Machinery & Energetics
Vol. 16, No. 2. 2025

Journal homepage:
https://technicalscience.com.ua/en

UDC 621.311.1:681.586
Doi: 10.31548/machinery/2.2025.146

Lyudmyla Mikhailova*
PhD in Technical Sciences, Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-3419-5446

Viktor Dubik
PhD in Technical Sciences, Associate Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-9743-1565

Oleksandr Kozak
PhD in Technical Sciences, Associate Professor
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-0919-0344

Oleg Gorbovy
Master, Assistant
Higher Educational Institution "Podillia State University"
32316, 12 Shevchenko Str., Kamianets-Podilskyi, Ukraine
https://orcid.org/0000-0002-0762-8410

Prospects for use of smart meters to reduce electricity losses in Ukraine's power grids

Abstract. The aim of this study was to determine the potential for reducing technical and commercial electricity losses through the integration of smart metering technologies into the existing distribution network infrastructure. The research employed scenario modelling, systems analysis, structural-functional comparison, and an examination of international experience. The level of electricity losses in Ukraine as of 2024 was analysed and found to be 18-19% of the total energy generated, with approximately 70% of these losses being technical in nature. The structure of electricity generation was found to comprise nuclear (55%), thermal (24%), hydro (9%), solar (7%), and wind (5%) energy. It was revealed that partial deployment of smart meters at a 50% penetration rate could reduce losses by 25%, while full coverage of the distribution network could reduce them by up to 45%. The technical characteristics of smart meters were summarised, including high-frequency data collection at 15-minute or hourly intervals, remote real-time data transmission via mobile networks or Power Line Communication (PLC) systems, and automatic detection of emergency situations and unauthorised interference. It was demonstrated that integrating smart meters with energy management systems enables effective load balancing, reduced peak demand, and optimised electricity distribution. The experiences of the United States, the EU, and China were also reviewed, confirming the feasibility of large-scale deployment of such systems to reduce losses and stimulate the development of distributed generation. The findings highlight the promise of smart meters in the digital transformation of Ukraine's energy system, enhancing its adaptability, reliability, and resilience to emerging challenges. The practical

Article's History: Received: 10.12.2024; Revised: 07.03.2025; Accepted: 22.05.2025.

Suggested Citation:
Mikhailova, L., Dubik, V., Kozak, O., & Gorbovy, O. (2025). Prospects for use of smart meters to reduce electricity losses in Ukraine's power grids. *Machinery & Energetics,* 16(2), 146-158 doi: 10.31548/machinery/2.2025.146.

*Corresponding author

value of the study lies in developing approaches to digitalising electricity consumption metering in Ukraine, which could be utilised in modernising energy networks and forming a resilient smart energy system

Keywords: automated metering; resource management; digital technologies; intelligent systems; consumption monitoring; energy efficiency

INTRODUCTION

Amidst an energy crisis driven by rising resource costs, the adverse environmental effects of climate change, and the complications caused by full-scale invasion, the need to implement advanced technologies to improve energy efficiency and reduce electricity losses has become increasingly urgent. Ukraine is currently facing electricity losses of around 19% of total consumption, which in 2021 amounted to 29.343 million kWh out of a total consumption of 154.826 million kWh (Putsenteilo, 2023). These figures underline the necessity of adopting innovative technologies, particularly smart meters, which are capable of addressing a range of issues in the energy sector.

Smart meters not only allow real-time monitoring of electricity consumption but also provide analytical tools for optimising network operations (Chen *et al.*, 2024). They contribute to reducing energy losses, improving system stability, and increasing energy efficiency across consumer categories – from households to industrial facilities (Palasevych *et al.*, 2024). Current energy consumption trends in Ukraine call for the modernisation of the country's energy infrastructure to meet growing demand, taking into account high consumption levels and associated losses. Moreover, the introduction of technologies such as smart meters can enable optimal resource management, reduce reliance on traditional energy sources, and create favourable conditions for the use of renewable energy (Karlilar Pata & Pata, 2025).

The issue of electricity losses in Ukraine's networks and the implementation of smart meters has been examined by various researchers. For instance, D. Hrechyn & I. Drobot (2024) focused on the technical aspects related to voltage deviations in electrical networks, which directly affect energy losses. They pointed to the possibility of reducing losses through the modernisation of cable lines, although noted that not all networks possessed the resources for such upgrades. Internationally, a study by M. Güçyetmez & H. Sakeen (2022) highlighted the importance of introducing smart meters in the context of expanding distributed generation facilities. They emphasised that smart meters can provide two-way energy metering, which is critical for effective grid management. This supports the argument that smart meters can significantly reduce electricity losses by ensuring accurate consumption measurement.

T.J. Al-Khafaji *et al.* (2024) proposed a wireless digital smart metering system using Groupe Special Mobile (GSM) technology to transmit electricity consumption data. This allowed consumers to access real-time information about their usage, potentially reducing losses due to electricity theft. S. Zhou (2021) investigated the impact of smart meter penetration levels on dynamic electricity pricing in the United States. In his empirical study, he analysed large datasets comprising time series of prices and consumption, demonstrating that users with access to real-time tariff information exhibit greater price sensitivity. Specifically, they tend to reduce consumption during peak hours, thereby alleviating grid strain and contributing to a more efficient and predictable energy demand. Zhou stressed that the mere deployment of smart meters is not enough; active consumer participation in dynamic tariff systems is also crucial, as it encourages behavioural change.

In contrast, T. Knayer & N. Kryvinska (2022) focused on the technical and functional analysis of smart metering technologies in the context of both residential and corporate energy management. Their research adopted a systemic approach: the authors classified meter types, data collection architectures, and integration options with smart home systems and energy analytics platforms. The study highlighted how the technological capabilities of smart metering – particularly frequency monitoring, automated load control, and consumption profiling – can offer not only immediate feedback to users but also serve as a tool for energy-efficient planning. The study also noted that the effectiveness of the technology largely depends on the level of users' digital literacy and the overall digital maturity of the infrastructure.

M. Kuznietsov & O. Lysenko (2024) focused on the challenges of energy balancing in local networks amid an increasing share of renewable generation. They emphasised that the stochastic nature of solar and wind power complicates the stable operation of networks, particularly in regional systems with limited reserve capacities. Their study highlighted the need for the introduction of energy storage systems and adaptive consumption forecasting algorithms to minimise imbalances. The study of electricity loss in Ukraine's networks and the deployment of smart meters reveals several gaps that require further research. There is a lack of studies exploring the integration of cutting-edge technologies such as blockchain into energy metering systems. Such integration could significantly enhance transparency and reduce the potential for fraud, though research in this area remains limited. Additionally, the impact of renewable energy sources on grid stability warrants deeper investigation, as their variability poses new challenges for management systems (Telbayeva *et al.*, 2024). These issues are becoming increasingly important in light of the rising share of renewables in the national energy mix.

The objective of this research was to explore opportunities to optimise Ukraine's distribution networks through the deployment of intelligent metering systems, thereby reducing technical and commercial electricity losses. The main tasks included assessing current electricity losses in Ukrainian networks, analysing existing approaches to energy system management, and developing optimal models for the use of smart technologies.

