Technological trends in the energy sector: challenges and threats

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Abstract. The global trends taking place within the framework of the change of the technological way of life have largely determined the modern transformations taking place in the energy sector. These transformations have become the result of the challenges that have manifested themselves in recent years, and which have already acquired a large-scale character in many ways. They are associated with the rapid development of carbon-free, nature-like energy generation technologies based on renewable energy sources, distributed energy generation, the growth of consumer activity in regulating their demand, intellectualization, digitalization, decarbonization, integration and other processes taking place in the energy sector. These processes are objective and do not depend on conjunctural, political or any other preferences. In these conditions, the most important task of the present and future development and functioning of energy systems and the fuel and energy complex as a whole of the energy sector is to preserve the stability of their functioning and stable operation, ensuring socio-economic growth and energy security of the country. **Keywords:** centrally distributed systems, energy systems of the future, energy transition, climate science, reliability, sustainability, intellectualization, integration, cybersecurity.

1 Introduction

Currently, the technological structure is changing in the energy sector, which assumes the priority of knowledge, intelligence, information and Internet technologies, nanoenergy, microelectronics, biotechnologies, and other nanoscale industries. At the same time, the role of consumers is growing, distributed energy generation competes with centralized sources, compromise solutions become relevant. This is facilitated by the growing market of affordable and modern hardware analytics technologies, control and accounting systems for electricity, telecommunications and information support, small energy, etc. They offer consumers of electricity and heat the opportunity to actively operate and organize their own energy production. The interconnection of systems is increasing, the volume of information exchanged is increasing, the management of systems is becoming more complex, and the risk of emergency situations is increasing. In recent years, the requirements for reducing the

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negative impact on the environment have been significantly strengthened. They are often associated with the clinical agenda, which is debatable in its validity.

2 Energy transfer

The climate direction in the energy sector, on the one hand, is perceived as a fight against global warming and the prevention of an environmental catastrophe, on the other hand, it is presented as a tool for the redistribution of the world energy market of resources, technologies and the revision of competitive energy technology niches. This direction, which has been called carbon-free energy in connection with the rejection of the use of hydrocarbon fuels, is often associated with energy transition. At the same time, energy transition is a larger and more complex process, covering not only the solution of climate problems, but also ensuring energy independence based on energy-efficient practices, the use of convergent nature-like technologies, reduction of greenhouse emissions and, in general, reduction of harmful effects on the environment. Energy transfer is one of the means of transformation of human society, it affects social, economic, political, environmental and other spheres, therefore it cannot be associated only with climate science. The transformation of energy systems and the fuel and energy complex as a whole in the aspect of energy transition is primarily associated with the manifestation of consumer activity in managing their energy supply (as an internal factor) and the availability of an affordable and developed market of technologies and equipment (as an external factor).

Here, in fact, two independent directions should be distinguished, the actual energy transition and the carbon-free economy, including energy. The first direction, the most ambitious, is due to the natural process of changing the technological structure. The second is associated with the elimination of the negative impact of anthropogenic environmental impact on the environment and climate change. At the same time, it is important to be able to assess the situation promptly and correctly, to have a proactive foresight of the future, to build a scientifically sound long-term plan that provides for a gradual transition from outdated to new technologies, ensuring stable reliable functioning of power systems.

3 Challenges and threats

Each stage of technological development generates not only new problems, the solution of which leads to another transition, but also contributes to breakthrough transformations. At the same time, this process is usually associated with strategic changes, they can activate both the opening of new opportunities and cause the emergence of risks and threats to the successful development of systems. The functional features of power systems make them a critical infrastructure for the economy and social sphere.

The new conditions and challenges (Table 1) that encourage energy systems to switch to a new technological order and to a certain extent contribute to their global changes are presented in an enlarged form in Fig. 1.

