COMPUTATIONAL PROBLEMS OF ELECTRICAL ENGINEERING

Vol. 14, No. 1, 2024

EMERGING TRENDS IN MICROGRIDS TECHNOLOGY AND PROSPECTS FOR THEIR IMPLEMENTATION IN UKRAINE

Vasyl Khai

Lviv Polytechnic National University, Lviv, Ukraine

vasyl.m.khai@lpnu.ua,

https://doi.org/

Abstract: This reseaech explores the expediency and future prospects of microgrids implementing. Their potential applications in various sectors like transportation, military operations, and civil infrastructure have been analyzed. The research involved reviewing current literature and real-world case studies to highlight the benefits that microgrids offer, such as enhanced energy reliability, reduced costs, and improved security.

A detailed PESTLE analysis (Political, Economic, Social, Technological, Legal, and Environmental factors) of implementing microgrids in Ukraine has been done. The reuslts have shown that with the right combination of regulatory support, financial investment, and technological innovation, including advancements in blockchain, artificial intelligence, and machine learning, microgrids can become a cornerstone of resilient and sustainable energy systems.

This research offers an overwiev for researchers, policymakers and investors interested in promoting energy independence and stability after afterwar rebuilding of Ukraine.

Keywords: microgrid, harmonics, RES (Renewable Energy Sources), smart grid.

1. Introduction

The current trends in the development of energy systems demonstrate the active implementation of distributed generation technologies, such as microgrids. These systems are becoming the base for modernizing energy networks and integrating distributed energy sources (both renewable and non-renewable), enhancing the power supply's reliability and efficiency. The study explores the concept of microgrids, their advantages, disadvantages, and the challenges that hinder their widespread adoption. The research focuses on individual microgrids and microgrids operating in connection with centralized energy systems. The subject of this research is the feasibility and prospects of implementing microgrid.

2. General overview of microgrid technology

A microgrid is an autonomous power system that generates electricity directly near the point of consumption. These systems can function in integration with the main power grid and operate in "island mode" in case of centralized grid outages or during periods of high electricity tariffs (such as when dynamic pricing is used), as well as in hybrid mode. In hybrid mode, a microgrid switches between grid-connected and autonomous operation depending on the availability and reliability of the primary power grid. To ensure stable operation, a microgrid must integrate, monitor, and manage its distributed energy resources (DERs), which helps to increase the efficiency and resilience of the system. The structure of a typical microgrid is shown in the Figure 1.

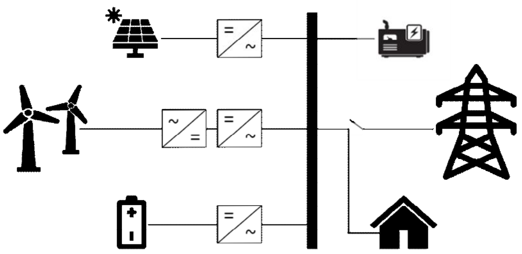


Fig. 1. Topological diagram of a typical microgrid.

Microgrids can be particularly useful in remote areas where the primary electrical grid is unavailable or unreliable. In developing countries, microgrids can provide an affordable and stable source of electricity for communities that previously lacked access to it. Additionally, microgrids promote energy independence and resilience, which is especially important for regions vulnerable to natural disasters or active conflict.

Microgrids represent an innovative technology that is still in the early stages of development. However, there are already several examples of successful implementation around the world. For example, the "Brooklyn Microgrid" project in New York (USA) is a community-level microgrid that uses solar panels, battery storage, and backup generators to provide reliable and affordable electricity to consumers [1]. Another example is the "Alamosa Solar" project in Colorado (USA), a hybrid microgrid that combines a large-scale solar power plant with battery storage and natural gas backup generators to deliver reliable and cost-effective electricity to the local community [2].

In addition to these examples, significant research and development aim to improve microgrids' performance and economic efficiency. Researchers are exploring new battery chemistries and storage technologies that could enhance energy density and battery lifespan. New control and monitoring systems are also being developed to improve the reliability and efficiency of microgrids and investigate the potential use of emerging renewable energy sources, such as wave energy and geothermal energy.