MATERIALS AND METHODS

Current energy losses in Ukraine's power system have been assessed and classified, with the principal causes identified and potential mitigation pathways outlined. To analyse the structure of electricity generation in Ukraine for 2024, statistical data from the Ukrainian Institute for the Future (2025) were employed, reflecting the distribution of generation by energy source. Additional information on the overall energy balance, consumption volumes, and key characteristics of Ukraine's energy system was obtained from the analytical review by Statista (n.d.) and the report of the International Energy Agency (2025). An analytical model was developed as part of the study. It included stages for assessing losses across various segments of the network, identifying the main types of losses (technical, commercial, and distributional), and modelling the impact of smart meter implementation on their reduction. Particular attention was devoted to analysing traditional electricity metering and control methods, which are still dominated by electromechanical and early electronic meters lacking remote data collection capability. To model smart meter implementation scenarios, the GridLAB-D software platform was used. This tool facilitates modelling of distribution networks with the ability to incorporate smart technologies, load management systems, and metering automation. Scenarios with varying levels of smart meter deployment (0%, 50%, and 100%) were created to assess their effects on energy losses, load balancing, and power supply quality. For data analysis, the Smart Meter Analytics Python (SMAP) library was applied to process electricity consumption time series and detect patterns and anomalies.

The functionality of smart meters was examined in relation to such technical features as data registration frequency (15-minute or hourly intervals), real-time data transmission methods (GSM/Power Line Communication (PLC)), the ability to detect emergency conditions (overloads, short circuits), and alerts for unauthorised interference. Integration of smart meters with Energy Management Systems (EMS) and Advanced Distribution Management Systems (ADMS) was also explored. This enables remote control, two-way data exchange, and connectivity with other Internet of Things (IoT) solutions in the energy sector. Special emphasis was placed on evaluating the compatibility of modern smart meters with Ukraine's grid infrastructure. The main challenges of implementation were also analysed: technical (lack of unified standards, compatibility issues, cybersecurity requirements), economic (high cost of grid modernisation), and social (personal data protection, consumer trust in new technologies). A separate analysis of smart meter deployment trends during 2020-2024 provided insights into the pace of Ukraine's energy infrastructure digitalisation and revealed structural barriers to its development. The research methodology included comparative analysis of official statistical data, scenario modelling using GridLAB-D and SMAP, systematisation of international experience in smart meter integration (including case studies from the United States (International Energy Agency, 2024), EU countries (Berg Insight, 2025), and China (Asia Pacific Smart, 2024)), and formulation of recommendations for accelerating Ukraine's grid digitalisation and the adoption of intelligent metering systems.

RESULTS

Assessment of current energy losses in Ukraine's power system (2024 data)

The analysis of Ukraine's electricity generation structure for 2024 revealed key trends in the development of the national energy system. According to the Ukrainian Institute for the Future (2025), nuclear power stations accounted for the largest share of total electricity generation, producing over 55% of the output. Thermal power stations ranked second with approximately 24%, while hydropower and renewable energy sources (solar and wind) collectively provided around 21% of total electricity. The detailed breakdown of electricity production in Ukraine for 2024 is presented in Table 1.

Table 1. Structure of electricity generation in Ukraine in 2024 by source

Energy source	Share in generation (%)
Nuclear power stations	55
Thermal power stations	24
Hydropower stations	9
Solar power stations	7
Wind power stations	5

Source: compiled by the authors based on Ukrainian Institute for the Future (2025)

As shown in Table 1, nuclear power remained the backbone of electricity production in Ukraine in 2024, with 55% of total output. Thermal power contributed 24%, indicating a continued reliance on conventional fossil fuel-based energy. Renewable sources – hydropower, solar, and wind – collectively accounted for around 21% of total electricity, highlighting their gradually increasing role in the generation mix. This distribution underscores the need for further diversification of energy resources and modernisation of grids to better integrate renewables. A key research task was to identify the main causes of electricity losses during generation, transmission, and distribution. Based on data from the Ukrainian Institute for the Future (2025) and International Energy Agency (2025), electricity losses in Ukraine were estimated to be approximately 18-19% of total generated energy. The main technical loss factors include outdated grid infrastructure, high resistance in overhead and underground lines, inefficient transformer equipment, and insufficient automation in load and emergency control systems.

Commercial losses primarily stem from unauthorised electricity consumption, theft, inaccuracies in traditional metering systems, and tampering (Sherstniov & Osadchuk, 2024). The absence of centralised and real-time data collection delays the detection of violations and complicates energy resource management. The combined impact of technical and commercial factors significantly reduces energy system efficiency, increases production and distribution costs, and undermines the reliability of power supply. A visual representation of electricity losses in Ukraine's power system in 2024 is shown in Figure 1.

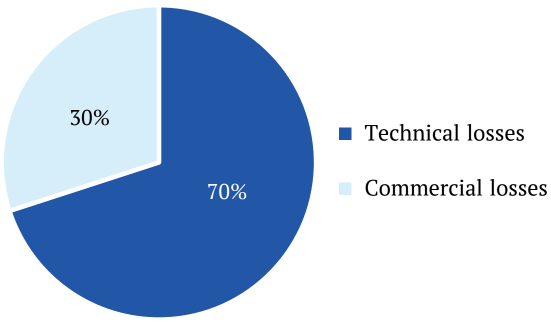

Figure 1. Share of electricity losses in Ukraine's power system in 2024

Source: compiled by the authors based on Ukrainian Institute for the Future (2025), International Energy Agency (2025)

As seen in Figure 1, technical losses dominated the structure of electricity losses in Ukraine in 2024, comprising around 70% of total losses. These are primarily due to high line resistance, outdated transformers, and low levels of grid infrastructure automation. Commercial losses, making up roughly 30%, were linked to unauthorised consumption, theft, metering inaccuracies, and interference. This distribution highlights the urgent need to modernise existing metering and dispatching systems to improve overall energy system performance.

Analysis of traditional electricity monitoring and metering methods

Traditional electricity metering in Ukraine has long relied on electromechanical and early-generation electronic meters. Electromechanical meters, characterised by mechanical indicators using a rotating disc, remained the main metering devices for many years due to their simplicity and reliability under standard operating conditions. Electronic meters, which began widespread use in the 2000s, offered higher measurement accuracy, multi-tariff functionality, and limited automation of data reading (Putsenteilo, 2023). However, both electromechanical and early electronic metering systems have significant limitations. Firstly, these systems require in-person data collection by inspectors, which increases operational costs and human error risk. Secondly, the lack of remote monitoring complicates the timely detection of consumption anomalies or tampering. Thirdly, these devices have limited integration with EMS and ADMS, reducing real-time resource management effectiveness. Such shortcomings are especially critical under modern conditions, where demand-side management, load balancing, and rapid violation detection are essential for stable energy system performance. The main features and limitations of traditional metering systems are summarised in Table 2.

