Computer system for energy distribution in conditions of electricity shortage using artificial intelligence

Andrii Voloshchuk[1,*,†], Diana Velychko[1,2,†], Halyna Osukhivska[1,†] and Andriy Palamar[1,†]

[1] *Ternopil Ivan Puluj National Technical University, Ruska str., 56, 46001, Ternopil, Ukraine*
[2] *Rochester Institute of Technology, 1 Lomb Memorial Dr, Rochester, 14623, New York, USA*

Abstract
This paper proposes energy distribution in conditions of electricity shortage carried out by a computer system using artificial intelligence (AI). The architecture of the data collection computer system is described based on the Internet of Things.
The proposed method employs Genetic Algorithms (GA) to optimize electricity distribution in deficit conditions, offering a rapid and efficient solution to energy shortages. The study evaluates AI's potential in managing electricity distribution during crises. It explores strategies for automated development and management of distribution algorithms, emphasizing the importance of AI in addressing critical challenges in the energy sector.

Keywords
computer system, artificial intelligence, genetic algorithm, electricity distribution, internet of things

1. Introduction

Nowadays, electricity shortages or blackouts can occur due to various situations. These circumstances include weather conditions, accidents or any other unforeseen events, a prime example of which is russia's missile attacks on Ukraine's civilian infrastructure. One of the massive attacks in November 2022 caused a massive blackout in the Ukrainian power grid. It resulted in electricity shortage for the Ukrainian civilian population and infrastructure. To improve the situation through redistribution of resources and allow access to electricity for all units, electricity availability schedules were introduced. Such schedules were being developed over a long period of time. They did not always ensure an even distribution of electricity among consumers and did not effectively take into account changes in its volumes. To respond to such challenges more quickly, it is advisable to use all

CITI'2024: 2nd International Workshop on Computer Information Technologies in Industry 4.0, June 12–14, 2024, Ternopil, Ukraine
* Corresponding author.
† These authors contributed equally.
andriy.voloschuk30@gmail.com (A. Voloshchuk); velychkodiana18@gmail.com (D. Velychko); osukhivska@tntu.edu.ua (H. Osukhivska); palamar.andrij@gmail.com (A. Palamar)
0009-0007-1478-1601 (A. Voloshchuk); 0000-0001-7635-1761 (D. Velychko); 0000-0003-0132-1378 (H. Osukhivska); 0000-0003-2162-9011 (A. Palamar)

the capabilities of modern technologies, particularly artificial intelligence, and implement intelligent energy accounting systems. AI-driven solutions play a pivotal role in automating and optimizing data processing, offering benefits to the energy sector. This allows for stable operation of the energy system, reduces energy supply costs, and assists in providing fast and efficient energy distribution in times of power shortages.

Overall, AI integration into energy accounting systems marks a significant leap forward in addressing the challenges posed by inaccurate consumption forecasts and in particular energy distribution in conditions of electricity shortage. These intelligent systems open opportunities to not only improve energy efficiency, ensure energy security, and integrate renewable energy sources but also contribute significantly to environmental sustainability. Maximizing the benefits of these systems entails careful consideration of financial, privacy, technological, and standardization aspects, ultimately ensuring their efficient and sustainable operation in a dynamic energy sector.

One of the most significant benefits of integrating AI is its ability to enhance data accuracy and reduce manual errors, a critical aspect of effective energy management, especially in times of energy shortages. These AI-powered systems not only eliminate the potential for human error but also ensure precision in measurement, aligning perfectly with the demands of modern energy ecosystems.

Furthermore, AI empowers these systems to delve deep into detailed energy consumption data, uncovering inefficiencies, and identifying opportunities for the implementation of energy-efficient solutions, one of which is power distribution in times of power shortages. Such insights lead to both substantial cost savings and improved overall system performance, as well as rapid response to power shortages and efficient redistribution of power, thus addressing one of the critical challenges faced by the energy sector.

The relevance of implementing intelligent energy accounting systems lies in their ability to ensure accurate measurement of electricity, control its consumption and distribution, and improve medium-term electricity consumption forecasting. This enhances the efficiency of energy supply systems and reduces management costs. Furthermore, this can contribute to the realization of the "smart city" concept, where energy supply systems and networks interact with each other and the population to achieve more efficient and stable energy supply in an energy-scarce environment.

