Ostapenko Olha. Chapter X. Application of artificial intelligence in scientific research in the field of heat power engineering. Штучний інтелект у науці : монографія / [авт. колектив]; за ред. Яцишина Андрія та Яцишин Анни. – Київ: ФОП Ямчинський О.В., 2025. – С. 125-135. ISBN 978-617-8830-09-0

CHAPTER X. APPLICATION OF ARTIFICIAL INTELLIGENCE IN SCIENTIFIC RESEARCH IN THE FIELD OF HEAT POWER ENGINEERING

DOI: 10.33407/lib.NAES.id/748273

Ostapenko Olha[1[0000-0001-9682-9419]]

[1] Vinnytsia National Technical University, Vinnytsia, Ukraine

ostapenko@vntu.edu.ua

Abstract. The study assessed the possibilities of applying artificial intelligence technologies in scientific research in the field of heat and power engineering. The possibilities of applying artificial intelligence for modeling, optimization and forecasting of heat and power systems, including those with non-traditional and renewable energy sources, were assessed. The possibilities of applying artificial intelligence for modeling thermodynamic processes and cycles, as well as heat and mass transfer processes were assessed. The possibilities of applying artificial intelligence in energy audit and energy modernization were shown. Practical examples of applying artificial intelligence in heat and power research were given. The advantages, disadvantages and risks associated with the use of artificial intelligence technologies in heat and power systems were assessed. Strategies for minimizing the risks associated with the use of artificial intelligence technologies in research, optimization and effective safe operation of heat and power systems were proposed.

Keywords: artificial intelligence, scientific research, heat power engineering, modeling, optimization

Introduction. Artificial intelligence is actively transforming the thermal power industry, introducing innovative solutions to optimize and increase the efficiency of energy systems. Artificial intelligence in thermal power research can be used for modeling and forecasting, for example, developing accurate digital twins of thermal power plants, predicting load and energy consumption, and modeling complex thermodynamic processes (Chekifi et al., 2024; Devasenan et al., 2024; Khalid et al., 2021; Olabi et al., 2023; Safari et al., 2024; Ukoba et al., 2024; Zhu and Wenqian, 2019).

Artificial intelligence can be applied in tasks of optimizing the operation of energy systems, for example, for adaptive control of thermal power plants, balancing generation and consumption in heat networks and minimizing energy losses in heat supply systems (Chekifi et al., 2024; Devasenan et al., 2024; Olabi et al., 2023; Safari et al., 2024; Ukoba et al., 2024; Zhu and Wenqian, 2019).

The use of artificial intelligence is possible for predictive diagnostics of equipment, detection of anomalies in the operation of energy equipment, forecasting failures and planning maintenance, optimizing the service life of thermal power plants (Khalid et al., 2021).

It is important to use artificial intelligence in solving tasks of increasing energy efficiency, for intelligent control of heating and air conditioning systems, optimizing energy consumption of industrial facilities, developing energy-efficient buildings with intelligent systems.

The contribution of artificial intelligence to the integration of renewable energy sources for forecasting solar and wind energy generation, optimal combination of traditional and renewable sources and management of hybrid heat supply systems can be significant.

Literature Analysis and Problem Statement. Modeling is one of the most important areas of application of artificial intelligence in heat and power engineering (Devasenan et al., 2024; Olabi et al., 2023; Safari et al., 2024; Ukoba et al., 2024; Zhu and Wenqian, 2019). These technologies allow to create high-precision models of complex thermodynamic processes and energy systems. Let's consider the main methods of artificial intelligence for modeling in heat and power engineering.

Neural networks in heat and power engineering research are used to model nonlinear thermodynamic processes; predict the operating parameters of boilers, turbines and heat exchangers; create surrogate models that replace complex CFD (Computational Fluid Dynamics) calculations.

Genetic algorithms and evolutionary calculations are used to optimize the geometry of heat exchangers, select optimal operating modes of heat and power plants, and minimize fuel consumption under given operating conditions.

Machine learning with reinforcement is used for optimal control of fuel combustion parameters, adaptive regulation of thermal regimes and training of autonomous control systems of power units.

