Energetika tizimlarining samaradorligini oshirishda innovatsion dasturiy ta’minotning o‘rni

Xilola Z. Nazirova[1], Saodat G‘. G‘oyibova[1,a)], Shohrux S. Samiyev[1,b)]

[1] katta o‘qituvchi. Toshkent davlat texnika universiteti, Toshkent, 100095, O‘zbekiston; hilolazahidjanovna1987@gmail.com https://orcid.org/0009-0002-7735-4862
[1, a)] Magistr. Toshkent davlat texnika universiteti, Toshkent, 100095, O‘zbekiston; saodat.goyibova@gmail.com
[1, b)] Assistent. Toshkent davlat texnika universiteti, Toshkent, 100095, O’zbekiston; shohruxsamiyev96@gmail.com https://orcid.org/0009-0009-6833-3075

Dolzarbligi: zamonaviy energetika tizimlarida samaradorlikni oshirish nafaqat texnik, balki raqamli yechimlar orqali ham amalga oshirilishini talab qilmoqda. Xususan, elektr energiyasi isroflarini aniqlash, tahlil qilish va prognozlashda aniq, barqaror hamda intellektual vositalarni joriy etish ehtiyoji keskin ortib bormoqda. Bu jarayonda ma’lumotlarni real vaqtda qayta ishlash, prognoz modellarini avtomat tanlash, klasterli va anomal ma’lumotlar bilan ishlash kabi vazifalarni amalga oshiradigan innovatsion dasturiy ta’minot vositalari katta ahamiyat kasb etmoqda.Ayniqsa, 0,4 kVli taqsimlash tarmoqlari kabi past kuchlanishli tarmoqlarda energetik samaradorlikni oshirish, aniq monitoring va prognozlash mexanizmlarini joriy etish orqali ta’minlanadi. Ana shunday sharoitda, intellektual funksiyalarga ega, modulli va adaptiv arxitekturada yaratilgan axborot tizimlari nafaqat texnik xizmat ko‘rsatish samaradorligini oshiradi, balki qaror qabul qilish jarayoning ob’ektivligini va tezkorligini ta’minlaydi.
Maqsad: energetika tarmoqlarida elektr energiyasi isroflarini tahlil qilish va prognozlash jarayonlarini avtomatlashtirishga xizmat qiluvchi innovatsion dasturiy ta’minotni ishlab chiqish, uning modulli arxitekturasi, funksional imkoniyatlari va integratsiya qilingan prognoz modellari asosida tizim samaradorligini ilmiy jihatdan baholash.
Usullari: modellash jarayonida ma’lumotlar tuzilmasini hisobga oluvchi klasterlash, prognozlashga ixtisoslashgan neyron tarmoqlar va klassik statistik usullarni o‘zaro integratsiyalashga asoslangan kompleks yondashuv tatbiq etildi.
Natijalar: 0,4 kVli taqsimlash tarmoqlarida elektr energiyasi isroflarini prognozlashni axborot tizimi - EIPAT ishlab chiqildi. Tizim tarkibiga polinomial regressiya, ARIMA, GMDH, MLP va gibrid prognozlash usullari kompleks tarzda integratsiya qilindi. Mazkur tizim ma’lumotlar tuzilmasining murakkabligi va o‘zgaruvchanligini hisobga oluvchi adaptiv mexanizmlar bilan jihozlangan bo‘lib, prognoz modelini mos ravishda tanlash, natijalarni vizual tahlil qilish hamda inson omilining ta’sirini kamaytirish orqali yuqori aniqlik va ekspluatatsion sharoitlarga moslashuvchanlikni ta’minlaydi.
Kalit so'zlar: energetika tizimlari, dasturiy ta’minot, elektr energiyasi isroflari, prognozlash modellari, , EIPAT axborot tizimi, avtomatlashtirish, adaptiv algoritmlar, samaradorlikni oshirish.