The aim of the research is to assess the potential of using artificial intelligence to optimize the management of electricity distribution in deficit conditions. The study is aimed at identifying effective strategies for utilizing artificial intelligence for automated development of electricity management algorithms in situations of energy crises and resource constraints. Additionally, the goal is to explore the possibilities of applying artificial intelligence to improve energy consumption forecasting and ensure efficient operation of energy systems in conditions of instability and resource constraints.

2. Related works

The state of the art in using artificial intelligence (AI) in sustainable energy, including renewable energy and energy efficiency is described by the authors [1-3]. In [3-5] researchers explore different scenarios of AI applications in sustainable energy and suggest ways to develop and implement AI in this industry. The papers also highlight the main challenges faced by this industry, as well as the opportunities offered by the use of AI. They delve into the role of machine learning techniques in improving the efficiency, reliability, and cost-effectiveness of renewable energy systems and highlight the practical applications of machine learning algorithms in predicting renewable energy generation, optimizing energy storage, and accurately forecasting energy demand.

Papers [2-4] are devoted to intelligent methods of electricity supply forecasting, an overview and prospects for the use of machine learning methods in the field of sustainable energy, electricity demand forecasting, etc.

Forecasting short-term electric load is presented in the papers [6, 7]. Research [6] offers a method for short-term electrical demand forecasting that incorporates three approaches: kernel principal component analysis (KPCA), Levy tree seed algorithm (LTSA), and extreme learning machine (ELM). The results of this experiments showed that the suggested KPCA-LTSA-ELM approach has various advantages over previous methods: LTSA assists in determining the appropriate parameters for ELM, resulting in more accurate forecasts. KPCA shortens training time by reducing data amount, allowing ELMs to learn faster. LTSA avoids local optima, guaranteeing that the model converges to the optimal solution. In paper [7] a method of calculating short-term electrical load that combines KPCA, LTSA, and ELM is proposed. Forecasting of medium-long-term electricity consumption using ARIMA methods and exponential smoothing is devoted to the article [8].

The main areas of use of artificial intelligence technologies in the energy sector of Ukraine, priority areas of application of modern technologies in energy supply systems, and problems that hinder the introduction of artificial intelligence at the corporate and public levels are described in [9]. The authors have prepared recommendations on the priorities for stimulating the development and application of artificial intelligence technologies in the energy sector of Ukraine and described the requirements for expanding the use of AI in the energy sector of Ukraine. In particular, the technical requirements are specified, which include hardware (smart meters for collecting a large amount of high-quality detailed data and smart grids); software and dedicated human expertise (i.e. data scientists who can develop machine learning algorithms and continuously improve models applicable to the Ukrainian energy sector [9]. However, this work does not address the problem of energy redistribution in the event of energy shortages, in particular for the automated generation of power outage schedules.

In [10-12] the use of a genetic algorithm is proposed for intelligent electricity management and optimization of power systems. It is worth noting that this study focuses on the method of fast and efficient energy distribution in case of energy shortages to provide a predictable temporary solution to the problem for consumers.

However, no effective solution has been proposed in the known works to distribute electricity in conditions of long-term electricity shortages, in particular, those that would be effective in the conditions that arose during the war in Ukraine. This paper is devoted to the actual problem of introducing and using AI in the energy sector of Ukraine to distribute electricity in conditions of shortage.

3. System architecture

To fulfill the data collection objective of the research, the proposal suggests utilizing the framework of a computerized energy enterprise system. Adopting the framework of a computerized energy enterprise system rooted in the Internet of Things (IoT) concept is advocated in [13]. Generally, intelligent systems comprise [14]: smart meters, local networks, Global networks, gateways.

For secure and dependable communication, smart networks employ various additional technologies, including wireless local networks, virtual private networks, and mobile networks [15]. By integrating these technologies, "smart" networks can surmount communication obstacles and establish a more efficient and secure energy management system.

Automation facilitated by AI streamlines the entire process of data collection and analysis, making energy accounting a seamless and efficient operation for both operators and consumers. However, it's essential to acknowledge that the implementation of AI-driven energy accounting systems does come with its challenges, including initial high costs, privacy and security concerns related to data collection, the dependence on modern technologies like smart meters, and the need for standardization and compatibility among systems from different manufacturers. The network architecture for data collection at an energy company is shown in Figure 1.