Table 1. Challenges of the new time.

n/a	Challenges to energy	Stimulating aspects
1	Competition	Between types and types of systems; for fuel resources; for the consumer; for investments
2	Successful development of distributed generation	Renewable and unconventional energy sources; cogeneration based on GTU, DSU; fuel cells

3	Active consumers	Demand management; combining the functions of consumption and energy production; energy exchange between consumers
4	Intellectualization	Neural networks, machine learning; decision-making and impact on executive mechanisms
5	Internet technologies	Internet Energy, machine-to-machine interaction (M2M), blockchain
6	Integration	Integration into a single metasystem of several functional systems; information technologies; intellectual and telecommunication complexes
7	Consumption growth	Transmission and management of large energy flows, electric vehicles
8	Information security-danger	Prevention of cyber attacks; cybersecurity
9	Available market of new technologies and equipment	Management systems, accounting; hardware, etc.

The above trends in the energy sector are focused on the wide application of methods and approaches of artificial intelligence, information and communication technologies. Their integration into the technological process is accompanied by certain risks. On the one hand, there is a fear that artificial intelligence may lead to incorrect and even dangerous decisions, on the other hand, there is an opinion that the widespread involvement of artificial intelligence in the energy sector and the economy as a whole will increase the efficiency of their management, reliability and quality of ensuring their functional purpose.

At the same time, there is an increasing threat of the spread of a harmful virus, gaining access and organizing control over technological processes. At the same time, the consequences can be any, ranging from damage to equipment, stopping individual technological processes to man-made disasters with human victims. The main threats to the energy sector, differentiated into internal – Russian and external – world, are shown in Fig. 1.

Despite the fact that much attention is paid to security issues in the energy sector, it remains one of the most vulnerable areas targeted by cyber attacks. This is largely due to the fact that the energy industry is characterized by great inertia in its development, relatively slowly updates the infrastructure and software, which makes it vulnerable to malicious attacks.

4 Structural transformation of energy systems in the conditions of energy transfer

The transformation of energy carried out within the framework of the fourth energy transition [1] is associated with cardinal changes, as a result of which a new architecture of energy systems is being created [2, 3]. It covers a wide range of issues, including the creation of an appropriate institutional framework defining regulatory, technological and economic rules for the reliable and efficient development and functioning of energy systems in new conditions. Significant transformations will undergo organizational models that provide technological coordination, investment activities, and management of the interaction of numerous entities belonging to different forms of ownership and having divergent interests in the energy business process [4-6].

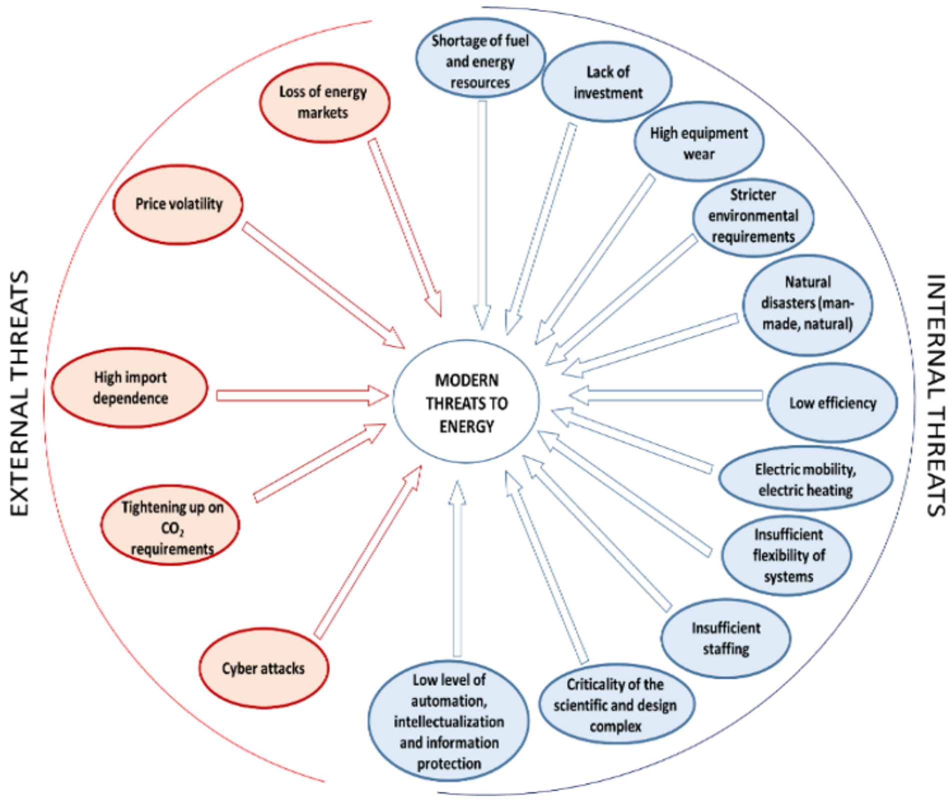

Fig. 1. Threats to sustainable energy development.