For citation: Nazirova X.Z., G‘oyibova S.G‘, Samiyev Sh.S. The role of innovative software in increasing the efficiency of energy systems. Scientific and technical journal of Problems of Energy and Sources Saving, 2025, no. 4, pp. 371-376.
https://doi.org/10.5281/zenodo.18694194

Received: 05.04.2025
Revised: 19.04.2025
Accepted: 10.07.2025
Published: 27.12.2025

Роль инновационного программного обеспечения в повышении эффективности энергетических систем

Хилола З. Назирова[1], Саодат Г.Гойибова[1,а)], Шохрух С. Самиев[1,б)]

[1] старший препадаватель,Ташкентский государственный технический университет, Ташкент, 100095, Узбекистан; hilolazahidjanovna1987@gmail.com , https://orcid.org/0009-0002-7735-4862
[1,а)] магистрант, Ташкентский государственный технический университет имени Ислама Каримова, г. Ташкент, 100095, Республика Узбекистан; saodat.goyibova@gmail.com
[1,б)] ассистент, Ташкентский государственный технический университет имени Ислама Каримова, г. Ташкент, 100095, Республика Узбекистан; shohruxsamiyev96@gmail.com https://orcid.org/0009-0009-6833-3075

Актуальность: повышение эффективности современных энергетических систем требует не только технических, но и цифровых решений. В частности, резко возрастает потребность во внедрении точных, устойчивых и интеллектуальных инструментов для выявления, анализа и прогнозирования потерь электроэнергии. В этом процессе большое значение приобретают инновационные программные средства, реализующие такие задачи, как обработка данных в режиме реального времени, автоматический выбор прогнозных моделей, работа с кластерными и аномальными данными. В частности, повышение энергоэффективности в низковольтных сетях, таких как распределительные сети 0,4 кВ, обеспечивается за счет внедрения точных механизмов мониторинга и прогнозирования. В таких условиях информационные системы с интеллектуальными функциями, созданные в модульной и адаптивной архитектуре, не только повышают эффективность технического обслуживания, но и обеспечивают объективность и оперативность процесса принятия решений.
Цель: разработка инновационного программного обеспечения, служащего для автоматизации процессов анализа и прогнозирования потерь электроэнергии в энергетических сетях, научная оценка эффективно-

сти системы на основе ее модульной архитектуры, функциональных возможностей и интегрированных моделей прогнозирования.
Методы: в процессе моделирования применен комплексный подход, основанный на взаимной интеграции кластеризации, специализированных нейронных сетей и классических статистических методов, учитывающих структуру данных.
Результаты: разработана инновационная информационная система - ИСПЭЭ, автоматизирующая процессы анализа и прогнозирования потерь электроэнергии в распределительных сетях 0,4 кВ. В структуру системы комплексно интегрированы методы прогнозирования полиномиальной регрессии, ARIMA, GMDH, MLP и гибридный подход. Данная система оснащена адаптивными механизмами, учитывающими сложность и изменчивость структуры данных, обеспечивающими высокую точность и адаптивность к эксплуатационным условиям за счет соответствующего выбора прогнозной модели, визуального анализа результатов и снижения влияния человеческого фактора.
Ключевые слова: энергетические системы, программное обеспечение, модели прогнозирования потерь электроэнергии, информационная система ИСПЭЭ, автоматизация, адаптивные алгоритмы, повышение эффективности.