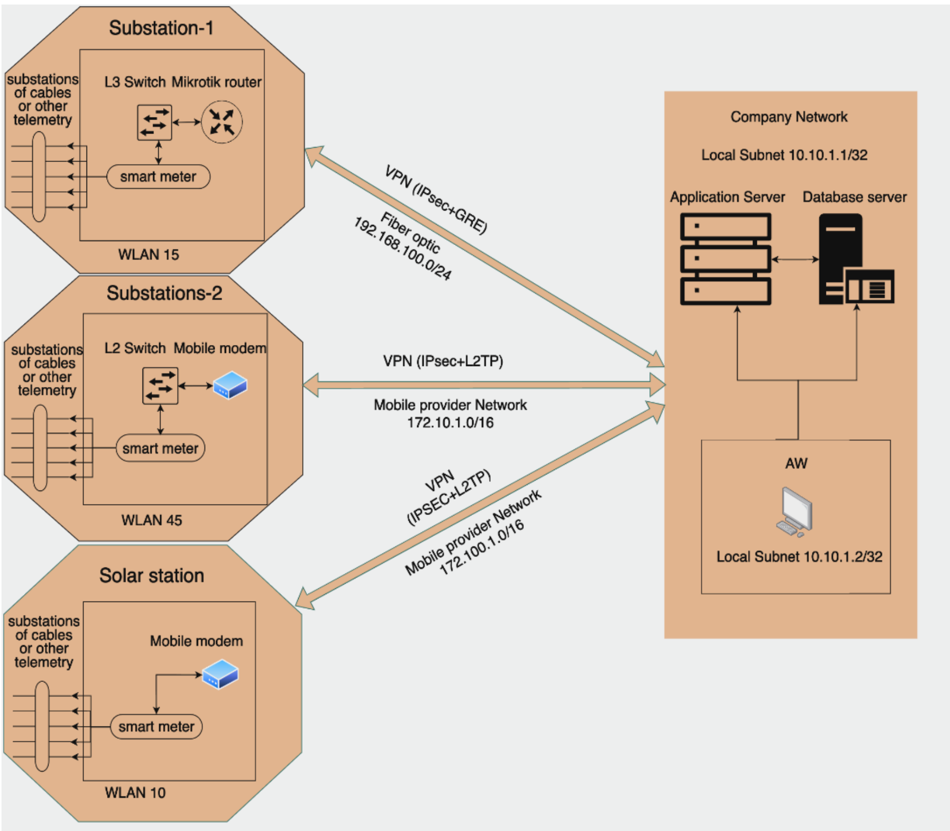

Figure 1: Network architecture for data collection.

The system receives real-time data streams from a variety of sources, including current and voltage transformers, protection relays, and various sensors distributed throughout the electrical network. This data is then processed and analyzed by sophisticated AI algorithms. During the analysis, the AI system identifies patterns, trends, and anomalies, providing valuable insights into the overall health and performance of the electrical system. Operators gain a comprehensive understanding of system dynamics, including load fluctuations, voltage stability, and equipment condition, enabling them to make informed decisions regarding maintenance, optimization, and resource allocation.

The network architecture for electrical systems presented here features two primary servers deployed within the enterprise. One server acts as an application server, handling client requests, executing calculations, managing logic, and fulfilling other essential tasks to generate responses for clients. Additionally, it oversees data management, interacts with the database server, and manages user authentication and authorization. The second server, referred to as the database server, is responsible for storing and organizing data, executing database operations such as creating, reading, updating, and deleting records, and processing queries to deliver results to clients based on stored information. The collaboration between these two servers ensures the smooth operation of applications and the safeguarding of critical data, thereby contributing to the optimization of electrical systems [16].

All management processes are controlled by an Automated Workstation (AW) for electrical systems which is an essential computer-based tool [17] that enables efficient management, monitoring, and optimization of electrical power systems.

One of the key functions of AW is monitoring and diagnostics, which involves collecting and analyzing data related to equipment status, network operations, and electrical parameters. This allows operators to detect anomalies, defects, or energy leaks promptly, ensuring timely responses and preventive measures against potential accidents. AW also helps in resource optimization by determining operating modes for equipment, load schedules, energy management, and energy consumption reduction. The use of data storage systems in AW allows for efficient record-keeping and analysis of system performance.