Table 2. Main characteristics and limitations of traditional electricity metering systems

Meter type	Key characteristics	Key limitations
Electromechanical Meters	Reliability, low cost	No remote reading, high risk of tampering
Early Electronic Meters	Higher accuracy, multi-tariff capability	Limited automation, dependence on manual data collection

Source: compiled by the authors based on S. Zhou (2021), T. Knayer & N. Kryvinska (2022)

As Table 2 shows, traditional metering systems have significant drawbacks that adversely affect energy resource management. Although electromechanical meters are reliable and inexpensive, their inability to transmit data remotely leads to delayed detection of irregularities and greater vulnerability to tampering. Early electronic meters, while more accurate and offering multi-tariff functionality, remain insufficiently integrated with modern dispatching systems and do not support real-time consumption analysis. These limitations point to the necessity of adopting more advanced technological solutions in energy metering to enable timely control, high accuracy, and flexible energy management.

Features and functionality of smart meters

The introduction of smart meters into energy networks fundamentally transforms traditional approaches to electricity metering and resource management. One of the key features of these devices is their high-frequency energy consumption data collection. Depending on system configuration, smart meters can record readings at intervals from 15 minutes to one hour, enabling detailed real-time tracking of load fluctuations. This allows operators to monitor consumption efficiently, promptly detect anomalies, and forecast peak loads (Güçyetmez & Sakeen, 2022).

Another crucial functional feature of smart meters is remote data transmission via wireless communication channels such as GSM, GPRS, 3G/4G, or wired PLC technologies. This ensures continuous information exchange between meters and control centres without requiring manual readings, significantly reducing operational costs and minimising human error.

Smart meters also have the capacity for automatic detection of emergency operating conditions in the grid. Upon identifying short circuits, overloads, or voltage losses, they can immediately send relevant signals to dispatch centres. This facilitates rapid response and improves supply reliability.

A significant technological advantage of modern smart meters is their integration with IoT and EMS platforms. Meters can interact with other network devices such as load-limiting systems, distributed energy generators, or residential energy systems. This integration enables the creation of intelligent energy networks that automatically manage load distribution, optimise consumption, and enhance resource efficiency. The architecture of smart meter integration into modern energy networks is illustrated in Figure 2

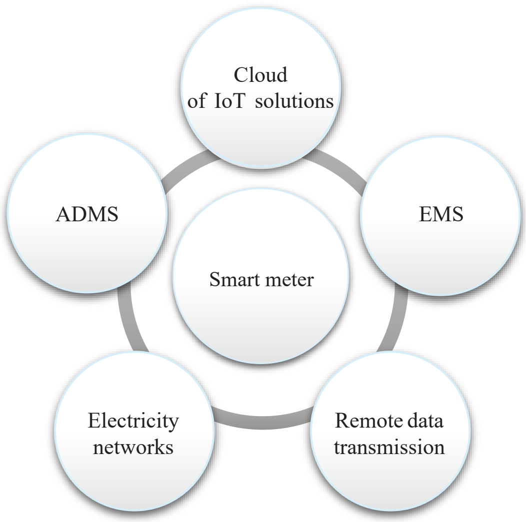

Figure 2. Architecture of the smart meter integration system with power grids
Source: created by the authors based on data from Z. Chen *et al.* (2024)

As shown in Figure 2, the central element is the smart meter, which provides bidirectional data exchange between the electricity consumer and the grid operator. Through integration with the Energy Management System (EMS), smart meters enable real-time operational management of energy consumption. The Advanced Distribution Management System (ADMS) coordinates the overall load in the network by receiving consumption data from smart meters and sending corresponding commands to optimise energy distribution. Internet of Things (IoT) devices interact with smart meters to locally manage consumption in buildings and enterprises, allowing automatic adjustment of loads according to preset parameters or dynamic pricing. Electricity consumers equipped with smart meters and connected devices can access up-to-date information on their energy consumption and optimise costs through more precise load management. Figure 2 illustrates the holistic architecture of an intelligent energy system that enhances energy efficiency, reduces electricity losses, enables rapid response to emergency events, and supports the integration of distributed energy resources.

Modelling the impact of smart meter implementation on electricity losses

To assess the impact of smart meter deployment on electricity losses in Ukraine's power system, modelling was conducted using the GridLAB-D platform and the SMAP analytical library. The study constructed three scenarios: baseline (0% smart meter penetration), partial (50% network coverage), and full (100% coverage of consumers with intelligent metering devices). In the baseline scenario without smart technology adoption, electricity losses remained at traditionally high levels due to low efficiency in detecting technical anomalies and unauthorised consumption. In the partial coverage scenario, modelling results indicated a 25% reduction in total losses compared to the baseline. Full-scale implementation of smart meters resulted in a 45% reduction in losses, demonstrating the significant potential of intelligent metering to enhance the efficiency of power grids.

The modelling accounted not only for direct technical losses in transmission lines and transformers but also for commercial losses associated with electricity theft and metering errors. GridLAB-D enabled precise simulation of various network operating modes considering actual equipment characteristics, while SMAP facilitated time series data processing of consumption to identify trends and anomalies in load dynamics. The results indicate that the smart metering system not only reduces loss levels but also improves system balancing, optimises load distribution, and enhances supply stability, especially during peak demand periods. Detailed results on loss reduction depending on smart meter penetration levels are presented in Table 3.

Table 3. Assessment of electricity loss reduction depending on smart meter penetration level

Implementation scenario	Reduction in total electricity losses (%)
0% smart meters (baseline)	0
50% network coverage	25
100% consumer coverage	45

Source: created by the authors

As shown in Table 3, the level of smart meter deployment directly influences the reduction of total electricity losses in Ukraine's power system. The baseline scenario, without the use of intelligent metering technologies, shows no loss reduction, confirming the inefficiency of traditional control methods. Partial deployment covering approximately 50% of the network achieves a 25% reduction in losses due to the capability for prompt detection of technical anomalies and commercial irregularities. Full-scale deployment enables up to a 45% reduction, indicating the high potential of metering intelligence for improving energy efficiency and stabilising grid operations. A graphical representation of electricity loss changes according to the level of intelligent metering deployment is shown in Figure 3.

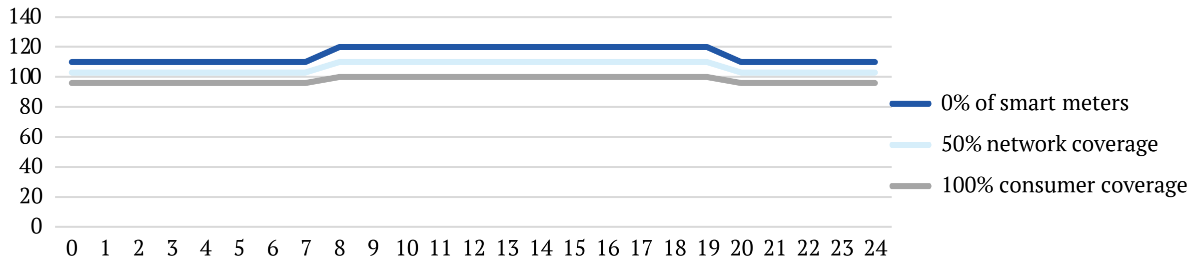

Figure 3. Changes in electricity losses under different smart meter deployment scenarios
Source: created by the authors

As seen in Figure 3, the pattern of electricity consumption changes depending on the level of smart meter deployment. In the baseline scenario (0% coverage), pronounced peak loads occur during daytime hours, creating significant risks for grid stability. Partial deployment (50% network coverage) noticeably smooths peak consumption spikes through improved load control and timely response to demand increases. Full deployment of intelligent metering systems (100% coverage) ensures the highest stability of consumption throughout the day, minimising sharp load fluctuations and creating conditions for optimised system balancing. Thus, the use of smart meters contributes to a more even load distribution within the network, reduction of peak losses, and overall enhancement of energy efficiency.

