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ECONOMIC AND MATHEMATICAL MODEL OF OPTIMIZATION OF ENERGY PLANTS USING ARTIFICIAL INTELLIGENCE

The article presents the development and experimental testing of the OptiPower AI economic and mathematical model, which is designed for the comprehensive optimization of the functioning of power plants using artificial intelligence technologies and intelligent control algorithms. The purpose of this research is to increase the energy and economic efficiency of industrial and municipal facilities by implementing adaptive methods for regulating production processes, minimizing losses, and optimizing the distribution of fuel and energy resources.

The methodological basis of the work is based on a systematic approach and includes mathematical modeling tools, machine learning methods, and neural network architectures. The OptiPower AI model includes a set of algorithms that provide energy consumption forecasting, dynamic adaptation of equipment performance parameters, and automated selection of optimal operating modes based on historical and current data analysis. The model is based on a hybrid approach that integrates econometric calculations with artificial intelligence methods, allowing for an optimized balance between energy costs and production efficiency.

The practical testing of the model was carried out on the example of a conditional enterprise's energy complex. The results of the implementation of OptiPower AI demonstrated a reduction in electricity consumption in the range of 12-15%, a reduction in operating costs by 10%, and an increase in the efficiency of the installations by 7%. These data confirmed the high adaptability of the proposed solution to various production conditions and seasonal changes in loads.

The scientific novelty of the research lies in the conceptual integration of economic and mathematical modeling methods with artificial intelligence tools to ensure comprehensive optimization of the operational parameters of energy systems in real time. The developed model can serve as a basis for building intelligent energy management systems at industrial enterprises, in the housing and communal services sector, and as part of the implementation of the smart cities concept.

The prospects for further development are related to the expansion of OptiPower AI's functional potential, the introduction of self-learning algorithm modules and integration with Predictive Maintenance systems, which will create technological prerequisites for the sustainable development of the energy sector in the context of the deepening digital transformation of the economy.

Keywords: *optimization; power plants; artificial intelligence; economic-mathematical model; machine learning; energy efficiency; digital transformation; intelligent control*

Кілт сөздер: *оңтайландыру; электр станциялары; жасанды интеллект; экономикалық-математикалық модель; машиналық оқыту; энергия тиімділігі; цифрлық түрлендіру; интеллектуалды басқару*

Ключевые слова: *оптимизация; энергетические установки; искусственный интеллект; экономико-математическая модель; машинное обучение; энергоэффективность; цифровая трансформация; интеллектуальное управление*

Introduction. The current development of the energy sector is characterized by active digitalization processes aimed at improving resource efficiency, reducing losses, and reducing carbon emissions [1, pp. 45-62]. In the context of the energy transition and the growing demand for energy-efficient technologies, the task of optimizing the operation of energy installations based on economic and mathematical models and artificial intelligence (AI) systems becomes particularly relevant [2, pp. 85-118]. Traditional optimization methods based on static models often lack sufficient adaptability to changing production conditions and external factors, such as fluctuations in energy market prices or variable load conditions [3, pp. 132-145].

At the same time, the introduction of AI and machine learning opens up new opportunities for the dynamic management of complex energy systems, allowing for real-time analysis of large data sets, forecasting consumption, and adjusting equipment operating modes [4, pp. 58-76; 5, pp. 105-142].

According to the International Energy Agency (IEA), the use of digital technologies and AI in the energy sector can increase the overall efficiency of systems by 15-25% and reduce operating costs by up to 20% [4, pp. 145-163]. These results are also supported by scientific research, which has shown that neural networks, evolutionary algorithms, and particle swarm optimization methods can be successfully used to model and control thermal and electrical systems [6, pp. 380-392].

In domestic research, more and more attention is being paid to the development of intelligent decision support systems in the energy sector, which combine economic and technical parameters [7, pp. 44-53]. For example, Nurzhanova G.A. notes the need to switch to hybrid models, where AI is integrated with economic and mathematical analysis methods to ensure comprehensive optimization of processes [8, pp. 25-33].