To achieve secure communication, all channels in the network are implemented with robust protection mechanisms, using various encryption methods through dedicated channels. This approach ensures the confidentiality and integrity of transmitted data, making interception and data manipulation significantly more challenging.

The utilization of these secure channels and access points is of paramount importance in ensuring the security, reliability, and confidentiality of electrical systems. By applying network protection measures, access can be restricted solely to authorised users and devices, preventing unauthorised access and protecting the system against potential threats and attacks. The encryption provided by secure channels significantly enhances the confidentiality and integrity of transmitted data, particularly critical when dealing with sensitive information about the status and functionality of electrical systems. That helps to be fault tolerant [18] and to ensure that a smart grid's network remains operational and resilient even when certain components or elements experience failures or faults. This could be important for maintaining a stable and reliable energy distribution system, especially in situations where the grid relies on software-defined networking for control and management.

The data obtained using the described architecture is an important tool for analyzing, forecasting and redistributing electricity. They provide valuable information about consumption over a certain period, helping to understand trends, patterns, and dependencies. Analyzing this data helps to identify seasonal changes in consumption, as well as to develop consumption forecasts, which are important for planning and managing energy resources, in case of energy shortages, they can be used for electricity distribution and automated creation of outage schedules.

4. Proposed method

For the optimal and fast distribution of energy resources between consumers, it is advisable to use the methods of Artificial Intelligence. To search for the most efficient combination of electricity consumption zones at a given time within limited resources, it is proposed to use the Genetic Algorithm (GA). In this context, GA can be used to build the schedule of electricity availability in these zones, which helps distribute energy resources quickly, more efficiently, and evenly.

This way, the GA has the following presentation: each gene on the chromosome represents a zone; each chromosome is a list of zones to be powered simultaneously. Each gene has its own "value" and "weight". In our case, the value is the number of entities that gain access to electricity in the zone. The weight is the electric power needed to electrify the zone. As the amount of electric power is limited in cases of energy shortage and this limit can change at any time, it is the most important resource to consider as a constraint for the fitness function. The following formula is proposed as a Fitness function:

$$Fitness = \begin{cases} \sum_{i=1}^{n} c_i \cdot v_i, & \text{if } \sum_{i=1}^{n} c_i \cdot w_i \leq W \\ 0, & \text{otherwise} \end{cases} , \quad (1)$$

where c_i – is the value of the gene, whether the region is included, v_i – is the number of entities affected (people/factories/organizations/hospitals), w_i – is the electricity needed for the set of entities affected in the region, and W – is the amount of electric power available.

It is important to understand that the schedule is divided into certain time periods. GA should be run for each time period separately. The GA is offered to be used in a sequence so that the schedule is generated for each time period separately, taking into consideration that certain zones are banned from selection if they are chosen in the previous step. During the operation of the algorithm, the regions are encoded binary, which is shown in Figure 2.

The GA algorithm is run for a few epochs while the importance values are changed in a way presented in Figure 2 to provide all regions with electricity without giving preference to just some of them. The best individuals from all epochs are saved as the schedule of electricity availability.

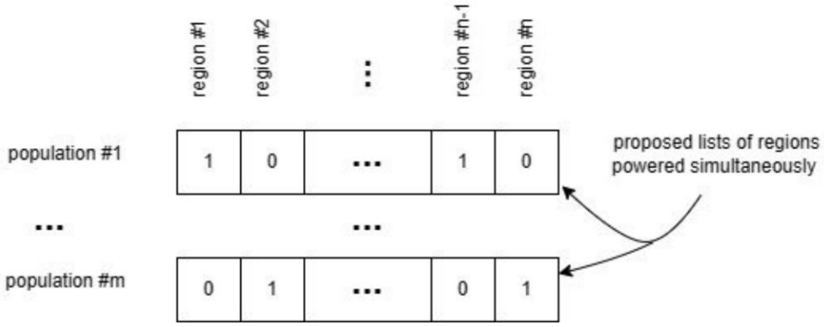

Figure 2: The encoding of data for GA.

To generate a simulation of the situation in which the algorithm should be used, we will use a data set of hourly energy usage that can be found on the Internet (kaggle.com). The dataset which contains hourly energy consumption levels provided by different US energy regions [19] is used as an example instead of data from Ukraine which is concealed for safety reasons.

