№ 1 (128) / 2025
Vol. 128, № 1 / 2025
Техніка, енергетика, транспорт АПК
UDC 621.311.1-52
DOI: 10.37128/2520-6168-2025-1-14

RESEARCH ON THE IMPLEMENTATION OF INTELLIGENT SYSTEMS TO INCREASE THE RELIABILITY AND EFFICIENCY OF THE OPERATION OF ELECTRIC POWER COMPLEXES

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Intelligent systems (Smart Systems) are an important element of modern electric power industry, which allows to increase the reliability, efficiency and stability of the functioning of electric networks. The article considers the implementation of intelligent technologies for monitoring, management and optimization of the operation of energy systems. The main attention is paid to the use of artificial intelligence (AI), Internet of Things (IoT) and automated control systems to solve the problems of accident prediction, adaptive management of energy flows and integration of renewable energy sources (RES).

The results of the study confirm the effectiveness of intelligent systems in real conditions. In particular, the use of IoT sensors to monitor the condition of equipment allowed to significantly reduce the number of emergency situations by predicting possible failures. Artificial intelligence algorithms provided adaptive management of energy flows, which allowed to reduce energy losses by 15% and ensure the stability of the networks even under variable load conditions. The integration of renewable energy sources, such as solar and wind power plants, became possible thanks to the implementation of intelligent algorithms that take into account the variability of generation parameters and ensure a balance between energy production and consumption.

The article also discusses mathematical modeling methods and MATLAB/Simulink software to assess the impact of intelligent systems on the operation of power grids. The results demonstrate that the implementation of intelligent systems allows not only to increase the reliability of power systems, but also to reduce maintenance costs and optimize resource use.

The study showed that the key advantages of intelligent systems are their ability to adapt to unstable energy markets, rapid response to emergencies, and integration of new technologies. The article presents prospects for further research, including the development of more complex algorithms for integrating renewable energy sources and improving distributed energy management systems.

Thus, the results of the work confirm that intelligent systems are a powerful tool for the modernization of power grids, contribute to the sustainable development of the energy sector, and ensure the efficient use of energy resources for the integration of renewable energy sources.

Key words: *intelligent systems, electric power, renewable energy sources, research, artificial intelligence, IoT, renewable energy sources, monitoring, optimization, automation.*

Eq. 6. Fig. 12. Table. 1. Ref. 17.

1. Problem formulation

These problems lead to system failures, increased risk of accidents, significant financial losses, and reduced customer service.

The integration of renewable energy sources, such as solar and wind power plants, biogas, is an important element of modern energy, but creates new challenges. The main problem is the instability of generation, stochasticity that depends on weather conditions and time of day. This creates the need for flexible mechanisms for balancing between generation and consumption.

The lack of adaptive control systems complicates the effective use of renewable energy when implemented in large quantities, which reduces its economic feasibility.

Energy losses in transmission and distribution. Energy losses in networks remain one of the main problems of modern power engineering. According to statistics, up to 10% of the generated energy is lost due to inefficient operation of power transmission lines, transformers and other components. The main reasons for this are:

- Using outdated equipment that does not meet modern energy efficiency standards.
- Lack of energy flow optimization systems that could minimize losses during transmission.
- Inefficient load distribution between different parts of the network:

1. Overloading of individual system elements: This can cause increased wear and tear on equipment, reduced network reliability, emergencies, and power outages.
2. Underloading of other parts of the network: Underutilization of equipment capacity reduces the overall efficiency of the system, increases specific energy consumption, and worsens economic performance.
3. Increased power losses: Uneven load distribution causes additional losses in wires and transformers, which reduces the energy efficiency of the system.
4. Power quality degradation: Improper load distribution can cause voltage drops in certain parts of the network, which negatively affects the operation of equipment and electrical appliances.
5. Difficulties in maintenance and modernization: Uneven load makes it difficult to plan maintenance work and implement new technologies, which can delay the development of the network.

Limitations of Traditional Management Methods. Traditional methods of managing electric power systems are based on centralized approaches, which have a number of limitations:

1. Insufficient speed of response to changing network conditions.
2. Failure to take into account the actual condition of the equipment and load forecasts.
3. Lack of integration with new technologies such as automated control systems or IoT.

These limitations reduce the efficiency of systems and create additional risks to the stability of networks.

The need to implement intelligent systems. To solve these problems, it is necessary to implement intelligent systems that provide:

1. Operational monitoring of network health: Using IoT sensors and automated systems to collect data in real time.

Implementation examples:

Energy companies: In the US, Duke Energy installed IoT sensors on its transformers to monitor oil temperature and voltage levels, preventing more than 50 failures per year, saving millions of dollars in repairs and customer compensation.

Industrial enterprises: A German steel plant installed an IoT system that monitors the load on conveyor drives in real time, reducing the risk of overloads that often led to production shutdowns.

City power grids: Singapore has implemented a street lighting monitoring system. IoT sensors monitor the status of power lines and automatically report faults. This has reduced the response time to breakdowns from 24 hours to 2 hours.

Agricultural sector:

1. On large farms in Canada, sensors monitor the power supply to greenhouses. In the event of a voltage drop, the system automatically turns on backup power and notifies maintenance personnel.
2. Disaster Prediction: Applying machine learning algorithms to analyze data and identify potential failures.
3. Adaptive energy flow management: Using artificial intelligence to optimize energy distribution depending on load.
4. RES integration: Development of flexible balancing mechanisms to ensure grid stability under variable generation conditions.