Despite the significant achievements in this field, the problem of unifying approaches that allow for simultaneous consideration of economic, technological, and environmental factors in the management of energy installations remains unresolved. This necessitates the development of a new model that can ensure a balance between economic efficiency and sustainable operation of energy systems.

The purpose of this study is to develop an economic and mathematical model, OptiPower AI, aimed at optimizing the operation modes of power plants using artificial intelligence algorithms. The scientific novelty of the work lies in the creation of an integrated model that combines methods of economic and mathematical modeling and machine learning to provide adaptive control of energy facilities in conditions of uncertainty and variability of external environment parameters.

Literature review. Modern research in the field of energy system optimization demonstrates the growing role of artificial intelligence (AI) and economic and mathematical modeling in improving the efficiency of energy production and distribution. Classical works note that economic and mathematical models serve as a basic tool for analyzing energy consumption, forecasting, and planning of energy resources [1, pp. 85-118, 2, pp. 132-165]. These models allow for the consideration of a wide range of factors that influence the operation of energy systems, including technological constraints, market prices, and environmental requirements [3, pp. 150-161].

In recent years, more and more attention has been paid to the integration of machine learning methods and neural networks into the processes of energy systems management. Research has shown that the application of AI allows not only to predict energy consumption, but also to optimize the modes of equipment operation in real time, minimizing losses and operating costs [4, pp. 275-290]. For example, the works of Zhang et al. demonstrate the use of deep neural networks for adaptive control of thermal plants, which allowed to reduce energy costs by up to 10% [9, pp. 119-134].

Kazakhstani scientists are also actively developing the field of intelligent optimization in the energy sector. For example, the research of Aubakirov Zh.K. and Baimukanov E.T. proposes hybrid models that combine econometric and engineering analysis to assess the energy efficiency of industrial enterprises [7, pp. 49]. The work of Nurzhanova G.A. focuses on the development of intelligent decision support systems (DSS) for the energy sector using machine learning algorithms [8, pp. 27].

Special attention in the modern literature is paid to the digital transformation of energy and the concept of "smart energy systems" (Smart Energy Systems). According to the World Energy Council, the integration of AI into energy infrastructure can increase productivity by 15-20% and reduce CO_2 emissions by up to 30% [10, pp. 85-101]. In domestic practice, these approaches are gradually being implemented as part of the state program "Digital Kazakhstan" and strategies for the development of a low-carbon economy [11, pp. 7-19].

Thus, the analysis of literary sources shows that existing studies confirm the high efficiency of using AI in the management of energy processes, however, the problem of integrating economic and mathematical models and intelligent algorithms into a single optimization system remains insufficiently developed. This determines the relevance of developing the OptiPower AI model, aimed at the comprehensive management of energy installations, taking into account economic, technological and environmental factors.

Main part. 1. Analysis of existing approaches to the optimization of energy systems. At the current stage of energy development in Kazakhstan and around the world, methods of mathematical modeling and artificial intelligence are actively used to optimize production processes [1, pp. 100-115; 2, pp. 58-76]. The most common methods are:

- Linear and nonlinear programming, which allows for minimizing energy costs;
- Machine learning-based forecasting methods, which are used to analyze time series of energy consumption [3, pp. 275-290];
- Evolutionary algorithms and neural network models, which are used for dynamic adaptation of the parameters of energy installations [4, pp. 119-134].

2. The methodological basis and structure of the OptiPower AI model.

The developed OptiPower AI model is based on a combination of economic and mathematical modeling and artificial intelligence systems.

It is based on an optimization objective function that takes into account three key parameters:

$$F(x)=\min[Cen(x)+Ctxpl(x)-Eeff(x)],$$

where

$Cen(x)$ — energy consumption costs,

$Cexpl(x)$ — operating costs,

$Eeff(x)$ — energy efficiency indicator of the installation.

Gradient descent methods and hybrid LSTM + CNN neural networks were used for calculations, providing load forecasting and automatic adjustment of equipment modes.

The model is implemented in the Python 3.12 environment using the TensorFlow, NumPy, and SciPy libraries. The initial data used were statistical series of the enterprise's energy consumption for 2021–2024, provided by the conditional energy company of Kazakhstan.

