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INNOVATIONS IN THE MODERNIZATION OF INDUSTRIAL ENERGY SYSTEMS TO INCREASE PRODUCTIVITY AND ENERGY EFFICIENCY

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ABSTRACT

Innovations in the modernization of industrial energy systems aim to increase enterprises' productivity and energy efficiency in the face of global economic pressure and stricter environmental standards. The study aims to study modern approaches to the modernization of energy systems using intelligent control systems and renewable energy sources. The methodology includes analysis and evaluation of the effectiveness of implementing digital platforms and automation of energy management processes in industrial enterprises. The results show that such innovations significantly increase energy efficiency, reduce the carbon footprint, and increase productivity. The findings confirm that the integration of modern technologies and the use of renewable energy sources allow enterprises to optimize the use of resources and increase their competitiveness in the market.

Keywords: Modernization, Energy Systems, Energy Efficiency, Renewable Sources, Intelligent Control Systems.

I. INTRODUCTION

The modernization of industrial energy systems under global economic pressure and tightening environmental standards is becoming increasingly important. Modern enterprises face challenges related to rising energy resource costs, an increasing carbon footprint, and the need to meet sustainability standards. As a result, there is a growing demand for innovative approaches that optimize energy resource usage and reduce production costs.

The relevance of this topic is driven by the need to enhance energy efficiency in enterprises due to the ongoing energy industry crisis and the adaptation of infrastructure to meet contemporary requirements. The implementation of intelligent management systems, digital technologies, and renewable energy sources has become a key element in maintaining competitiveness and enabling sustainable growth in the industry. These innovations allow not only for the optimization of production processes but also for significant reductions in operational costs, which is crucial for maintaining economic stability and efficiency.

This study aims to investigate modern approaches to the modernization of industrial energy systems aimed at increasing their productivity and energy efficiency.

II. MATERIALS AND METHODS

According to expert analysis, the annual amount of electricity consumed inefficiently in Ukraine requires industrial enterprises to use energy resources more rationally, as they are the primary consumers of these resources. Increasing energy efficiency becomes an essential factor for reducing production costs and boosting profits. One factor in the low efficiency of energy resource use is the entrenched notion that energy costs have minimal impact on product costs. Additionally, there is a common perception of the accessibility and relatively low cost of energy resources [1].

Enterprise managers often underestimate the potential savings from implementing energy management programs, associating such projects with financial and technical risks. As a result, these initiatives are deprioritized compared to traditional commercial projects. However, according to expert evaluations, energy efficiency programs are worthwhile even for enterprises where electricity accounts for only 5% of the product cost.

Currently, many enterprises in the country lack information about the structure of their energy consumption and are unable to identify which facilities consume the most electricity. This hinders the development of optimization strategies and engagement with energy suppliers. Although there are opportunities to purchase electricity at more favorable rates, some enterprises continue to pay retail prices due to an inability to normalize consumption.

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The systematic rise in energy costs and traditional resource-use approaches reduce product competitiveness. This leads to reduced production volumes and increased specific energy costs in product pricing. As a result, capacity utilization declines, and inefficient use of production resources intensifies [2].

A key element in implementing an energy-saving strategy at industrial facilities is the use of modern technologies to increase the efficiency of energy resource use. Developing and implementing programs aimed at optimizing energy consumption within industrial enterprises, using current equipment, and organizing production processes correctly, have become important directions.

The optimal way to implement these initiatives is through a program-targeted approach, enabling the identification of the most promising projects with high innovative potential in energy savings.

The analysis identified the primary goal of energy conservation in the industry as increasing enterprise profitability through the modernization of production cycles and improvement of product quality, achieved by reducing costs through energy optimization. Based on this goal, a comprehensive set of measures should be developed, targeting not only reduced energy use but also achieving other aspects, such as improving product quality [3].

To select the best projects, an algorithm for evaluating alternative options for energy saving must be developed. Various methodological approaches are used, such as calculating the energy intensity index of products, expressed by the following formula:

$$I_{eii} = \frac{E_{avg}}{E_{base}} \quad (1)$$

Where:

I_{eii} - product energy intensity index, ,

E_{avg} — average projected energy intensity,

E_{base} — base energy intensity.