3. Potential microgrids development sectors

- Transport sector: given the increasing number of electric vehicles, the demand for a reliable and efficient infrastructure to charge them is growing. Microgrids can provide a local energy source for electric vehicle charging stations, reducing the load on the primary energy grid and creating a more resilient and flexible energy system [3].
- Military sector: microgrids can provide a secure and reliable energy source for military bases and critical infrastructure, reducing risks associated with power supply interruptions [4].
- Municipal and private sectors: empowering local communities to manage their energy systems through microgrids promotes greater social equity and active management of community energy needs. Community-based microgrids can create a more decentralized and democratic energy system, enhancing energy security and reducing the risk of blackouts in centralized systems.
- New financial mechanisms and business models are needed to attract investments in these projects. Local financing could include community ownership models, where residents pool resources to develop microgrids [5].

A critical area for the development of microgrids is disaster response and recovery. The primary energy grid typically suffers significant damage during natural disasters (hurricanes, earthquakes, floods) or, as in Ukraine, during military conflicts, leading to prolonged power outages and the destruction of critical infrastructure. In such conditions, microgrids can serve as a reliable and flexible energy source, supporting more efficient response and faster recovery [5].

Another direction of development is sustainable urban development. Microgrids can power individual buildings or neighborhoods, reducing the load on the primary grid and improving the energy system's overall resilience. They are able to integrate renewable energy sources, such as solar and wind power, into the overall energy infrastructure.

4. Microgrids potential advantages

Microgrids offer several significant advantages over traditional energy systems:

- increased reliability: microgrids operate autonomously, meaning they can continue to supply electricity even if the primary grid fails or is disrupted;
- reduced energy costs: microgrids that combine renewable energy sources and storage systems can lower electricity costs and enhance energy efficiency;
- improved energy security: Microgrids can be reliable in regions with unreliable or absent centralized grids;
- environmental benefits: using renewable energy in microgrids helps reduce carbon emissions, positively contributing to efforts against climate change;
- flexibility: microgrids can be customized to meet specific local needs.

5. Prospective aspects of microgrid technology development

Blockchain, artificial intelligence, and machine learning in microgrids: one of the most promising directions for microgrids is integrating blockchain technology. Blockchain is a decentralized ledger that provides a secure and transparent mechanism for recording transactions. In the context of microgrids, blockchain can create a decentralized energy market, allowing participants within the microgrid to trade electricity. This will enable the real-time sale of surplus energy between participants, fostering a more efficient and flexible energy market. Additionally, blockchain offers secure and transparent tools for tracking energy transactions, reducing the risk of fraud and enhancing the overall efficiency of the energy market [6]. An added benefit of blockchain in microgrids is its potential to incentivize the use of renewable energy sources. Participants can utilize blockchain-based tokens or renewable energy certificates to encourage the use of renewable sources, such as solar or wind energy. These tokens will contribute to the transition towards a more sustainable and decentralized energy system while providing economic benefits for participants [7]. Despite these advantages, implementing blockchain in microgrids comes with particular challenges. Key issues include scalability and the energy efficiency of blockchain itself, which can pose obstacles, particularly in microgrids with limited resources. Moreover, the regulatory framework for blockchain-based energy markets is still under development, creating uncertainty for developers and microgrid participants [8]. Ongoing research is focused on improving blockchain scalability and energy efficiency, as well as creating a robust regulatory framework to govern blockchain-based energy markets [9]. Overcoming these hurdles could pave the way for more efficient, transparent, and sustainable energy markets for microgrids.

Machine learning and artificial intelligence: the usage of artificial intelligence (AI) and machine learning technologies offers significant potential for optimizing the operation of microgrids. These technologies can analyze large volumes of data related to energy consumption and generation, identifying patterns and trends that can be leveraged to improve microgrid performance [10]. This could involve the implementation of advanced sensors and analytical tools, as well as the development of new algorithms for processing vast amounts of data in real time, allowing for better management of DER and increasing the efficiency of microgrid operations.

6. Microgrids implementation challenges

There some problems that can appear during implementing of microgrids into typical electric power supply sysytems:

- Technical aspects of implementation: harmonics and increasing system stability. Harmonics are high-frequency voltage and current distortions in electrical systems due to nonlinear loads such as electronic devices or power electronic converters [11]. These distortions can lead to power losses, equipment overheating, and reduced power factor. In microgrids, harmonics can be caused by using DER like solar panels or wind turbines, which use converters to integrate with the system. The primary strategies for reducing harmonics are using harmonic filters and specialized control algorithms. Microgrid stability refers to the system's ability to restore regular operation after failures. It includes both steady-state and dynamic stability. Steady-state stability maintains stable voltage and frequency under normal or abnormal conditions [12]. Dynamic stability relates to the system's ability to recover from disturbances such as load or generation changes. Strategies to enhance stability include using energy storage systems to regulate voltage and frequency, as well as advanced protection and monitoring systems to detect and localize failures within the grid;
- Monitoring and control: one of the critical factors to consider when designing a microgrid is the need for reliable monitoring and control systems. Microgrids can be complex systems with several DERs that require proper management and coordination to ensure reliable and efficient system operation. This process requires advanced monitoring and control systems that can collect real-time data on energy supply and demand, detect potential issues or anomalies, and adjust DER operations as needed [13]. Researchers are exploring the potential of advanced sensors and data analytics tools to improve microgrid performance. These tools can provide real-time data on DER performance and the entire microgrid system, enabling operators to make informed decisions to optimize energy supply and demand. Additionally, machine learning algorithms can identify patterns and trends in the data, enabling more accurate forecasting and increased operational efficiency [14];
- Cybersecurity: As microgrids become more popular, they become more vulnerable to cyberattacks [15]. Therefore, specialized cybersecurity solutions for microgrids are urgently needed [16]. These solutions may include advanced encryption methods, attack detection and prevention systems, multi-level authentication, and access control. It is crucial to adopt a proactive security approach, considering cyber threats during the design and implementation stages of microgrid systems;
- Energy storage: although lithium batteries are becoming increasingly reliable and economically viable, their implementation requires significant initial investment [17]. To address this issue, new energy storage technologies, such as thermal energy storage systems, are being developed [18];
- Financing: the development of microgrids requires significant investments, particularly in the initial stages. In developing countries, financing opportunities are often limited, and microgrids may face challenges in attracting investment due to technology-related risks and the absence of clearly defined business models [19]. Researchers and policymakers are working to create new business models and financing mechanisms to overcome these challenges. An important direction is the use of grants, subsidies, and other financial incentives to support the implementation of microgrids. Another potential tool is carbon credits [20]. Microgrids that utilize renewable energy sources can generate carbon credits, which can be sold on carbon markets, creating an additional source of revenue for their developers [21];
- Environmental aspects: while microgrids have significant potential to reduce carbon emissions and contribute to the sustainability of the energy system, there is a risk of negative environmental impacts, such as potential ecosystem degradation or depletion of natural resources [22].

7. PESTLE analysis of microgrids and distributed generation implementation in Ukraine

Prerequisites: the most critical prerequisite for the development of distributed generation and microgrids in Ukraine is the destruction of a significant portion of generation capacities and distribution networks as a result of the armed aggression of the Russian Federation. As of the summer of 2024, more than half of the generation capacity had been disabled (73% of thermal power plants, 20 hydroelectric units, etc.). The relative ease of disabling centralized generation indicates that it may not be feasible to restore it fully. The use of distributed generation, smart grids, and microgrids will allow for the diversification of risks associated with natural or man-made disasters and minimize their consequences for both the grid itself and consumers by isolating only a small part of the system. The global trend toward renewable energy sources, as well as advancements and cost reductions in technology (both in generation and storage), suggests the potential for future investments in the development of this energy sector from partners. According to researchers' estimates, the total economically viable potential of renewable and unconventional energy sources in Ukraine amounts to approximately 454.4 billion kWh or 59.2 million tons of conventional fuel per year [23].

Political factor: the government of Ukraine and the Ministry of Energy actively support renewable energy sources and the development of distributed generation to enhance the country's energy independence, especially after 2022. For instance, Ukraine's Energy Strategy up to 2035, titled "Security, Energy Efficiency, Competitiveness" [24], envisions achieving a 25% share of renewables in the total primary energy supply by 2035, as stated in the Energy Strategy: "Renewables will develop at the most dynamic pace compared to other types of generation." The Energy Strategy also justifies the need to develop distributed generation from renewables, particularly the creation and implementation of microgrids and smart energy networks (Smart Grids). However, a downside to the development strategy is the lack of specific plans regarding offshore wind energy. According to the World Bank, Ukraine has one of the best potentials for offshore wind energy development in the Black Sea among all Black Sea countries. The theoretical technical potential for offshore wind energy in the Black Sea and Ukraine's shallow waters is as high as 250 GW [25], while the total theoretical potential for all Black Sea countries is 435 GW

