ВІСНИК ПРИАЗОВСЬКОГО ДЕРЖАВНОГО ТЕХНІЧНОГО УНІВЕРСИТЕТУ
2025р. Серія: Технічні науки Вип. 50
p-ISSN: 2225-6733; e-ISSN: 2519-271X

UDC 629.5:62-5 DOI: 10.31498/2225-6733.50.2025.336376

SYMBIOSIS OF ARTIFICIAL INTELLIGENCE AND SHIP'S AUTOMATED ELECTRICAL ENERGY SYSTEMS: PRESENT AND FUTURE

Simanenkov A.L. *PhD (Engineering), senior lecturer, Kherson State Maritime Academy, Kherson, ORCID: https://orcid.org/0000-0003-0797-5276, e-mail: simanenkov.andrii@gmail.com;*

Samoilov S.O. *postgraduate student, Kherson State Maritime Academy, Kherson, ORCID: https://orcid.org/0009-0006-4454-0510, e-mail: samoilovserhii.ksma@gmail.com*

The paper addresses the current challenge of enhancing the efficiency, safety, and environmental sustainability of maritime transport. The main article's idea is that this aim can be achieved by integrating artificial intelligence (AI) technologies into a ship's automated electrical energy systems (SAEES). The first article's part is dedicated to the evolution of the SAEES architecture and six main energy management strategies: centralized and decentralized systems, hierarchical methodologies, model predictive control, agent-oriented control systems, and energy management systems. The analysis of each approach includes its advantages and disadvantages, considering parameters such as efficiency, stability, implementation and maintenance costs, environmental impact, complexity, and scalability. The second part concentrated on reviewing applications of AI technologies in the maritime industry. It presented practical examples of AI usages in the marine industry, particularly in navigation, diagnostics, and route optimization. Another attention was focused on the profit of integrating AI into SAEES. It was found that this symbiosis can bring improvement to every core parameter in these systems. The main challenges associated with global issues of safety and cybersecurity of AI systems, exceptional employees' qualification, complexity of integration with existing systems, guaranteeing the stability and predictability of AI algorithms, problems of data quality and standardization, regulatory and ethical aspects. Moreover, the paper presents potential future developments of AI and ship electrical energy control systems' symbiosis. The primary objectives include further SAEES automatizations, integrating with new energy sources, optimizing ship equipment operation, and solving existing challenges and limitations.

Keywords: *ship energy systems, energy efficiency, optimization, machine learning, artificial intelligence, maritime transport, environmental impact, maritime safety, cybersecurity.*

Statement of the problem

Maritime transport plays a key role in globalization, providing a significant part of international trade's transportation. The efficiency, safety, and environmental friendliness of marine operations are industrial aspects of the ongoing development of the world economy. According to the International Maritime Organization (IMO), in 2023, the global shipping industry emitted more than 1 billion tons of CO2. In this view, the requirements for the maritime industry to improve energy efficiency, reduce operating costs, and minimize environmental impact are constantly growing [1, 2].

Robust and efficient ship's automated electrical energy systems (SAEES) are the core of safe and uninterrupted operations in the maritime industry. A ship, like a floating city, requires electricity to guarantee the vital activities of the crew, the functioning of navigation equipment, cargo systems, and other critical mechanisms [3].

At the same time, with the growing demands on the maritime industry, we can see the fast development of artificial intelligence (AI) technologies, which demonstrate outstanding potential to transform various fields of life, including maritime transportation. AI is already helping to optimize routes, predict maintenance needs, enhance shipping safety, and automate numerous processes. According to a report by Lloyd's Register, the global market for AI developments in the maritime industry is estimated at 1.5 billion $ per year. It is expected to double over the next five years [[4]].

In this context, the study of AI and SAEES symbiosis is relevant. The integration with AI can open up numerous opportunities for solving existing problems, enhancing the efficiency, stability, and safety of ship operations. On the other side, it will contribute to the environmental achievements by international regulatory bodies.

Modern SAEES are complex systems that include various energy sources, distribution networks, and numerous electrical consumers. During the operation of these systems, typical problems occur, including blackouts caused by equipment failures, personnel errors, or external factors. Inefficient energy use or unnecessary fuel consumption leads to increased harmful emissions, as well as maintenance and repair problems, especially in a complex marine environment. Due to corrosion, equipment wear, and difficulties in investigating faults, there are increased risks. Batteries, used as a backup energy source, lose their capacity over time and require frequent replacement. Probabilities of overload and short circuits in electrical networks, energy quality, voltage and frequency fluctuations, can also negatively affect the operation of shipboard systems.

Traditional methods are not effective enough to solve all these problems in the conditions of increasing systems complexity and requirements for their productivity. AI technologies have great potential to provide more intelligent, adaptive, and efficient management of SAEES. AI can be used to forecast loads, optimize generator parameters, diagnose faults early, and make informed decisions in real-time. All this will contribute to the improvement of efficiency, robustness, and safety of ship operations. Therefore, research into the perspectives of AI and SAEES symbiosis is up to date.