In relation to the transformation of energy systems in the conditions of energy transition, constructions in the form of the 3D concept (Decarbonization, Decentralization and Digitalization) are often used, and recently – 3C (Co-provision, Co-organization, Co-development). Both of them have the right to exist, especially since they are built on the same principles, including: satisfaction of energy needs from the surrounding space without compromising the environment; development of systems in the form of a distributed architecture with collective participation in their management; intellectualization of the processes of functioning on the basis of human-machine systems with coordinated control. At the same time, they only generally represent the outlines of the contour of the future of energy, participate in the form of certain restrictions that form the scope of acceptable solutions and objectively cannot give a full-fledged vision of future systems, which is much more complex and diverse than what is put into the concept of these restrictions.

As part of the ongoing transformation, it is necessary to ensure an increase in their efficiency in terms of manageability, reliability, safety, efficiency, etc., reducing the negative impact on the environment, including greenhouse gas emissions, and the availability of energy supply for all consumers. The solution of this triune task is impossible without a transition to a new technological paradigm based on modern information achievements, broad intellectualization and integration of energy systems (electricity, heat, cooling, gas supply) into a single metasystem [7].

The implementation of the integration process involves the unification of technological systems, their intellectualization, the use of traditional, renewable and secondary energy resources, the construction of centralized energy hubs (nodes) with energy storage, the construction of "smart" buildings with energy storage to smooth the peak load. The processes of integration of energy systems into a metasystem lead to an increase in the level of their integrity and organization, while increasing the volume and intensity of interconnections and interaction between individual elements. Integration in production and consumption necessitates joint consideration of electrical, thermal, gas networks, their operating modes, especially in emergency situations, and their management, analysis of the reliability of energy supply taking into account the interconnectedness of systems, etc.

The increasing role of distributed generation of electricity and heat, including directly from consumers, predetermined the creation of centrally distributed energy systems with the formation of new properties and diversification of existing ones. [8]. These factors lead to the need to revise the principles of construction of production and transport energy systems and energy supply systems, including at the consumer level, as well as the management of their modes based on the integration of these systems. The stochastic nature of the RES operation and the activity of consumers in managing their own energy consumption causes significant uncertainty in the operating modes of energy systems.

An atypical aspect of energy security is related to computer security or cybersecurity. This is due to the fact that the equipment and a number of devices are connected to the data transmission information system, which provides access to the system in order to disrupt its operation. At the same time, the importance of protecting computer infrastructure and reliable management of the energy system is dramatically increasing. With the development of digitalization and intellectualization of energy, the risks of cyber threats are significantly increasing, while they can be associated with any element, even with individual electricity meters and energy consumers. Cybersecurity management is becoming a key task of the functioning of the energy system [9, 10].

The topological and structural complexity of energy systems, which has increased due to the strengthening of intra- and intersystem connections, an increase in the diversity of energy sources by type and capacity, their discrete-stochastic nature of functioning has provided a deep penetration of digitalization and intellectualization into the energy process. Intelligent energy systems are a balanced combination of traditional and new technologies, such as the Internet, 5G mobile networks, cloud storage and computing, data analytics, artificial intelligence, machine learning, etc. This, as well as other factors mentioned above, predetermine the need to consider EPS, TSS and GSS as complex cyber-physical systems [11]. Technological transformation of energy systems of different levels ensures the implementation of new functionality, promotes the use of more advanced technologies in operation and the creation of integrated centrally distributed systems with coordinated management of their modes and active participation of consumers in the process of their energy supply. Such systems have a more developed functional potential relative to traditional systems. Their main features are reflected in Fig. 2.