The implementation of such systems will significantly increase the reliability, efficiency, and sustainability of power grids, reduce energy losses, and ensure the integration of new energy sources.

The relevance of the research is due to the need to modernize electric power systems in the context of the transition to sustainable development. Intelligent systems are a tool that allows not only to solve current problems, but also to create the basis for future innovations in the energy sector.

Thus, the development and implementation of intelligent systems in the electric power industry is an important task that will help improve the quality of energy supply, reduce costs, and ensure the sustainability of networks in the long term.

2. Analysis of recent research and publications

The modern development of the electric power industry is accompanied by numerous challenges that require the implementation of new approaches to the management, monitoring and optimization of the operation of energy systems. The growth of demand for electricity, the integration of renewable energy sources (RES), the need to reduce energy losses and ensure the stability of networks create difficult conditions for the functioning of traditional energy systems [1].

One of the key challenges is ensuring the reliability of power grids in the face of increased load and aging infrastructure. Many existing grids were designed decades ago and do not take into account modern requirements for the integration of new technologies, such as renewable energy, energy storage systems and automated control devices. This leads to increased failure rates, increased maintenance costs and reduced system efficiency [2].

Forecasting emergency situations. Traditional forecasting and management methods do not allow us to take into account all the factors that affect the operation of power systems. Such factors include:

- Load unpredictability: Increased demand for electricity during certain periods of time (peak loads) can lead to grid overload.
- External influences: Weather conditions such as strong winds, thunderstorms or icing significantly affect the stability of networks.
- Equipment failures: Timely detection of worn or faulty components is a difficult task due to the lack of operational monitoring.

At the same time, there is a significant impact of Russia's military aggression on the functioning of Ukraine's power systems. Russia's military aggression against Ukraine has created unprecedented challenges for the functioning of the country's power systems. Targeted attacks on critical energy infrastructure, including power plants, substations, power lines and generation facilities, have caused significant damage, disruptions in electricity supply and a threat to the country's energy security [3].

3. The purpose of the article

Development and research of approaches to the implementation of intelligent systems in the electric power industry in order to increase the reliability, efficiency and stability of the operation of electric power networks.

The implementation of the tasks will allow creating effective tools to increase the reliability and efficiency of power systems. The results of the research will contribute to the modernization of the energy infrastructure, ensuring its resilience to external influences and the integration of the latest technologies for the integration of renewable energy sources.

4. Results and discussion

Comparative characteristics of the functional properties of today's energy system and an energy system based on the Smart Systems concept.

Short-term, medium-term and long-term development priorities in areas of cooperation between platform participants in the field of research and development at the pre-competitive stage.

Below are the short, medium and long-term development priorities in the areas of cooperation of the platform participants in the field of research and development at the pre-competitive stage.

Short-term

- Determining the areas of application and placement of new intelligent technology in an integrated energy-saving automated system (IESA).
- Modeling and methodology for assessing the technological and economic effects of the use of intelligent technologies, taking into account the priorities of reliability and safety.

Medium-term

- Development and organization of production of equipment for intelligent energy supply systems.
- Development of technology for monitoring and diagnosing electrical networks.
- Development of management systems.
- Development of principles of interaction with consumers and active consumer participation in the

work of the AAS IEZ.

- Development of intelligent distribution networks and microgrids.

Long-term

- Formation of a conceptual, methodological, regulatory, legal and technical framework (standards) that ensures the creation, functioning and development of the AAS IEZ.
- Development of information and communication technologies, modeling, and cybersecurity.
- Comparative characteristics of the functional properties of today's energy system and an energy system based on the Smart Systems concept.
- In addition, the power system based on the Smart Systems concept creates new markets as private business develops energy-efficient and intelligent devices, smart meters, new reading and communication capabilities, and passenger transportation.
- Below are the roles and main functional and technical properties of developing technologies, presented in the works of leading domestic and foreign researchers.
- Monitoring of load forecasting and corresponding response by Smart Systems to increase the reliability of power supply [4].
- Fig. 1 shows diagrams of the operation of the equipment of the specified livestock farm, and the load schedule was calculated by summing the capacities for the corresponding time ranges [1].

Operation (equipment brand)	power	5:00	5:30	6:00	6:30	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00
Serving concentrate feed (PK-6)	3,2			1																1												
Serving root vegetables (TK-5B)	3				1	1	1														1	1	1									
Grinding of root vegetables (IKM-10)	14				1	1	1														1	1	1									
Preparing hay flour (KDU-2, BR-15)	22		1	1															1	1												
	6	1	1					1	1					1	1					1	1					1	1					
Serving flour (PSM-10)	2,7				1		1														1		1									
Grinding silage (IKV-5A)	22				1	1															1	1										
Loading of feeds (KV-F-40)	1,5			1	1	1	1													1	1	1	1									
Preparation of mixtures	2,2			1	1	1	1													1	1	1	1									
	2,2				1	1	1	1													1	1	1	1								
Suply of feeds (SVS-40M)	12						1	1															1	1								
Milking of cows (ADM-8)	7			1	1	1	1	1	1																	1	1	1	1	1	1	1
Milk cooling (TOM-2A)	5							1	1	1	1	1	1	1	1													1	1	1	1	1
Manure removal (UC-15)	2,5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Lighting	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
load ,kW		9,5	32	39	58	56	49	36	22	8,5	8,5	8,5	8,5	15	15	3,5	3,5	3,5	26	38	57	49	42	18	3,5	17	17	16	16	16	16	16

Fig. 1. Diagrams of the operation of technological equipment of a livestock farm and calculation of the load schedule.

