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INNOVATIVE ASPECTS OF DIGITAL TECHNOLOGIES IN TRACTION POWER SUPPLY

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Abstract
The article studies the process of changing the structure of traction power supply in the context of digitalization, and explores the potential and prospects of introducing information technologies in traction power supply. The article examines and systematizes the factors and conditions that contribute to the large-scale introduction of digital technologies in the field of traction power supply. The article concludes that it is crucial to develop a comprehensive digital transformation in the traction power supply of railways in order to increase the efficiency of the energy system and expand the scope of interaction with external factors that contribute to the overall growth of the national economy.

Keywords: Digital economy, economic efficiency, electric power industry, traction power supply

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INTRODUCTION

Currently, in the context of global economic development, the electric power industry is undergoing significant transformations due to the need to improve the efficiency of countries' energy systems. The relevance of implementing digital technologies in railway traction power supply is determined by a combination of financial, technical, innovative, and social factors that create the preconditions for large-scale modernization of railway traction power supply.

MATERIALS AND METHODS

The current structure of railway traction power supply is characterized by a significant degree of physical and moral deterioration of the main production facilities, which significantly limits the possibilities for improving the efficiency of electricity generation, transmission, and distribution using traditional methods. According to statistical data, the average level of equipment deterioration in railway traction power supply reaches almost 70%, resulting in increased operating costs, reduced reliability of traction power supply, and increased technological losses during the transmission and production of electricity [1].

The economic prerequisites for digitalizing traction power supply for rolling stock are primarily related to the need to optimize the operating costs of energy companies [2]. The introduction of digital technologies can significantly reduce the cost of maintenance and repair of equipment by switching to a predictive maintenance model based on big data analysis and asset condition forecasting [3]. According to experts, the potential for reducing operating costs through the implementation of digital solutions can reach 20-30% [4].

Another important economic factor is the need to improve the energy efficiency of rolling stock. Digital transformation is one of the main prerequisites for the formation of new business models and sources of income, which is especially important in the context of limited opportunities for increasing electricity tariffs. The introduction of intelligent metering and demand management systems allows for the implementation of flexible pricing and optimization of electricity consumption patterns [5].

Macroeconomic factors also play a significant role in shaping the prerequisites for the digitalization of the electric power industry. In the context of global

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competition and the need to ensure the technological sovereignty of countries, the rationalization of the electric power industry has become a critical element in ensuring the competitiveness of national economies, which justifies the relevance of this work [6]. Digital technologies can significantly improve the efficiency of energy use and reduce the carbon intensity of the economy [7].

The development of distributed generation and renewable energy sources creates additional prerequisites for the digitalization of the industry. The integration of many small generating facilities into a single power system requires the implementation of modern management and coordination systems that can ensure the reliable and efficient operation of a complex infrastructure [8]. Digital technologies are becoming an essential tool for managing decentralized energy systems.

Of particular importance are the technological prerequisites for digitalization, related to the development of information and communication technologies and the emergence of new opportunities for data collection, processing, and analysis. The development of the industrial Internet of Things, cloud computing, and artificial intelligence technologies creates a technological basis for building next-generation smart energy systems.

RESULTS AND DISCUSSION

At the current stage, the main factor is the growing availability of digital technologies and the need to reduce the cost of their implementation. The development of local software and hardware solutions creates opportunities for large-scale digital transformation of railway traction power supply using innovative developments, which is especially important in the context of the need to ensure the information security of critical railway infrastructure (Table 1).

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Table 1 Application of digital technologies in traction power supply

Financial and technical	High wear and tear and aging of fixed assets (up to 70%), the need to reduce energy costs
Innovative	Modernization of information technologies
Public	The need to improve qualifications and improve modern methods and means of communication
Natural and climatic	Reducing hydrocarbon emissions
Demand-side	Development of decentralized energy, business innovations
Management-side	Formation of state development concepts, state standards
Hardware-side	The need to rationalize networks, cognitive accounting
International-side	The need to ensure technical autonomy, domestic production

The economic efficiency of digital technologies is confirmed by the successful experience of their implementation in the traction power supply of railways in developed countries. An analysis of international experience shows that digitalization allows for significant energy savings, improved quality and quantity parameters of energy supply reliability and energy efficiency, and better utilization of generating capacities. However, it is important to consider the specific features of the electric power industry in developed countries and the need to apply the best global technologies to the conditions of a particular country, taking into account its natural and climatic conditions.