The role of innovative software in increasing the efficiency of energy systems

Xilola Z. Nazirova[1], Saodat G‘.G‘oyibova[1,a)], Shohrux S. Samiyev[1,b)]

[1] Senior Lecturer, Tashkent State Technical University, Tashkent, 100095, Uzbekistan; hilolazahidjanovna1987@gmail.com https://orcid.org/0009-0002-7735-4862
[1,a)] Master's degree candidate, Tashkent State Technical University, Tashkent, 100095, Uzbekistan; saodat.goyibova@gmail.com
[1,b)] Assistant. Tashkent State Technical University, Tashkent, 100095, Uzbekistan; shohruxsamiyev96@gmail.com https://orcid.org/0009-0009-6833-3075

Relevance: increasing efficiency in modern energy systems requires not only technical, but also digital solutions. In particular, there is a sharp increase in the need to introduce accurate, sustainable, and intelligent tools for identifying, analyzing, and forecasting electricity losses. In this process, innovative software tools that perform tasks such as real-time data processing, automatic selection of forecasting models, and working with cluster and anomalous data are of great importance. This is especially ensured by increasing energy efficiency in low-voltage networks, such as 0.4 kV distribution networks, and implementing precise monitoring and forecasting mechanisms. In such conditions, information systems with intelligent functions, created in modular and adaptive architecture, not only increase the efficiency of maintenance but also ensure the objectivity and speed of the decision-making process.
Aim: development of innovative software that serves to automate the processes of analysis and forecasting of electricity losses in energy networks, scientific assessment of the effectiveness of the system based on its modular architecture, functional capabilities, and integrated forecasting models.
Methods: in the modeling process, a comprehensive approach was applied, based on the integration of clustering, specialized neural networks for forecasting, and classical statistical methods that take into account the structure of data.
Results: An information system for forecasting electricity losses - ISFEL in 0.4 kV distribution networks has been developed. Polynomial regression, ARIMA, GMDH, MLP, and hybrid forecasting methods were integrated into the system. This system is equipped with adaptive mechanisms that take into account the complexity and variability of the data structure, ensuring high accuracy and adaptability to operating conditions through the appropriate selection of a forecast model, visual analysis of results, and reduction of the influence of the human factor.
Keywords: energy systems, software, electricity losses, forecasting models, ISFEL information system, automation, adaptive algorithms, efficiency improvement.

1. Introduction

Improving the efficiency and reliability of modern energy systems requires the integration of not only technical, but also intelligent digital solutions capable of processing multidimensional data, detecting anomalies, and supporting operational decision-making. The increasing complexity of network operating modes, the growth of data volumes, and the presence of heterogeneous and irregular observations create the need for specialized forecasting systems that go beyond the functionality of traditional software packages.

One of the main problems in modern energy systems is the limited possibility of effective analysis and forecasting due to heterogeneous data structures, irregular operating modes, and the insufficient adaptability of existing analytical tools. Widely used systems such as ETAP, OpenDSS, SCADA, and EnergyCS are efficient for steady-state calculations and simulation tasks; however, they do not perform automated model selection, do not account for cluster structures, and lack mechanisms for adaptive forecasting under variable data conditions [1-3].

Considering these limitations, an innovative information system ISFEL - was developed to automate the processes of analyzing and forecasting electricity losses in 0.4 kV distribution networks. The system is designed in a modular and adaptive architecture, ensuring flexibility, scalability, and stable operation with real, multidimensional datasets typical of AMI-based distribution networks. ISFEL integrates advanced analytical tools, structural data assessment mechanisms, and algorithms capable of adapting to the complexity and variability of real-world operational data. ISFEL includes the following functional modules:

The security module - is a basic functional block that includes user authentication, user communication management in the system, and mechanisms for protecting data from unauthorized access. It provides information environment protection through encryption algorithms, identification tools, and an active security policy.

The data collection and storage module - is a functional block that receives, processes, and systematically stores data collected from the electrical network, ACASE devices, and sensors in real time. It lays the foundation for further analysis processes through data filtering, formatting, and storage mechanisms according to an arbitrary structure. The module ensures the continuity of data reception and reliability of storage.

The analysis and modeling module - is the central block that manages the processes of analyzing, processing, and creating intelligent models of the collected data structure. It forms optimal models for forecasting using such methods as data normalization, correlation analysis, PCA, and clustering. This module combines machine learning and statistical methods to create a collection of clean data prepared for the forecast model.