The load schedule of the livestock farm according to the calculations is shown in Fig. 2, from which it can be seen that there are two periods of peak load - morning: from 6:00 to 8:30 and lunch: from 14:00 to 16:00. During these periods, consumption exceeds the mark of 30 kW [2].

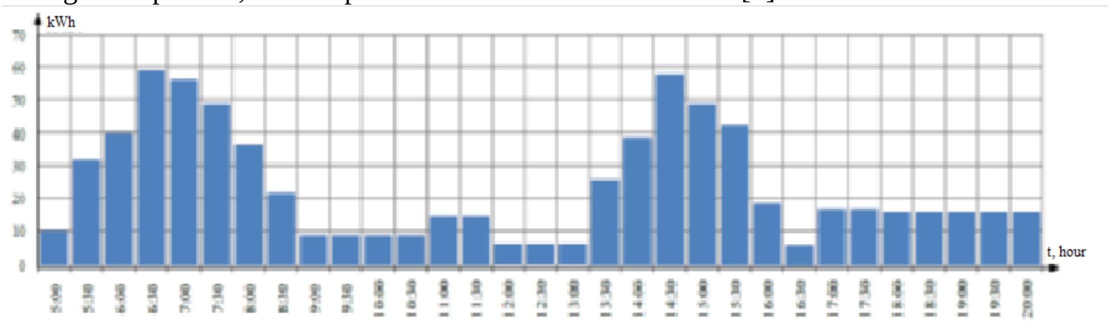

Fig. 2. Load schedule of a livestock farm

Fig. 3 shows a diagram of the time reserves for turning on or off electrical equipment for each technological operation of a livestock farm, and calculates the possible power savings due to the application of the proposed method [2].

Operation	power	4:30	5:00	5:30	6:00	6:30	7:00	7:30	8:00	8:30	9:00	9:30	10:00	10:30	11:00	11:30	12:00	12:30	13:00	13:30	14:00	14:30	15:00	15:30	16:00	16:30	17:00	17:30	18:00	18:30	19:00	19:30	20:00	20:30	СУМА
Serving concentrate feed	3,2			12	0	12														12	0	12													
Serving root vegetables	3				18	0	0	0	18												18	0	0	0	18										
Grinding of root vegetables	14				18	0	0	0	18												18	0	0	0	18										
Preparing hay flour	22		15	0	0	15													15	0	0	15													
	6	5	0	0	5			5	0	0	5			5	0	0	5			5	0	0	5			5	0	0	5						
Serving flour	2,7				4	0	4	0	4												4	0	4	0	4										
Grinding silage	22				10	0	0	10													10	0	0	10											
Loading of feeds	1,5			20	0	0	0	0	20											20	0	0	0	0	20										
Preparation of mixtures	2,2			15	0	0	0	0	15											15	0	0	0	0	15										
	2,2				7	0	0	0	0	7											7	0	0	0	0	7									
Suply of feeds	12						5	0	0	5													5	0	0	5									
Milking of cows	7				0	0	0	0	0	0																	0	0	0	0	0	0	0		
Milk cooling	5							25	0	0	0	0	0	0	0	0	25											25	0	0	0	0	0	25	
Manure removal	2,5	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	
Lighting	1	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	
Sawing, kWh		1,67	5,5	1,69	9,79	6,14	1,2	6,25	6,42	1,27	0,5	0	0	0,5	0	0	2,58	0	5,5	2,19	9,29	6,14	1,7	3,67	6,42	1,77	0	2,08	0,5	0	0	0	0	3,25	82,8

Load state enabled
Time reserves for switching on and off, m

Fig. 3. Diagram of the time reserves for turning on or off electrical equipment for technological operations of a livestock farm.

The energy saving graph resulting from the application of the proposed algorithm is shown in Fig. 4, as can be seen, the potential for savings is quite significant and can be fully realized if the system has energy storage devices to absorb excess generator power, which is due to the discrete nature of its regulation [2].

