between base and peak loads;

Table 2
Comparison of the effects created by the SNE with the participants in the electricity and capacity market

Direction of influence	Potential effect from the spread of accumulation systems
End users: industry, business and households	1. Application as an uninterruptible power supply end-use in case of accidents in networks 2. Ensuring the required level of quality and uninterrupted power supply for equipment sensitive to power quality or equipment that assumes the continuity of the technological process 3. Reducing the cost of technological connection to networks by covering the difference between base and peak loads 4. Reducing the resulting costs for electricity during the hours of high peak prices in the UES in parallel operation with a unified energy system 5. Source of extra agility both to participate in smart grid models and for active consumer
Generating companies	1. Increased operational efficiency, as well as the accuracy of the power plant installations following the load schedule 2. Participation in the system services market
Power grid companies	1. Optimization of section loading of the main transmission lines by smoothing the peaks 2. Participation in ensuring static and dynamic stability 3. Unloading power distribution centers 4. Increasing the reliability of power supply 5. Improve power quality, voltage and frequency stabilization
Organizational structure of the electricity and capacity market	Emergence of new interaction models between consumers and energy companies, including smart grids and models of active consumers

Source: compiled by the author.

- in the presence of their own distributed generation (including the use of RES), they are able to optimize the operating mode of generating equipment. Thereby, they increase its efficiency and extend its useful life, as well as reduce the balance of flows with UES networks.

4. Hybrid generator - ESS, located within the boundaries of the power plant balance sheet. With the help of such a drive, it is possible to increase operational efficiency, as well as the accuracy of following the load schedule by the installations located at the power plant.

At the same time, the use of ESS as a hybrid generator will be somewhat different for four groups of power plants:

- ESS as part of a large generator of the Unified Energy System;
- ESS as part of a small or local station;
- ESS linked to a generator with a high share of fuel costs;
- ESS as part of generators based on renewable energy sources.

The report of the consulting company VYGON Consulting notes that the greatest efficiency of of ESS use is achieved when they are used in different market segments at the same time. When applied to multiple commercial models jointly, for example, in order to provide system services and smooth out peak loads, storage can have an acceptable payback period tod[14].

Just as in the case of distributed generation, ESS are an additional source of flexibility for the participation of end users in demand management projects, and can also become one of the key technologies for building smart grids, microgrids and involving users in active consumer models [Nalbandyan, Khovalova , 2018; Application of energy storage systems.., 2019].

Comparison of the effects created by the spread of electricity storage systems with the directions of influence are presented in Table 2.

1.3. Intelligent electricity metering systems

Studies show that one of the main digital transition technologies in the electric power industry is the technology of intelligent electricity metering systems (IMS) [Khovalova, Zholnerchik, 2018]. Such systems are based on electricity meters equipped with modules for collecting, processing, storing, sending and receiving data.

Unlike traditional electricity meters, smart metering systems have a wider range of functions, these are:

- real-time monitoring of consumption volume;
- the possibility of aggregating data from various counters into a single database;
- storage of statistical data on electrical characteristics;
- Obtaining information on power flows and reliable determination of the level of technological and commercial losses in power grids;
- identification of unmetered energy consumption and facts of impact on meters;
- formation of energy saving strategies and assessment of their implementation;
- remote limitation of power consumption.

However, despite the existing extensive functionality of intelligent metering systems, IMS built on the basis of Non-Intrusive Load Monitoring (NILM) technology have even more capabilities. NILM is a method to analyze data on the total electrical load obtained by measuring the current and voltage at one point and then dividing the total load into the loads of individual devices [Kuzmin, 2019].

Researchers note that non-intrusive load monitoring technology can play a key role in the digital transition in the power industry [Zoha et al., 2012]. It cannot only improve the current operating activities of electric power companies, but also form the basis for the formation of new relations between energy market entities [Bergman et al., 2011; Lin and Wang, 2011].

IMS based on non-intrusive load monitoring have two key differences that determine the specifics of their application:

- non-intrusive – such an IMS meter measures current and voltage in one place of the building distribution network and does not require direct integration into the network, while providing measurement accuracy that is not inferior to traditional meters (including meters equipped with Wi-Fi and GSM modules);
- data disaggregation – currently, if it is necessary to separate energy consumption profiles for each device located in the room, a direct meter is installed at the entrance to each device. The NILM meter, using cloud technologies and special machine learning methods, breaks down the integrated energy consumption data collected at one point in the network into consumption profiles of each device. Since the cost of installing direct on-line meters is directly proportional to their number, the use of NILM sensors contributes to significant savings [Naghibi, Deilami, 2014]. This effect is even stronger when large commercial real estate is equipped with meters, as well as in industries using a large amount of equipment.

Based on their technological features, IMS are able to find application in many areas:

- Disaggregation of total energy consumption and visualization: with the help of NILM sensors, consumers are able to highlight the energy consumption of each device. The result of disaggregation in the form of an interactive infographic is displayed in a

[14] Energy storage in Russia: an injection of sustainable development (2020). VYGON Consulting. https://vygon.consulting/upload/iblock/e44/vygon_consulting_storage.pdf.

