



## ENHANCING EFFICIENCY, RELIABILITY, AND SUSTAINABILITY IN THE ENERGY SECTOR THROUGH THE APPLICATION OF DIGITAL TECHNOLOGIES

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**Abstract:** The article examines the implementation and development of digital technologies in the energy sector. It discusses the transition from traditional management systems to the concept of digital energy, the integration of big data, automated control algorithms, and cloud and fog computing to enhance the efficiency, reliability, and safety of energy infrastructure. Digital energy systems enable remote monitoring and control, advanced diagnostics and prognostics, as well as cybersecurity, allowing for rapid detection of emergencies and minimization of human errors. Special attention is given to the importance of national technologies and locally developed software and hardware solutions to ensure technological sovereignty and system resilience. The article highlights the role of digital solutions in improving the efficiency, safety, and environmental sustainability of energy system operations.

**Keywords:** Digital energy, energy sector, smart grids, remote monitoring, advanced diagnostics, predictive maintenance, cyber-physical systems, Internet of Things (IoT), fog computing, energy system efficiency, cybersecurity, integration of renewable energy sources, technological sovereignty.

### Introduction:

In the context of the rapid development of information and communication technologies, the energy sector is undergoing a stage of profound transformation associated with the transition from traditional management principles to the concept of digital energy. The growth in electricity generation and consumption, the increasing complexity of energy system structures, and the integration of renewable energy sources and distributed generation impose new requirements on the reliability, controllability, and efficiency of energy infrastructure. Under these conditions, the use of digital technologies becomes one of the key factors ensuring the sustainable development of the industry.

**Digital energy** involves the integration of automation systems, big data collection and processing tools, intelligent control algorithms, as well as cloud and fog computing into a unified information and control environment. The formation of a single information model of the energy system makes it possible to obtain reliable real-time data on the condition of equipment, network operating modes, and consumption parameters, thereby creating a basis for informed managerial decision-making, operating mode optimization, and reduction of operating costs.

An important area of development is the advancement of remote monitoring and control systems based on the use of cyber-physical systems and 3D models of energy facilities. Such solutions provide enhanced diagnostic capabilities, failure prediction, risk reduction of accidents, and an increase in the level of industrial and environmental safety. At the same time, the importance of cybersecurity issues is growing, since digitalization is accompanied by increased vulnerability of information infrastructure to both external and internal threats.

**The development of national digital technologies and software-hardware systems adapted to the conditions of a particular country and meeting the requirements of technological sovereignty is gaining special importance.** At the same time, the human factor remains at the center of attention—both as an operator of complex control systems and as the ultimate beneficiary of improved reliability of energy supply and enhanced quality of provided services.

In this regard, a relevant scientific and practical task is a comprehensive analysis of modern digital solutions in the energy sector, an assessment of their advantages, implementation features, and their impact on the safety, efficiency, and sustainability of energy system operation. This paper attempts to highlight the key directions in the development of digital energy, to examine the specifics of applying digital services based on big data, remote control systems, and advanced diagnostics, as well as to identify current challenges in the field of cybersecurity and the protection of human interests.

#### **Main part:**

**Digital energy systems and their advantages.** Digital services utilize large volumes of data, which makes it possible to optimize maintenance intervals, increase production efficiency, and detect faults in advance. Data obtained from energy facilities are integrated with additional sources—such as weather conditions, ambient temperature, air quality, accident reports, and others. This ensures more accurate system analysis [1].

For the correct understanding and effective use of big data, expert knowledge and analytical thinking are required. Millions of smart devices and sensors create a bridge between the physical and virtual worlds by generating enormous volumes of data. These data are processed using intelligent algorithms and analytical methods, which contributes to the optimal operation of energy systems [2].

As an example, one can consider the development of the American company **Eaton**—the “**Enotify Remote Monitoring**” service, which provides remote monitoring of uninterruptible power supplies (UPS) and battery systems. The software collects performance data from UPS units and transmits them to a centralized monitoring center. Based on the analysis, monthly reports are generated and submitted to management, enabling timely and well-informed decisions regarding maintenance activities [3].