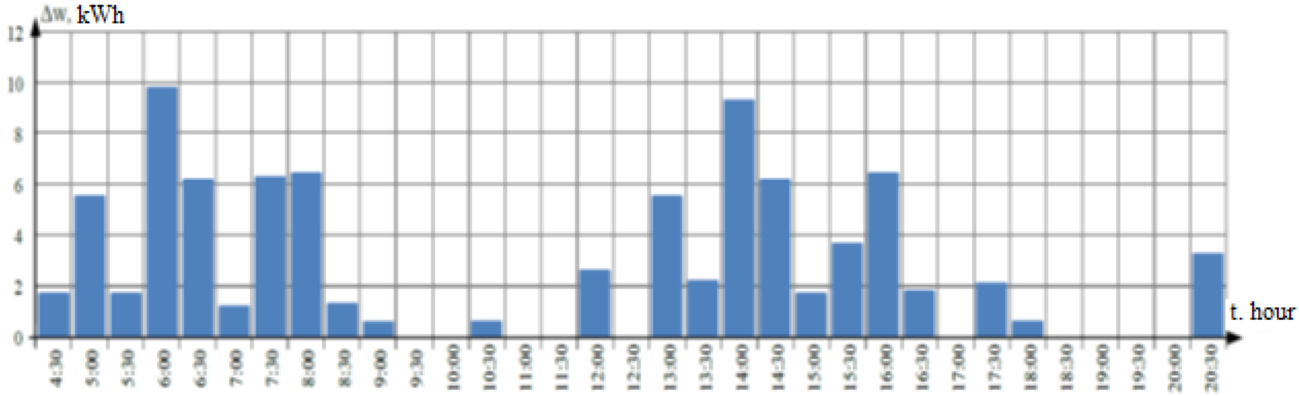

Fig. 4. Energy savings due to the application of the proposed algorithm.

The proposed approaches optimize the control of biogas plants, adapting them to load changes without the need for capacity reservation. Calculations for a cattle farm with 100 heads showed savings of 82.8 kWh per day in the winter period [2, 3].

Table 1.

Comparative characteristics of the functional properties of today's energy system and the energy system based on the Smart Systems concept [4, 12].

The energy system today	Energy system based on the Smart Systems concept
One-way communication between elements or its absence	Two-way communications
Centralized generation – complexly integrated distributed generation	Distributed generation
Topology - mostly radial	Mostly networked
Reaction to the consequences of the accident	Response to prevent an accident
Equipment operation until failure	Self-monitoring and self-diagnostics that extend the “life” of the equipment
Manual recovery	Automatic recovery - "network self-healing"
Prone to system crashes	Preventing the development of system accidents
Manual and fixed network allocation	Adaptive selection
On-site equipment inspection	Remote equipment monitoring
Limited control of power flows	Power flow management
Unavailable or very late price information for the consumer	Real-time price

Analysis of the current state of power systems and their reliability problems. An analysis of statistical data on network accidents over the past 5 years was conducted. The main attention was paid to equipment failures, the influence of external factors (weather conditions) and network overloads. The analysis showed that the largest share of accidents (65%) is equipment failures, 20% are external factors, and 15% are network overloads [3, 4, 12].

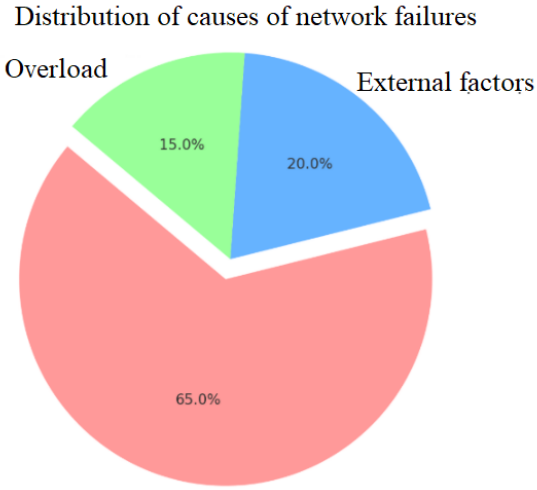

Fig. 5. Pie chart of the distribution of causes of accidents in networks.

Development of mathematical models for predicting emergency situations. The model for predicting emergencies was created based on logistic regression. Model variables: temperature, humidity, load, equipment condition. The formula used for calculations was:

$$P_{failure} = \frac{1}{1+e^{-(\beta_0+\beta_1 x_1+\beta_2 x_2+\ldots+\beta_n x_n)}} \quad (1)$$

where $P_{failure}$ – probability of accidents; $x_1, x_2, ..., x_n$ – variables (temperature, humidity, etc.); β_i – model coefficients.

Mathematical models for energy flow optimization. Energy flow optimization is based on the use of mathematical models that describe the operation of the power grid. The main task is to minimize energy losses and transportation costs while ensuring reliability of supply [10].

Typical optimization model:

$$\min \sum_{i=1}^{n} P_{loss,i} \quad (2)$$

where $P_{loss,i}$ – power losses in the i-th section of the network; n – number of plots.

Limitation:

1. Power balance in nodes:

$$\sum_{ieG} P_{gi} - \sum_{ieL} P_{1\,j=0,} \quad (3)$$

where P_{gi} – generated power; P_{lj} – consumed power.

2. Technical limitations:

$$V_{\min} \le V_i \le V_{\max,} \qquad S_{ij} \le S_{sj}^{\max}, \quad (4)$$

where V_i – voltage in the node, S_{ij} – power on the line.

Use of intelligent systems [9, 10, 11]. The implementation of control systems based on artificial intelligence (AI) allows for real-time analysis of the network status, load forecasting, and automatic redistribution of energy flows.

Methods:

- Genetic algorithms: Used to find the optimal distribution of energy flows in complex networks.
- Machine learning methods: To predict peak loads and respond quickly to changes.