Integration of smart meters with EMS and ADMS

Integration of smart meters with EMS and ADMS opens new opportunities for comprehensive energy resource management. One key advantage of such solutions is the ability to remotely monitor energy consumption parameters in real time. Thanks to bidirectional data exchange, smart meters not only transmit information to control centres but also receive signals to adjust consumption modes, optimise loads, and prevent failures. Remote data access allows EMS to dynamically manage energy consumption, including implementing mechanisms for real-time tariff response or load distribution according to consumer priorities. ADMS systems, in turn, provide centralised load balancing, automatic fault detection and localisation, as well as network topology optimisation to reduce energy losses (Kubiczek *et al.*, 2023). Intelligent functions of smart meters – such as overload detection, short-circuit identification, phase asymmetry recognition, and unauthorised connection registration – enhance the responsiveness of EMS and ADMS systems, positively affecting the quality and continuity of power supply. The implementation of this integration contributes not only to lowering overall energy consumption but also to improving the balance between energy production and consumption, particularly with the increasing share of distributed generation based on renewable sources. The main functional capabilities of smart meters in the context of interaction with EMS and ADMS are summarised in Table 4.

Table 4. Comparison of smart meter functionalities for EMS and ADMS operations

Functional feature	Smart meters in EMS	Smart meters in ADMS
Consumption Data Collection	Real-time	Real-time
Remote Load Control	Yes	Yes
Fault Detection	Limited	Extended (faults, overloads)
Integration with Pricing Mechanisms	Direct	Indirect
Network Topology Optimisation	No	Yes
Load Balancing Support	Local	Centralised

Source: created by the authors

As evident from Table 4, the functionalities of smart meters when integrated with EMS and automated ADMS differ due to the distinct tasks of each system. Within EMS, smart meters mainly provide local consumption management and support dynamic pricing mechanisms, whereas within ADMS they play a critical role in centralised load balancing, fault detection, and network topology optimisation. All scenarios involve real-time data collection and remote load control; however, ADMS systems implement more advanced functionalities for monitoring the technical condition of network infrastructure. This highlights the importance of a comprehensive approach to smart meter deployment to ensure stability, flexibility, and efficiency of modern energy systems.

Challenges and issues of smart meter deployment in Ukraine

Despite numerous advantages, the deployment of smart meters in Ukraine faces a number of technical, economic, and social challenges that require comprehensive solutions. One of the key technical barriers is the absence of unified national standards for integrating smart meters into heterogeneous distribution networks. This leads to compatibility issues among devices from different manufacturers and complicates the creation of a unified automated infrastructure. An additional concern is cybersecurity: open data transmission channels pose risks of unauthorised access and manipulation of consumption information. Current requirements demand a high level of data encryption, device authentication, and system resilience against external attacks. Economic challenges are primarily associated with the high cost of upgrading existing networks, installing smart meters, and establishing infrastructure for data collection and processing (Kuznetsov, 2024). Significant upfront investments burden energy companies, especially amid the economic instability characteristic of Ukraine between 2020 and 2024. Insufficient government programmes to stimulate or subsidise these costs also impede large-scale rollout of intelligent metering systems.

Social barriers include low consumer trust in new technologies, concerns about personal data protection, and reluctance to change habitual interactions with energy providers (Lisovyk *et al.*, 2024). Disseminating information about the benefits of smart meters, transparency of data processing, and security guarantees should form part of the information policy to successfully overcome these obstacles. The main technical, economic, and social barriers to smart meter deployment are summarised in Table 5.

Table 5. Key technical, economic, and social barriers to smart meter deployment

Challenge category	Description of main barriers
Technical	Lack of standards; compatibility issues; cybersecurity risks
Economic	High installation costs; lack of investment; weak government support
Social	Consumer distrust; concerns about personal data protection; low awareness of technology benefits

Source: created by the authors based on data from P.R. Putsenteilo (2023), M. Kuznietsov & O. Lysenko (2024), M.B. Palasevych *et al.* (2024)

As seen in Table 5, smart meter deployment in Ukraine is accompanied by multi-level challenges encompassing technical, economic, and social spheres. At the technical level, the main barriers are the lack of unified device integration standards, equipment compatibility problems among various manufacturers, and high cybersecurity risks. Economic difficulties relate to significant upfront costs for infrastructure modernisation and insufficient state support for digitalising power grids. Social barriers involve consumer caution towards new technologies, concerns about data security, and low awareness of smart meter benefits. Comprehensive overcoming of these challenges is a critical factor for the successful implementation of digital transformation projects in Ukraine's energy system.

International experience in smart meter implementation

International experience in the implementation of smart meters demonstrates a variety of approaches to the digitalisation of energy systems, depending on economic conditions, technological infrastructure, and energy transition policies.

In the United States, intelligent metering systems form part of large-scale programmes for the modernisation of distribution networks, financed by both federal and local initiatives. Key focuses include ensuring two-way communication between consumers and operators, enabling dynamic pricing, consumer participation in load management programmes, and integration with home energy systems. By 2024, the penetration rate of smart meters among residential consumers in the US exceeded 70% (International Energy Agency, 2024).

In EU countries, smart meter deployment is supported at the level of EU directives, particularly Directive 2019/944 (Berg Insight, 2025) concerning common rules for the internal electricity market. The approach emphasises a high level of data protection, integration with demand-side management systems, and the promotion of distributed generation development. In several EU countries (such as Italy, Spain, Sweden), smart meter coverage of the residential sector surpasses 90%.

In China, the implementation process of smart meters follows a centralised model coordinated by the State Grid Corporation of China. The focus is not only on consumption accounting but also on integrating smart meters into network condition monitoring systems, balancing supply and demand, and supporting the large-scale deployment of distributed generation from renewable energy sources. By 2022, the number of installed smart meters in China exceeded 500 million units (Asia Pacific Smart..., 2024).

The experience of these countries indicates that successful smart meter implementation is based on principles such as centralised project coordination, mandatory standardisation of technical requirements, a high level of cybersecurity, transparency regarding consumer data protection, and providing end users with real tools to manage their energy consumption.

Considering international experience, it is advisable for Ukraine to adopt flexible integration models for smart meters with an emphasis on data protection, stimulation of distributed generation, and the development of national standards for device compatibility. The main characteristics of smart meter implementation models in the US, EU countries, and China are presented in Table 6.