The dataset contains hourly energy consumption over several years, so for simplicity, the dataset was trimmed to contain the hourly consumption during one full day. The algorithm was run for 11 regions, although the number of regions is not important. The algorithm can work for any number of regions in the dataset. The dataset containing information on electricity consumption by 11 regions during one day is shown in Figure 3.

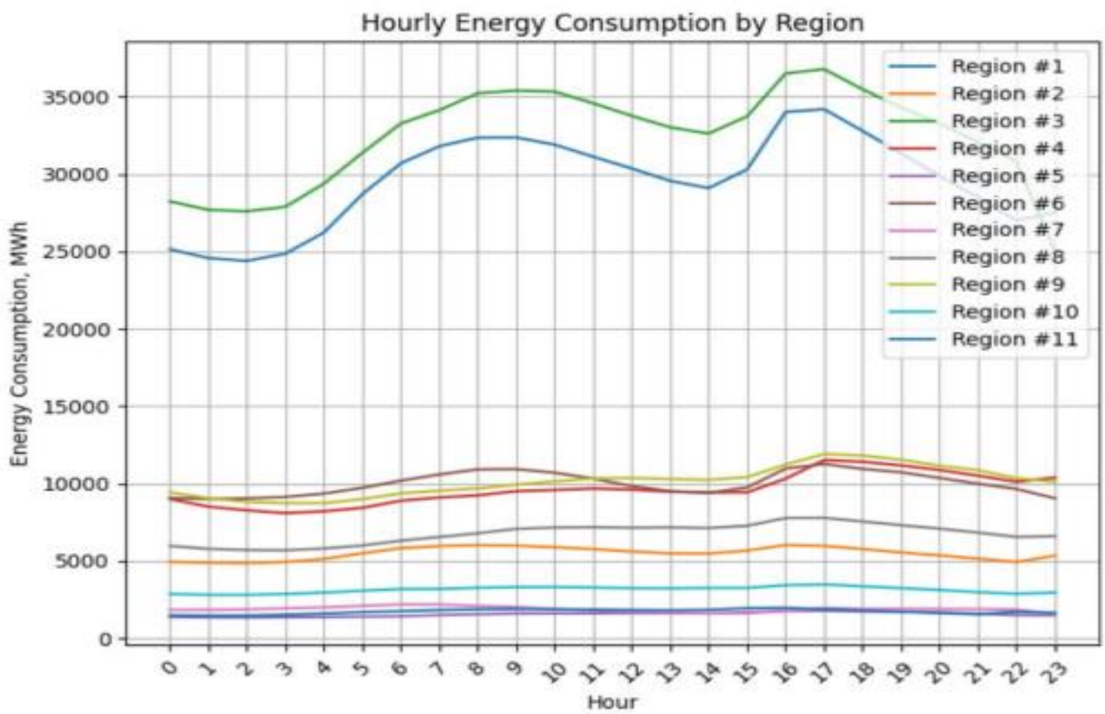

Figure 3: The dataset contains information on the electricity consumption of 11 regions during the day.

5. Results and discussions

The GA should only be a part of the system software, it should be used in the cycle outlined. Firstly, it is important to understand that the schedule is divided into certain time periods, e.g. 2 hours. GA should be run for each time period separately. The regions are already defined, as well as, the number of entities affected, the average amount of electricity power needed for the region, and the power limit.

For the first time period, the population is generated automatically. For the second time period, the regions chosen in the previous iteration are banned, the rest can be chosen. For the third iteration, the regions chosen are the ones that have not been chosen in the 1st and the 2nd are allowed, etc. This process is repeated until the sum of powers needed for all regions left is less than the maximum, and then the regions from iteration #1 are allowed to participate in the "population" again. The same pattern is repeated. The generated schedule of electricity availability using the proposed algorithm for 11 regions with a conditional limit of 70000 MW is shown in Figure 4. The algorithm was implemented using Python.

The main advantage of the algorithm is the fact that it provides results significantly faster than any human operator and promotes equal distribution of energy sources based on importance. In addition, the schedule can be changed dynamically when more energy is available.