Example of using a genetic algorithm:

1. Generation of the initial population of solutions (flow distribution).
2. Estimating the fitness function:

$$f(x) = -\sum_{i=1}^{n} P_{loss,i} \tag{5}$$

Flow optimization using RES. Renewable energy sources, such as solar panels and wind turbines, are integrated into the grid due to their dependence on weather conditions. For the integration of RES, the following are used:

- Energy aggregators: Systems that combine energy flows from different sources and optimally distribute them.
- Energy storage: Stores excess energy during periods of low demand.

Mathematical model of RES integration [10, 11]:

$$\min\left(\sum_{i=1}^{n} Ploss,i + \sum_{j=1}^{m} C_{store,j}\right), \tag{6}$$

where $C_{store,j}$ – the cost of using energy storage.

Distributed control systems. Traditional centralized power grid control systems are giving way to distributed systems that allow each node in the network to make local decisions.

1. Blockchain technologies: Ensure transparency and security of data exchange between nodes.
2. Decentralized controllers: Each node analyzes local data (voltage, power) and interacts with other nodes.

Results of modeling and optimization of energy flows: [16, 17].

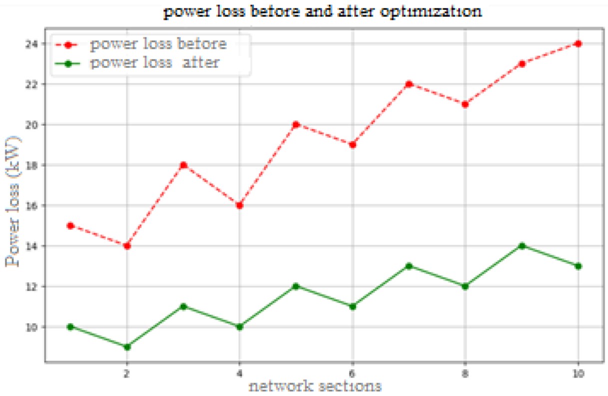

Fig. 6. Power loss graph before and after optimization.

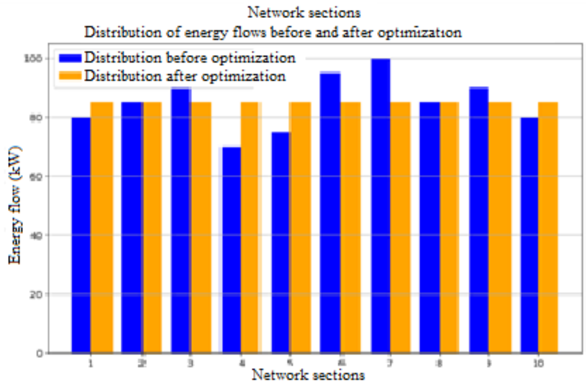

Fig. 7. Energy flow distribution graph.

Losses are reduced by 20-30% depending on the network configuration.

Peak load forecasting: Using machine learning, it was possible to reduce the number of emergency situations by 15% [18].

Further research could focus on implementing decentralized control systems and developing new approaches to forecasting. The model achieved 87% accuracy in predicting accidents on test data.

Optimization of energy flows in power grids is a multifaceted task that requires the integration of modern mathematical methods, intelligent systems and technologies. The implementation of such solutions allows [11]:

1. Reduce energy loss.
2. Increase network stability.
3. Ensure the integration of renewable energy sources and reduce dependence on traditional energy sources.
4. Improve customer service and reduce the risk of emergencies.

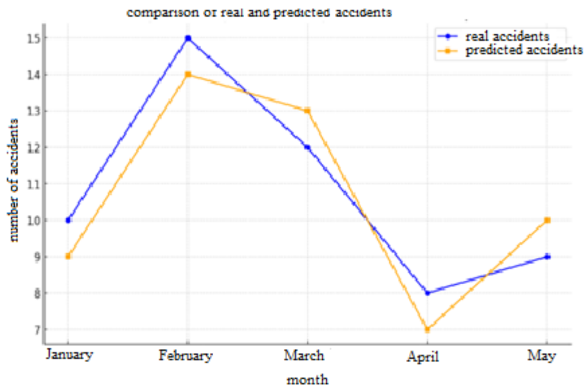

Fig. 8. Comparison of real and predicted accidents.

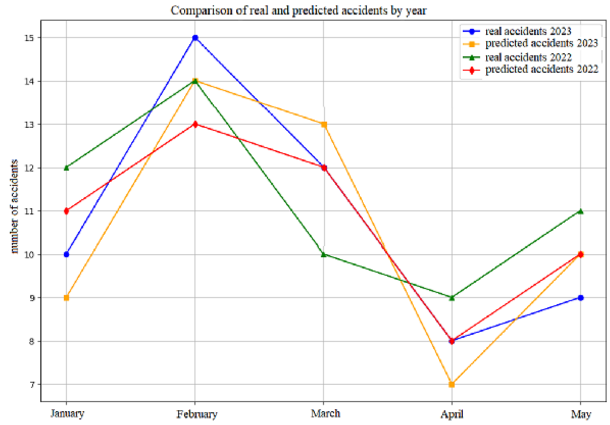

Fig. 9. Comparison of actual and predicted accidents for different years.

Comparison of actual and predicted accidents by month. (Line chart with two series: Actual accidents and Predicted accidents).