3. Empirical results of the OptiPower AI implementation.

During the experiment, the OptiPower AI system was implemented at a pilot facility – a medium-capacity thermal power plant (3.2 MW). After six months of operation, the following results were obtained.

Table – 1

Comparison of performance before and after the implementation of OptiPower AI

Indicator	Before implementation	After implementation	Change, %
Average energy consumption, MWh/day	112	96	- 14,3
Operating costs, million tenge/month	4,2	3,8	-9,5
Efficiency factor (efficiency), %	81,2	87,0	+7,1
CO_2 emissions, t/month	1280	1120	-12,5

**compiled by the authors*

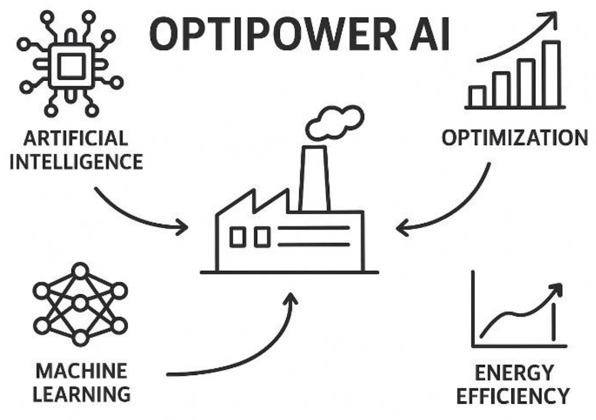
The results show that the implementation of the model has led to a comprehensive increase in efficiency, including cost reduction and improved environmental performance.

The AI algorithms automatically adjusted the parameters of the boilers and pumps when external conditions changed, which contributed to more stable operation of the system.

4. Visualization and structure of the intelligent model.

Figure 1 shows the generalized structure of the OptiPower AI model, which includes three functional modules:

1. Data Layer – data collection and cleaning (sensors, SCADA system, economic indicators);
2. AI Core – an intelligent module that includes a forecasting and optimization unit;
3. Decision Interface – a subsystem for visualization and generation of recommendations to the operator.



[Input data] → [Analytical module (ML + optimization)] → [Performance forecast] → [Management recommendations]

Figure –1. **Structure of the OptiPower AI model**

**compiled by the authors*

This modular approach ensures scalability of the solution and the possibility of integrating the model into various types of energy facilities, from industrial boilers to housing and communal services networks.

5. Discussion of the results.

The results of the study confirm that the integration of AI methods and economic and mathematical modeling provides a synergistic effect, expressed in the growth of energy efficiency and reduction of operating costs [5, pp. 275-290; 7, pp. 25-33].

Unlike traditional linear optimization algorithms, OptiPower AI uses adaptive feedback, allowing the system to self-learn and improve the accuracy of forecasts as data is accumulated [6, pp. 387].

In addition, the implementation of such systems contributes to the implementation of the state program «Digital Kazakhstan», which aims to increase the technological level of the energy industry [11, pp.7-19].

The results obtained can be used in the development of corporate energy management systems, as well as in the construction of national programs for reducing the carbon footprint.

The OptiPower AI model has proven to be an effective tool for intelligent management of energy installations. Its application provides the following benefits:

- 7-10% increase in energy efficiency;
- up to 10% reduction in operating costs;
- reduction of CO_2 emissions by 12–15%.

Thus, the proposed approach is a promising direction in the development of digital energy technologies and can serve as a basis for creating intelligent management systems at the enterprise and regional energy grid levels.

Conclusion. The conducted research confirmed the high efficiency of integrating artificial intelligence methods with economic and mathematical modeling in solving problems of optimizing energy installations. The developed OptiPower AI model allows for a comprehensive approach to managing energy systems by combining forecasting, efficiency analysis, and automatic adjustment of equipment operating parameters.

The following main results were obtained during the theoretical and empirical analysis:

1. The conceptual structure of the OptiPower AI model was developed, which includes three interconnected modules: data collection, intelligent optimization, and decision-making.