The lower this indicator's value after implementing energy-saving measures, the higher the project's priority. However, this method does not always account for the project's impact on achieving the strategic goal of energy conservation, potentially leading to the selection of an economically unviable option.

Thus, it is necessary to develop criteria for ranking activities, which will consider their impact on the primary objective of the enterprise and optimize the sequence of energy-saving measures. Before developing energy-saving models, a list of measures should be defined that impact not only energy consumption but also product quality and production process improvement. In this context, technological energy conservation, which includes innovations and equipment upgrades, becomes particularly significant. Table 1 provides examples of measures for enterprises in the machine-building sector.

Table 1: Examples of measures for enterprises in the machine-building sector [3]

Measures	Description
Localization of thermal and chemical-thermal processes	Concentrating thermal operations in designated areas to improve control and reduce energy costs.
Use of pneumatic drives in equipment control	Utilizing pneumatic systems to enhance control accuracy and reduce energy consumption during equipment operation.
Optimization of technological operations	Improving production processes to increase efficiency, reduce time, and cut production costs.
Modification of the thermal treatment process for blanks	Altering heat treatment processes to improve product quality and reduce energy costs in metal processing.
Implementation of high-speed casting methods	Employing advanced casting methods to boost productivity and reduce production time for parts.

Installation of automated pump control systems	Implementing automated systems to improve control precision of pump equipment and save energy.
Use of soft-start devices for electric motors	Using devices that gradually increase motor speed, reducing network load and equipment wear.
Reduction of metal consumption in the casting process	Optimizing casting processes to reduce metal usage without compromising product quality.
Elimination of outdated equipment	Replacing or modernizing outdated equipment to improve production efficiency and reduce maintenance costs.

The economic effect of implementing a set of energy-saving measures is determined by the combination of the following factors:

1. Reduction in energy consumption (ΔI_en);
2. Increase in the modernization coefficient;
3. Decrease in product defect rate.

This effect can be expressed by the following equation:

$$E_{ee} = \Delta I_{en} + K_{mod} + \Delta D \quad (2)$$

Where:

E_{ee}— economic effect of energy saving,

ΔI_{en} — reduction in energy consumption,

K_{mod} — modernization coefficient,

ΔD — change in defect rate.

To assess the economic feasibility of measures, it is advisable to use approaches applied in investment analysis (e.g., NPV, IRR), taking into account the specifics of energy saving and focusing on the enterprise's main strategic goal. The most prioritized projects are those that provide maximum returns in terms of economic efficiency and energy-saving indicators [4].

Thus, energy-saving measures in industrial enterprises should not only reduce resource use but also contribute to improved production performance, ensuring enhanced product quality and competitiveness. Energy-efficient innovations significantly reduce energy consumption and decrease the environmental footprint. This area includes the creation and implementation of highly efficient household appliances, lighting systems, and "green" buildings designed to minimize energy costs and reduce overall resource consumption.

Nuclear energy continues to play an essential role in global energy supply. In this area, new types of reactors with increased safety and productivity are actively being developed, along with improved methods for processing and disposing of radioactive waste.

Microgeneration networks, or microgrids, also represent an innovation capable of transforming energy infrastructure. These autonomous systems can operate independently of central power grids, providing local energy supply through diverse sources, including renewables, and offering backup power in case of main grid failures.

Internet of Things (IoT) technologies are actively being integrated into energy systems to collect and analyze consumption data. They enable the monitoring and optimization of energy usage, helping companies and end-users improve cost control and reduce expenses [5].

Artificial intelligence (AI) and machine learning algorithms play a key role in increasing the efficiency of energy infrastructure. These technologies are used for consumption forecasting, optimizing generation and resource distribution processes, and identifying and eliminating system failures.

Current innovations in the energy sector open opportunities for radical improvements in efficiency, sustainability, and infrastructure reliability. Smart grids, renewable energy, AI, and IoT all contribute to transforming methods of resource production, distribution, and usage, promising significant advancements in energy systems in the future [6].