Two fundamental circumstances can be distinguished in the formation of technical policy in the energy sector. The first of them is a structural and technological transformation of energy systems associated with a change in the system principles of their structure. They should be focused on creating a customer-oriented energy supply with the consistent formation of integrated systems that provide a comprehensive supply of consumers with different types of energy (electricity, heat, cold, etc.). The second is connected with innovative energy-efficient technologies and equipment, on the one hand, implementing new system approaches to building energy systems, and on the other hand, adequately taking into account the diverse structure of loads (electrical, thermal, etc.), their ratio, as well as the active behavior of the consumer [4].

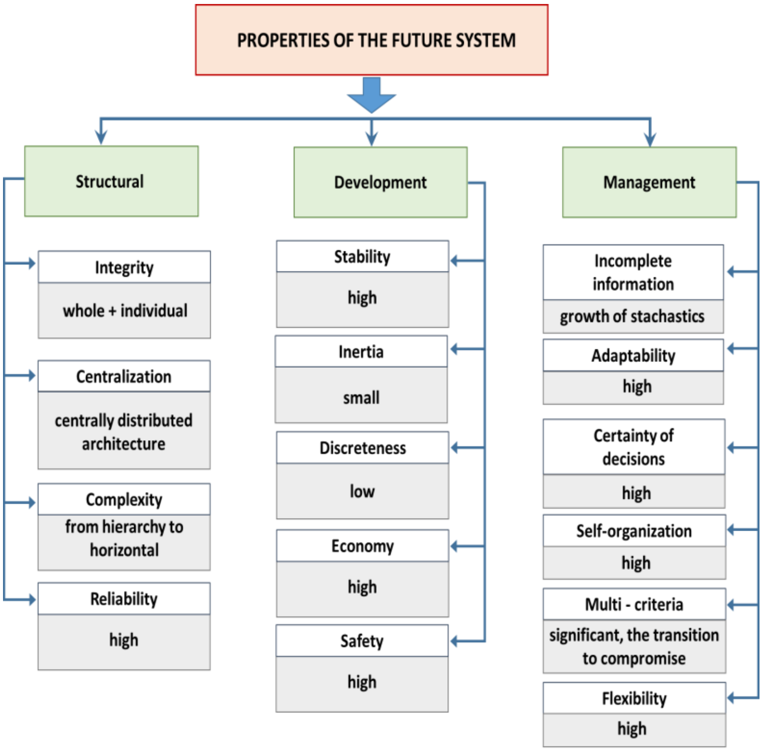

Fig. 2. Characteristics of the power systems of the future.

5 Methodological principles of building new-level energy systems

Combining all functional technologies into a single platform makes it necessary to take a fresh look at the construction of both individual systems and their integration, moving from the rigid existing structure of "generation - network - consumer" to a more flexible one, in which each node of the network can be an active element (as a consumer, and the energy supplier). Such an IIEP becomes a self-adjusting system and, depending on internal and external conditions, automatically performs reconfiguration, ensuring that it fits into the changed operating conditions. It should have three most important and interrelated properties: customer orientation - high–quality and timely energy supply to consumers at an affordable price and their ability to accept the energy and power they produce; activity in the management of both the systems themselves and consumers; adaptability with a high level of self-organization and cyber security; environmental friendliness.with minimal negative impact on the environment [12-14]. The traditional ones are developing significantly, new properties characterizing energy systems are emerging, this is clearly seen in Fig. 3.

The technology of functioning of such a meta-system is also becoming new, since in it, as noted above, unidirectional movement of energy flows (source - consumer) turns into multidirectional (not only from source to consumer, but also from consumer to source). The system design being formed should combine a certain independence of many decision-making centers and their coordination in ensuring sustainable energy supply to consumers. It should be based on the principle of subsidiarity and self-regulation, according to which management is carried out not by influencing the regulatory system from the outside, but is formed in it itself. At the same time, the systems have their own management, goals, tasks and work independently, coordinating with other systems within the framework of the implementation of common targets through a cloud of horizontal connections.