Table 3
Comparison of the effects created by the Smart meters with the participants in the electricity and capacity market

Participant of the electricity and capacity market	The effect from the introduction of an intelligent electricity metering system
Households	1. Split of the bill for electricity and identification of energy-consuming appliances 2. Optimization of the consumption profile when using a multi-zone tariff for the purchase of electricity and, as a result, cost reduction 3. Preventive control of breakdowns and malfunctions 4. Parental control and social monitoring 5. Involvement in effective load management and participation in demand management projects
Manufacturing and large commercial real estate	1. Separation of the bill for electricity and identification of energy-consuming appliances 2. Optimization of the consumption profile when using a multi-zone tariff for the purchase of electricity and, as a result, cost reduction 3. Preventive control of breakdowns and malfunctions 4. Separation of energy consumption by premises (especially relevant for real estate developers) 5. Control of unauthorized access to the equipment 6. Involvement in effective load management and participation in demand management projects
Management companies and housing and communal services	1. Improving the energy efficiency of apartment buildings and commercial real estate 2. Detection of illegal connection to electricity networks and reduction of the risk of electricity theft
Power grid organizations	1. Preventive control of breakdowns and malfunctions 2. Increasing the speed and accuracy of energy balance formation 3. Improving efficiency in combating unmetered energy consumption 4. Reducing the volume of technological and commercial losses in networks 5. Commercialization of data collected by smart accounting systems
Energy sales organizations and last resort suppliers	1. Increasing the efficiency of activities in the wholesale and retail electricity markets 2. Increasing the efficiency of participation in projects to implement the concept of load aggregator 3. Commercialization of data collected by smart accounting systems
State administration and regulators	1. Ability to analyze big data on energy consumption 2. Improving the quality and accuracy of decisions made on the strategic development of the electric power industry

Source: compiled by the author.

mobile application or in a custom online platform. The amount of useful data can be significantly increased by installing several sensors (for example, it is possible to divide energy consumption between floors in a multi-storey building or collect information on the workload of production equipment in various rooms of a large enterprise);

- Identification of non-normative operating modes of devices and preventive monitoring of breakdowns: since sensors collect data in real time, the system remembers patterns of device behavior. Using the methods of neural network analysis, the system recognizes changes in the operating mode of the device and promptly sends a notification to the user about the detected violation;
- Electricity bill splitting: Using the device-by-appliance splitting of energy consumption, you can split the bill in a proper way. With a differentiated cost of electricity by zones of the day, you can generate a report on the costs of operating the device in a given

period of time. Thus, it becomes possible to optimize the operation mode of devices, develop a schedule for optimal energy consumption and reduce the cost of purchasing electricity;

- embeddability in third-party solutions: device-by-device load sharing is one of the most important technological features of NILM. This solution can also be integrated into traditional direct on-line meters;
- sending alerts messages and notifications: by means of a mobile application or a user online platform the NILM system sends a user notifications about violations of device operation modes or when user-defined marks are exceeded (for example, if the stove operation time exceeds the set number of hours or when the specified energy consumption bar is exceeded).

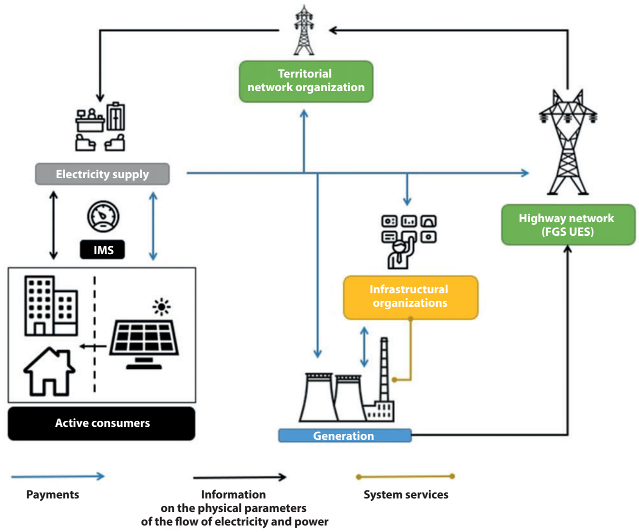
The introduction of intelligent electricity metering systems (including those based on NILM technology) generates a wide range of effects for both end consumers and companies in the electricity industry [Khovalova, Zholnerchik, 2018; Kuzmin, 2019]. Comparison of the effects created by the IMS with the participants in the electricity and capacity market are presented in Table. 3.

1.4. Industry 4.0 digital technologies

Industry 4.0 digital technologies are designed to become the information basis and link between the technologies described above. The key technologies include:

- digital twins. As part of online and offline decision support system development, digital twins make it possible to create mathematical models of generating equipment, networks, facilities, processes, etc., which in the future can increase the operational efficiency of energy companies[15];
- industrial internet of things. It allows you to collect data from remote objects and network devices. The internet of things is designed to provide machine-to-machine interaction, the exchange of information and guiding signals between the equipment of the local energy system [Architecture .., 2021];
- big data (Big Data). Big data received from intelligent network elements (primarily from IMS) and their subsequent processing will improve the efficiency of industrial enterprises, the quality of forecasting and decision-making in the future, as well as commercialize the collected data through their direct sale [Kuzmin, 2019];
- machine learning (Machine Learning). It allows automated processing of big data, as well as increases the optimality of decision-making on operational and prospective activitiesи[16];
- distributed registries (blockchain). Blockchain and Smart contracts technologies will allow to eliminate intermediaries in the chain of electricity sales to the end consumer and make the transition to automated Smart contracts, which is one of the basic elements of such active consumer models as the Internet of Energy [Architecture .., 2021].

Fig. 1. The basic model of the active consumer: A schematic diagram of interaction



Source: compiled by the author.