With the help of artificial intelligence, digital twins of thermal power facilities are created, fully functional virtual models of power units of thermal power plants and combined heat and power plants are created, real-time modeling of all plant processes is performed, personnel training and testing of new regimes without risk for real equipment is performed. Combustion and heat transfer modeling is performed, which includes optimization of combustion processes of various types of fuel, modeling of turbulent flows in combustion chambers, calculation of heat transfer in complex geometric systems.

In the tasks of modeling heat networks, heat loss prediction in pipelines, optimization of hydraulic modes of heat networks, modeling of emergency situations and development of measures to prevent them are performed. In integrated energy systems, modeling of the interaction of electrical and heat networks, optimization of cogeneration plants, balancing of supply and demand in intelligent heat supply systems are performed (Chekifi et al., 2024; Devasenan et al., 2024; Olabi et al., 2023; Safari et al., 2024; Ukoba et al., 2024; Zhu and Wenqian, 2019).

The advantages of using artificial intelligence in modeling are a significant reduction in calculation time compared to traditional methods, the ability to take into account a large number of parameters and their mutual influence, the detection of non-obvious dependencies that are difficult to formalize analytically; adaptation of models to changes in operating conditions in real time.

The aim of our research is to assess the possibilities of applying artificial intelligence technologies in scientific research in the field of heat power engineering.

Research Results. The integration of renewable energy sources into thermal power generation is being carried out using artificial intelligence. Artificial intelligence plays a key role in solving the problems of integrating renewable energy sources (RES) into thermal power systems. Let's consider the main directions and technologies.

To predict the generation of RES, short-term forecasts are performed, for which AI models analyze meteorological data to predict the production of solar and wind energy for hours/days ahead with an accuracy of 90-95%; for long-term forecasts, neural networks are used that take into account seasonal patterns and help plan the energy balance for weeks/months; local microforecasts are performed, for which specialized algorithms are used for individual installations that take into account microclimatic features.

Using artificial intelligence technologies, energy systems are balanced with renewable energy sources. Intelligent control systems use machine learning algorithms to optimally distribute the load between traditional and renewable sources.

Virtual power plants that simulate the integration of distributed energy sources (solar panels, heat pumps, biomass plants) into a single controlled system. Predictive demand management is performed, where energy consumption is shifted to periods of maximum renewable energy generation.

In hybrid heat and power systems using artificial intelligence, the operation of heat pumps is optimized, for which AI regulates operating modes depending on the availability of "green" electricity; solar thermal collectors are also integrated, for which algorithms predict heat input and optimize heat accumulation; biomass plants with intelligent control are being developed, for which biofuel combustion processes are optimized depending on the quality of raw materials and heat needs.

For energy storage systems, thermal accumulator operation optimization is performed, in which artificial intelligence determines the optimal charge/discharge modes according to generation and consumption forecasts. Also for energy storage systems, distributed storage system management is performed, in which the coordination of a network of small thermal accumulators at different consumers is ensured. Also, seasonal heat storage modeling is performed, in which underground heat storages are forecasted and controlled.

In intelligent heat supply networks, adaptive temperature control is performed, which ensures optimization of temperature schedules depending on the forecast of renewable energy sources. In decentralized decision-making systems, local controllers with AI are used, which interact with each other to optimize the entire system. In the tasks of detecting and minimizing losses, monitoring of the state of heat supply networks with renewable sources is provided.

Practical examples of the use of artificial intelligence in the heat and power industry are:

• Smart Thermal Grids, in particular, such systems are used in Denmark, Finland, where wind energy is integrated for heat production;

• Solar thermal systems with seasonal storage. Such projects have been implemented in Germany and Austria with AI control;

• Biogas plants with predictive control, in which biogas production is optimized according to heat and electricity needs.

Modeling thermodynamic processes in thermal power plants using artificial intelligence opens up new opportunities for optimizing equipment operation and increasing its efficiency. Let's consider the main aspects of this direction.