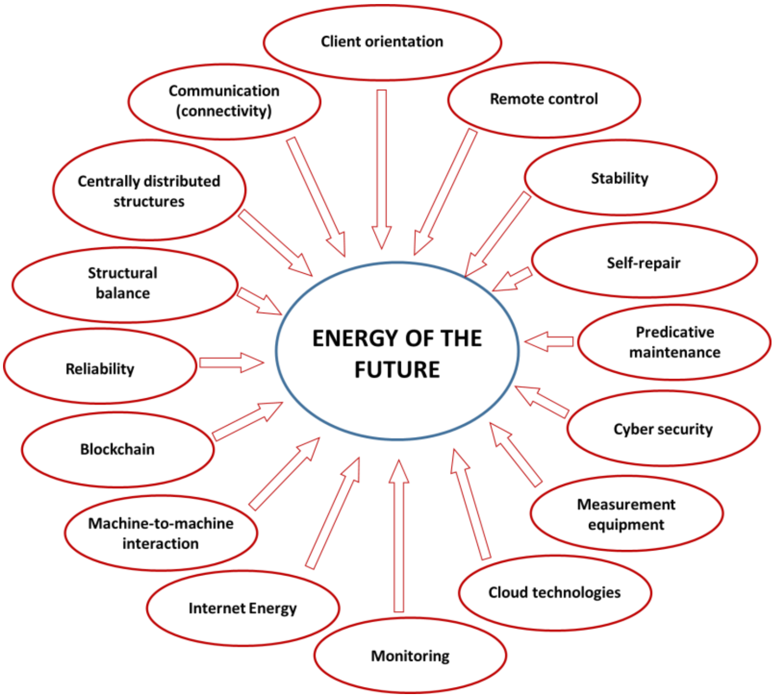

Fig. 3. Characteristics of the energy systems of the future.

An integral part of such a system is its "intelligence", which is based on an agent-oriented paradigm, when each consumer, receiving information through his intelligent agents about all other participants in the energy supply process, evaluates his role in this process and forms his behavior. Having the necessary technological knowledge, he can reasonably optimize his energy consumption process. The process of system intellectualization has intensified due to the emergence of renewable energy sources with a stochastic mode of operation located at consumers.

These fundamental provisions predetermine the network model of relations, which is based on the principle of complementarity, when the actions of one participant related to the solution of the following tasks simultaneously contribute to the solution of certain tasks of other participants. The grid organization is a system of a higher order relative to the hierarchically subordinate structure of the Russian energy industry. It implies the weakening of vertical ties, de-bureaucratization and the development of horizontal ties. Network organizational processes are highly adaptive, diverse, and can be integrated into any management system.

The multidimensional structure of the IPP, a high level of unification and self-organization, intelligence, the integrated use of technologies for transformation, transport, energy storage and active consumption significantly expand the functionality of the formed energy metasystem and provide it with new properties that ensure, first of all, the implementation of high-quality and timely provision of consumer requests

The presented conceptual provisions of integrated intelligent energy systems allow us to consider the problem from different positions and formulate research tasks more systematically. Among them, the most difficult tasks are those related to knowledge modeling, including the development of methods for formalizing knowledge for entering it into computer memory as a knowledge base, and modeling reasoning, i.e. creating computer programs that simulate the logic of human thinking when solving various management tasks.

6 Conclusion

The main factors driving the transformation of the energy sector are the increasing activity of consumers, the dynamically developing technology and equipment market, the increasing competitive advantages of distributed energy generation sources, the penetration of digital and intelligent technologies into the energy sector, the development of high-speed cloud information infrastructure, etc. These trends, along with positive trends associated with the formation of intelligent integrated centrally distributed systems with horizontally distributed control of their modes, developed functional capabilities, lead to the emergence of various kinds of threats and risks that can restrain the innovative development of energy. In these conditions, the most important task in the energy sector is to ensure the sustainable, reliable adaptive functioning of energy systems.

The presented results systematize the work performed, form the main conceptual provisions and reflect some properties of future energy systems. The ideology, construction and management of such systems is the most important problem that requires active scientific and practical research.

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