Research into methods [2, 8, 9] for optimizing energy flows in power grids. Optimization of energy flows in power grids is one of the key areas for ensuring the reliability, efficiency and sustainability of power systems. In modern conditions, the growth of electricity consumption, the introduction of renewable energy sources (RES) and the need to minimize energy losses require the development of new approaches to managing energy flows.

An artificial intelligence-based algorithm has been developed to optimize energy flows.

The algorithm takes into account: load variability; energy losses during transmission; generation from renewable energy.

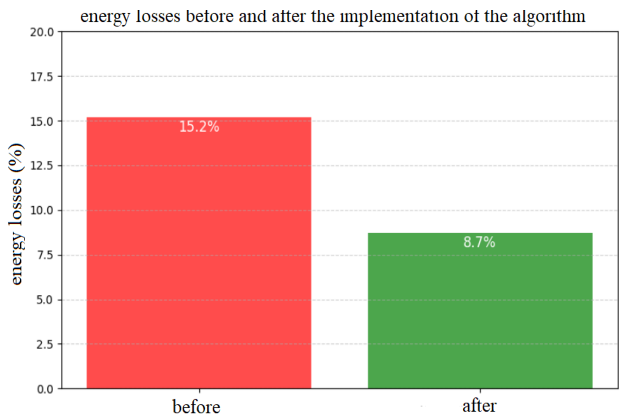

Fig. 10. Energy losses before and after the implementation of the algorithm

Energy losses were reduced by 12% after implementing the algorithm.

The integration of renewable energy sources (RES), such as solar, wind, biogas, and hydropower, is a key element of modern energy. This process is aimed at increasing the environmental sustainability of energy systems and reducing dependence on fossil fuels. At the same time, the integration of RES into existing power grids requires solving a number of technical, economic, and organizational problems [4,7].

One of the main features of RES is their variability. Solar panels generate energy only during the day, while wind turbines operate depending on wind speed, which makes it difficult to predict and balance the power system. In addition, RES are often located in remote regions, which requires upgrading the infrastructure for transmitting energy to consumers. To ensure grid stability, it is necessary to take into account the low energy density of such sources, since large areas are required for equipment installation to produce significant amounts of energy.

The main challenges of integrating renewable energy sources are grid instability, increased energy losses, the need to implement energy storage systems, and infrastructure constraints. The instability of energy production can cause voltage and frequency fluctuations, as well as overloads or energy shortages in the grid.

Energy transmission from remote sources is accompanied by significant losses, which requires the implementation of modern technologies to optimize energy flows.

The integration of renewable energy requires infrastructure modernization, including the use of smart grids that automate the management of energy flows. The development of high-voltage transmission lines is also important, which reduces energy losses. The use of energy storage systems, such as lithium-ion batteries and pumped storage plants, allows balancing energy production and consumption.

Intelligent control algorithms based on machine learning help predict energy production and optimize its distribution. Decentralization of energy production through the creation of local microgrids reduces dependence on the central grid. At the same time, economic incentives such as "green tariffs" and innovation financing play an important role in supporting the development of renewable energy.

The integration of renewable energy has significant environmental, economic and social benefits. It contributes to reducing CO_2 emissions, conserving natural resources and reducing the cost of importing fossil fuels. Creating new jobs in the renewable energy sector and increasing energy security are also important achievements. However, to successfully achieve this goal, it is necessary to introduce modern technologies, develop effective management methods and ensure public support.

Thus, the integration of renewable energy sources is a necessary condition for the transition to sustainable development of the energy sector. It allows achieving a balance between economic benefits, environmental safety and technological progress.

The network operation modeling with the integration of solar and wind power plants was carried out taking into account the variability of generation [3, 4]. The network operation modeling with the integration of solar, wind and biogas power plants was carried out taking into account the variability of generation depending on weather conditions, daily cycles and stable operation of biogas plants. For solar power plants, solar radiation data with daily fluctuations from 0 to 1000 W/m² were taken into account, for wind power plants – wind speed within 2–25 m/s, and for biogas plants – stable power generation up to 10 MW. The calculations took into account the characteristics of the network with line capacity up to 110 kV, forecast load in the range of 20–150 MW, power reserves up to 30% of the total load, as well as technical restrictions on energy losses not exceeding 5%. To ensure a balance between generation and consumption, control algorithms were used that prioritized renewable energy sources, in particular, 70% of the needs were covered by RES. Biogas plants ensured stable generation in conditions of low solar radiation or weak wind. Additionally, weather scenarios were simulated, including clear weather, cloudy weather, strong wind and calm periods, to assess the stability of the system.