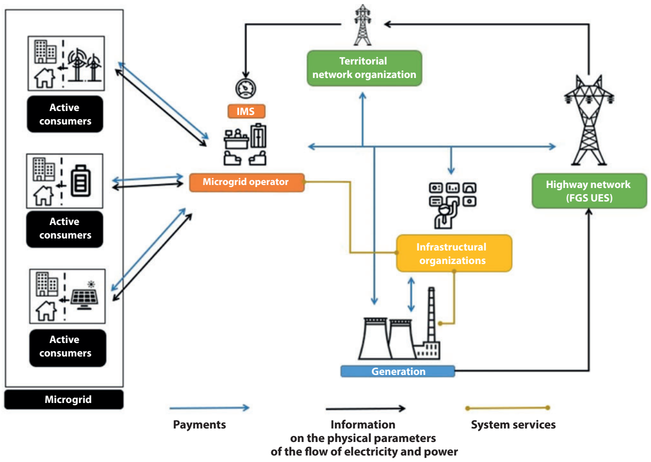
The study [Harnessing.., 2021] concludes that artificial intelligence technologies can significantly accelerate the digital transformation of the energy sector by identifying patterns and analyzing data, coordinating energy systems with a growing share of renewable energy sources, managing complex decentralized energy systems using distributed power generation, distributed storage and enhanced demand response capabilities.

Considering the spread of smart metering, energy storage systems, digital technologies that provide two-way information transit, load controllability will increase, which together with the spread of distributed generation can lead to the transformation of a passive consumer into an active one who is able to manage energy consumption, and in the presence of generating equipment - supply power to the network. Active consumers, who can not only change the energy consumption profile, but also generate energy and sell it to the grid, are often referred to in the literature as prosumers [Parag, Sovacool, 2016; Brown et al., 2019; Architecture.., 2021].

In a number of Russian studies in the field of demand management and digital technologies in the electric power industry, such as [Digital transition.., 2017; Demand management.., 2019], it is noted that not only large industrial consumers who know the wholesale market rules and use the flexibility of their production process to optimize costs, can participate in active consumer models. Their authors argue that a significant potential for demand management

[15] Concept. Digital Transformation 2030 (2018). PJSC Rosseti. https://www.rosseti.ru/investment/Kontseptsiya_Tsifrovaya_transformatsiya_2030.pdf.
[16] Id.

Fig. 2. Microgrid: A schematic diagram of interaction



Source: compiled by the author.

and balancing the energy system is concentrated in small consumers – retail market entities. Foreign studies also note the important role of small businesses and households in digital transformation and the trend towards the emergence of active consumers [Brown et al., 2019].

Thus, the combined influence of digital transition technologies in the electric power industry forms the prerequisites for the emergence of a new type of electricity consumer - an active consumer. This in turn can transform the current business models of energy companies and contribute to the formation of new value propositions not only for existing energy market participants but for subjects that have not previously interacted with those of the electric power industry.

2. Overview of active consumer models

The study [Parag, Sovacool, 2016] notes that active consumers have the opportunity to be directly involved in balancing the power system and providing system services by managing their load and (or) issuing power to the grid.

Despite the fact that the current market regulations and regulatory framework of most countries are focused primarily on the existing energy market model in the country, a number of promising interaction models can be proposed that are beneficial to all participants in the electricity trade [Brown et al., 2019]. These models reflect the main ways of organizing the interaction of consumers with energy companies and are not exhaustive.

1. The basic model of an active consumer. In the basic model, on the consumer side, before the meter, there may be a source of electricity or a storage device. Thus, the consumer can use electricity produced by a generator belonged to him and buy it from the network if his own energy production is not enough to cover consumption (for example, if the consumer has a RES generator installed and the weather conditions are not favorable for generation). If there is no generation or accumulation system, the consumer has the opportunity to change the load profile taking into account hourly or zone prices for electricity.

An important aspect of the basic model of an active consumer is the organization of both technological and market systems, which provides a bidirectional energy flow and allows an active consumer to supply excess power to the grid [Klimovets, Zubakin, 2016]. A schematic diagram of the interaction between subjects of the electricity market in the basic model of an active consumer is shown in Fig. 1.

The studies [Demand Management.., 2019; Brown, 2019] highlight a significant drawback of such a model, casting doubt on its viability. Consumers in the retail market (and sometimes in the wholesale market) have a relatively small amount of manageable load, which makes interaction with them unprofitable for infrastructure organizations: transaction costs significantly exceed the theoretical benefit. Thus, this model has limited opportunities to participate in active electricity trading.

2. Active energy complex/microgrid. This concept, shown in Fig. 2 is based on end-users and retail generators (including generating facilities owned by active consumers and/or power storage systems) connected to a low-voltage power grid in the microgrid area owned by the microgrid operator. Electricity is accounted for at the border of an active energy complex as a balance of generated and consumed electricity.

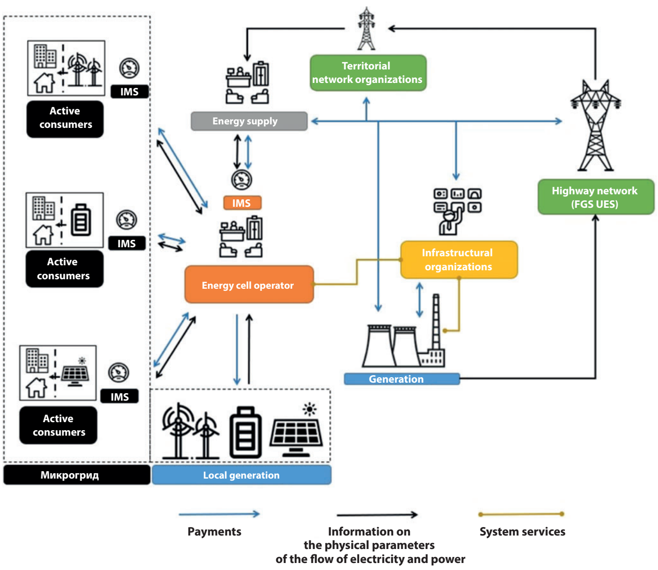
For a long time, the concept of a microgrid seemed applicable to power supply to isolated areas, the connection of which to a single power system would be economically unjustified. However, this concept turned out to be applicable in the case of a connection to a unified energy system as a model of an active consumer [Local supply.., 2018].