Analysis of the latest achievements on the identified problem

The latest research in the field of SAEES management demonstrates a growing interest in introducing intelligent and optimization approaches to enhance the quality of energy systems.

One of the leading directions is the evolution and application of energy management systems (EMS). It integrates several energy sources (including renewable) and energy storage kits aimed at optimizing the overall energy consumption on a ship [5].

Researchers are heavily focused on model predictive control (MPC) strategy to optimize energy distribution, load management, and voltage/frequency regulation. MPC allows consideration of nonlinear system dynamics and the multiplicity of operational constraints, providing proactive control based on predictions of future system behaviour.

The next path of study is the development of agent-oriented control systems (AOC). AOC uses autonomous agents to coordinate the various components of the SAEES, thereby enhancing the system's survivability. It can bring high fault resistance and the ability to reconfigure dynamically.

Moreover, researchers investigated the ability to use digital twins for monitoring, optimizing, and predicting the state of SAEES. Digital twins enable the modelling of a physical system's behavior in a virtual environment. This technology allows for easier monitoring of processes, faster problem resolution, and more accurate prediction of the ship's configuration. Digital twins are successfully used in employee training programs.

One more direction is decentralized control systems. This approach helps to increase the stability and scalability of the SAEES by distributing control functions between local controllers. Decentralization of control leads to faster response to local events and reduces the risk of single points of failure [6].

The integration of renewable energy sources, such as solar panels and wind turbines, into the SAEES is also receiving significant attention. It has a global goal to reduce dependence on fossil fuels and minimize emissions [5].

Interest in using AI to solve various tasks in the maritime industry has quickly grown. In navigation, AI is considered an instrument to develop autonomous ships with decision-making support systems for the crew. For example, SeaPod AI system by Orca AI, can perform the functions of an automated observer on the bridge, increasing situational awareness and preventing collisions. AI is used for equipment diagnostics and to predict the technical condition of systems and units, enabling predictive maintenance and the prevention of emergencies. Intending to optimize ship routes, AI analyses meteorological data, ocean flows, and other factors that affect fuel consumption and travel time. Moreover, AI can assist in managing cargo operations in ports and on vessels, thereby improving maritime safety by detecting obstacles and monitoring the crew's state [7].

In general, the analysis of existing research indicates that integrating artificial intelligence into ship energy management systems is a promising direction; however, the number of publications directly devoted to this topic remains limited. Most research focuses on individual aspects of using AI in the maritime industry.

Thus, a certain gap exists in knowledge regarding the perspectives and challenges associated with the symbiosis of AI and SAEES systems, which confirms the relevance of further research in this direction.

Purpose and task statement

The aim of this work is to analyse the perspectives of artificial intelligence and shipboard energy systems control's symbiosis.

Specific research objectives include:

- Review of operation principles and typical problems of shipboard energy systems.
- Analysis of modern approaches to energy supply management on ships, including traditional methods and new technologies.
- Research on the implementation of AI technologies in the maritime industry, particularly in navigation, diagnostics, and route optimization.
- Identification of potential advantages from integrating AI into SAEES, such as increasing energy efficiency, environmental friendliness, and safety.
- Consideration of main issues and challenges associated with the combination of AI and SAEES, focused on safety issues, cybersecurity, and crew qualifications.

Concluding future trends and directions of AI integration with SAEES control systems.

Materials and methods

The scientific publications analysed in this research were obtained during April-May 2025, from the databases of scientific article aggregators ResearchGate and MDPO. These sources are considered high-quality databases for bibliometric analysis. It provides the necessary information for identification and a reality check of publications. Works published in authoritative professional journals from 2020 to 2025 were selected. The language of the publications was limited to English, which is currently the most common academic language.

The analysis of the topic «symbiosis of artificial intelligence and ship energy systems» contains two main parts: «comparison of existing strategies for controlling ship energy systems» and «analysis of existing and potential integrations of AI and machine learning in the maritime industry». The research is conducted to clarify the impact of modern technologies on key indicators, including energy efficiency, environmental impact, safety, cost, and the complexity of implementing and maintaining ship systems.

Summary of the main material

SAEES are complex systems designed for the generation, distribution, and consumption of electrical energy on board the vessel (Fig. 1). The main components of these systems are generators, for example, diesel-driven ones, which convert mechanical energy into electrical energy using the principle of electromagnetic induction [3].

Shipboard electrical systems are complex and multilevel, requiring attentive monitoring and management to ensure a stable and effective energy supply to all onboard consumers. Understanding the fundamental concept of every individual component's operation and its interaction is necessary for the integration possibilities with AI, which can be used to analyse further and optimize the work of each element and the entire system as a complex whole.

Analysis of modern approaches to energy supply management.