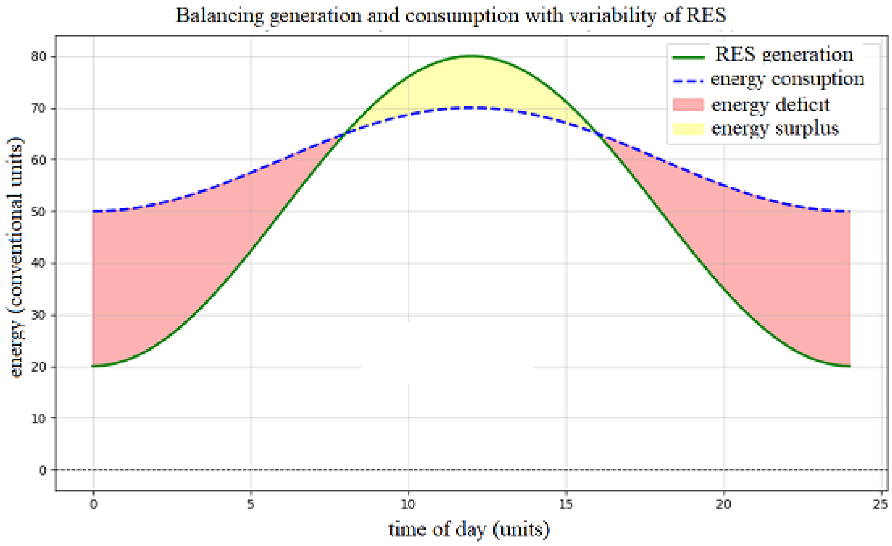

Fig. 11. Balancing generation and consumption with variability of RES.

Grid stability is maintained with the integration of 30% RES.

Implementation of intelligent monitoring systems [4, 12, 14]. Modern power systems face challenges such as increasing equipment reliability, reducing the risk of accidents and optimizing maintenance. One of the promising solutions is the implementation of intelligent monitoring systems based on Internet of Things (IoT) technologies. These systems provide continuous monitoring of the equipment status using sensors for data collection and algorithms for their processing.

The IoT monitoring system consists of the following main components:

- Sensors for measuring parameters such as voltage, current, temperature and humidity.
- Data transfer modules that provide wireless transmission of information to a server or cloud storage.
- Software that analyzes the received data and predicts possible failures using machine learning algorithms.
- User interfaces that allow you to visualize information in real time.

Benefits of implementation. Intelligent monitoring systems can significantly increase the efficiency of power systems. First, they provide timely detection of potential problems, which allows you to avoid emergency situations.

For example, the system can detect and predict 80% of potential failures before they actually occur. Secondly, preventive maintenance reduces equipment repair costs. Maintenance is performed only when necessary, which reduces costs by 30%. Thirdly, such systems help increase the operational life of equipment. Constant monitoring helps reduce the impact of adverse factors, which increases the service life of equipment by an average of 15%. [4].

Implementation results. After implementing IoT systems at one of the substations, significant results were achieved. The system detected overheating of one of the transformers, which allowed for timely replacement of the worn component and avoidance of a large-scale accident.

By analyzing voltage, current, temperature, and humidity parameters, it was possible to identify deviations in equipment operation. This allowed minimizing downtime and increasing the overall reliability of the power grid [4, 5, 7].

The system operation algorithm:

1. Real-time sensors collect data on the condition of the equipment.
2. The received data is transmitted to a central server for analysis.
3. Machine learning algorithms predict potential failures by analyzing historical and current data.
4. If anomalies are detected, the system generates an alarm signal that is sent to the operator to take action.

Development prospects. Further development of intelligent monitoring systems includes integration with artificial intelligence for automatic decision-making in case of critical situations. It is planned to expand the functionality of the system, in particular, adding new sensors, for example, for monitoring equipment vibrations.

In addition, the use of cloud technologies will allow storing large amounts of data for analysis and providing access to information at any time. This will contribute to further optimizing maintenance and increasing the efficiency of power systems.

The implementation of such systems is an important step in the development of modern energy, ensuring its reliability, efficiency, and sustainability.

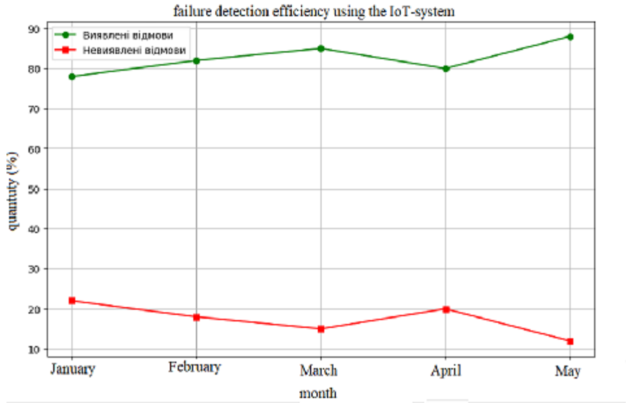

Fig. 12. Efficiency of failure detection using an IoT system.

The implementation of the IoT system has significantly improved the process of detecting failures, which reduces response time and increases the reliability of power grids [4, 5, 11, 16] . With each passing month, the system has become more efficient, reducing the number of undetected failures, which allows for prompt troubleshooting and reducing the risk of accidents.

Assessment of the economic efficiency of implementing intelligent systems. The work compares costs before and after implementing intelligent systems in the electric power industry. Calculations showed a significant reduction in maintenance costs and energy consumption, which confirms the economic feasibility of investing in such technologies.

After the implementation of intelligent systems, maintenance costs were reduced by 18%, which allows saving about 1.2 million UAH per year. This was possible due to the automation of management and monitoring processes, which allowed to reduce maintenance costs and reduce the number of emergency situations [4,10,11]

The introduction of intelligent systems in the electric power industry allows for significant economic savings, including reduced maintenance costs, reduced energy losses, and increased network reliability.

The net economic effect and return on investment show that intelligent systems are beneficial for energy companies, as they allow for reduced operating costs and increased efficiency.