In studies of fuel combustion processes, artificial intelligence is used to model the kinetics of chemical reactions in boiler furnaces, optimize air supply for complete combustion, predict the composition of flue gases and the formation of pollutants.

Artificial intelligence in heat transfer process research is used to model convective heat transfer in heat exchangers, calculate radiant heat transfer in high-temperature zones, and optimize the geometry of heat transfer surfaces.

In thermodynamic cycle research, artificial intelligence is used to analyze Rankine cycles in steam turbines, optimize Brayton cycles in gas turbine plants, and simulate combined cycles to increase efficiency.

In hydrodynamic process modeling, artificial intelligence technologies are used to model coolant flows in pipelines, analyze the distribution of velocities and pressures in flow parts, and identify areas with uneven distribution of parameters.

The following artificial intelligence technologies are used to model thermodynamic processes: deep neural networks (creation of CFD (Computational Fluid Dynamics) surrogate models, prediction of temperature fields in complex geometric systems, modeling of non-stationary processes in real time); recurrent neural networks and LSTM (Long short-term memory) (analysis of time sequences of thermodynamic parameters, prediction of the dynamics of temperature and pressure changes, detection of anomalies in equipment operation); convolutional neural networks (processing of thermograms and flow visualizations, analysis of spatial structures of flames and thermal fields, detection of features in thermal images); Bayesian optimization (selection of optimal parameters of thermodynamic processes, minimization of entropy losses in systems, maximization of the efficiency of thermodynamic cycles).

Examples of practical applications of artificial intelligence technologies in steam boiler research include solving problems of optimizing combustion modes of various fuels, predicting thermal stresses in boiler elements, minimizing emissions of NOx, SOx and other pollutants. In steam and gas turbine research, artificial intelligence capabilities can be used to model pressure distribution across turbine stages, optimize the flow part of the turbine, and predict efficiency under variable loads. In research and design and optimization of heat exchangers, artificial intelligence is used to identify areas with low heat transfer intensity, optimize coolant velocities, and predict contamination of heat exchange surfaces. In cooling system research, artificial intelligence technologies are used to optimize cooling towers and other heat removal systems, simulate condensation and evaporation processes, and predict cooling efficiency under different weather conditions.

In modeling thermodynamic processes, the use of artificial intelligence technologies has a number of advantages. These include: calculation speed (which consists in reducing the modeling time from days to minutes; detection of non-obvious dependencies (which allows for finding optimal modes that are difficult to detect analytically); adaptability (models can be adjusted to specific operating conditions);

multiparametric optimization (simultaneous consideration of efficiency, environmental friendliness and cost-effectiveness is ensured).

Examples of successful application of artificial intelligence in scientific research in the field of thermal power engineering are optimization of gas turbine combustion chambers with an increase in efficiency by 2-3%, reduction of NOx emissions in TPP boilers by 15-20% without reducing power, increase in heat exchanger efficiency by 10-15% due to optimization of operating modes, reduction of thermal stresses in steam generator elements by 25-30%.

Optimization of energy supply systems with heat pumps is carried out using artificial intelligence. The use of artificial intelligence to optimize energy supply systems with heat pumps allows to significantly increase their efficiency, economy and environmental friendliness. Let's consider the key aspects of this direction.

Intelligent control of the operation of heat pumps is carried out. In particular, predictive control based on forecasts is carried out (machine learning models are used to predict weather conditions and heat load, optimization of operating modes is carried out with anticipation to maximize COP (energy conversion coefficient), adaptive regulation of the coolant temperature is carried out depending on the forecast of needs). Optimization of the operating cycle is carried out, for this purpose neural network models are used to determine the optimal compressor frequency, machine learning with reinforcement for controlling defrosting processes, intelligent control of the speed of circulation pumps.

Using artificial intelligence technologies, integration with thermal accumulators is ensured, for this purpose algorithms for optimal charge/discharge of thermal accumulators are used, excess renewable energy is used for heat storage, and strategies for using stored heat are optimized.