Centralized control systems are based on a single central controller that manages all energy processes on the ship. Typically, this system builds on specialized hardware controllers, communication networks to collect data and transmit control signals, and preprogrammed logic or algorithms. The primary advantage is the potential for global optimization of the entire energy system, providing a comprehensive overview of its current state. This also simplifies the coordination of different energy sources and loads under normal operating conditions. But there are also considerable negatives. The main one is the risk of a single failure point, when a breakdown of the central controller can conduct to a full blackout. Furthermore, centralized systems have scalability problems when it is necessary to expand or reconfigure current systems. Centralized decision-making can lead to increased latency, particularly in large and complex systems [6].

Decentralized control systems comprise several local controllers that are responsible for individual subsystems or zones, making autonomous, information-based decisions and interacting with other controllers. These technologies also include distributed computing units, local sensors/actuators, and peer-to-peer communication protocols. The decentralized approach fixes the previous strategy's main problem by eliminating a single failure point. These systems are easily scalable due to their ability to plug-and-play connectivity. Potential disadvantages include the difficulty of gaining global system optimization and coordination between different subsystems. Decentralized control offers important strengths in terms of stability and scalability, making it a preferred choice in the marine sector, which requires high survivability. The ability to operate independently and quickly react to local events raises the system's resistance to failures and cyberattacks [6].

Hierarchical control methodologies involve a multilevel structure that typically includes primary control (local control of individual units), secondary control (voltage/frequency coordination and regulation), and tertiary control (overall system optimization and coordination). Each level solves specific tasks, where higher levels are monitoring and coordinating lower ones. The difficulty of designing and coordinating different control levels is a potential problem. Hierarchical control provides a robust structure for managing the growing complexity of SAEES by delegating the control task into manageable levels with clear responsibilities. This way allows local optimization and global coordination, which guarantees efficient and stable work under various conditions [8].

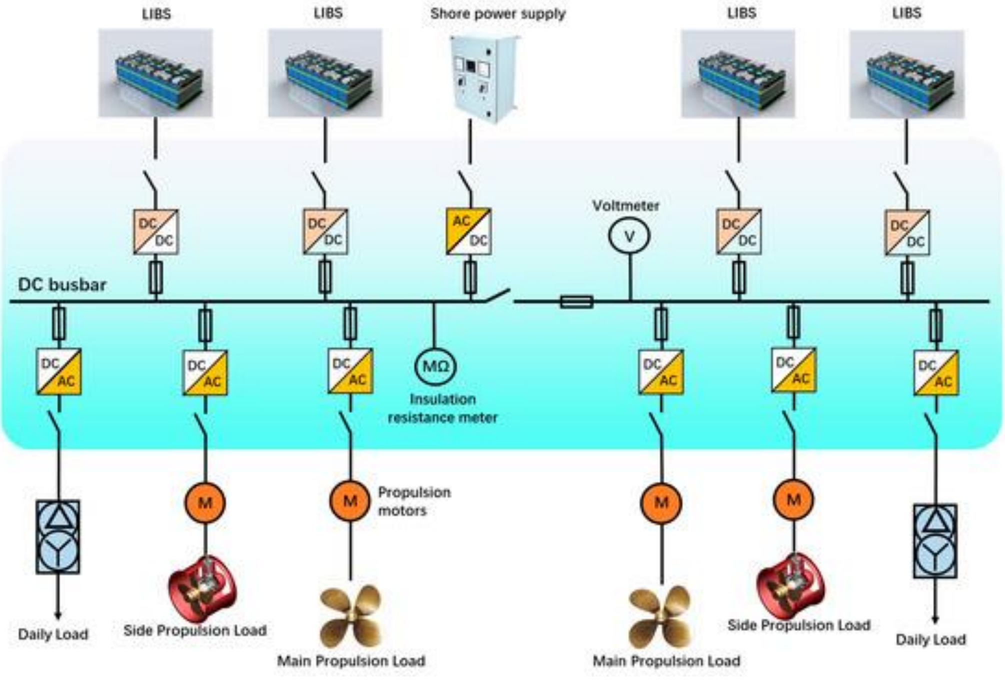

Fig. 1 – Ship's electric energy system schematic diagram

p-ISSN: 2225-6733; e-ISSN: 2519-271X

Model predictive control (MPC) uses a model of the system to predict its future behaviour and optimizes control actions. In SAEES, MPC is used for optimal energy management, load sharing, and voltage/frequency regulation. MPC is a powerful control technology that offers great potential for optimizing the performance of SAEES, especially in systems with composite operational requirements and dynamic loads. Its ability to predict future needs and constraints allows a more well-planned and stable process compared to traditional feedback control methods [5].

Agent-based control systems use autonomous software agents, each associated with a specific component or subsystem, that interact and cooperate to achieve the goals. In these systems, all agents can collect information, process data independently, and make decisions according to different conditions. There is a potential for seamless integration of new components and functionality. Agent-based control offers an adaptive approach to the management of SAEES, especially in scenarios that require fault resistance and dynamic reconfiguration, such as manoeuvring operations. The autonomous nature of the agents allows the system to continue to operate effectively even if some parts are damaged or unavailable.