Also, the microgrid can be supplemented with the concept of a virtual power plant / virtual energy company. Such a company can provide billing services, as well as act as a demand management operator, thereby providing system services [Local supply.., 2018]. Based on a smart metering system, distributed generation and energy storage systems, with the help of price signals and various tariff solutions, a virtual energy company is able to reduce energy consumption during peak hours and optimize energy consumption at all the day to reduce the final cost of electricity for microgrid participants.

The paper [Brown et al., 2020] puts forward the idea that such models can have maximum efficiency for energy clusters under construction, since the costs of installing a smart metering system, storage and distributed generation will be taken into account at the design stage.

The world experience of pilot microgrid projects implemented for industrial and commercial consumers demonstrates a reduction in electricity costs from 5 to 25% (including participation in demand management programs), a reduction in CO_2 emissions into the atmosphere (which is especially important for industrial enterprises in the era of widespread decarbonization and the introduction of ESG principles) as well as improving the reliability and quality of

Fig. 3. Energy cell: A schematic diagram of interaction



Source: compiled by the author.

electricity supply. At the same time, it is noted that the final share of the reduction in energy supply costs depends on the configuration of specific participants in the microgrid, the potential costs for technological connection to the networks of the unified energy system (or upgrading networks to ensure large power flows), as well as on the requirements for the reliability of power supply and environmental friendliness[17].

It should be noted that in addition to the above listed effects, the introduction of microgrids with the widest functionality allows participants to act as additional sources of energy system flexibility and provide system services, including:

- participation in demand management projects;
- participation in frequency regulation;
- voltage regulation in the power system;
- provision of power reserves (including those for consumers outside the microgrid);
- reactive power compensation.

In order to test the microgrid concept and further develop this area in Russia, from 2020 to 2023, a pilot project is being carried out to organize active energy complexes, regulated by Decree of the Government of the Russian Federation No. 320 dated by March 21, 2020.

An active energy complex (AEC) is one of the types of microgrid used to supply industrial and commercial consumers with energy and unites both generators and consumers of eclectic energy and power entering into economic relations both within the active energy complex and with a unified energy system external to the AEC. The pilot project defines the AEC as a microgrid united with the UES, which includes generators with an installed capacity of up to 25 MW, which are not involved in electricity and capacity trading on the wholesale market, and consumers are represented by commercial and industrial enterprises, as well as business and shopping centers. At the same time, the balance of production and consumption of electricity within the AEC and the provision of power flows with the unified energy system within the permitted capacity is carried out by means of controlled intelligent connection.

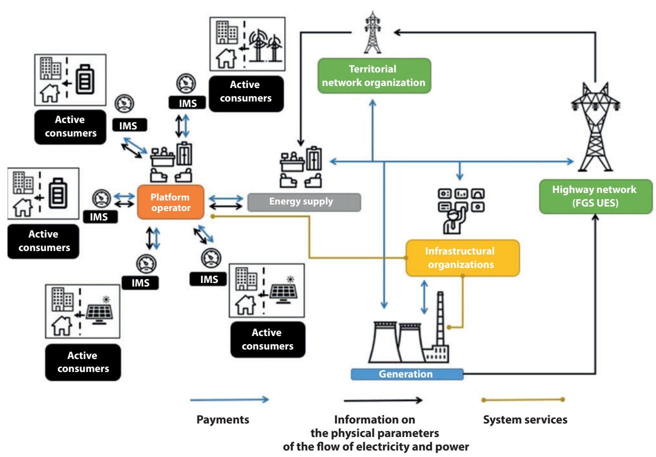
It should be noted that in addition to the opportunities for energy companies to participate in microgrid projects as their operators, the spread of microgrids opens up opportunities for implementing business models related to the export of technologies and the provision of implementation services. The active development of commercial and industrial microgrids creates a window of opportunity for Russian energy and technology companies for high-tech export of their solutions[18].

At the moment, the main barriers to the development of microgrids and AECs in the Russian market are regulatory barriers that do not allow retail market participants to freely and transparently organize energy exchange and share power grid capacities.

The world experience of piloting microgrids shows that the key to success in this dynamically developing market is the use of high-tech solutions and innovative business models both by end consumers of electricity and by companies operating microgrids. Implemented microgrids should be able to adapt to the conditions of a rapidly changing energy market, as well as consumer demands. Thus, the following technologies are of great importance for the creation of efficient microgrids throughout the entire life cycle:

- energy sources diversified by generation types;
- electric power storage systems;
- power receiving devices with the ability to control the load;

Fig. 4. P2P model: A schematic diagram of interaction



Source: compiled by the author.

[17] Microgrids for commercial and industrial companies (2017). World Business Council for Sustainable Development.
Microgrid analysis and case studies report (2018). California Energy Commission.
[18] Active energy complexes... https://drive.google.com/file/d/1PwyNYskwbaES_5oE3utFDDOnbucosZ0q/view.

- digital technologies for integration and management of microgrids (including those using artificial intelligence), providing plug&play connection of microgrid participants.

Thus, active energy complexes / microgrids are promising models of an active consumer in the retail market, which have a high development potential in conjunction with the spread of digital transition technologies in the electric power industry.