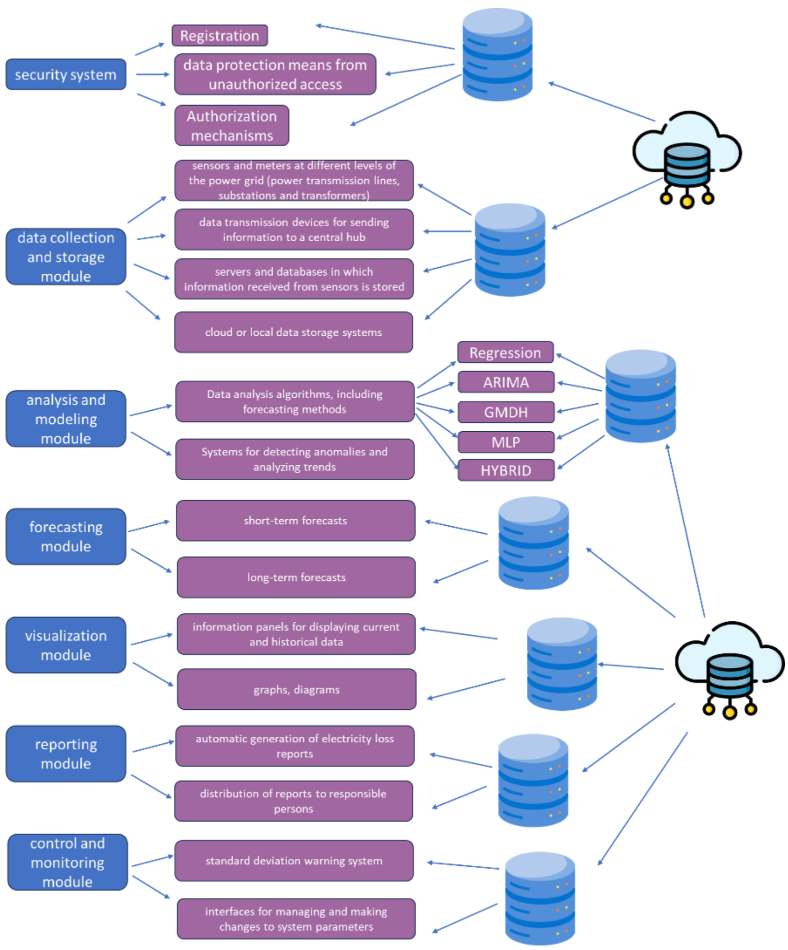

Fig.1 Structural diagram of the information system for forecasting electricity losses

The forecasting module - is the main computing unit that performs the task of accurate forecasting of electricity losses over time. The module performs forecasting based on adaptive and intelligent models (polynomial regression, ARIMA, GMDH, MLP, hybrid models), taking into account data variability and structure. Forecast results recognize anomalous situations and provide automatic adjustment to and maintaining an acceptable level of forecasting error.

The visualization module - is an information block that provides the user with forecast results and data analysis in a clear graphical and interactive form. It describes time series, clusters, load dynamics, and errors using histograms, line graphs, and diagrams. The interface is designed in accordance with user needs and is designed in a clear and easy-to-analyze form.

The reporting module - is a functional block that automatically generates the results of analysis and forecasting processes in the system in the form of a report. The module prepares reports in PDF, Excel, or HTML format, which reflect key indicators, visual diagrams, accuracy criteria, and model selection conclusions. Reports are intended for transmission to internal information systems of the user or organization.

The monitoring and control module - is a module responsible for monitoring the system's performance, managing planned processes, and managing the state of data in real time. It monitors changes in cluster structures, errors in model selection, interruptions in data flow, and transmits signals to the user. It also provides technical integration capabilities and API interfaces for continuous operation with external devices.