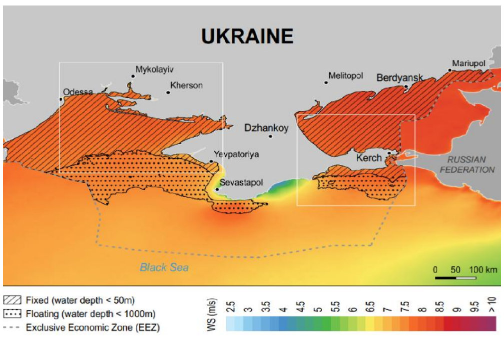


Fig. 2. Map of Average Wind Speeds in Ukraine's Economic Waters (according to the World Bank, 2020).

Corruption risks: the energy sector in Ukraine has traditionally been plagued by corruption, which can hinder investments and projects related to microgrids and distributed generation. Corruption risks may create obstacles in project approvals, inflate costs, or deter potential foreign investors, thereby slowing the adoption and expansion of these crucial technologies. Ensuring transparency and accountability in regulatory frameworks and project implementation will be vital in overcoming these risks and fostering a more favorable investment environment.

Economic factors:

- Investment and financing: the high cost of initial investments in the development of microgrids can be a limiting factor for widespread adoption. However, international financial institutions (IMF, EBRD) and donors are actively investing in the development of renewable energy. In 2024, total investments in renewables are expected to reach around $2 trillion, which will also positively impact the financing of microgrid development [26];
- Economic stability: The war's impact on Ukraine's economy has led to challenges in securing investments and financing for energy projects. At the same time, the development of microgrids can help reduce energy supply costs and contribute to economic recovery;
- Energy costs: microgrids and distributed generation can help reduce dependence on traditional energy suppliers and lower energy transmission costs over long distances, which is particularly important for industrial and residential consumers.

Social factors:

- Public perception: people increasingly support environmentally friendly solutions and energy independence, especially after experiencing power outages during the war. Both businesses and the general population positively receive the implementation of microgrids and distributed generation;
- Workplace creation: introducing new technologies in the energy sector contributes to creating new jobs, particularly in rural and remote areas, fostering social and economic development in these regions;
- Training and skill development: personnel must be adequately trained to implement new technologies. Education and the preparation of a sufficient number of specialists in the energy sector will be crucial challenges.

Technological factors:

- Innovation: technologies for distributed generation, such as solar panels, wind turbines, and energy storage systems, are rapidly advancing. The emergence of new technologies helps reduce the costs of implementing microgrids and increases their efficiency;
- Digital technologies: The use of Smart Grid technologies and other digital solutions contributes to the effective management of microgrids, enhancing their reliability and flexibility;

 Implementation barriers: despite progress in technological development, certain barriers, such as insufficient infrastructure development and the lack of large-scale production capabilities in Ukraine, may slow down the implementation of microgrids.

Environmental factors:

 Reduction of environmental impact: microgrids utilizing renewable energy sources reduce greenhouse gas emissions, decrease dependence on fossil fuels, and contribute to greater resilience in the energy system;

 Environmental regulations: environmental protection requirements and international agreements, such as the Paris Agreement, encourage the development of clean energy sources.

Legal factors:

 Regulatory framework: Ukraine has not yet fully developed a legislative framework to regulate microgrid operations and support their implementation. However, before the war, several regulatory documents and national strategies were adopted, outlining the future direction of renewable energy development in Ukraine for this and future decades;

 Standardization: ensuring the standardization of equipment for microgrids and distributed generation is crucial to facilitate their implementation and integration with national grids;

 Intellectual property protection: as innovative technologies are introduced in the energy sector, the issue of intellectual property protection and safeguarding technologies becomes increasingly relevant.

8. Conclusions

To analyze current trends in microgrid development, this paper reviews scientific works on the topic published in international academic journals over the past five years. The advantages, disadvantages, promising directions for microgrid development, and the challenges that may hinder their implementation were identified. A PESTLE analysis was conducted to assess the prospects and prerequisites for microgrid technology implementation in Ukraine. The study demonstrated that microgrid technology should play a prominent role in the future development of Ukraine's energy sector. However, successful implementation will require a focus on attracting significant financial investments, preparing regulatory and legal frameworks, standardization, training qualified personnel, and advancing new technologies.