3. Energy cell. The concept of an energy cell (or local energy company), the schematic diagram of which is shown in Fig. 3 is in many respects similar to the microgrid concept, however, unlike the microgrid, the energy cell also includes local distributed generation connected to other consumers and microgrids through networks of territorial grid organizations.

Just like microgrids, energy cells seek primarily to provide energy exchange between producers and end consumers within the cell, if necessary, using power from a single power system.

The concept assumes more effective interaction of active consumers with the owners of distributed generation included in the energy cell, thereby it contributes to the establishment of lower electricity prices.

When using digital control technologies, as well as intelligent metering systems, it becomes possible to use dynamic pricing, which allows optimizing the load of generating capacities and consumption volumes inside the cell and leading to the establishment of an economically justified price for electricity [Brown et al., 2019].

Pilot projects in the UK have shown that the positive economic impact of deploying such models is achieved primarily by reducing the grid component in the electricity price structure, optimizing the cell's power schedule, selling electricity during peak consumption hours in the grid and participating in demand management programs.

In Russian studies, the concept of an energy cell is expanding from an independent concept to a participant in a more complex innovative model of interaction - the Internet of Energy. At the same time, an energy cell is one of the key elements of the Internet of energy and can act as an active consumer for neighboring energy cells, thereby trading electricity with them [Architecture .., 2021].

4. P2P model / internet energy. Peer-to-peer business models (Fig. 4) are based on the elimination of the electricity supplier as an intermediary between active consumers. These models use a third-party platform where consumers trade electricity among themselves. The promise of these models lies in fairer pricing, as the price is set by bidding between active consumers rather than determined by a third-party supplier. If generating capacities of active consumers are not enough to balance the platform participants, or, conversely, there is an excess, electricity can be purchased from the centralized power system or sold to it [Brown et al., 2020; Architecture.., 2021].

In Russian studies, the phrase "Internet of energy" is more often used to refer to the P2P model, although a common understanding of the term has not yet been formed.

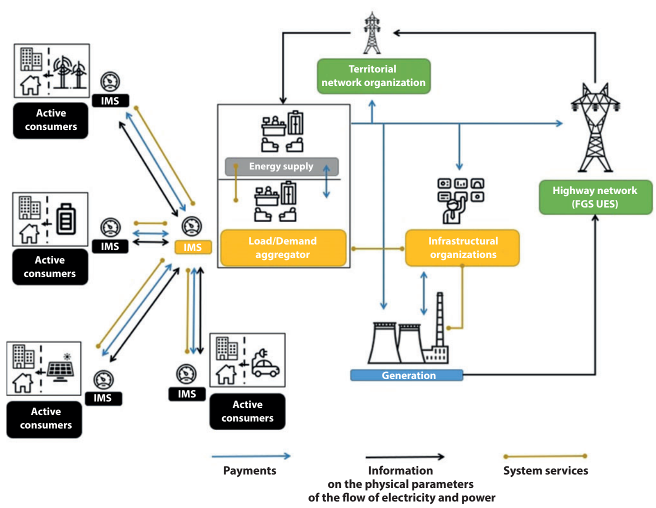
Despite the ambiguity of interpretations, general provisions can be distinguished in the description of the Internet of energy:

- the system is implemented on the basis of information technologies that ensure the exchange of information between participants in the Internet of Energy;
- the system should provide a balance between the production and consumption of electricity among active consumers, who own, among other things, distributed generation, generation based on RES and energy storage systems;
- Internet of energy is a cyber-physical system in which information flows are aimed at establishing the optimal mode of the system operation and ensuring reliable and high-quality power supply;
- To ensure bidirectional flows of both electricity and information in the Internet of Energy, digital sensors and actuators are used to control and monitor the state of the system [Nalbandyan, Khovalova, 2018].

Thus, the Internet of Energy is, in fact, an application to power systems of the Internet of things concept, which is a group of devices and equipment connected to intelligent computing networks which use data collected from devices for their active control. With regard to the electric power industry, these can be both built-in sensors that control the operation of turbines and intelligent control systems for distribution substations, as well as sensors and actuators installed on the consumer side and allow real-time control of the load.

The main drivers for the development of the Internet of Energy are the need to integrate distributed generation

Fig. 5. Risk map with a new technological level



Source: compiled by the author.

(including stochastic generation based on renewable energy sources) into energy systems, increased requirements for the environmental friendliness of electricity supply and the growing popularity of feed-in tariffs as well as tightening the requirements for reliability and quality of electricity by high-tech sectors of the economy [Baer et al., 2002]. Thus, the study [Morley et al., 2018] predicts an increase in energy consumption by digital infrastructure and precision industrial production at the level of 7% per year, while the share of consumption of digital devices in peak energy consumption will also increase.

Also, the changing nature of consumption in the retail market stimulates the development of the Internet of energy: according to the forecast of McKinsey & Company the daily unevenness of the household energy consumption schedule with the widespread use of electric vehicles will increase by 30% compared to the current level [Engel et al., 2018], which will lead to the need for investment into additional capacity subject to a slight increase in the volume of electricity consumed, which in turn will lead to an increase in the capacity payment for end consumers.

The effects of implementing the concept of the Internet of Energy include both effects generated by the models discussed earlier, as well as unique ones arising from the use of more digital solutions than in other models:

- reduction of investments in generating and power grid capacities due to more accurate forecasting of the consumption schedule;
- reduction of losses in Internet energy networks due to optimization of flow routes;
- the most effective participation in demand management programs through a deeper analysis of end-user behavior patterns;
- the most efficient integration of distributed and renewable energy generation, as digital technologies will allow you to quickly respond to changes in generation;
- reducing operating costs and improving the reliability of power supply due to predictive equipment analytics;
- creating unique value propositions for end consumers by collecting and processing big data from consumer devices [Nalbandyan, Khovalova, 2018; Brown et al., 2020; Architecture.., 2021].