The created ISFEL information system differs from existing analogues in a number of scientific and practical advantages. Firstly, the system has a mechanism for automatic selection of a forecast model based on the integral indicator θ when assessing the structure and variability of data, which ensures objectivity and adaptability in the selection of models. Secondly, in order to increase the accuracy of structuring and forecasting anomalous and cluster data, the DBSCAN clustering algorithm is integrated with the MLP artificial neural network, which allows for effective accounting of the structural complexity and perceived variability of the data. Thirdly, the architecture is designed as modular and scalable in accordance with the operational characteristics of local 0.4 kV distribution networks and has the ability to adapt to energy facilities of various scales. Fourthly, the system has the ability to adapt to changes in the quality and structure of data in real time, taking into account the forecast results.

2. Methods and materials

The methodological framework for forecasting electricity losses in 0.4 kV distribution networks is based on the integration of statistical techniques, machine-learning algorithms, and cluster analysis. Real operational data from the 0.4 kV distribution networks of the Yunusabad district of Tashkent, obtained from AMI devices and network sensors, were used for model development and validation. The dataset included active load power P, ambient temperature, relative humidity, actual loss values, and time stamps. The data exhibit seasonality, nonlinearity, and pronounced cluster heterogeneity, which necessitates the use of specialized preprocessing and analytical procedures. [6-8]:

At the initial stage, data cleaning, removal of anomalous observations, feature normalization, and stationarity checks were performed. To identify key dependencies and evaluate factor significance, correlation analysis was conducted, revealing that active power, temperature, and humidity exert the strongest influence on loss formation. Principal Component Analysis (PCA) was applied to visualize the internal structure of the multidimensional dataset, detect latent clusters, and reduce dimensionality without compromising information content.

A central element of the methodology is the integral structural complexity indicator θ, which reflects data variability, heterogeneity, and the degree of nonlinear dependence. In the ISFEL system, θ serves as the basis for automated model selection. To account for local irregularities and uncover stable internal patterns, the DBSCAN clustering algorithm was applied. DBSCAN enables the identification of natural clusters and the detection of anomalous points, forming localized subsets for separate model training. This improves the robustness of forecasting and enhances the adaptability of models to varying data structures.

The ISFEL system employs several forecasting models selected adaptively depending on the value of θ and the structural characteristics of the dataset. Polynomial regression is used when dependencies are smooth with a low level of nonlinearity. The ARIMA model is effective for stationary time series, capturing short-term trend and seasonal components. The Group Method of Data Handling (GMDH) generates self-organizing polynomial models capable of representing complex multi-factor dependencies. The multilayer perceptron (MLP) captures nonlinear interactions between variables and is particularly suitable for multidimensional data. The hybrid DBSCAN + MLP approach combines structural segmentation with localized neural-network training, enabling adaptation to internal cluster patterns and improving forecasting stability.

Forecasting accuracy was evaluated using the Mean Absolute Percentage Error (MAPE):

$$MAPE = \frac{1}{n}\sum_{i=1}^{n}\left|\frac{y_i - \overline{y_i}}{y_i}\right| \cdot 100\% \qquad (1)$$

This metric ensures comparability of results across models of different nature and allows assessment of relative forecasting error independently of scale.

The described methodological framework provides adaptive model selection and stable forecasting performance even under conditions of high data variability and structural heterogeneity. The next section presents the results obtained using the proposed methodology, including comparative accuracy assessment and analysis of model effectiveness under real operating conditions of 0.4 kV distribution networks.

3. Results and discussion

The proposed forecasting methodology was evaluated using real operational data from 0.4 kV distribution networks in the Yunusabad district of Tashkent. This made it possible to assess the performance of the selected algorithms and to identify model-specific behavior under conditions of structural heterogeneity and variability. Based on the integral complexity indicator θ, several forecasting models were constructed, differing in their sensitivity to nonlinear dependencies, robustness to outliers, and ability to account for the internal cluster structure of the dataset.