Table 6. Comparison of smart meter implementation models in the US, EU Countries, and China

Country/region	Key implementation features
United States	Dynamic pricing; integration with home energy systems; load management programmes
European Union	High level of data protection; mandatory coverage of over 80% of consumers; integration with demand market
China	Centralised implementation management; network condition monitoring; large-scale support of distributed generation

Source: created by the authors based on data from International Energy Agency (2024), Asia Pacific smart metering market report 2024: Asia-Pacific now home to more than 1 billion connected energy meters – ResearchAndMarkets.com (2024), Berg Insight (2025)

As seen in Table 6, the models for smart meter deployment in the US, EU countries, and China differ both in priorities and in approaches to integrating intelligent metering systems into energy networks. In the US, the primary emphasis is on consumer participation in load management and the use of dynamic pricing, which encourages flexible energy consumption. The European approach is based on mandatory high levels of personal data protection and ensuring widespread smart meter deployment under regulatory requirements. China demonstrates a centralised development model focused on large-scale network modernisation and integration of distributed generation. A common feature of successful international practices is a comprehensive implementation strategy that includes technical standardisation, high cybersecurity levels, and active consumer involvement in energy consumption management processes.

Current state of smart meter integration in Ukraine

The integration of smart meters into Ukraine's energy system is at an early stage of development, although individual projects for digitalising distribution networks were implemented even before large-scale reforms in the sector began. According to the Energy Map platform (2024), developed within the USAID project framework, by the end of 2024 the level of smart meter penetration among residential electricity consumers was approximately 17-18%. The most notable progress was recorded in major cities, particularly Kyiv, Lviv, and Dnipro, where pilot programmes for network modernisation and testing of intelligent energy metering systems were implemented within international technical assistance projects.

Despite these achievements, smart meter deployment remains fragmented and uneven, due to several objective problems. Key obstacles include the technical obsolescence of a significant portion of distribution networks, insufficient standardisation of equipment and data exchange requirements, limited financial capacity of energy companies for large-scale modernisation, and underdeveloped regulatory frameworks regarding consumer data protection. An additional limitation is the low level of public awareness of the benefits of smart meters and concerns about data storage and processing security. Overall, analysis of the current integration status indicates a gradual but rather slow pace of digitalisation growth in Ukraine's energy networks. Figure 4 illustrates the changes from 2020 to 2024, showing a positive trend, although the scale of growth still falls short of the needs of a modern energy system.

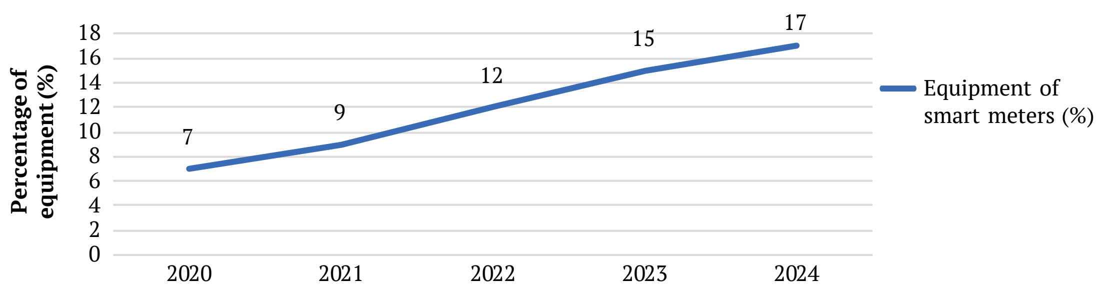

Figure 4. Dynamics of smart meter implementation in Ukraine (2020-2024)
Source: created by the authors based on data from Energy Map (2024)

As shown in Figure 4, between 2020 and 2024, Ukraine experienced a gradual increase in the penetration of smart electricity meters among consumers. Starting from 7% in 2020, this indicator steadily grew, reaching 17% in 2024. The dynamics point to a positive trend in the adoption of intelligent metering systems, although growth rates remain moderate. Relatively modest annual increases highlight the influence of both economic and technical barriers limiting broader digitalisation of energy networks. Thus, smart meter deployment in Ukraine is delayed compared to EU countries but shows a gradual expansion trend.

The results of the analysis underscore the need to accelerate the introduction of intelligent electricity metering systems to ensure the effective functioning of Ukraine's energy system amid growing challenges and demands. Accelerating the digitalisation of distribution networks should become a key priority in energy sector reforms in the near future. Crucial steps to speed up smart meter integration include developing and implementing unified national metering standards to ensure interoperability of equipment from different manufacturers and the creation of a unified information space for consumption data. Simultaneously, cybersecurity requirements for metering systems must be strengthened to prevent interference risks and safeguard user data privacy. At the policy level, incentive programmes for distribution system operators and electricity suppliers should be introduced to compensate part of the costs for network modernisation and smart technology deployment. Equally important is raising consumer awareness about the advantages of intelligent metering through extensive information campaigns. Strategically, digitalisation of energy networks should be accompanied by the integration of smart meters with ADMS and EMS. This will not only optimise load balancing and minimise electricity losses but also create conditions for the broad involvement of distributed generation from renewable energy sources.

DISCUSSION

The results of the study confirmed that the implementation of smart meters in Ukraine's energy system can significantly reduce electricity losses, optimise load balancing, and improve the efficiency of energy resource distribution. The identified patterns correspond with contemporary scientific approaches that also highlight the role of intelligent metering systems in improving electricity supply quality, reducing peak loads, and enhancing energy network resilience. A.V. Voloshko & V.V. Shevchuk (2024) emphasise the importance of rapid detection of voltage dips to minimise technical losses, aligning with the modelling results on smart meter impacts on supply stability. I. Havrylyuk (2024) stresses the necessity of harmonising Ukraine's regulatory framework with European standards, consistent with the identified need for standardising smart meter integration. S. Skrypnyk (2021) highlights the requirement for precise mathematical modelling of network operation, which corresponds with the use of GridLAB-D and SMAP software in this study for evaluating digitalisation scenarios.

Analysis by V.O. Zubenko *et al.* (2024) on local renewable energy utilisation demonstrates the importance of developing intelligent metering infrastructure to support decentralised generation. These findings align with this study's results showing that smart meter integration facilitates more effective balancing of local electricity production and consumption, which is critical for optimising Ukraine's distribution networks. A. Madi *et al.* (2022) investigated the use of PLC channels for data transmission in smart metering systems, confirming the importance of selecting reliable communication channels, as revealed in the modelling. Comparative results suggest that, in Ukraine's context, implementing multichannel solutions (GSM and PLC) is critical to ensure stable smart meter operation even in networks with complex topology. D. Fettermann *et al.* (2024) indicate that smart meter performance and transparency are key factors influencing consumer technology adoption. This corresponds with social barriers identified in the study, where Ukrainian consumers show distrust of new technologies mainly due to concerns about data protection and consumption monitoring. J.L. Gallardo *et al.* (2021) highlight the role of IoT architectures in creating smart energy networks, fully consistent with the conclusion about the necessity of integrating smart meters with EMS and ADMS.