Just as in the case of microgrids, the development of the Internet of Energy increases the domestic demand for high-tech equipment and also allows energy companies to act as solution providers based on the concept of the Internet of Energy, both in the domestic market and in the external market.

5. Load aggregator. Under the spread of distributed generation and generation based on renewable energy sources, the concept of energy system flexibility is becoming increasingly important. Flexibility is understood as the ability of the power system to maintain the balance of power in conditions of high volatility in power consumption and generation power (especially in the case of a high percentage of RES in the power system), compensating for emerging imbalances with sources of flexibility. In turn, demand management can be considered as a source of energy system flexibility [Demand management..., 2019; Brown et al., 2020]. According to estimates made by the Center for Strategic Research, about 30% of the power receiving devices of end consumers can be controlled. A significant part of this capacity is distributed among consumers of the retail market and cannot be used due to high transaction costs. This problem is solved by the concept of a load aggregator - an entity that sells flexibility in the wholesale market and generates this flexibility by managing many small consumers in the retail market. The schematic diagram of interaction for the load aggregator model is shown in Fig. 5.

Russia is also implementing a pilot project on demand management with the use of load aggregators: in 2019 decree № 287 of the Russian Government was approved. It defined the basics of new demand management mechanism functioning and introduced the concept of demand management aggregator – an organization combining the resources of retail consumers for providing services on demand control as a new type of services for system reliability.

Under the pilot project a consumer concludes a services contract on system reliability with JSC IPS/UPS TSO. The need to change the load is formed by JSC ATS based on the results of a double model calculation of the DAM (with and without unloading), after which the system operator instructs the aggregator to reduce consumption by a certain amount of capacity, and the aggregator distributes this volume among consumers who have concluded an agreement with it. After the load is confirmed, the payment is rendered: JSC IPS/UPS TSO pays for the aggregator services, whereas the aggregator pays for customer services.

The main effects of the implementation of demand management programs are both long-term and short-term:

- reduction of electricity costs for end consumers due to more efficient balancing and establishment of an equilibrium price in the day-ahead market by shifting and smoothing consumption peaks;
- substitution of flexible load for expensive and inefficient capacities in the wholesale market in the medium term;
- in the long term, reducing the need for investment in new generating and grid capacities to cover peak consumption [Demand Management.., 2019].

[Kuzmin, 2019] assumes that in order to fully unlock the potential of the load aggregator concept, it is necessary to develop intelligent metering systems that allow to collect data on energy consumption and efficiently process them using artificial intelligence technologies. In the study [Demand Management.., 2019] the list of technologies necessary for the successful operation of aggregators is supplemented

Table 4
Weighted average estimates of effects broken down by active consumer models

The effect of the spread of the active consumer model	Active consumer model				
	Basic active consumer model	Active energy complex/ microgrid	Energy cell	P2P model / internet energies	Load aggregator
Reducing the cost of purchasing electricity for end consumers	4.0	5.7	6.0	4.3	6.0
Reducing the equilibrium price of the DAM due to the shift and smoothing of consumption peaks	4.0	6.0	5.0	4.3	6.7
Substitution of flexible load for expensive and inefficient capacities in the wholesale market in the medium term	4.7	6.0	6.0	5.7	6.7
Reduced need for investment in new generation capacity to cover peak demand in the long term	3.0	4.7	5.0	4.7	5.7
Reduced need for investment in new grid capacity to cover peak demand in the long term	4.3	5.7	4.7	4.3	5.0
Reduced losses in networks due to optimization of flow routes	4.3	6.0	6.0	5.7	4.7
Reducing the volume of technological and commercial losses in low voltage networks	3.0	5.0	5.0	5.0	5.0
The most efficient integration of distributed and renewable energy generation	4.7	5.0	4.7	3.7	2.0
Reduce operating costs and improve power supply reliability due to predictive equipment analytics	3.0	6.0	6.0	4.7	3.0
Increased effectiveness of participation in demand management programs due to a deeper analysis of end-customer behavior patterns	5.0	6.0	6.0	6.0	5.3
Creation of additional revenue generation for electric power companies through the provision of system and support services	3.0	5.3	5.3	5.0	5.7
Creation of additional revenue generation for electric power companies by commercializing big data on energy consumption	4.3	5.3	5.7	5.3	4.7
Increasing the greenness of the energy system and reducing the share of CO_2 emissions	4.3	6.0	6.0	5.7	6.3

Source: compiled by the author.

by digital transactional solutions and industrial Internet of things technologies.

The big data collected by IMS allows to analyze the load profiles of a large array of users and identify devices with high potential as part of demand management.

High-precision comparative analysis of demand management participants makes it possible to build new price models based on determining prices for each group of consumers involved in demand management, thereby maximizing their benefits [Lin, Wang, 2011]. Incentive demand management programs allow the dispatcher to involve new participants, and IMS, in turn, greatly simplifies the verification of load reduction, which is especially important for monitoring the fulfillment of demand management duties in the private sector, since there are no sufficiently accurate models for assessing demand management potential on the side of retail consumers [Bergman et al., 2011].

Thus, the demand aggregator model is able to involve consumers without their own generation into active participation in the operation of the energy system and not only to reduce the cost of electricity but also earn money on the system services provision.

3. Research results

In order to verify the previously identified potential effects of the spread of active consumer models, in-depth semi-structured interviews were conducted with seven representatives of electric power companies.