In thermal energy research, artificial intelligence is used to increase the energy efficiency of complex systems. In particular, hybrid systems are optimized, where intelligent load distribution between a heat pump and additional heat sources (boilers, solar collectors) is carried out, decision-making models are used for switching between energy sources, and the operation of heat pump cascades is optimized. Energy management of buildings is ensured through comprehensive modeling of the building's heat balance taking into account heat pumps, predictive temperature control taking into account the thermal inertia of the building, and coordination of the operation of heating, ventilation, and air conditioning systems. Integration with smart grids is carried out through algorithms for heat pumps to participate in balancing electricity grids (Demand Response), optimize operation taking into account variable electricity tariffs, and coordinate with other flexible loads in microgrids.

In the optimization of energy supply systems with heat pumps, modeling and optimization of thermodynamic processes using artificial intelligence technologies is performed. Optimization of the thermodynamic cycle is performed by modeling heat pump cycles for different temperature regimes, optimization of refrigerant parameters depending on the operating mode, increasing the efficiency of heat exchange processes in the evaporator and condenser. Simulation of low-potential heat sources is performed: in particular, prediction of soil temperature dynamics for geothermal heat pumps is provided, optimization of heat extraction from air, water or soil is provided; prevention of soil freezing during intensive heat extraction is provided. Optimization of heat distribution is provided by modeling low-temperature heating systems, optimization of hydraulic regimes of heat distribution systems, analysis and minimization of heat losses in the system are performed.

There are practical results of using artificial intelligence in optimizing energy supply systems with heat pumps. This includes ensuring energy efficiency, which consists in increasing the seasonal coefficient of performance (SCOP) by 15-30%; cost-effectiveness, which is manifested in reducing operating costs by 20-40%; ensuring comfort by improving the accuracy of maintaining temperature regimes by 30-50%; ensuring effective integration of renewable energy by increasing the share of renewable energy use by 25-60%; ensuring durability by increasing the service life of equipment by 15-25% due to optimization of operating modes.

Examples of successful implementations of artificial intelligence technologies include efficient smart homes with heat pumps that adapt their operation to the habits of residents and weather forecasts; industrial systems with cascades of heat pumps for heat recovery and its efficient use; district heating systems with large heat pumps that use renewable energy sources; agricultural complexes with integrated heat pump systems to create a microclimate.

Despite significant advantages, the introduction of artificial intelligence technologies into heat and power systems is accompanied by certain risks and challenges. Let's consider the main ones.

These are, in particular, technological risks of using artificial intelligence in thermal energy systems. To ensure the reliability of algorithms and forecasts, errors in load forecasting should be avoided, which can lead to insufficient heat supply. Incorrect solutions of optimization algorithms can reduce the efficiency of the system. "Black box" risks confirm the complexity of interpreting neural network solutions. This also includes cybersecurity risks due to the vulnerability of intelligent control systems to cyberattacks, the risks of unauthorized access to the management of energy facilities and the possibility of manipulating input data for artificial intelligence systems (data poisoning). Also significant is the dependence on data quality: there are risks of making decisions based on incomplete or inaccurate data, problems with sensors and measurement systems, risks due to the sensitivity of models to changes in operating conditions.

Operational risks associated with the use of artificial intelligence are also significant. When integrating with existing systems, one should take into account the complexity of harmonizing new solutions based on artificial intelligence with traditional control systems, assess risks during the transition period of implementation and take into account the need to modernize the infrastructure for the full functioning of artificial intelligence. The human factor should be taken into account, namely: a decrease in the level of understanding of processes by personnel due to automation, the risk of excessive trust in automated systems and dependence on a limited number of specialists capable of servicing systems based on artificial intelligence. Operational risks include risks associated with the reliability and stability of systems, namely: risks of failure of systems with artificial intelligence in critical situations, the complexity of diagnosing errors in intelligent systems and the potential instability of artificial intelligence during atypical operating modes.

Separately, it is necessary to assess the economic risks of using artificial intelligence for modeling, research and optimization of thermal energy systems. These are high initial investments due to significant costs for the development and implementation of artificial intelligence systems, a long payback period for investments and risks of technological obsolescence before full payback. There are also risks associated with operating costs, namely: costs for maintaining the technological infrastructure of artificial intelligence, the need for regular updating of models and algorithms, costs for training and retraining of personnel.