H.M. Hu *et al.* (2020) explore personal data protection in the context of smart meter deployment. Their results support the study's conclusion on the need to improve Ukraine's cybersecurity regulatory framework, an important factor in enhancing consumer trust. M. Ahmed et al. (2020) emphasise intelligent load management for improving microgrid stability. This directly aligns with the modelling results, which demonstrated that even 50% smart meter penetration can significantly smooth peak loads and reduce energy losses by 25%. O.S. Akkaya & H. Soy (2021) draw attention to the benefits of multichannel wireless communication technologies in smart meter design, supporting the importance of data transmission flexibility in Ukraine, where network infrastructure is heterogeneous. R.-G. Wang *et al.* (2024) proved the effectiveness of deep learning methods for analysing large datasets from smart meters. Compared with the present results, this confirms the advisability of further developing analytical data processing modules in metering systems to enhance energy efficiency and consumption forecasting accuracy. R.S. Gaikwad (2024) substantiates the advantages of integrating smart meters into IoT platforms, fully consistent with this study's recommendation for widespread IoT technology adoption to create adaptive, integrated, and flexible next-generation energy networks in Ukraine.

The modelling results demonstrating the reduction of electricity losses through the implementation of smart meters are consistent with the findings of O. Yakubu *et al.* (2021), who emphasise the advantages of deploying smart meters with backup power to ensure uninterrupted data collection even during outages. This supports the relevance of considering data transmission stability in digitalisation scenarios for Ukrainian networks. Data from K.A. Al-Sammak *et al.* (2025) regarding risks of electricity theft through data manipulation align with the social and technical challenges identified in this study. Smart meters, thanks to their real-time capabilities, significantly mitigate risks of unauthorised consumption. L. Deguenon *et al.* (2024) demonstrated the effectiveness of energy demand forecasting in reducing network distortions, which coincides with the conclusions of the current modelling where the use of the SMAP library enabled detection of consumption anomalies to better balance loads. Results from V. Pliuhin & V. Teterev (2021) concerning constraints on Smart Grid implementation in Ukrainian conditions corroborate the identified barriers, notably the technical obsolescence of networks requiring modernisation for effective large-scale smart meter deployment. C. Stagnaro (2025) proved that the second generation of smart meters in Italy justified economic feasibility despite high initial costs, aligning with the present analysis that highlights prospects for long-term investment payback in Ukraine. A.N. Babu *et al.* (2022) confirm that smart meters supporting multi-standard communications enhance system flexibility and resilience – an important factor given the heterogeneous infrastructure observed in Ukraine.

V. Ntouros *et al.* (2021) stress the importance of raising consumer awareness of smart meters, fully corresponding with the identified need for public information campaigns to overcome social barriers in Ukraine. D. Hock *et al.* (2020) substantiated the use of entropy-based metrics to detect anomalies in energy consumption, consistent with the employment of SMAP for time series analysis in this study. M. Mirsharifi & F. Rezaei (2024) emphasise the necessity of strengthening cybersecurity in smart metering networks, echoing the conclusions about high cyber risks under Ukrainian conditions and the need for data protection standards. S.K. Tripathi *et al.* (2024) demonstrated the effectiveness of IoT technologies in expanding EMS functionalities, supporting the modelling results on integrating smart meters with load management systems herein. IoT deployment enables not only real-time data collection but also prompt response to changes in energy consumption, enhancing grid flexibility and stability. M.Z. Gunduz & R. Das (2024) proved the effectiveness of deep learning methods in detecting electricity theft based on large-scale smart meter data analysis. This aligns with the current findings stressing the importance of implementing advanced analytics and intelligent algorithms for time series processing to timely detect consumption anomalies and reduce commercial electricity losses in Ukraine. Such approaches significantly improve resource consumption control and strengthen the financial stability of energy companies during the digital transformation of the energy system.

Thus, the consolidated analysis shows that the study results are consistent with contemporary international practices and confirm the advisability of large-scale smart meter deployment as an effective tool for improving energy efficiency, reliability, and security of Ukraine's energy system. It has been established that metering intelligence not only reduces technical and commercial electricity losses but also enhances operational load management, improves power supply quality, and integrates distributed generation from renewable sources. The concurrence of the study's outcomes with global trends in energy digitalisation indicates the relevance and potential of smart meter implementation in Ukraine. Simultaneously, the necessity of parallel infrastructure modernisation, cybersecurity reinforcement, development of unified technical standards, and intensification of consumer education activities to build trust in new technologies has been confirmed. Such a comprehensive approach is key to the successful digital transformation of the energy sector and the formation of a more resilient, efficient, and secure energy system of the future.

CONCLUSIONS

The research confirmed that smart meter implementation is among the most effective instruments to reduce energy losses, optimise loads, and enhance energy efficiency of Ukraine's energy system. In 2024, over 55% of electricity was generated by nuclear power plants, while the share of renewables was only 21%, necessitating greater network flexibility to integrate new generation sources. Electricity losses reached 18-19%, of which 70% were technical and 30% commercial. The main causes remain ageing infrastructure, low automation levels, and inaccurate metering. Modelling showed that with 50% consumer coverage by smart meters, losses reduce by 25%, and with full coverage – up to 45%. Smart meters provide accurate accounting, data transmission via GSM/PLC, fault detection, and interaction with EMS and ADMS, creating conditions for effective real-time consumption management.

However, implementation faces several barriers: lack of unified technical standards, cybersecurity risks, high modernisation costs, and low consumer awareness. Comparative analysis of the US, EU, and China's experience confirmed the importance of centralised standardisation, data protection, and stimulation of user participation. In Ukraine, coverage rose from 7% in 2020 to 17% in 2024, yet achieving the level of developed countries requires active state support, regulatory update, and public awareness raising. The practical value of the research lies in creating an implementation model that reduces losses and ensures stable energy system development.

The study has limitations, notably dependence on open statistical sources and lack of broad empirical data from real Ukrainian microgrids, which may affect the completeness of result interpretation. Prospects for further research include developing adaptive forecasting algorithms, integration models for different generation types, and in-depth economic analysis of smart meter implementation efficiency in Ukraine's energy system conditions.

ACKNOWLEDGEMENTS

None.

FUNDING

None.

CONFLICT OF INTEREST

None.

REFERENCES

[1] Ahmed, M., Meegahapola, L., Vahidnia, A., & Datta, M. (2020). Stability and control aspects of microgrid architectures – a comprehensive review. *IEEE Access*, 8, 144730-144766. doi: 10.1109/access.2020.3014977.

[2] Akkaya, O.S., & Soy, H. (2021). Hardware design of single-phase smart electricity meter based on multiple wireless connectivity technologies. *European Journal of Science and Technology*, 32, 332-338. doi: 10.31590/ejosat.1040829.

[3] Al-khafaji, T.J., Sadiq Al-kafaji, M.S., Hamza, B.J., & Duhis, A.H. (2024). Wireless digital smart energy meter based on GSM/SMS technology. *Salud, Ciencia Y Tecnología – Serie De Conferencias*, 3, article number 876. doi: 10.56294/sctconf2024876.