Employees of electric power companies - energy sales, electric grid and generating companies were chosen as the object of the interview. Each of the respondents holds a leadership position and has:

- scientific interest in the field of digital technologies in the electric power industry;
- direct relation to the sphere of innovative development in the electric power industry.

Based on the results of the interview analysis, the effects of active consumer model distribution were confirmed and updated, and a questionnaire was developed for scoring the effects.

In order to measure the identified effects from the spread of active consumer models, the statements of the questionnaire were formulated. Respondents were asked to choose the degree of agreement with the statements given in the questionnaire. To measure the degree of agreement, a seven-point Likert scale was used, where 1 - "completely disagree", 4 - "do not know, agree or disagree", 7 - "strongly agree". The content of the questionnaires, as well as the weighted average assessments of the experts, broken down by models of the active consumer, are presented in Table 4.

Conducted interviews with subsequent questioning showed that the active energy complex / microgrid, energy cell, P2P model / Internet energy, as well as the load aggregator have the greatest potential.

The basic model of an active consumer received relatively low ratings from experts due to the complexity of implementing such a model in practice and the high level of expected transaction costs during its operation, which is consistent with the theoretical review.

The P2P model/internet energy received lower scores than microgrid and energy cell. Such an assessment may be due to a high degree of uncertainty in the cost of high-tech components necessary for the implementation of this model, which may adversely affect the achievement of positive effects from the Internet of Energy model deployment.

During the interview, some of the experts pointed out the similarity of the active energy complex/microgrid and energy cell models, while noting that the differences between these models are due to differences in the regulatory legal framework of the countries in which such models are applied. The experts also noted potential barriers to the implementation of active energy complex/microgrid models, due to the insufficiently high price of electricity purchased from the unified energy system for the consumer to make a decision to switch to electricity using the microgrid model, as well as a possible conflict of interest between the owners of enterprises and the owners of generating capacities located on the territory of the active energy complex.

Conclusion

The paper presents the results of the analysis of key technological trends in the electric power industry, as well as active consumer models that appear as a result of a change in the nature of interaction between consumers and energy companies due to the spread of new technologies.

A review of domestic and foreign literature made it possible to identify the main effects from the spread of distributed generation (including the use of renewable energy sources), electricity storage systems, intelligent electricity metering systems, and industry 4.0 digital technologies.

These technologies in themselves have a number of effects: reducing the cost of purchasing electricity for the end consumer, reducing investment in new generating and grid capacities, improving the reliability and quality of power supply, and reducing CO_2 emissions into the atmosphere. In addition, these technologies expand the range of opportunities for interaction between consumers and energy companies, thereby forming a new category of consumer - an active consumer.

A study of innovative models of interaction between consumers and energy companies showed that there are many ways to involve the consumer in an active participation in the process of production, distribution and consumption of electricity. Each of the models has different characteristics, requirements for the technologies used in this model, and effects both for consumers and energy companies, and for the market system of electricity and capacity trading as a whole.

As a further line of the research, we see a detailed study of the barriers to the spread of active consumer models identified by experts, as well as a study of the factors for the success of these models' implementation.

