

ANNOTATION

dissertations for the degree of Doctor of Philosophy (PhD) in the frame of educational program 8D07112 - "Electric Power Engineering"

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STRATEGIES FOR MARKET INTEGRATION OF RENEWABLE ENERGY OBJECTS AND ASSESSMENT OF THEIR IMPACT ON THE SUSTAINABILITY OF THE ENERGY SYSTEM OF KAZAKHSTAN

Relevance of the topic. The modern world faces pressing energy challenges: depletion of traditional resources, climate change and growing demand for energy. These factors are pushing countries to transition to cleaner and more sustainable energy sources. Renewable energy sources (RES), such as solar and wind, are increasingly seen as a key element of this transition.

Kazakhstan, which has significant renewable energy potential, is actively participating in the global trend. The country's strategic plans provide for a significant increase in the share of renewable energy in the energy balance. However, the integration of renewable energy into the existing energy system is associated with a number of technical, economic and social challenges that require a comprehensive solution.

The relevance of this study lies in the need to develop effective strategies and mechanisms for the successful integration of renewable energy sources into the energy system of Kazakhstan.

The results of the study will allow:

- Assess the potential RES in Kazakhstan and determine the optimal directions for their development.
- Identify key issues and risks associated with the integration of renewable energy sources.
- Develop recommendations for improving the regulatory framework and market mechanisms.
- Provide sustainable development of the energy sector and achievement of climate and energy security goals.

The study will also contribute to the scientific debate on the challenges of integrating renewable energy sources and develop practical recommendations for energy companies, government agencies and other stakeholders.

According to the above, this dissertation work is relevant and in demand in the context of global trends and national priorities of Kazakhstan.

The goal. This dissertation is a study of strategies for the market integration of renewable energy facilities into the energy system of Kazakhstan and an assessment of their impact on the sustainability of the energy system.

Objectives of the doctoral dissertation:

- Conduct an analysis of the current state of the energy market of Kazakhstan from the point of view of the introduction and integration of renewable energy

sources into the structure of the country's energy system.

- To assess the existing technical, economic and market barriers to the integration of renewable energy facilities into the energy system of Kazakhstan, including an analysis of legislative and regulatory acts governing the energy market.

- To explore methods for forecasting renewable energy generation using modern mathematical models and machine learning algorithms, including time series methods and stochastic approaches applicable to wind and solar power plants.

- To analyze the impact of increasing the share of renewable energy sources on the stability of the energy system of Kazakhstan.

- To develop and propose strategies for the market integration of renewable energy facilities into the energy system of Kazakhstan, taking into account the features of variable generation of renewable energy sources and improving the balance between supply and demand for electricity.

Object and subject of research.

The object of the study is renewable energy sources, including solar and wind power plants, as well as the energy system of Kazakhstan, which is a complex and multi-level structure. It combines traditional and alternative energy sources, electrical networks, control systems and energy consumers. The energy system under study is in the conditions of transformation caused by the need to integrate renewable energy sources, which requires taking into account the specific characteristics of these sources, such as their variability and dependence on weather conditions. The object of the study also includes individual aspects of the market infrastructure regulating the mechanisms of interaction between energy market participants, including producers, suppliers and consumers of energy.

The subject of the study is the mechanisms, models and methods of market integration of renewable energy sources into the energy system of Kazakhstan. The main attention is paid to the processes of forecasting the volumes of renewable energy generation, their impact on the power balance, modeling the interactions between renewable energy sources and traditional energy sources, as well as the analysis of the stability of the energy system when the share of renewable generation changes. The subject also includes the technological and economic aspects of the integration of renewable energy sources, including the development of algorithms to improve the accuracy of forecasts, optimization of the energy system taking into account seasonal and daily fluctuations in generation, as well as an analysis of the impact of renewable energy sources on the tariff policy and environmental indicators of the energy system.

Research methods. In the theoretical and applied research in the dissertation, the following methods were used: data analysis to study historical indicators of renewable energy generation, wind speed and insolation, as well as to predict their future behaviour based on statistical data for previous years; mathematical methods of Auto Regressive Moving Average, Random forest, Linear Programming of the energy balance; computer modelling and

calculations using the programs Dig Silent Power Factory, MatLab, PV Syst, Auto Cad, Wind PRO.