Energy Management Systems (EMS) are integrated systems that monitor, control, and optimize the generation, storage, distribution, and consumption of electricity on board. EMS technologies and functionalities include advanced management algorithms, data analytics, real-time monitoring, and interfaces with different energy system components. The system offers adaptive and scalable power for propulsion and onboard mechanisms. Core features consist of standardized design, integration with shore energy systems, and suitability for low- and medium-voltage networks. The ship's electrical network distributes available energy throughout the ship, increasing energy efficiency and helping to reduce emissions [4].

The comparative analysis given in Table 1 demonstrates some trade-offs between different approaches. Decentralized and agent-based systems are highly robust and scalable, while MPC and EMS offer high optimization potential. Hierarchical control provides a balance, while centralized control is simpler but less safe. The choice of the most suitable approach depends on the specific requirements and priorities of the ship's owners and vessel type.

Table 1

Comparative analysis of modern approaches to the management of ship energy systems

Criterion	*Centralized*	*Decentralized*	*Hierarchical*	*MPC-based*	*Agent-based*	*EMS*
Efficiency	2* (global optimization)	2-3 (locally suboptimal)	3 (balance local/global)	4-5	4 (adaptive optimization)	4-5
Reliability	1-2 (single point of failure)	4-5	3-4	3	4-5	4-5
Implement cost	3	3-4	4-5	4-5	4-5	4-5
Maintenance cost	3	3	3	4-5 (model maintenance)	3	3-4
Environmental impact	1-2 (indirect impact)	1-2 (indirect impact of local actions)	2-3 (effects on higher levels)	2-3 (direct optimizes emissions)	1-2 (indirect impact)	2-3 (direct optimizes emissions)
Complexity	3	4-5 (coordination)	4-5	4-5	4-5	4-5
Scalability	2	4-5	3-4	3	4-5	4-5
Handling dynamic loads	1-2 (can be slow)	3-4 (rapid local response)	3-4 (multilevel reaction)	4-5 (proactive)	4-5 (adaptive response)	4-5 (integrated processing)
Real-time adaptability	1-2 (limited)	4-5	3	4-5	4-5	4-5

*Rating from 1-small value/impact to 5-high.

Integration of artificial intelligence in the maritime industry.

Artificial intelligence (AI) with machine learning is revolutionizing all sectors of the maritime industry, offering innovative solutions to enhance the efficiency, safety, and sustainability of shipping. With the invention of autonomous large language models (LLMs), the usage of these technologies became available even in conditions of a lack of communication. It gave a significant impulse to the development of technologies in the maritime industry. In navigation, AI helps develop autonomous ship systems that can make decisions on course, speed, and manoeuvring independently. Moreover, AI is being integrated into decision-making support systems for the crew, providing recommendations based on the analysis of large amounts of data. In the process of technical maintenance, AI is used to predict the state of equipment and systems. This allows it to move from active to predictive maintenance. AI algorithms analyse data from sensors installed on various units, detecting anomalies and predicting possible breakdowns. This makes it possible to implement necessary repairs on time, preventing serious accidents and reducing vessel downtime [7, 15].

Optimization of ship routes is another important area of AI application. By analysing meteorological data, information on ocean waves, ship traffic, and other factors, AI algorithms can determine the most efficient routes, which can decrease fuel consumption and reduce travel time.

AI serves to manage cargo operations in port terminals and on ships, optimizing loading and unloading processes, cargo placement, and planning operations. The application of AI contributes to improving maritime safety by detecting obstacles on the vessel's path, predicting collision risks, and monitoring the crew's condition to prevent errors related to the human factor.

In general, as shown in Table 2, artificial intelligence is already demonstrating promising potential for improving the efficiency, safety, and sustainability of maritime operations in various areas. The practical implementation of AI technologies in the marine industry creates a solid foundation for its integration into SAEES, which also requires intelligent data analysis, forecasting, and decision-making optimization [7, 12, 13].

Benefits of integrating AI and SAEES.

Increased efficiency. AI can analyse historical and current data, such as weather conditions, operating modes, and equipment performance, to optimize energy consumption. As a result of its load-predicting ability, AI can dynamically regulate energy generation and distribution, preventing overproduction. Intelligent load management allows AI to prioritize and plan the use of electrical loads based on operational needs and available energy capacity. This can show a path to more efficient utilization of generated energy and reduce additional generator runtime. Optimizing energy generation with AI enables defining the optimal number of generators to run simultaneously and their corresponding load levels to achieve maximum efficiency. This is especially important for managing hybrid energy systems, where AI can optimize the interaction between traditional generators, energy storage systems, and renewable energy sources [6].