References

[1] M. Debouza, A. Al-Durra, T. H. M. EL-Fouly, and H. H. Zeineldin, “Survey on microgrids with flexible boundaries: Strategies, applications, and future trends”, *Electric Power Systems Research*, vol. 205, p. 107765, Apr. 2022, doi: https://doi.org/10.1016/j.epsr.2021.107765.

[2] J. L. López-Prado, J. I. Vélez, and G. A. Garcia-Llinás, “Reliability Evaluation in Distribution Networks with Microgrids: Review and Classification of the Literature”, *Energies*, vol. 13, no. 23, p. 6189, Nov. 2020, doi: https://doi.org/10.3390/en13236189.

[3] M. F. Roslan, M. A. Hannan, P. J. Ker, and M. N. Uddin, “Microgrid control methods toward achieving sustainable energy management”, *Applied Energy*, vol. 240, pp. 583–607, Apr. 2019, doi: https://doi.org/ 10.1016/j.apenergy.2019.02.070.

[4] G. Shahgholian, “A brief review on microgrids: Operation, applications, modeling, and control”, *International Transactions on Electrical Energy Systems*, vol. 31, no. 6, Mar. 2021, doi: https://doi.org/10.1002/2050-7038.12885.

[5] C. Wei, Z. Shen, D. Xiao, L. Wang, X. Bai, and H. Chen, “An optimal scheduling strategy for peer-to-peer trading in interconnected microgrids based on RO and Nash bargaining”, Applied Energy, vol. 295, p. 117024, Aug. 2021, doi: https://doi.org/10.1016/j.apenergy.2021.117024.

[6] A. Cagnano, E. De Tuglie, and P. Mancarella, “Microgrids: Overview and guidelines for practical implementations and operation”, *Applied Energy*, vol. 258, p. 114039, Jan. 2020, doi: https://doi.org/10.1016/j.apenergy.2019.114039.

[7] S. Choudhury, “A comprehensive review on issues, investigations, control and protection trends, technical challenges and future directions for Microgrid technology”, *International Transactions on Electrical Energy Systems*, Apr. 2020, doi: https://doi.org/10.1002/2050-7038.12446.

[8] S. Ali, Z. Zheng, M. Aillerie, J.-P. Sawicki, M.-C. Péra, and D. Hissel, “A Review of DC Microgrid Energy Management Systems Dedicated to Residential Applications”, *Energies*, vol. 14, no. 14, p. 4308, Jul. 2021, doi: https://doi.org/10.3390/en14144308.

[9] H. Fontenot, B. Dong, “Modeling and control of building-integrated microgrids for optimal energy management – A review”, *Applied Energy*, vol. 254 Nov. 2019, doi: https://doi.org/10.1016/ j.apenergy.2019.113689.

[10] T. B. Lopez-Garcia, A. Coronado-Mendoza, and J. A. Domínguez-Navarro, “Artificial neural networks in microgrids: A review”, *Engineering Applications of Artificial Intelligence*, vol. 95, Oct. 2020, doi: https://doi.org/10.1016/j.engappai.2020.103894.

[11] M. Farrokhabadi *et al.*, "Microgrid Stability Definitions, Analysis, and Examples," in *IEEE*

Transactions on Power Systems, vol. 35, no. 1, pp. 13-29, Jan. 2020, doi: 10.1109/TPWRS.2019.2925703.

[12] Z. A. Arfeen, A. B. Khairuddin, R. M. Larik, and M. S. Saeed, "Control of distributed generation systems for microgrid applications: A technological review", *International Transactions on Electrical Energy Systems*, vol. 29, no. 9, Jul. 2019, doi: https://doi.org/10.1002/2050-7038.12072.

[13] M. A. Hannan, M. Faisal, P. Jern Ker, R. A. Begum, Z. Y. Dong, and C. Zhang, "Review of optimal methods and algorithms for sizing energy storage systems to achieve decarbonization in microgrid applications", *Renewable and Sustainable Energy Reviews*, vol. 131, p. 110022, Oct. 2020, doi: https://doi.org/10.1016/j.rser.2020.110022.

[14] N. Tomin *et al.*, "Design and optimal energy management of community microgrids with flexible renewable energy sources", *Renewable Energy*, vol. 183, pp. 903–921, Jan. 2022, doi: https://doi.org/10.1016/j.renene.2021.11.024.

[15] F. Nejabatkhah, Y. W. Li, H. Liang, and R. Reza Ahrabi, "Cyber-Security of Smart Microgrids: A Survey", *Energies*, vol. 14, no. 1, p. 27, Dec. 2020, doi: https://doi.org/ 10.3390/en14010027.