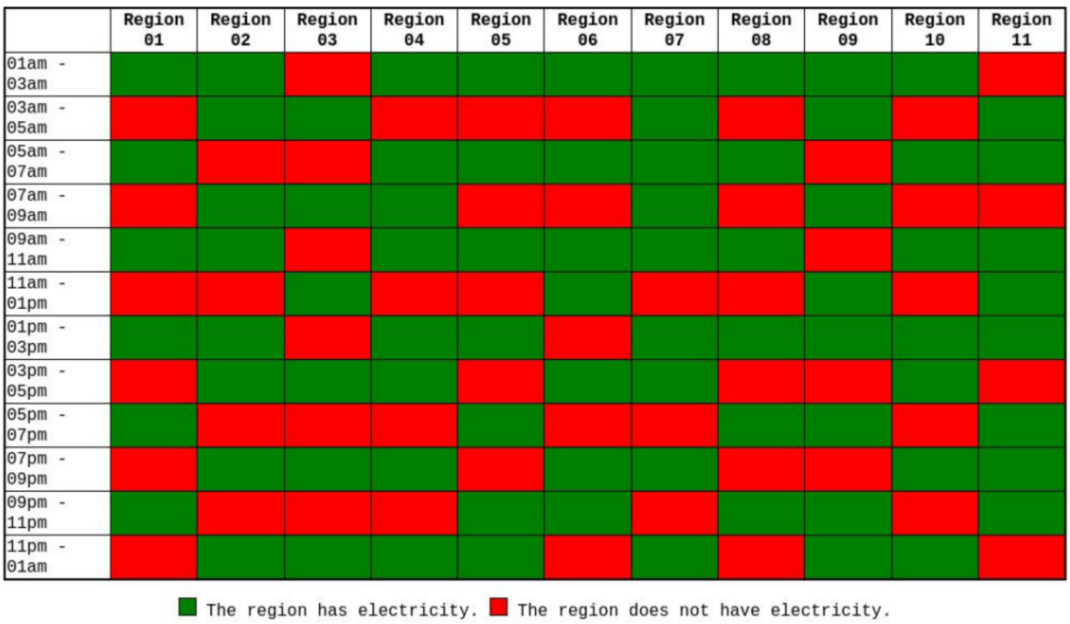

Figure 4: The schedule of electricity availability for 11 regions with a conditional limit of 70000 MW.

Knowing how much electricity is needed to meet the needs of all regions has important benefits. Having that data will allow you to plan some maintenance, and rebuild some communication nodes without inconveniencing consumers. This can solve a lot of problems increase performance and provide a lot of benefits.

An improved understanding of regional electricity needs enables better supply planning, enhancing the reliability of electricity supply, especially in critical scenarios such as emergencies and crises.

In conclusion, comprehending both current and future electricity demand is a fundamental component of ensuring the efficient and reliable operation of the energy system, ultimately promoting economic and environmental efficiency.

6. Conclusions

The proposed computer system was designed for energy distribution in conditions of electricity shortage using artificial intelligence. The integration of AI into energy accounting systems presents significant advantages in improving data accuracy, minimizing manual errors, and boosting overall system performance. AI-powered solutions facilitate efficient energy distribution, cost reduction, and swift response to power shortages. The proposed GA method provides a streamlined approach to distributing energy resources, ensuring equitable distribution and dependable energy supply. Understanding regional electricity needs leads to better supply planning, and heightened system reliability, and fosters economic and environmental efficiency in the energy industry. Ultimately, AI-driven solutions play a pivotal role in tackling challenges and optimizing energy management during crises and resource limitations.

This computer system may be used not only in Ukraine but in any country/region where a power outage or shortage may appear due to severe weather conditions or any other unpredictable events.

References

[1] T. Ahmad, D. Zhang, C. Huang, H. Zhang, N. Dai, Y. Song, H. Chen, Artificial intelligence in sustainable energy industry: Status Quo, challenges and opportunities, Journal of Cleaner Production, 289 (2021) 125834. doi: 10.1016/j.jclepro.2021.125834.

[2] K.P. Amber, R. Ahmad, M.W. Aslam, A. Kousar, M. Usman, M.S. Khan, Intelligent techniques for forecasting electricity consumption of buildings, Energy, 157 (2018), pp.886-893. doi:10.1016/j.energy.2018.05.155.

[3] S. Williams, M. Short, Electricity demand forecasting for decentralised energy management, Energy and Built Environment, 1(2), 2020, pp.178-186. doi:10.1016/j.enbenv.2020.01.001.