A similar solution is offered by **Ingersoll-Rand PLC** through the “**Trane Intelligent Services**” system, which provides remote monitoring and analysis of HVAC systems (heating, ventilation, and air conditioning). This system reduces operating costs and accelerates the detection and elimination of faults [4].



Figure 1. Technological structure of digital energy

#### Advanced diagnostic and prognostic systems:

Advanced diagnostic services combine global engineering expertise, online data collection, data analysis, and the capability to predict failures. Using expert knowledge bases, the condition of the system is assessed and recommendations for improving production processes are developed.

For example, **Caterpillar**, in collaboration with the startup **Uptake**, has developed predictive diagnostics tools. This system analyzes data obtained from bulldozers and excavators, enabling the early detection of faults [4].

In addition, **Siemens' "Power Diagnostics"** service performs remote analysis of gas and steam turbines, generators, and boilers, thereby reducing the risk of failures and increasing equipment reliability.

Digital technologies make it possible to carry out remote control and monitoring of power plants located in remote areas. For example, in the event of transformer overload and overheating, sensors measure oil temperature and current, after which the results are transmitted to a cloud-based system. In this way, potential failures are prevented. Even if a sensor fails, the system is capable of detecting this condition [5].

Remote monitoring services extend the service life of equipment, increase its reliability, and ensure operational flexibility. In such systems, the concept of a **"digital pole"** (or **"digital pylon"**) can be applied. Sensors installed on these structures transmit data via fiber-optic cables or communication channels such as 5G, LTE, and GSM. The collected information is analyzed at the level of the national energy system and stored on cloud servers.

**Table 1. Components of a digital energy system, their functions, and applied technologies**

| No | Component Name                   | Function                                              | Applied Technologies                                       |
|----|----------------------------------|-------------------------------------------------------|------------------------------------------------------------|
| 1  | Smart Sensors                    | Measure current, voltage, temperature, and pressure   | IoT, Microelectronics                                      |
| 2  | Data Collection Module           | Collects and transmits signals from sensors           | GSM, LTE, 5G, SCADA systems                                |
| 3  | Cloud Computing System           | Stores and processes large volumes of data            | Cloud Computing, Big Data                                  |
| 4  | Analytical and Predictive System | Early fault detection and recommendation generation   | Artificial Intelligence, Machine Learning, Neural Networks |
| 5  | Control Center                   | Provides remote control and real-time monitoring      | SCADA, HMI interfaces                                      |
| 6  | Cybersecurity Module             | Ensures data protection and prevents external attacks | Encryption algorithms, National servers                    |
| 7  | Personnel Safety System          | Monitors employee location and alarm signals          | IoT sensors, GPS, Network monitoring                       |

**In such systems, cybersecurity issues are a key factor.** Servers processing data must be located within the country and operate under state control. Servers, sensors, and other equipment should be manufactured based on national microelectronics, and software must be developed by local specialists. Otherwise, the use of foreign components could compromise the security of the entire system [6].

A unified information model built on cloud servers provides centralized management of the energy system. Operators monitor network changes in real time and implement measures to ensure personnel safety. For example, sensors embedded in the protective clothing of technical staff determine their location and send a signal to the operator regarding a safe distance.

Digital energy systems enable rapid detection of emergencies, prompt development of response plans, and minimization of human error. Thanks to visual information, video surveillance, and real-time monitoring, the safety and efficiency of energy facilities are significantly enhanced.

**Advanced technologies such as the Internet of Things (IoT), blockchain, neural networks, automated reporting, predictive analytics, and self-diagnostics can be integrated into such systems.** This approach significantly enhances controllability, the level of automation, and the reliability of energy systems.

#### **Conclusion:**

The implementation of digital technologies in energy systems is a crucial factor for modern economic development and sustainable growth. These technologies make the processes of energy production, distribution, and consumption more efficient, safe, and cost-effective.

Digital management, advanced diagnostics, remote monitoring, and cloud computing elevate the energy sector to a new level of development. The advancement of national technologies and the assurance of cybersecurity, in turn, ensure the independence and resilience of the energy system.

Locally developed software solutions and electronic components enhance safety and strengthen international competitiveness.

Overall, digital energy is not merely a technological innovation but a promising direction that ensures energy efficiency and environmental sustainability.

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