III. RESULTS AND DISCUSSION

The issue of upgrading energy networks is increasingly important, addressing key aspects of energy, ecology, and public interests. The modernization process includes updating the infrastructure that enables the transmission and distribution of electricity to improve its reliability, efficiency, and resilience [7]. These innovations are integral to sustainable development strategies and enhancing the competitiveness of enterprises under global economic pressure and tightening environmental requirements. Digital solutions, process automation, and the integration of intelligent energy management systems play a crucial role. Practical examples of leading companies that successfully implement such innovations are considered.

Siemens serves as a prominent example of an approach to modernizing industrial energy systems through digital technologies. As part of its strategy, Siemens offers comprehensive solutions, including the installation of digital platforms for monitoring and managing energy consumption in industrial enterprises. One such solution is the SIMATIC Energy Management system, which enables real-time tracking and analysis of energy consumption data. Consequently, enterprises can promptly adjust energy costs, optimize production processes, and reduce expenses.

The company's digital platform also integrates with cloud technologies, allowing centralized management and data analysis across multiple sites, particularly relevant for large corporations with extensive production networks. This approach significantly enhances the accuracy of energy demand forecasting and enables rapid adaptation to changing production conditions, reducing the carbon footprint and increasing productivity [8].

General Electric is actively introducing innovations in high-efficiency turbines and intelligent control systems. As part of modernizing energy systems at industrial sites, GE offers the installation of next-generation gas turbines, which are distinguished by improved fuel efficiency and reduced greenhouse gas emissions. These turbines utilize advanced technologies for more complete fuel combustion, enabling significant energy and environmental benefits.

Additionally, the company is actively developing software solutions that integrate with turbine systems and other energy installations at production sites. These intelligent systems allow real-time monitoring of equipment conditions, prediction of potential failures and energy leaks, and automation of maintenance processes. For example, the GE Digital Twin solution creates a digital replica of the energy system, allowing engineers to monitor its operation and adjust parameters to achieve maximum efficiency. As a result, operational costs are reduced, and equipment reliability is increased, contributing to higher productivity [9].

Schneider Electric is also a leader in the modernization of industrial energy systems, offering solutions to improve energy efficiency through the integration of intelligent monitoring and control systems. One of the company's key products is the EcoStruxure platform, which enables comprehensive management of production facilities. This platform is based on the use of numerous sensors installed on production lines and energy installations. These sensors collect real-time data and send it to an analytical system where the data is processed and used to optimize processes.

EcoStruxure allows for automatic energy consumption management, reducing excess energy costs and minimizing losses. Additionally, the platform provides predictive capabilities, enabling the early identification of potential issues and adjustment of system operations to changing conditions. Figure 1 below illustrates the engineering systems of the building.

Ultimately, these technologies contribute to significant reductions in operating costs and improvements in energy efficiency indicators at production facilities. Integrating such technologies not only reduces the carbon footprint and costs but also meets modern sustainability requirements. Table 2 below outlines the advantages and disadvantages of innovations in the modernization of industrial energy systems for enhancing productivity and energy efficiency.