[4] Al-Sammak, K.A., Al-Gburi, S.H., Marghescu, I., Drăgulinescu, A.M., Marghescu, C., Martian, A., Al-Sammak, N.A., Suciu, G., & Alheeti, K.M. (2025). Optimizing IoT energy efficiency: Real-time adaptive algorithms for smart meters with LoRaWAN and NB-IoT. *Energies*, 18(4), article number 987. doi: 10.3390/en18040987.

[5] Asia Pacific smart metering market report 2024: Asia-Pacific now home to more than 1 billion connected energy meters – ResearchAndMarkets.com. (2024). Retrieved from https://www.businesswire.com/news/home/20240701905786/en/Asia-Pacific-Smart-Metering-Market-Report-2024-Asia-Pacific-Now-Home-to-More-than-1-Billion-Connected-Energy-Meters---ResearchAndMarkets.com?utm_.

[6] Babu, A.N., Kavya, C.V., Praneetha, A., Dhanush, T.T., Ramanaiah, T.V., Nidheesh, K., & Brahmanandam, P.S. (2022). Smart energy meter. *Indian Journal of Science and Technology*, 15(29), 1451-1457. doi: 10.17485/ijst/v15i29.1241.

[7] Berg Insight. (2025). *Smart electricity meter penetration rate in Europe reached 63 percent at the end of 2024*. Retrieved from https://www.berginsight.com/smart-electricity-meter-penetration-rate-in-europe-reached-63-percent-at-the-end-of-2024.

[8] Chen, Z., Amani, A., Yu, X., & Jalili, M. (2024). Control and optimisation of power grids using smart meter data: A review. *Sensors*, 23(4), article number 2118. doi: 10.3390/s23042118.

[9] Deguenon, L., Yamegueu, D., & Gomna, A. (2024). Overcoming the challenges of integrating variable renewable energy to the grid: A comprehensive review of electrochemical battery storage systems. *Journal of Power Sources*, 580, article number 233343. doi: 10.1016/j.jpowsour.2023.233343.

[10] Energy Information Administration. (2024). *Annual electric power industry report, form EIA-861 detailed data files*. Retrieved from https://www.eia.gov/electricity/data/eia861/.

[11] Energy Map. (2024). Level of equipment with smart electricity meters. Retrieved from https://map.ua-energy.org/uk/resources/b676f89a-188b-4179-8d56-1b984a2e477f/.

[12] Fettermann, D., Christoffel, P., Castillo, J., & Sant'Anna, A. (2024). The role of performance in smart meter's acceptance: A survey in Joinville, Brazil. *Urban Science*, 8(1), article number 1. doi: 10.3390/urbansci8010001.

[13] Gaikwad, R.S. (2024). IoT based smart meter using Esp32. *International Journal of Research Publication and Reviews*, 5(5), 2360-2370. doi: 10.55248/gengpi.5.0524.1204.

[14] Gallardo, J.L., Ahmed, M.A., & Jara, N. (2021). Lora IoT-based architecture for advanced metering infrastructure in residential smart grid. *IEEE Access*, 9, 124295-124312. doi: 10.1109/access.2021.3110873.

[15] Güçyetmez, M., & Sakeen, H. (2022). A real-time invoice based smart meter design with mobile application. *International Journal of Engineering Research and Development*, 14(2), 884-894. doi: 10.29137/umagd.1036454.

[16] Gunduz, M.Z., & Das, R. (2024). Smart grid security: An effective hybrid CNN-based approach for detecting energy theft using consumption patterns. *Sensors*, 24(4), article number 1148. doi: 10.3390/s24041148.

[17] Havrylyuk, I. (2024). External economic activity of Ukraine with EU countries. *Economy and Society*, 59. doi: 10.32782/2524-0072/2024-59-3.

[18] Hock, D., Kappes, M., & Ghita, B. (2020). Entropy-based metrics for occupancy detection using energy demand. *Entropy*, 22(7), article number 731. doi: 10.3390/e22070731.

[19] Hrechyn, D., & Drobot, I. (2024). Investigating voltage deviations in the enterprise's power supply network during the electrical equipment operation. *Bulletin of Lviv National Environmental University Agroengineering Research*, 27, 61-69. doi: 10.31734/agroengineering2024.27.061.

[20] Hu, H.M., Zhao, X., Wu, Y., Huang, M., Zhu, Z., & Yang, Q. (2020). Privacy preservation of smart meters based on identity authentication. *Energy and Power Engineering*, 12(4), 53-62. doi: 10.4236/epe.2020.124b006.

[21] International Energy Agency. (2025). *Ukraine*. Retrieved from https://www.iea.org/countries/ukraine/electricity.

[22] Karlilar Pata, S., & Pata, U.K. (2025). Comparative analysis of the impacts of solar, wind, biofuels and hydropower on load capacity factor and sustainable development index. *Energy*, 319, article number 134991. doi: 10.1016/j.energy.2025.134991.

[23] Knayer, T., & Kryvinska, N. (2022). An analysis of smart meter technologies for efficient energy management in households and organizations. *Energy Reports*, 8, 4022-4040. doi: 10.1016/j.egyr.2022.03.041.