Table 2

Examples and benefits of the successful integration of AI in the maritime industry

Scope of application	*AI methods*	*Examples/Benefits*
Failure prediction	Machine learning, neural networks	VoyageX AI PMS (40% downtime reduction), ABB Ability™ (increased reliability), MarineInsight™ (proactive maintenance)
Energy consumption optimization	Machine learning, neural networks	Maersk (reducing fuel consumption), ABB Ability™ OptimE (propulsion optimization), Neural Networks (fuel consumption prediction)
Load management	Machine learning	AI for optimal load planning (maximizing space utilization), NanoPredict (balancing energy supplies)
Autonomous navigation and control	Machine learning, neural networks	Yara Birkeland (fully autonomous vessel), ABB Ability™ Marine Pilot Control (automation of keys operations)
Safety and security	Machine learning, expert systems	AI for anomaly detection (fire, water intrusion), AI for risk assessment, AI for cybersecurity
Optimization of port operations	Machine learning	AI to berth allocation, traffic management, cargo handling (increasing efficiency)

Increasing robustness. AI has a high impact on improving the robustness of SAEES through its ability to predict equipment failures. By analysing data from multiple sensors, such as vibration, temperature, and voltage sensors, AI can detect potential faults and anomalies at an early stage, allowing preventive maintenance execution before major breakdowns occur. This approach to maintenance can significantly reduce ship downtime and repair costs. AI can also ensure uninterrupted monitoring of critical electrical components, such as generators, motors, and transformers, thereby preventing unexpected failures. Additionally, AI aids in improving fault diagnosis by quickly and accurately identifying the causes of problems in the electrical system. AI can also be used to estimate the remaining life of equipment, predicting its real service life.

Improving safety. AI can analyse real-time data to detect potential dangers, such as equipment overheating or electrical errors, allowing it to prevent accidents at the right time. AI-based inspection systems can monitor preconditions of hazardous situations, such as gas leaks or smoke, enabling immediate response to emergencies. In navigation, AI can help prevent collisions by analysing sensor data and predicting risks [10]. Automating routine tasks in energy management helps reduce the human factor, one of the primary causes of accidents at sea. AI-based decision support systems provide operators with timely and accurate information, enabling them to make more informed and well-reasoned conclusions.

Reduced operating costs. AI, combined with the control part of the SAEES, can enhance the cost efficiency of ships. Fuel savings are a primary goal achieved through AI-based route optimization and speed management. It is predicted that fuel savings can reach from 3% to 15%. Minimizing service cost is possible by predictive maintenance, which prevents costly breakdowns and limits necessary responses to unexpected failures. AI also helps optimize resource utilization by more efficiently managing the operation of generators, energy storage systems, and other components of the energy system. In the long term, with growing automation, the percentage of energy supply management and ship operations will lead to a reduction of personnel expenses.

Process automation. AI opens a great opportunity to increase the level of automation in SAEES. Autonomous energy management allows AI to make real-time decisions about energy production and distribution without human intervention. This is especially relevant for autonomous ships, where AI plays a key role in managing all onboard systems. The market for autonomous ships is showing outstanding growth and is predicted to reach billions of dollars in the near future.

The integration of renewable energy sources into shipboard energy systems is an essential part of the emission reduction process. AI can analyse the ability and volume generation of renewable energy sources (solar, wind) based on meteorological data. This allows better control and planning of the usage of these periodic energy sources. AI can also optimize the utilization of accumulated renewable energy reserves, giving them priority over traditional sources in cases where it is feasible. Additionally, AI can effectively manage energy storage, optimizing charging and discharging processes.

Problems and Challenges of Artificial Intelligence Integration.

Cybersecurity. The inclusion of AI in shipboard energy systems, while bringing benefits, also creates several problems, among which cybersecurity occupies a special place. Increasing connectivity and dependence on digital systems make ships more vulnerable to cyberattacks. AI systems can become a target of attacks aimed at disrupting their operation or gaining unauthorized access to confidential data. Therefore, the development and implementation of robust protection measures against malware is important. At the same time, AI can also be used to improve security, detect anomalies, and predict potential threats [9, 14].

The stability of AI systems is another big challenge. The effectiveness of AI directly depends on the quality of data on which it is trained and with which it works. Poor-quality data can lead to inaccurate predictions and unreliable decisions. For this reason, the validation and verification of AI systems are critical to ensure their safe and reliable operation. AI systems must be able to function stably in the challenging conditions of the marine environment, including exposure to vibration, extreme temperatures, and high humidity.

Specialized knowledge is necessary. The successful integration of AI into SAEES requires qualified personnel in both the spheres of marine engineering and artificial intelligence. The scarcity of qualified specialists needs to be overcome. To resolve this problem, we need to train new employees and retrain existing personnel [11].

Integrating AI systems with existing shipboard infrastructure can be challenging due to hardware and software compatibility issues. Ensuring seamless data exchange between AI models and other onboard systems is crucial, but the use of different data formats and communication protocols can complicate this process.