[4] D. Rangel-Martinez, K.D.P. Nigam, L.A. Ricardez-Sandoval, Machine learning on sustainable energy: A review and outlook on renewable energy systems, catalysis, smart grid and energy storage, Chemical Engineering Research and Design, 174 (2021), pp. 414-441. doi:10.1016/j.cherd.2021.08.013.

[5] R. Teixeira, M. Antunes, D. Gomes, Using Deep Learning and Knowledge Transfer to Disaggregate Energy Consumption. Adelaide, In 2021 International Conference on Wavelet Analysis and Pattern Recognition (ICWAPR), 2021, pp. 1-7. doi:10.1109/ICWAPR54887.2021.9736149.

[6] X. Chen, K. Przystupa, Z. Ye, F. Chen, C. Wang, J. Liu, O. Kochan, Forecasting short-term electric load using extreme learning machine with improved tree seed algorithm based on Lévy flight. Eksploatacja i Niezawodność, 24(1), 2022, pp. 153-162.
[7] L. Sun, H. Qin, K. Przystupa, M. Majka, O. Kochan, Individualized short-term electric load forecasting using data-driven meta-heuristic method based on LSTM network. Sensors, 22(20), 2022, 7900.
[8] E.M. de Oliveira, F.L.C. Oliveira, Forecasting mid-long term electric energy consumption through bagging ARIMA and exponential smoothing methods, Energy, 2018, 144, pp. 776–788.
[9] O.M. Sukhodolia, Artificial Intelligence in Energy: Analytical Report, Kyiv: NISD, 2022, 49 p. (in Ukrainian). doi:10.53679/NISS-analytrep.2022.09.
[10] L. Lin, A. Abdallah, M.K. Ishak, Z.M. Ali, I. Khan, K. Rabie, I. Safak Bayram, X. Li, D. Madsen, K.I. Kim, Hierarchical optimization and grid scheduling model for energy internet: a genetic algorithm-based layered approach, Frontiers in Energy Research, 10 (2022) 921411. doi:10.3389/fenrg.2022.921411.
[11] R. Torkan, A. Ilinca, M. Ghorbanzadeh, A genetic algorithm optimization approach for smart energy management of microgrids, Renewable Energy, 197, 2022, pp. 852-863. doi:10.1016/j.renene.2022.07.055.
[12] M. Dehghani, M. Mardaneh, O.P. Malik, J.M. Guerrero, C. Sotelo, D. Sotelo, M. Nazari-Heris, K. Al-Haddad, R.A. Ramirez-Mendoza, Genetic algorithm for energy commitment in a power system supplied by multiple energy carriers, Sustainability, 12(23), (2020) 10053. doi:10.3390/su122310053.
[13] A. Palamar, M. Karpinski, M. Palamar, H. Osukhivska, M. Mytnyk, Remote Air Pollution Monitoring System Based on Internet of Things, In CEUR Workshop Proceedings, volume 3309, 2022, pp. 194–204.
[14] D.B. Avancini, J.J. Rodrigues, S.G. Martins, R.A. Rabêlo, J. Al-Muhtadi, P. Solic, Energy meters evolution in smart grids: A review,Journal of cleaner production, 217, 2019, pp. 702-715. doi:10.1016/j.jclepro.2019.01.229.
[15] H. Osukhivska, I. Tysh, T. Lobur, I. Shylinska, S. Lupenko, Method for estimating the convergence parameters of dynamic routing protocols in computer networks, In IEEE 16th International Conference on Computer Science and Information Technologies (CSIT), volume 2, 2021, pp. 228–231.
[16] K. Liu, C. Wang, X. Zhou, Decentralizing access control system for data sharing in smart grid, High-Confidence Computing, 3(2), (2023) 100113. doi:10.1016/j.hcc.2023.100113.
[17] A. Palamar, M. Karpinskyy, V. Vodovozov, Design and implementation of a digital control and monitoring system for an AC/DC UPS, In 7th International Conference-Workshop “Compatibility and Power Electronics” (CPE), 2011, pp. 173–177. doi:10.1109/CPE.2011.5942227.
[18] C. Lee, S. Shin, Fault tolerance for software-defined networking in smart grid, In IEEE International Conference on Big Data and Smart Computing (BigComp), 2018, pp. 705-708. doi:10.1109/BigComp.2018.00131.
[19] Hourly Energy Consumption (kaggle.com). URL: https://www.kaggle.com/datasets/robikscube/hourly-energy-consumption/data.