[24] Kubiczek, J., Hadasik, B., Krawczyńska, D., Przedworska, K., & Ryczko, A. (2023). Going beyond frontiers in household energy transition in Poland – a perspective. *Frontiers in Energy Research*, 11, article number 1239115. doi: 10.3389/fenrg.2023.1239115.
[25] Kuznetsov, P. (2024). Development and implementation of a smart home automation system in the context of the Ukrainian housing sector: Challenges and prospects. *Bulletin of Cherkasy State Technological University*, 29(1), 62-72. doi: 10.62660/bcstu/1.2024.62.
[26] Kuznietsov, M., & Lysenko, O. (2024). Ensuring the energy balance in the local system with renewable generation. *Renewable Energy*, 72(1), 6-18. doi: 10.36296/1819-8058.2023.1(72)6-18.
[27] Lisovyk, V., Shevchenko, O., & Shovkaliuk, M. (2024). Increasing the capacity of communities in recovery projects through energy efficiency training. *Technologies and Engineering*, 25(5), 57-70. doi: 10.30857/2786-5371.2024.5.6.
[28] Madi, A., Elsayed, W., Nascimento, D., Beshir, A.H., Leżyński, P., & Smoleński, R. (2022). Influence of chaotic spreading factor modulation based random modulation on G3-PLC system. In *Proceedings of the international symposium on electromagnetic compatibility – EMC Europe* (pp. 770-773). Gothenburg: IEEE. doi: 10.1109/emceurope51680.2022.9901316.
[29] Mirsharifi, M., & Rezaei, F. (2024). Improving the security of management software of smart meters networks. *International Journal of Information and Communication Technology Research*, 15(4), 32-40. doi: 10.61186/itrc.15.4.32.
[30] Ntouros, V., Kampelis, N., Senzacqua, M., Karlessi, T., Assimakopoulos, M.-N., Kolokotsa, D., & Cristalli, C. (2021). Smart meter awareness in Italy, Ancona. In A. Bisello, D. Vettorato, D. Ludlow & C. Baranzelli (Eds.), *Smart and sustainable planning for cities and regions* (pp. 47-66). Cham: Springer. doi: 10.1007/978-3-030-57764-3_4.
[31] Palasevych, M.B., Savka, O.V., & Lepak, T.A. (2024). Impact of smart technologies on economic development and the increase in energy efficiency of the national economy. *Academic Visions*, 34.
[32] Pliuhin, V., & Teterev, V. (2021). Possibility implementation analysis of the smart grid network in a current state conditions of the united energy systems of Ukraine. *Lighting Engineering & Power Engineering*, 60(1), 15-22. doi: 10.33042/2079-424x.2021.60.1.03.
[33] Putsenteilo, P.R. (2023). The concept of smart grid: Technological, organizational and economic aspects of the development of the energy sector. *Innovation Economy*, 1, 137-150. doi: 10.37332/2309-1533.2023.1.19.
[34] Sherstniov, Yu., & Osadchuk, Yu. (2024). Development of an algorithm for optimizing electrical energy consumption levels at mining and beneficiation plant substations using intelligent systems. *Journal of Kryvyi Rih National University*, 22(1), 116-124. doi: 10.31721/2306-5451-2024-1-58-116-124.
[35] Skrypnyk, S. (2021). Substantiation of the choice of the replacement scheme of line for mathematical modeling of 20 kV power supplies. *Scientific Papers of Donetsk National Technical University. Series: Electrical and Power Engineering*, 24(1), 69-72. doi: 10.31474/2074-2630-2021-1-69-72.
[36] Stagnaro, C. (2025). Second-generation smart meter roll-out in Italy: A cost-benefit analysis. *Journal of Industrial and Business Economics*, 52(1), 201-220. doi: 10.1007/s40812-024-00324-1.
[37] Statista. (n.d.). *Energy – Ukraine*. Retrieved from https://www.statista.com/outlook/io/energy/ukraine.
[38] Telbayeva, S., Nurmaganbetova, G., Avdeyev, L., Kaverin, V., Issenov, S., Janiszewski, D., Smagulova, K., & Nurmagambetova, G. (2024). Development of mathematical models of power consumption at coal plants. *Eastern-European Journal of Enterprise Technologies*, 5(8(131)), 22-32. doi: 10.15587/1729-4061.2024.313932.
[39] Tripathi, S.K., Maurya, S., Kumar, A., Raj, K.S., & Rawat, R. (2024). Advanced energy metering system using IoT. *International Journal of Innovative Research in Computer Science and Technology*, 12(3), 148-153. doi: 10.55524/ijircst.2024.12.3.25.
[40] Ukrainian Institute for the Future. (2025). *Ukraine's energy sector development*. Retrieved from https://uifuture.org/en/news-en/ukraines-energy-sector-developments-2/.
[41] Voloshko, A.V., & Shevchuk, V.V. (2024). Voltage failures in electrical networks and determination of their characteristics. *Visnyk of Vinnytsia Polytechnical Institute*, 5, 12-17. doi: 10.31649/1997-9266-2023-170-5-12-17.
[42] Wang, R.-G., *et al.* (2024). Analyzing long-term and high instantaneous power consumption of buildings from smart meter big data with deep learning and knowledge graph techniques. *Energies*, 16(19), article number 6893. doi: 10.3390/en16196893.
[43] Yakubu, O., Babu, C.N., & Adjei, C.O. (2021). A novel IoT based smart energy meter with backup battery. *International Journal of Computing*, 20(3), 357-364. doi: 10.47839/ijc.20.3.2281.
[44] Zhou, S. (2021). The effect of smart meter penetration on dynamic electricity pricing: Evidence from the United States. *The Electricity Journal*, 34(3), article number 106919. doi: 10.1016/j.tej.2021.106919
[45] Zubenko, V.O., Bereziuk, I.A., Volkov, I.V., & Teliuta, R.V. (2024). Analysis of the opportunities of wind energy providing for farms in Kirovograd region. *Visnyk of Kherson National Technical University*, 87(4), 63-69. doi: 10.35546/kntu2078-4481.2023.4.7.

Людмила Михайлова
Кандидат технічних наук, професор
Заклад вищої освіти «Подільський державний університет»
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-3419-5446

Віктор Дубік
Кандидат технічних наук, доцент
Заклад вищої освіти «Подільський державний університет»
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-9743-1565

Олександр Козак
Кандидат технічних наук, доцент
Заклад вищої освіти «Подільський державний університет»
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-0919-0344

Олег Горбовий
Магістр, асистент
Заклад вищої освіти «Подільський державний університет»
32316, вул. Шевченка, 12, м. Кам'янець-Подільський, Україна
https://orcid.org/0000-0002-0762-8410

Перспективи використання смарт-лічильників для зниження втрат електроенергії в мережах України

Анотація. Метою роботи було визначення потенціалу зниження технічних і комерційних втрат електроенергії шляхом інтеграції інтелектуальних технологій обліку в існуючу інфраструктуру розподільчих мереж. У дослідженні було використано методи сценарного моделювання, системного аналізу, структурно-функціонального порівняння та вивчення міжнародного досвіду. Було досліджено рівень втрат електроенергії в Україні станом на 2024 рік, який становив 18-19 % від загального обсягу виробленої енергії, причому близько 70 % цих втрат мали технічний характер. Було встановлено, що структура генерації електроенергії була сформована за участю атомної (55 %), теплової (24 %), гідро (9 %), сонячної (7 %) та вітрової (5 %) енергетики. Було проаналізовано, що часткове впровадження смарт-лічильників на рівні 50 % забезпечує зниження втрат на 25 %, тоді як повне охоплення розподільчої мережі може скоротити втрати до 45 %. Було узагальнено технічні характеристики інтелектуальних лічильників, які передбачають високочастотний збір даних з інтервалами 15 хвилин або однієї години, дистанційне передавання інформації в режимі реального часу через мобільні мережі або системи Power Line Communication (PLC), автоматичне виявлення аварійних ситуацій та несанкціонованого втручання. Було доведено, що інтеграція смарт-лічильників із системами управління енергоспоживанням дозволяє ефективно балансувати навантаження, знижувати пікові споживання й оптимізувати розподіл електроенергії. Також було узагальнено досвід США, ЄС і Китаю, який підтверджує доцільність широкомасштабного впровадження таких систем для зниження втрат і стимулювання розвитку розподіленої генерації. Отримані результати свідчать про перспективність застосування смарт-лічильників у цифровій трансформації української енергосистеми, що забезпечить її адаптивність, надійність та стійкість до нових викликів. Практична цінність дослідження полягає у розробці підходів до цифровізації обліку енергоспоживання в Україні, що може бути використано при модернізації енергомереж та формуванні стійкої розумної енергосистеми

Ключові слова: автоматизація обліку; управління ресурсами; цифрові технології; інтелектуальні системи; моніторинг споживання; ефективність споживання