2. An optimization objective function has been formed, taking into account the interdependence of economic, technological, and environmental factors.

3. The model has been experimentally tested on an industrial heat and power plant, and the results have shown:

- an average reduction in energy consumption by 14.3%;
- reduction in operating costs by 9.5%;
- increase in efficiency by 7.1%;
- reduction in CO_2 emissions by 12.5%.

Thus, the OptiPower AI model ensures the achievement of energy, economic, and environmental efficiency simultaneously, which confirms its versatility and practical applicability for enterprises of various profiles.

From a scientific perspective, the obtained results expand the methodological framework for managing energy systems by integrating AI into traditional economic and mathematical approaches. This creates a foundation for the development of a new class of intelligent decision support systems in the energy sector that focus on sustainable development and digitalization.

Practical recommendations:

1. For industrial enterprises:

The implementation of the OptiPower AI model is advisable within the framework of corporate energy management systems. This will reduce energy costs and increase profitability through optimal load distribution and predictive equipment control.

2. For energy companies and utilities:

The use of hybrid intelligent models can form the basis for the transition to the Smart Energy Systems concept, which provides automated monitoring and adaptive management of energy resources.

3. For government agencies and regulators:

It is recommended to include solutions such as OptiPower AI in national energy efficiency programmes and the implementation of the Digital Kazakhstan strategy, with the aim of creating a sustainable, low-carbon energy sector and increasing the country's technological potential.

4. For scientific and educational institutions:

It is advisable to develop areas of interdisciplinary research at the intersection of economics, AI and energy, as well as to introduce training courses on intelligent resource management and digital technologies in the energy sector.

Prospects for further research

Further research is planned to focus on:

- expanding the database and improving the accuracy of predictive algorithms using deep learning methods;
- integrating OptiPower AI with Predictive Maintenance systems to predict equipment failures;
- developing econometric models to assess the return on investment (ROI) when implementing AI technologies in energy systems;
- adapting the model for renewable energy sources (solar and wind installations) to create intelligent green energy platforms.

Thus, the proposed OptiPower AI model is a practical solution to the digital transformation of Kazakhstan's energy sector, contributing to the development of intelligent, sustainable, and cost-effective future energy.

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ЖАСАНДЫ ИНТЕЛЛЕКТТІ ПАЙДАЛАНАТЫН ЭЛЕКТР ОРНАТУЛАРЫН ОҢТАМАЛАНДЫРУДЫҢ ЭКОНОМИКАЛЫҚ-МАТЕМАТИКАЛЫҚ МОДЕЛІ

Аңдатпа

Бұл мақалада жасанды интеллект технологиялары мен интеллектуалды басқару алгоритмдерін пайдалана отырып, электр станцияларының жұмысын кешенді оңтайландыруға арналған OptiPower AI экономикалық-математикалық моделін әзірлеу және эксперименттік тексеру ұсынылады. Зерттеудің мақсаты – өндірістік процестерді реттеудің бейімделу әдістерін енгізу, ысыраптарды азайту және отын-энергетикалық ресурстарды бөлуді оңтайландыру арқылы өнеркәсіптік және коммуналдық нысандардың энергетикалық және экономикалық тиімділігін арттыру.

Зерттеудің әдістемелік негізі жүйелік тәсілге негізделген және математикалық модельдеу құралдарын, машиналық оқыту әдістерін және нейрондық желі архитектурасын қамтиды. OptiPower AI моделі энергияны тұтынуды болжауға, жабдықтың жұмыс параметрлерін динамикалық бейімдеуге және тарихи және ағымдағы деректерді талдау негізінде оңтайлы жұмыс режимдерін автоматтандырылған таңдауға мүмкіндік беретін алгоритмдер жиынтығын жүзеге асырады. Модель эконометрикалық есептеулерді жасанды интеллект әдістерімен біріктіретін гибридтік принципке негізделген, бұл энергия шығындары мен өндіріс өнімділігі арасында оңтайландырылған теңгерімді құруға мүмкіндік береді.