[16] M. Rasool, M. A. Khan, and S. Tahir, "Optimal On-Grid Hybrid AC/DC Microgrid for a Small Village in Muzaffargarh District, Pakistan", Apr. 2021, doi:https://doi.org/10.1109 /icept51706.2021.9435501.

[17] S. Batiyah, R. Sharma, S. Abdelwahed, W. Alhosaini, and O. Aldosari, "Predictive Control of PV/Battery System under Load and Environmental Uncertainty", *Energies*, vol. 15, no. 11, p. 4100, Jun. 2022, doi: https://doi.org/10.3390/en15114100.

[18] A. Alzahrani, K. Sajjad, G. Hafeez, S. M. Mohsin and others, "Real-time energy optimization and scheduling of buildings integrated with renewable microgrid", *Applied Energy*, vol. 335, Apr. 2023, doi: https://doi.org/10.1016/j.apenergy.2023.120640.

[19] J. Xu and Y. Yi, "Multi-microgrid low-carbon economy operation strategy considering both source and load uncertainty: A Nash bargaining approach", *Energy*, vol. 263, p. 125712, Jan. 2023, doi: https://doi.org/10.1016/j.energy. 2022.125712.

[20] B. Lei, Y. Ren, H. Luan, R. Dong, and others, "A Review of Optimization for System Reliability of Microgrid", *Mathematics* , vol. 11, p. 822, Dec. 2023, doi: https://doi.org/10.3390/math11040822.

[21] S. Fazal, M. Enamul Haque, M. Taufiqul Arif, A. Gargoom, and A. M. T. Oo, "Grid integration impacts and control strategies for renewable based microgrid", *Sustainable Energy Technologies and Assessments*, vol. 56, p. 103069, Mar. 2023, doi: https://doi.org/10.1016/j.seta.2023.103069.

[22] "Renewable energy in Ukraine", *Wikipedia*, Mar. 30, 2022. https://cutt.ly/oeZtn8KR.

[23] "Government approved Energy Strategy of Accessed: Sep. 29, 2024. [Online]. Available: https://merp.org.ua/images/Docs/MERP_USAID_ESU_2035.pdf

[24] "Going Global: Expanding Offshore Wind to Emerging Markets (Vol. 42): Technical Potential for Offshore Wind in Ukraine - Map", *World Bank*, 2019. https://cutt.ly/NeZtmIAr.

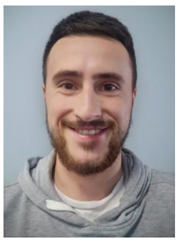
[25] "Global investment in clean energy will reach $2 trillion in 2024", *Finclub.net*, Jun. 06, 2024. https://cutt.ly/heZtQx9E

СУЧАСНІ ТЕНДЕНЦІЇ РОЗВИТКУ МІКРОМЕРЕЖ ТА ПЕРСПЕКТИВИ ЇХ ВПРОВАДЖЕННЯ В УКРАЇНІ

Василь Хай

Дослідження розглядає практичність і майбутні перспективи впровадження мікромереж. Було проаналізовано потенційні застосування в різних секторах, таких як транспорт, військові операції та громадська інфраструктура. Дослідження включало перегляд поточної літератури та практичних прикладів, щоб підкреслити переваги, які пропонують мікромережі, такі як підвищена надійність енергії, зниження витрат і покращена безпека.

Проведено детальний аналіз PESTLE (політичні, економічні, соціальні, технологічні, правові та екологічні фактори) впровадження мікромереж в Україні. Отримані дані свідчать про те, що за умови правильного поєднання регуляторної підтримки, фінансових інвестицій і технологічних інновацій, включаючи досягнення в блокчейні, штучному інтелекті та машинному навчанні, мікромережі можуть стати наріжним каменем стійких і стійких енергетичних систем. Подано огляд для науковців, політиків та інвесторів, зацікавлених у просуванні енергетичної незалежності та стабільності у повоєнному відновленні України.



Vasyl Khai – Master of Engineering, postgraduate student of Lviv Polytechnic National University. Product Engineer at Atlas Magnetics.

Scientific interests: renewable energy, distributed energy resources, synchronous generators**.**

Received: 24.08.2024, Accepted: 25.09.2024
ORCID ID: 0009-0000-7878-5192