Regulatory aspects. The development of the regulatory framework for the use of AI in the maritime industry is still ongoing, resulting in a lack of clear regulatory boundaries [10]. Creation of international standards is necessary for the global implementation of AI in the maritime industry.

Ethical considerations. The use of AI in managing SAEES also raises some ethical concerns. Determining responsibility for incidents related to the operation of AI-controlled systems can be a challenging task. There is also a risk that the data on which AI algorithms are trained may be biased, potentially leading to unfair or discriminatory decisions. Transparency and validity of AI decision-making are also important aspects, especially in the maritime industry.

Implementation cost. Implementing AI systems in shipboard energy systems involves significant initial investments in hardware, software, and development. This

p-ISSN: 2225-6733; e-ISSN: 2519-271X

can be a barrier to adoption, especially for smaller shipping companies.

Comparison of traditional control methods and AI approaches. Traditional methods of managing ship energy systems are often built on rule-based systems and manual regulation, which can perform suboptimally in dynamic environments. AI systems are capable of continuously learning and adapting to optimize energy consumption and distribution in real-time. Traditional systems may have slower response times to sudden load changes or fault conditions. In contrast, AI-controlled systems can respond quickly and intelligently to changing conditions, preventing failures and enhancing safety. Traditional EMS configurations are typically static and require manual reprogramming for major changes. AI systems can learn from operational data and transform their control strategies to improve performance and efficiency continuously. Traditional methods can struggle to manage the increasing complexity of modern marine energy systems. AI is well-suited to working with complex systems, analysing large amounts of data, and discovering composite relationships.

Conclusions

The conducted research made it possible to analyse different approaches to managing the ship's energy systems and draw conclusions regarding the use of these technologies on various types of ships.

For military vessels, the most important criteria are stability and the ability to operate in conditions of partially damaged systems. Therefore, decentralized, agent-oriented, and EMC systems are chosen.

For commercial ships, which are focused on maximizing profit, the best choices are MPC-based and EMC systems.

Cruise ships need stability for a large amount of equipment. Decentralized and agent-oriented systems can help with this.

Small ships can select any technology depending on their financial capabilities.

The second part of the research reviewed examples of AI applications in the maritime industry and analysed the prospects for developing a symbiosis of AI-based control systems and onboard energy systems. The obtained results confirm the great potential of AI technologies for enhancing energy efficiency, stability, and safety of ship operations. The speed of operation and minimization of errors lead to decreased operational costs and a negative impact on the environment.

At the same time, the implementation of AI in the maritime industry is associated with serious problems and challenges, including cybersecurity concerns, the need for qualified personnel, and the complexity of integrating AI with existing equipment. Along these lines, further research and development are needed to resolve these difficulties and create reliable and safe AI solutions for the maritime industry.

Future research directions include developing universal, complex software that can work with AI assistants and various large language models, both remotely and locally. It should work according to the modular principle, allowing for the connection of interaction blocks with different systems. It is also crucial to have the option of quick configuration for specific equipment on the various ships.

The next step should be to integrate this software with models of real equipment in the MATLAB Simulink ecosystem. This step should focus on testing, optimizing, and improving the stability and performance of the system. Special attention will be focused on improving cybersecurity.

The result of the research should be the implementation of an autonomous AI-based energy management system on a ship that will support work with various energy sources and storage systems, use machine learning for more accurate load forecasting and equipment optimization.

In summary, the integration of artificial intelligence and shipboard electrical energy systems is a key factor in the resource-efficient development of maritime transportation.

References

[1] Z. Wang, M. Li, N. Cao, P. Liao, Y. Ji, and F. Han, «Enhancing renewable energy utilization and energy management strategies for new energy yachts», *Heliyon*, vol. 10(18), article e37863, 2024. **doi: 10.1016/j.heliyon.2024.e37863**.

[2] Z. Bei et al., «Challenges and Solutions of Ship Power System Electrification», *Energies*, vol. 17(13), article 3311, 2024. **doi: 10.3390/en17133311**.

[3] What is Marine Electricity And How It is Generated. [Online]. Available: https://www.marineinsight.com/marine-electrical/what-is-marine-electricity/ Accessed on: April 10, 2025.

[4] Maritime Artificial Intelligence & Machine Learning: Ultimate Guide. [Online]. Available: https://spire.com/maritime/maritime-artificial-intelligence-and-machine-learning/. Accessed on: April 10, 2025.

[5] W. Chen et al., «Robust Real-Time Shipboard Energy Management System With Improved Adaptive Model Predictive Control», *IEEE Access*, vol. 11, pp. 110342-110360, 2023. **doi: 10.1109/access.2023.3321692**.

[6] M.D.A. Al-Falahi, T. Tarasiuk, S.G. Jayasinghe, Z. Jin, H. Enshaei, and J.M. Guerrero, «AC Ship Microgrids: Control and Power Management Optimization», *Energies*, vol. 11(6), article 1458, 2018. **doi: 10.3390/en11061458**.