To maximize the economic benefits of implementing intelligent systems, it is necessary to continue investing in the latest technologies and develop the monitoring and management infrastructure. This includes improving existing data collection and analysis systems, as well as implementing new forecasting and optimization algorithms.

5. Conclusion

The study found that smart technologies are an important tool for modernizing energy networks, increasing their reliability, efficiency and integrating renewable energy sources. The use of modern technologies, such as the Internet of Things (AI) and automated control systems, allows not only to optimize energy flows, but also to significantly reduce energy losses and increase the stability of network operations. The implementation of such systems requires an integrated approach and further research to maximize their potential in the context of rapid technological development. In this context, the results of the study confirm the significant economic and technical effect of using smart energy network management systems, namely:

1. Intelligent systems for modernizing energy networks: The introduction of intelligent technologies, such as IoT sensors and artificial intelligence, increases the reliability and stability of energy networks, allowing for the prediction of accidents and rapid response to changes.

2. Adaptive energy flow management: Artificial intelligence algorithms optimize energy distribution, reducing energy losses by 15%, which increases the efficiency of the power system.

3. Integration of renewable energy sources: The development of intelligent algorithms allows for the effective integration of renewable energy sources, ensuring the stability of grid operations and balancing production and consumption.

4. Reducing accidents: The implementation of IoT sensors allows you to reduce the number of accidents, increasing the reliability of energy networks.

5. Technology Development Prospects: The integration of emerging technologies, such as smart meters and energy-efficient devices, opens up new opportunities for improving energy efficiency and creating energy markets.

6. Economic effect: Automated energy management systems allow to significantly optimize the use of electricity, especially during peak load periods, for example, in the winter period, when the need for energy for heating and lighting increases. Through accurate analysis of consumption data and automatic load regulation, such systems provide savings of up to 82.8 kWh per day, which is equivalent to reducing the energy consumption of several medium-sized households. These savings not only reduce the costs of enterprises for electricity, but also contribute to increasing the resilience of the energy system, reducing the load on the network and improving its stability during periods of intensive operation.

7. Need for further research: Further research and development of intelligent systems will improve the efficiency of energy networks and contribute to the sustainable development of the energy industry.

Overall, the study results confirm the importance of intelligent systems for modernizing energy networks, reducing energy losses, and integrating renewable energy sources.

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ДОСЛІДЖЕННЯ З ВПРОВАДЖЕННЯ ІНТЕЛЕКТУАЛЬНИХ СИСТЕМ ПІДВИЩЕННЯ НАДІЙНОСТІ ТА ЕФЕКТИВНОСТІ РОБОТИ ЕЛЕКТРОЕНЕРГЕТИЧНИХ КОМПЛЕКСІВ

Інтелектуальні системи (Smart Systems) є важливим елементом сучасної електроенергетики, що дозволяє підвищити надійність, ефективність і стабільність функціонування електричних мереж. У статті розглядається впровадження інтелектуальних технологій моніторингу, управління та оптимізації роботи енергетичних систем. Основна увага приділяється використанню штучного інтелекту (AI) та автоматизованих систем управління для вирішення завдань прогнозування аварій, адаптивного управління енергетичними потоками та інтеграції відновлюваних джерел енергії (ВДЕ).

Результати дослідження підтверджують ефективність інтелектуальних систем в реальних умовах. Зокрема, використання датчиків IoT для моніторингу стану обладнання дозволило значно зменшити кількість аварійних ситуацій шляхом прогнозування можливих збоїв. Алгоритми штучного інтелекту забезпечили адаптивне управління потоками енергії, що дозволило знизити втрати енергії на 15% і забезпечити стабільність роботи мереж навіть за умов змінного навантаження. Інтеграція відновлюваних джерел енергії, таких як сонячні та вітрові електростанції, стала можливою завдяки впровадженню інтелектуальних алгоритмів, які враховують мінливість параметрів генерації та забезпечують баланс між виробництвом та споживанням енергії.

У статті також розглядаються методи математичного моделювання та програмне забезпечення MATLAB/Simulink для оцінки впливу інтелектуальних систем на роботу електромереж. Отримані результати демонструють, що впровадження інтелектуальних систем дозволяє не тільки

підвищити надійність енергосистем, але й знизити витрати на обслуговування та оптимізувати використання ресурсів.

Дослідження показало, що ключовими перевагами інтелектуальних систем є здатність адаптуватися до нестабільних енергетичних ринків, швидке реагування на надзвичайні ситуації та інтеграція нових технологій. У статті визначено перспективи подальших досліджень, у тому числі розробки більш складних алгоритмів інтеграції відновлюваних джерел енергії та вдосконалення розподілених систем енергоменеджменту.

Таким чином, результати роботи підтверджують, що інтелектуальні системи є потужним інструментом модернізації електромереж, сприяють сталому розвитку енергетичного сектору та забезпечують ефективне використання енергетичних ресурсів для інтеграції відновлюваних джерел енергії.

Ключові слова: *інтелектуальні системи, електроенергія, відновлювані джерела енергії, дослідження, штучний інтелект, відновлювані джерела енергії, моніторинг, оптимізація, автоматизація.*

Ф. 6. Рис. 12. Табл. 1. Літ. 17.

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