The formation of a regulatory framework for the digital transformation of traction power supply also creates the necessary prerequisites for the large-scale introduction of new digital technologies. The adoption of a number of legislative acts and program documents that define the strategic directions and mechanisms for digitalization in the industry creates an administrative environment that facilitates the implementation of digital projects.

The economic effects of digitalization of traction power supply are manifested not only at the level of individual companies, but also at the scale of the entire

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national economy. Improving the energy efficiency of traction power supply for railways creates a multiple effect that contributes to reducing the energy intensity of GDP and increasing the competitiveness of local manufacturing enterprises in international markets. According to experts, the potential economic effect of digital transformation of traction power supply for railways can reach up to 0.5% of the country's GDP.

A significant prerequisite for digitalization is the need to improve the quality of service for consumers of traction electricity. Modern digital technologies allow for a customer-oriented approach in the electricity industry, taking into account existing electricity consumption tariffs, providing consumers with new services and opportunities for managing their energy consumption. The development of intelligent metering systems creates the foundation for an active consumer who can optimize their energy consumption and participate in demand management programs.

Environmental aspects also form significant prerequisites for the digitalization of traction power supply. The need to reduce the negative impact on the environment and meet international commitments to reduce emissions of organic fuel waste gases requires the implementation of technologies that optimize the operating modes of generating equipment and reduce losses during electricity transmission. Digital technologies create a technological basis for implementing the concept of «green» energy.

An important factor that determines the need for digital transformation is the growing complexity of managing electric power systems. The increasing number of participants in the energy market, the development of distributed generation, and the complexity of traction power supply modes require the implementation of modern digital management tools. Traditional methods of dispatch management are no longer sufficient to ensure the reliable and efficient operation of the increasingly complex energy infrastructure. (Table 2).

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Table 2 Application of digital technologies in traction power supply

Application of digital technologies in traction power supply	
Financial and technical	Equipment failure
	Operating costs
	Attracting investment
Innovative	Neural network
	Internet
	Protection against hackers
Social	Preservation of ability
	Market demand
	Digital competence
Natural and climatic	Decarbonization
	Low cost
	Renewable energy
Demand-based	Decentralized energy
	Business innovation
	Market competition
Management	State Standards
	State Development Concepts
	Unification
	Normalization
Hardware components	Network rationalization
	Cognitive accounting
	Computerization of management
	Reliability of power supply
International	Technical autonomy
	Domestic production
	International cooperation
	Energy security

Demographic and social factors also contribute to the acceleration of the industry's digital transformation. The aging of the workforce at electric power companies and the need to preserve critical competencies create the preconditions for the implementation of digital knowledge management systems and the

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automation of production processes, as well as the reporting of technical and production activities. Digital technologies can partially compensate for the shortage of qualified personnel and ensure the transfer of experience to the next generation of specialists.

Geopolitical factors also have a significant impact on the formation of prerequisites for the digitalization of traction power supply. In the context of increased demand and the need to ensure the country's energy and technological sovereignty, the development of regional digital solutions for the consumption of electricity for railway rolling stock has become a strategic task. The creation of its own technological competencies in the field of digital energy is an important element of ensuring the national security of each country.

The development of regional energy ties and the need for energy system integration create additional prerequisites for the digitalization of the industry. The participation of developed countries in international energy projects requires ensuring technological compatibility and compliance with international standards for the digitalization of energy systems.

Investment aspects also play an important role in shaping the prerequisites for digital transformation. Despite the significant initial costs, the implementation of digital technologies allows energy companies to optimize their investment programs by more accurately planning and prioritizing infrastructure modernization projects. The use of digital twins and predictive analytics systems significantly enhances the efficiency of investment decisions [8].

The formation of digital ecosystems in various sectors of the economy creates additional incentives for the digitalization of traction power supply. The integration of energy infrastructure with digital platforms of smart cities, industrial enterprises, and transport systems requires the implementation of modern information and communication technologies in traction power supply [9].

CONCLUSION

From the above, it can be concluded that a combination of economic, technological, social, and environmental prerequisites creates an objective need for a large-scale digital transformation of the electric power industry, particularly

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the traction power supply of railways. The successful implementation of digitalization programs will not only improve the efficiency of the energy system, but also create a foundation for the innovative development of all regional economies.

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