Taking into account the abovementioned, it is necessary to evaluate strategies for minimizing risks from the use of artificial intelligence in research and operation of thermal power facilities and energy systems. As technical measures in this regard, the implementation of systems with a gradual transition from "man in the loop" to full automation, the creation of backup traditional control systems and regular testing and validation of artificial intelligence models should be considered. Organizational measures should be taken, in particular, to ensure the creation of interdisciplinary teams for the development and implementation of solutions, to develop a comprehensive personnel training program, to ensure the development of standards and procedures for the use of artificial intelligence in thermal power. Important regulatory measures to minimize risks from artificial intelligence in thermal power and energy facilities and systems are the creation of a regulatory framework for the use of artificial intelligence in critical infrastructure, the introduction of certification procedures and verification of artificial intelligence systems; the development of industry security standards for intelligent systems.

Understanding and proactively managing these risks is a prerequisite for successfully integrating artificial intelligence technologies into the thermal energy industry and obtaining the maximum benefit from these innovations.

Conclusions. The study assesses the possibilities of applying artificial intelligence technologies in scientific research in the field of thermal energy. The possibilities of applying artificial intelligence for modeling, optimization and forecasting the operating modes of thermal energy systems, including those with non-traditional and renewable energy sources and storage systems, are assessed. The possibilities of applying artificial intelligence for modeling thermodynamic processes and cycles, as well as heat and mass transfer processes and fuel combustion are assessed. The possibilities of applying artificial intelligence in energy audit and energy modernization are illustrated. Practical examples of applying artificial intelligence in thermal energy research and optimization are given. The advantages, disadvantages and risks associated with the use of artificial intelligence technologies in thermal energy systems are assessed. Strategies for minimizing the risks associated with the use of artificial intelligence technologies in research, optimization and effective safe operation of thermal energy systems are proposed.

References

1. Chekifi, Tawfiq & Boukraa, Moustafa & Benmoussa, Amine. (2024). Artificial Intelligence for Thermal Energy Storage Enhancement: A Comprehensive Review. Journal of Energy Resources Technology. 146. 1-29. 10.1115/1.4065197.

2. Devasenan, Madhesh & Madhavan, Saritha. (2024). Thermal intelligence: exploring AI's role in optimizing thermal systems – a review. Interactions. 245. 10.1007/s10751-024-02122-6.

3. Khalid, S., Hwang, H., & Kim, H. S. (2021). Real-World Data-Driven Machine-Learning-Based Optimal Sensor Selection Approach for Equipment Fault Detection in a Thermal Power Plant. *Mathematics*, *9*(21), 2814. https://doi.org/10.3390/math9212814

4. Olabi, A. G., Abdelghafar, A. A., Maghrabie, H. M., Sayed, E. T., Rezk, H., Radi, M. A., Obaideen, K., & Abdelkareem, M. A. (2023). Application of artificial intelligence for prediction, optimization, and control of thermal energy storage systems. *Thermal Science and Engineering Progress*, *39*, Article 101730. https://doi.org/10.1016/j.tsep.2023.101730

5. Safari, A., Daneshvar, M., & Anvari-Moghaddam, A. (2024). Energy Intelligence: A Systematic Review of Artificial Intelligence for Energy Management. *Applied Sciences*, *14*(23), 11112. https://doi.org/10.3390/app142311112

6. Ukoba, K., Olatunji, K. O., Adeoye, E., Jen, T.-C., & Madyira, D. M. (2024). Optimizing renewable energy systems through artificial intelligence: Review and future prospects. *Energy & Environment*, *35*(7), 3833-3879. https://doi.org/10.1177/0958305X241256293 (Original work published 2024)

7. Zhu, Wenqian. (2019). Intelligent Construction and Management of Thermal Power Plant Based on Internet + Mode. IOP Conference Series: Earth and Environmental Science. 252. 032068. 10.1088/1755-1315/252/3/032068.

* * *