Graphical comparison of the actual and forecasted values revealed substantial differences among the models. Polynomial regression demonstrated acceptable accuracy on segments with smooth dynamics; however, its ability to reproduce abrupt fluctuations was limited. The ARIMA model provided stable short-term results and captured the seasonal–trend structure of the data, yet remained sensitive to structural breaks and local anomalies.

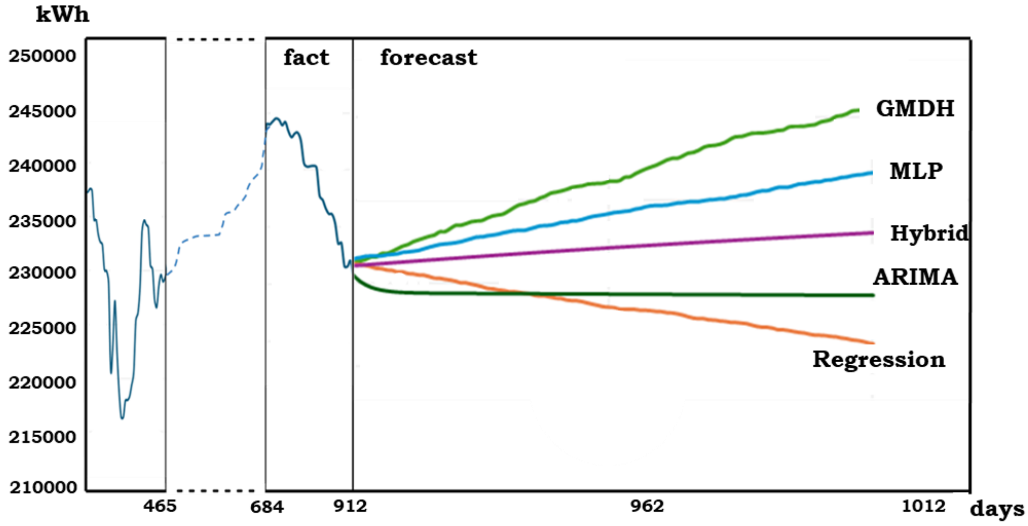

Fig.2. Graph of comparison of actual and forecast values of electricity losses according to different models

Table 1. Comparative evaluation of forecasting model accuracy by the MAPE criterion

MAPE	Polynomial regression	ARIMA	GMDH	MLP	Hybrid
	5,01	3,15	5,05	2,58	2,1

The GMDH method demonstrated the ability to capture complex multi-factor relationships; however, under high variability, a tendency toward overfitting was observed, which led to an increase in error on the test data. The multilayer perceptron (MLP) provided considerably higher robustness to nonlinearity, effectively capturing the structure of the time series and performing well in the presence of seasonal and stochastic fluctuations.

The most significant improvement was achieved using the hybrid DBSCAN + MLP model. Preliminary data structuring with DBSCAN allowed the dataset to be partitioned into locally homogeneous clusters and anomalous observations to be separated. As a result, the subsequent training of cluster-specific MLP models ensured a substantial increase in forecasting stability, reduced the influence of irregular points, and improved the quality of approximation. The hybrid model achieved the lowest MAPE value, indicating its superior ability to reproduce the real dynamics of electricity losses under conditions of pronounced structural heterogeneity. This behavior is especially important for time series with local transitional modes, irregular load variations, and fluctuating environmental factors.

The comparative evaluation demonstrated that traditional statistical models retain advantages when processing datasets with simple structure and moderate variability due to their interpretability and low computational cost. However, in the presence of nonlinear dependencies, cluster patterns, and high variability, neural-network-based and hybrid methods exhibit clear superiority. The structural complexity indicator θ plays a key role, providing an objective measure for matching the properties of the data with the forecasting model type, thereby ensuring adaptive model selection.

Overall, the experimental results confirm the effectiveness of the proposed approach, which integrates structural data analysis, clustering, and intelligent modeling. The hybrid DBSCAN + MLP model demonstrated the highest stability and accuracy and can be considered a promising tool for practical applications in real 0.4 kV distribution networks.