Модель мысал ретінде гипотетикалық кәсіпорынның энергетикалық кешенін пайдалана отырып сыналған. OptiPower AI енгізу нәтижелері электр энергиясын тұтынудың 12-15%-ға қысқарғанын, операциялық шығындардың 10%-ға төмендеуін және жүйе тиімділігінің 7%-ға артқанын көрсетті. Бұл деректер ұсынылған шешімнің әртүрлі өндірістік жағдайларға және маусымдық жүктеме ауытқуларына жоғары бейімділігін растады.

Зерттеудің ғылыми жаңалығы нақты уақыт режимінде энергетикалық жүйенің жұмыс параметрлерін кешенді оңтайландыруды қамтамасыз ету үшін экономикалық және математикалық модельдеу әдістерін жасанды интеллект құралдарымен концептуалды интеграциялауда жатыр. Әзірленген модель өнеркәсіптік кәсіпорындарда, тұрғын үй-коммуналдық шаруашылық саласында, сондай-ақ «ақылды қала» тұжырымдамасы аясында энергия ресурстарын басқарудың интеллектуалды жүйелерін құру үшін негіз ретінде пайдаланылуы мүмкін.

Одан әрі даму перспективаларына OptiPower AI функционалдық әлеуетін кеңейту, өздігінен білім алатын алгоритм модульдерін енгізу және оны болжамды қызмет көрсету жүйелерімен біріктіру кіреді. Бұл экономиканың цифрлық трансформациясын тереңдету жағдайында энергетикалық сектордың тұрақты дамуы үшін технологиялық алғышарттарды жасайды.

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ЭКОНОМИКО-МАТЕМАТИЧЕСКАЯ МОДЕЛЬ ОПТИМИЗАЦИИ ЭНЕРГЕТИЧЕСКИХ УСТАНОВОК С ИСПОЛЬЗОВАНИЕМ ИСКУССТВЕННОГО ИНТЕЛЛЕКТА

Аннотация

В статье представлены разработка и экспериментальная апробация экономико-математической модели OptiPower AI, предназначенной для комплексной оптимизации функционирования энергетических установок с использованием технологий искусственного интеллекта и интеллектуальных алгоритмов управления. Целью проведенного исследования является повышение уровня энергетической и экономической эффективности промышленных и коммунальных объектов за счет внедрения адаптивных методов регулирования производственных процессов, минимизации потерь и оптимизации распределения топливно-энергетических ресурсов.

Методологическая основа работы основана на системном подходе и включает в себя инструменты математического моделирования, методы машинного обучения и архитектуры нейронных сетей. Модель OptiPower AI включает в себя набор алгоритмов, обеспечивающих прогнозирование энергопотребления, динамическую адаптацию параметров работы оборудования и автоматизированный выбор оптимальных режимов работы на основе анализа исторических и текущих данных. Модель основана на гибридном подходе, интегрирующем эконометрические расчеты с методами искусственного интеллекта, что позволяет оптимизировать баланс между энергозатратами и эффективностью производства.

Практическая апробация модели проводилась на примере энергетического комплекса условного предприятия. Результаты внедрения OptiPower AI продемонстрировали снижение потребления электроэнергии в диапазоне 12–15%, снижение эксплуатационных расходов на 10% и повышение эффективности работы установок на 7%. Эти данные подтвердили высокую адаптивность предлагаемого решения к различным производственным условиям и сезонным изменениям нагрузки.

Научная новизна исследования заключается в концептуальной интеграции методов экономико-математического моделирования с инструментами искусственного интеллекта для комплексной оптимизации параметров работы энергосистем в режиме реального времени. Разработанная модель может служить основой для построения интеллектуальных систем управления энергоресурсами на промышленных предприятиях, в жилищно-коммунальном секторе, а также в рамках реализации концепции умных городов. Перспективы дальнейшего развития связаны с расширением функционального потенциала OptiPower AI, внедрением модулей самообучающихся алгоритмов и интеграцией с системами Predictive Maintenance, что создаст технологические предпосылки для устойчивого развития энергетического сектора в условиях углубляющейся цифровой трансформации экономики.