References

1. *Architecture of the Internet of Energy IDEA* (2021). Moscow, EnergyNet Infrastructure Center. https://drive.google.com/file/d/13JM0NIY4jUXOP6Mv4irjb2k77bK60p-Q/view. (In Russ.)
2. Ivanov A.V., Kucherov Yu.N., Samkov V.M., Korev D.A. (2018). Development of standardization of intelligent power supply systems of the future. *Energy of the Unified Network*, 3(38): 81-84. (In Russ.)
3. Klimovets O.V., Zubakin V.A. (2016). Methods for assessing the effectiveness of investments in own generation in conditions of risk. *Effective Anti-Crisis Management,* 2(95): 78-84. (In Russ.)
4. Kuzmin P.S. (2019). Non-intrusive load monitoring: Implementation effects and distribution prospects. *Strategic Decisions and Risk Management*, 10(4): 306-319. DOI: https://doi.org/10.17747/2618-947X-2019-4-306-319. (In Russ.)
5. Kuzmin P.S. (2021). Smart metering systems: An empirical analysis of technology perception factors. S*trategic Decisions and Risk Management,* 12(1): 8-23. DOI: https://doi.org/10.17747/2618-947X-2021-1-8-23. (In Russ.)
6. Linder N., Trachuk A.V. (2017). The impact of cross-subsidization in electricity and heat energy on changing the behavior of participants in the wholesale and retail markets for electricity and heat. *Strategic Decisions and Risk Management*, 3: 78-86. DOI: https://doi.org/10.17747/2618-947X-2017-3-78-86. (In Russ.)
7. Nalbandian G.G., Khovalova T.V. (2018). Concept of the Internet of Energy in Russia: Drivers and prospects. *Strategic Decisions and Risk Management*, 3: 60-65. ISSN 2618-947X. (In Russ.)
8. Nalbandyan G.G., Zholnerchik S.S. (2018). Key factors for the effective application of distributed generation technologies in industry. *Strategic Decisions and Risk Management*, 1: 80-87. DOI: https://www.jsdrm.ru/jour/article/view/755/635. (In Russ.)
9. *Application of energy storage systems in Russia: Opportunities and barriers* (2019). Moscow, EnergyNet Infrastructure Center. https://drive.google.com/file/d/1QraG6ghruRMyc9gcN3a0LNWUsnUonId3/view. (In Russ.)
10. Sellyakhova O., Tarnovskaya O., Fateeva E. (2016). Virtual Power Plant. *Energy Market Magazine,* 2(137): 43-50. (In Russ.)
11. Trachuk A.V., Linder N.V. (2017). Cross-subsidization in the electric power industry: Approaches to modeling the reduction of its volumes. *Strategic Decisions and Risk Management* 1(100). https://cyberleninka.ru/article/n/perekrestnoe-subsidirovanie-v-elektroenergetike-podhody-k-modelirovaniyu-snizheniya-ego-obemov. (In Russ.)
12. Trachuk A.V., Linder N.V. (2018). Distributed generation technologies: empirical assessments of application factors. *Strategic Decisions and Risk Management,* 1: 32-48. DOI: https://doi.org/10.17747/2078-8886-2018-1-32-48. (In Russ.)
13. *Demand Response in the Russian electric power industry: Opening opportunities* (2019). Moscow, Infrastructure Center EnergyNet. https://www.so-ups.ru/fileadmin/files/company/markets/dr/publication/EnergyNet_2019.pdf. (In Russ.)
14. Khovalova T.V., Zholnerchik S.S. (2018). Effects of the implementation of intelligent electric power grids. *Strategic Decisions and Risk Management,* 2: 92-101. https://www.jsdrm.ru/jour/article/view/776/649. (In Russ.)
15. Khokhlov A., Melnikov Y., Veselov F., Kholkin D., Datsko K. (2018). *Distributed energy in Russia: Development potential*. Moscow, Skolkovo. https://energy.skolkovo.ru/downloads/documents/SEneC/Research/SKOLKOVO_EneC_DER-3.0_2018.02.01.pdf. (In Russ.)
16. *Digital transition in the electric power industry* (2017). Moscow, Center for Strategic Research. https://www.csr.ru/issledovaniya/tsifrovoj-perehod-velektroenergetike-rossii/. (In Russ.)
17. Baer W.S., Hassel S., Vollaard B.A. (2002). *Electricity requirements for a digital society*. RAND Corporation. https://www.rand.org/pubs/monograph_reports/MR1617.html.
18. Bergman D.C., Jin D., Juen J.P., Tanaka N., Gunter C.A., Wright A.K. (2011). Non-intrusive load shed verification. *IEEE Pervasive Computing,* 10(1): 49-57.
19. Brown D., Hall S., Davis M. (2019). Prosumers in the post subsidy era: An exploration of new prosumer business models in the UK. *Energy Policy*, 135. DOI: https://doi.org/10.1016/j.enpol.2019.110984.
20. Brown D., Hall S., Davis M. (2020). What is prosumerism for? Exploring the normative dimensions of decentralised energy transitions. *Energy Research & Social Science*, 66. DOI: https://doi.org/10.1016/j.erss.2020.101475.
21. Engel H., Hensley R., Knupfer S., Sahdev S. (2018). *The potential impact of electric vehicles on global energy systems*. McKinsey & Company. https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/the-potential-impact-of-electric-vehicles-on-global-energysystems#.
22. Frankel D., Wagner A. (2017). *Battery storage: The next disruptive technology in the power sector.* McKinsey. https://www.mckinsey.com/businessfunctions/sustainability-and-resource-productivity/ourinsights/battery-storage-the-next-disruptive-technology-inthe-power-sector.

23. Hansen C.J., Bower J. (2004). *An economic evaluation of small-scale distributed electricity generation technologies.* Oxford, Oxford Institute for Energy Studies.

24. *Harnessing artificial intelligence to accelerate the energy transition* (2021). World Economic Forum. https://www3.weforum.org/docs/WEF_Harnessing_AI_to_accelerate_the_Energy_Transition_2021.pdf.

25. Lin C., Wang Z. (2011). *A new DSM energy-pricing model based on load monitoring system.* Proceedings of the 2nd International Conference on Artificial Intelligence. Management Science and Electronic Commerce, AIMSEC: 3650-3653.

26. Morley J., Widdicks K., Hazas M. (2018). Digitalization, energy, and data demand: The impact of Internet traffic on overall and peak electricity consumption. *Energy Research & Social Science*, 38: 128-137.

27. Naghibi B., Deilami S. (2014). *Non-intrusive load monitoring and supplementary techniques for home energy management*. Australasian Universities Power Engineering Conference. DOI: https://doi.org/10.1109/aupec.2014.6966647.

28. Parag Y., Sovacool B.K. (2016). Electricity market design for the prosumer era. *Nature Energy*, 1: 16032. DOI: https://doi.org/10.1038/nenergy.2016.32.

29. *Local supply: Options for selling your energy locally* (2018). Regen. https://www.regen.co.uk/wp-content/uploads/Local_Supply_Options_for_Selling_Your_Energy_Locally__Edition_2__2016.pdf.

30. Wegner M.S., Hall S., Hardy J., Workman M. (2017). Valuing energy futures; a comparative analysis of value pools across UK energy system scenarios. *Applied Energy*, 206: 815-828. DOI: https://doi.org/10.1016/j.apenergy.2017.08.200.

31. Zoha A., Gluhak A., Imran M., Rajasegarar S. (2012). Nonintrusive load monitoring approaches for disaggregated energy sensing: A survey. *Sensors,* 12: 16838-16866.

About the author

Pavel S. Kuzmin

Chief specialist of the Risk Management Department, JSC TENEX (Moscow, Russia). SPIN-code: 8042-4060, Author ID: 991705.

Research interests: digital transformation, company development strategy and management, company development strategy formation.

kuzminps.fa@yandex.ru

The article was submitted on 30.10.2021; revised on 28.11.2021 and accepted for publication on 16.12.2021. The authors read and approved the final version of the manuscript.