4. Conclusion

The ISFEL information system developed in this study represents an intelligent platform designed to fully automate the processes of analyzing and forecasting electricity losses in 0.4 kV distribution networks. By integrating structural analysis, model selection mechanisms, and advanced forecasting algorithms, the system is capable of effectively working with heterogeneous datasets that contain clustered structures and anomalous observations. The use of the integral complexity indicator θ enables objective assessment of data properties and supports adaptive selection of the most suitable forecasting model.

ISFEL incorporates several predictive approaches-including polynomial regression, ARIMA, GMDH, MLP, and the hybrid DBSCAN + MLP model-which are automatically selected according to the structural variability and complexity of the input data. The hybrid approach, combining DBSCAN-based clustering with MLP models trained within each cluster, demonstrated the most reliable results. Practical testing confirmed that this architecture provides the lowest MAPE value (2.1%), indicating its superior ability to reproduce the actual behavior of electricity losses under real operating conditions.

The architectural and algorithmic solutions implemented in ISFEL are technically scalable and may be adapted for distribution and transmission networks operating at voltage levels higher than 0.4 kV. However, the present study focused specifically on 0.4 kV networks, as statistical and operational data indicate that this voltage level accounts for the largest share of electricity losses. Consequently, the developed models and functional modules are optimally aligned with the operational characteristics and data structure of local 0.4 kV systems.

Future research directions include extending the applicability of ISFEL to medium- and high-voltage networks, evaluating system performance in various grid topologies, and improving computational efficiency for large-scale datasets. Additional developments may also involve the integration of real-time data streams, reinforcement learning mechanisms, and advanced anomaly detection techniques to further enhance forecasting reliability and practical applicability.ics and data structure of local 0.4 kV systems.

REFERENCES

1. Allaev K.R. Electric Power Industry of Uzbekistan and the World. Tashkent: Fan va texnologiya, 2009. 463 p

2. Allaev K.R. Modern Energy and Its Development Prospects / Ed. by Acad. A.U. Salimov. Tashkent: Fan va texnologiyalar, 2021. 953 p.

3. Allaev K.R. Prospects for the Development of Uzbekistan’s Energy Sector up to 2035 and Beyond: Issues of Energy and Resource Saving // In: Modern Problems of Power Engineering. Tashkent: Fan, 2022. Pp. 25–37.

4. Allaev K.R., Nazirova Kh.Z. Comparative Assessment of Power Losses in Electric Networks Us-ing ANN and GMDH Methods // Problems of Energy and Resource Saving. 2024.

5. Allaev K.A., Nazirova Kh.Z. Comparison of Various Methods for Forecasting Power Losses in Electrical Networks // Problems of Energy and Resource Saving. 2024. Pp. 41–50.

6. Kaur, D., Aujla, G. S., Rani, S., & Kumar, N. (2020). Energy forecasting in smart grid systems: A review of the state-of-the-art techniques. Computer Communications, 151, 525–544. https://doi.org/10.1016/j.comcom.2020.01.014

7. Sharifhosseini, S. M., Marzband, M., & Lehtonen, M. (2024). Investigating intelligent forecasting and optimization in electrical power systems: A machine learning approach. Energies, 17(21), 5385. https://doi.org/10.3390/en17215385

8. Li, Y., & Zhao, J. (2025). Machine learning applications in energy systems: Current trends and future directions. Energy Informatics, 4(1), Article 18. https://doi.org/10.1186/s42162-025-00524-6

9. Zhang, L., Wang, H., & Liu, Y. (2024). Energy forecasting: A comprehensive review of techniques and technologies. Energy Reports, 10, 420–437. https://doi.org/10.1016/j.egyr.2024.01.027

10. Ghasemi, M., & Ahmadi, A. (2023). Smart management of energy losses in distribution networks using artificial neural networks. Energies, 16(12), 3156. https://doi.org/10.3390/en16123156