[7] D. Simion, F. Postolache, B. Fleacă, and E. Fleacă, «AI-Driven Predictive Maintenance in Modern Maritime Transport-Enhancing Operational Efficiency and

Reliability», *Applied Sciences*, vol. 14(20), article 9439, 2024. **doi: 10.3390/app14209439**.

[8] Z. Jin, L. Meng, J.M. Guerrero, and R. Han, «Hierarchical Control Design for a Shipboard Power System With DC Distribution and Energy Storage Aboard Future More-Electric Ships», *IEEE Transactions on Industrial Informatics*, vol. 14(2), pp. 703-714, 2018. **doi: 10.1109/tii.2017.2772343**.

[9] T. Miller, I. Durlik, E. Kostecka, S. Sokołowska, P. Kozlovska, and R. Zwolak, «Artificial Intelligence in Maritime Cybersecurity: A Systematic Review of AI-Driven Threat Detection and Risk Mitigation Strategies», *Electronics*, vol. 14(9), article 1844, 2025. **doi: 10.3390/electronics14091844**.

[10] Utilizing AI for Maritime Transport Optimization. [Online]. Available: https://cmr.berkeley.edu/2024/12/utilizing-ai-for-maritime-transport-optimization/. Accessed on: April 10, 2025.

[11] Y. Zahraoui et al., «AI Applications to Enhance Resilience in Power Systems and Microgrids. A Review», *Sustainability*, vol. 16(12), article 4959, 2024. **doi: 10.3390/su16124959**.

[12] I. Durlik, T. Miller, E. Kostecka, and T. Tuński, «Artificial Intelligence in Maritime Transportation: A Comprehensive Review of Safety and Risk Management Applications», *Applied Sciences*, vol. 14(18), article 8420, 2024. **doi: 10.3390/app14188420**.

[13] L. Ilias et al., «Leveraging extreme scale analytics, AI and digital twins for maritime digitalization: the VesselAI architecture», *Frontiers in Big Data*, vol. 6, 2023. **doi: 10.3389/fdata.2023.1220348**.

[14] J. Xue et al., «Machine Learning in Maritime Safety for Autonomous Shipping: A Bibliometric Review and Future Trends», *Journal of Marine Science and Engineering*, vol. 13(4), article 746, 2025. **doi: 10.3390/jmse13040746**.

[15] M.Á. Gómez Ruiz, I.M. de Almeida, and R. Pérez Fernández, «Application of Machine Learning Techniques to the Maritime Industry», *Journal of Marine Science and Engineering*, vol. 11(9), article 1820, 2023. **doi: 10.3390/jmse11091820**.

СИМБІОЗ ШТУЧНОГО ІНТЕЛЕКТУ І СИСТЕМ КЕРУВАННЯ СУДНОВОЮ ЕЛЕКТРОЕНЕРГЕТИЧНОЮ УСТАНОВКОЮ: СУЧАСНЕ ТА МАЙБУТНЄ

Сіманенков А.Л. *канд. техн. наук, ст. викладач, Херсонська державна морська академія, м. Херсон, ORCID: https://orcid.org/0000-0003-0797-5276, e-mail: simanenkov.andrii@gmail.com;*

Самойлов С.О. *здобувач ступеня PhD, Херсонська державна морська академія, м. Херсон, ORCID: https://orcid.org/0009-0006-4454-0510, e-mail: samoilovserhii.ksma@gmail.com*

Стаття присвячена актуальній проблемі підвищення ефективності, безпеки та екологічності морського транспорту. Основна ідея статті полягає в тому, що цієї мети можна досягти шляхом інтеграції технологій штучного інтелекту (ШІ) в суднові автоматизовані електроенергетичні системи (САЕЕС). Перша частина дослідження присвячена еволюції архітектури САЕЕС та шести основним стратегіям управління енергопостачанням: централізовані та децентралізовані системи, ієрархічні, керування на основі модельного прогнозування, агентно-орієнтовані та системи управління енергоспоживанням. Аналіз кожного підходу включає його переваги та недоліки у розрізі таких параметрів, як ефективність, стабільність, витрати на впровадження та обслуговування, вплив на навколишнє середовище, складність та масштабованість. Друга частина статті зосереджена на огляді застосування технологій ШІ в морській індустрії. Було представлено практичні приклади інтеграції ШІ в морську галузь, зокрема в навігації, діагностиці та оптимізації маршрутів. Також увага була зосереджена на перевагах інтеграції ШІ в САЕЕС. Було виявлено, що цей симбіоз може покращити кожен ключовий параметр у цих системах. Основні виклики пов'язані з глобальними питаннями безпеки та кібербезпеки систем штучного інтелекту, спеціальною кваліфікацією працівників, складністю інтеграції з існуючими системами, гарантією стабільності та передбачуваності алгоритмів штучного інтелекту, проблемами якості та стандартизації даних, регуляторними та етичними аспектами. Крім того, у статті представлені потенційні напрямки майбутнього розвитку симбіозу штучного інтелекту та систем керування судновою енергосистемою. Основна мета охоплює подальшу автоматизацію систем керування, інтеграцію з новими джерелами енергії, оптимізацію роботи суднового обладнання та вирішення наявних проблем та обмежень.