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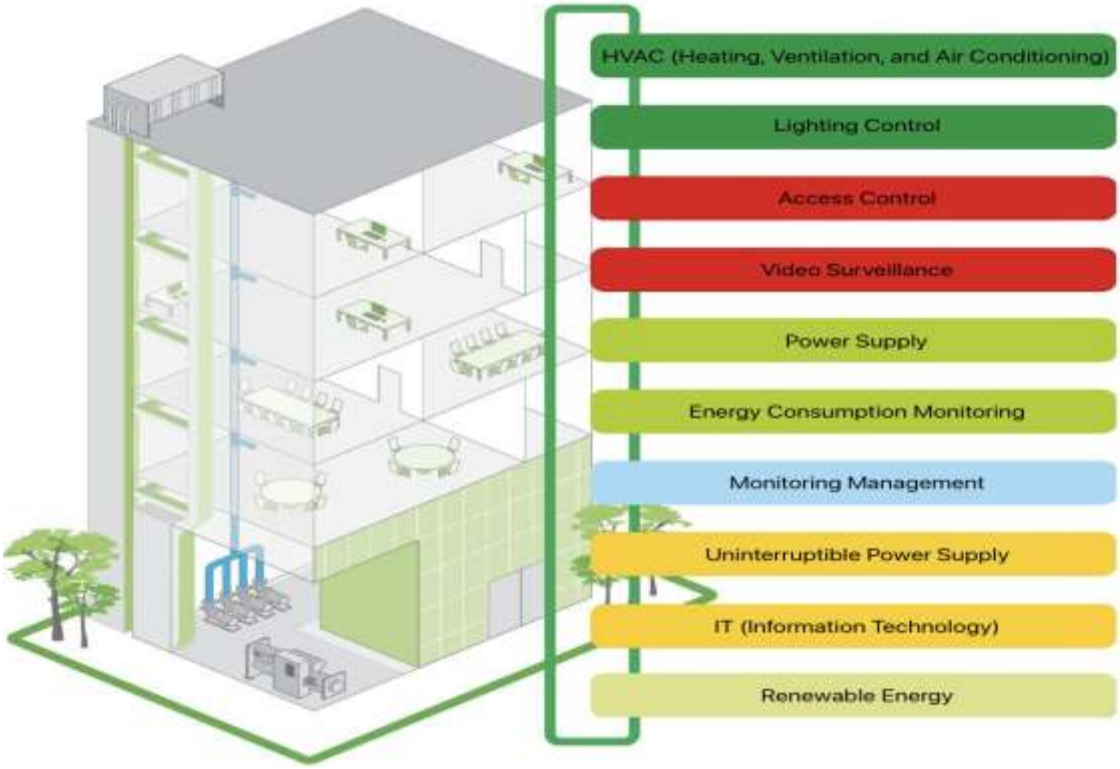

Fig 1: Building engineering systems [10]

Table 2: Advantages and disadvantages of innovations in the modernization of industrial energy systems in increasing productivity and energy efficiency [10]

Innovations in Modernization	Advantages	Disadvantages
Implementation of automated energy consumption control systems	- Reduction in energy losses due to more precise control.	- High initial installation costs.
	- Increased overall productivity of enterprises.	- Requirement for skilled maintenance and upgrades.
	- Reduced energy resource costs.	
Use of renewable energy sources	- Reduced dependence on traditional energy sources.	- High investment costs.
	- Reduction in greenhouse gas emissions.	- Dependence on weather conditions (for solar and wind sources).
	- Long-term savings.	
Use of energy-efficient electric motors	- Reduced electricity consumption.	- High cost of purchasing new electric motors.
	- Extended equipment lifespan.	- Need for replacement of old equipment.
	- Reduced maintenance costs.	
Implementation of smart grids	- Increased reliability of energy	- Complexity and high cost of

(Smart Grid)	supply.	implementation.
	- Optimization of energy distribution.	- Need for integration with existing energy systems.
	- Rapid response capability to changing energy demands.	
Use of energy recovery systems	- Reduction in energy losses through reuse of emitted energy.	- Need for infrastructure upgrades.
	- Improved overall production efficiency.	- Significant initial investments.
Use of energy-saving technologies (LED lighting, insulation)	- Reduced operating costs.	- Initial costs for acquisition and installation.
	- Extended lifespan of equipment and facilities.	- Need for planning and integration with existing systems.
	- Environmental benefits.	

As a result, the modernization of industrial energy systems becomes a key factor in achieving sustainable economic growth and competitiveness in the global market.

IV. CONCLUSION

The study established that the modernization of industrial energy systems through innovative technologies significantly enhances enterprise productivity and energy efficiency. The implementation of intelligent energy management systems, digital platforms, and renewable energy sources optimizes production processes, reduces operating costs, and decreases the carbon footprint. These measures not only support the achievement of environmental goals but also improve the competitiveness of enterprises amid global economic changes.

The analysis showed that enterprises utilizing modern technological solutions can adapt more quickly to changing conditions and manage their energy resources more effectively. This, in turn, leads to improved economic performance and sustainable development of the industrial sector. It is important to note that further development and implementation of such technologies require a comprehensive approach, including the development of modernization programs, staff training, and active collaboration with energy suppliers.

Thus, the study's objectives of assessing the effectiveness and importance of innovative approaches to energy system modernization were achieved, and the results confirm the relevance and promise of these measures for the industrial sector.

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