Scientific novelty:

- An application based on the Random Forest method has been developed in the Telegram channel that predicts temperature, solar radiation, wind speed;
- Methods for forecasting renewable energy generation are proposed, based on modern mathematical models and machine learning methods;
- Strategies are proposed that can improve the sustainability of the energy system while increasing the share of renewable energy sources in the country's energy balance;
- The energy system of the Almaty region was modeled and the impact of renewable energy sources on its stability was assessed.

Practical significance The obtained results will consist in developing a model for forecasting the generation of renewable energy sources based on artificial intelligence methods, which improves power balance planning, reducing dependence on traditional energy sources. The results of the dissertation were used in the implementation of the grant funding project of the IRN BR21882294 on the topic "Autonomous energy supply system for remote regions of Kazakhstan based on renewable energy sources". The results of the study can be used to develop strategies for integrating renewable energy sources into the energy system of Kazakhstan, which will increase its sustainability and reliability. The developed Proposed economic approaches will help in creating investment plans aimed at optimizing costs and attracting investment. Also, scenario modelling will enable regional authorities to develop long-term plans for infrastructure modernization, which will improve the environmental situation in the Almaty region and create new jobs, contributing to the socio-economic development of the region.

The main scientific provisions and research results submitted for defence:

- Methodology for assessing the impact of renewable energy integration on the sustainability of the energy system. Approaches to the analysis of the impact of variable generation from solar and wind power plants on the stability of the energy system of the Almaty region have been developed and substantiated, taking into account the dynamics of supply and demand for electricity.
- Mathematical model of the power system taking into account the integration of renewable energy sources. A mathematical model of the energy system is presented, allowing to assess the impact of increasing the share of renewable energy sources on the reliability and stability of the region's power supply. The model takes into account climatic factors, variable capacities and the manoeuvrability of traditional energy sources.
- Scenarios for the development of the energy system with an increase in the share of renewable energy sources. Various scenarios for the development of the energy system of the Almaty region with an increase in the share of

renewable energy sources have been modeled, which makes it possible to assess the impact of various integration strategies on the stability of the energy system and on consumers.

Connection of work with the plan of state scientific programs.

Scientific research on the topic of dissertations was conducted in accordance with the plans of research work of the Department of Power Engineering of KazNITU named after K.I. Satpayev within the framework of the state educational grant for doctoral studies. Personal contribution of the author. All results of the dissertation scientific research were obtained by the author himself. Approval of tasks for achieving the goal of the study, analysis of research methods and results of scientific research were carried out under the supervision of the author, his scientific supervisor and foreign scientific supervisor. The results of other researchers used in the course of the study were indicated by references to the relevant literature.

Justification and reliability of results and conclusions. The obtained research results are theoretically substantiated and confirmed by computer modelling and experimental studies, as well as calculations using application software packages; they were discussed by foreign reviewers when published in an international journal on renewable energy.

Testing the work. The main materials and results of the dissertation work were presented and discussed:

- IEEE 23rd International Conference of Young Professionals in Electron Devices and Materials (EDM)(Novosibirsk, Russia, 2022);
- at the international scientific and practical conference Energy and Digital Transformation, Tinchurin Readings, No. 15 (Kazan, Tatarstan, 2022)
- scientific seminars of the Department of Power Engineering of KazNITU named after K.I. Satpayev.

Main scientific results published in 5 scientific papers, including 1 publication included in the SCOPUS information database (percentile - 87), 3 publications in publications recommended by Ministry of Science and Education, and 2 publications in the materials of international scientific and practical conferences.

1. Numerical analysis on inlet position and orientation for enhanced thermal performance of a solar thermochemical reactor for two-step WS cycle for hydrogen production. Journal of Thermal Analysis and Calorimetry. Vol.149, pages 8409-8429 2024. <https://doi.org/10.1007/s10973-024-13154-z> Scopus (miscellaneous) – 87-й процентиль.
2. Experimental study of operation of a solar water heating system in winter. Статья. Вестник Каз АТК, №2 (131), 2024, с.523-529 ISSN 1609-1817
3. Жаңартылатын генерациялау бірліктерінің нарықтық интеграциялық стратегиялары. Вестник Каз АТК, №4 (133), 2024, ISSN 1609-1817
4. Үш деңгейлі кернеу түрлендіргішінің математикалық моделі.

Статья. Вестник ТоУ, №2 (174), 2024, с. 242-248 ISSN 2710-3420

Structure and scope of the dissertation: The dissertation consists of an introduction, the main part of four chapters, and a conclusion. The volume of the dissertation is 102 pages of typewritten text, contains 50 figures, 12 tables, a list of references, including 98 titles, and 3 appendices.