Ключові слова: *електроенергетичні системи суден, енергоефективність, оптимізація, машинне навчання, штучний інтелект, морський транспорт, вплив на навколишнє середовище, безпека на морі, кібербезпека.*

Перелік використаних джерел

[1] Enhancing renewable energy utilization and energy management strategies for new energy yachts / Z. Wang et al. 2024. *Heliyon*. Vol. 10(18). Article e37863. DOI: https://doi.org/10.1016/j.heliyon.2024.e37863.

[2] Challenges and Solutions of Ship Power System Electrification / Z. Bei et al. 2024. *Energies*. Vol. 17(13).

Article 3311. DOI: https://doi.org/10.3390/en17133311.
[3] What is Marine Electricity And How It is Generated. URL: https://www.marineinsight.com/marine-electrical/what-is-marine-electricity/ (date of access 02.04.2025)
[4] Maritime Artificial Intelligence & Machine Learning: Ultimate Guide. URL: https://spire.com/maritime/maritime-artificial-intelligence-and-machine-learning/ (date of access 02.04.2025).
[5] Robust Real-Time Shipboard Energy Management System With Improved Adaptive Model Predictive Control / W. Chen et al. *IEEE Access*. 2023. Vol. 11. Pp. 110342-110360. DOI: https://doi.org/10.1109/access.2023.3321692.
[6] AC Ship Microgrids: Control and Power Management Optimization / M.D.A. Al-Falahi et al. *Energies*. 2018. Vol. 11(6). Article 1458. DOI: https://doi.org/10.3390/en11061458.
[7] AI-Driven Predictive Maintenance in Modern Maritime Transport-Enhancing Operational Efficiency and Reliability / Simion D., Postolache F., Fleacă B., Fleacă E. *Applied Sciences*. 2024. Vol. 14(20). Article 9439. DOI: https://doi.org/10.3390/app14209439.
[8] Hierarchical Control Design for a Shipboard Power System With DC Distribution and Energy Storage Aboard Future More-Electric Ships / Jin Z., Meng L., Guerrero J.M., Han R. *IEEE Transactions on Industrial Informatics*. 2018. Vol. 14(2). Pp. 703-714. DOI: https://doi.org/10.1109/tii.2017.2772343.
[9] Artificial Intelligence in Maritime Cybersecurity: A Systematic Review of AI-Driven Threat Detection and Risk Mitigation Strategies / T. Miller et al. *Electronics*. 2025. Vol. 14(9). Article 1844. DOI: https://doi.org/10.3390/electronics14091844.
[10] Utilizing AI for Maritime Transport Optimization. URL: https://cmr.berkeley.edu/2024/12/utilizing-ai-for-maritime-transport-optimization/ (date of access 02.04.2025).
[11] AI Applications to Enhance Resilience in Power Systems and Microgrids. A Review / Y. Zahraoui et al. *Sustainability*. 2024. Vol. 16(12). Article 4959. DOI: https://doi.org/10.3390/su16124959.
[12] Artificial Intelligence in Maritime Transportation: A Comprehensive Review of Safety and Risk Management Applications / Durlik I., Miller T., Kostecka E., Tuński T. *Applied Sciences*. 2024. Vol. 14(18). Article 8420. DOI: https://doi.org/10.3390/app14188420.
[13] Leveraging extreme scale analytics, AI and digital twins for maritime digitalization: the VesselAI architecture / L. Ilias et al. *Frontiers in Big Data*. 2023. Vol. 6. DOI: https://doi.org/10.3389/fdata.2023.1220348.
[14] Machine Learning in Maritime Safety for Autonomous Shipping: A Bibliometric Review and Future Trends / J. Xue et al. *Journal of Marine Science and Engineering*. 2025. Vol. 13(4). Article 746. DOI: https://doi.org/10.3390/jmse13040746.
[15] Gómez Ruiz M.Á., de Almeida I.M., Pérez Fernández R. Application of Machine Learning Techniques to the Maritime Industry. Journal of Marine Science and Engineering. 2023. Vol. 11(9). Article 1820. DOI: https://doi.org/10.3390/jmse11091820.

Стаття надійшла 16.05.2025
Стаття прийнята 20.06.2025
Стаття опублікована 30.06.2025

Цитуйте цю статтю як: Simanenkov A.L., Samoilov S.O.Symbiosis of artificial intelligence and ship's automated electrical energy systems: present and future. *Вісник Приазовського державного технічного університету. Серія: Технічні науки*. 2025. Вип. 50. С. 191-199. DOI: https://doi.org/10.31498/2225-6733.50.2025.336376.