



MODELING THE EFFECT OF THE ELECTRICITY PRODUCED BY THE HPP ON NETWORK OPERATION MODES

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Abstract

This article is devoted to the modeling and analysis of the influence of hydroelectric power plants (HPP) in the Republic of Uzbekistan on the operating modes of the network in the process of electricity generation. The study analyzed the influence of hydroelectric power plants on load management and energy distribution in the network, especially in terms of frequency and voltage instability. The research methodology used modeling methods based on Matlab/Simulink and artificial intelligence (ANN, SVM). Based on the simulation results, high-precision models were developed for predicting fluctuations in energy production and distribution at hydroelectric power plants. At the same time, the role of HPPs in ensuring network stability and the importance of regulation systems, as well as scientific solutions for increasing the efficiency of energy distribution, were proposed. The research findings also include practical recommendations for optimizing the national power grid and strengthening the integration of renewable energy sources into the grid.

Keywords: Hydroelectric power plants (HPP), electrical network, modeling, energy distribution, frequency regulation, energy efficiency, renewable energy sources.



Introduction

In the 21st century, energy security, stability, and efficiency of energy production are acquiring strategic importance on a global scale. This situation prompted the Republic of Uzbekistan to fundamentally revise its energy policy and actively introduce alternative and renewable energy sources. In particular, the hydropower sector plays an important role in this process. In accordance with the Decree of the President of the Republic of Uzbekistan No. PP-2947 dated May 2, 2017, consistent programs for the modernization of hydroelectric power plants and the commissioning of new capacities were implemented for 2020-2024. In particular, according to JSC "Uzbekgidroenergo," by the end of 2023, the total capacity of hydropower plants in Uzbekistan exceeded 2,233 MW, and the volume of hydropower generated reached 6.5 billion kWh. This amounted to 8.3 percent of electricity production, almost twice as much as in 2018.

However, the increase in hydropower production generates new challenges for the power grid, both technically and administratively. The electricity generated by hydroelectric power plants is usually regime-dependent, i.e., strongly dependent on seasonal and daily fluctuations in water flow. This directly affects the frequency and voltage stability of the network. Especially in conditions of growing population and industrial loads, the operation of network modes in an unoptimized state can lead to large energy losses and even emergency interruptions. Short-term outages in the energy system of Central Asia in January 2024 were explained precisely by the mismatch in the reactive power balance. At the same time, the scientific analysis and mathematical modeling of the role of hydroelectric power plants have become a pressing problem.

The main goal of this study is to develop scientifically based proposals for increasing the stability of the system by identifying, assessing, and modeling the influence of electricity generated by HPPs on the operating modes of the electric power grid (voltage, frequency, power flow, and reactive power balance). The study also shows how to balance the operating modes of the power grid through automatic frequency regulation (AFC) of HPPs, voltage regulation systems, and optimal management of water resources.

According to statistics, by the end of 2024, it is planned to commission 12 more new hydropower plants in Uzbekistan, which are expected to create an additional



450 MW of capacity. This increases the pressure on the existing network and further complicates the management systems. Also, within the framework of the "Sustainable Development Goals - 2030," proclaimed by the UN, the task of dramatically increasing the share of renewable energy sources has been set, and any technical approach in this regard must be based on modern scientific foundations.

In-depth study of the influence of electricity generated by hydroelectric power plants on the operating modes of the electrical grid and simulation using mathematical models is one of the most pressing issues of today. This scientific research serves as a theoretical and practical basis for the effective implementation of the energy strategy of Uzbekistan, the state policy on the modernization and digitalization of electrical networks.

LITERATURE ANALYSIS

In recent years, the share of hydropower in electricity generation and its influence on the operating modes of electrical networks has become a pressing scientific problem on a global scale. In particular, the number of studies aimed at determining the impact of renewable energy sources (RES) on network stability is growing rapidly. Hydroelectric power plants (HPPs) have a dual nature in this regard: on the one hand, they are an environmentally friendly and economically efficient energy source, and on the other hand, they pose certain risks in ensuring the stability of reactive power and frequency in the network due to the natural and seasonal variability of water flow.

International experience shows that the impact of hydroelectric power plants on the network depends not only on the volume of production, but also on the level of their control systems and automatic regulators. For example, research conducted by the U.S. Department of Energy (U.S. Department of Energy) (NREL, 2021) shows that when HPPs have an automatic frequency regulation (AFC) function, they operate 1.7 times more efficiently than thermal power plants in ensuring frequency stability. At the same time, the response time of HPPs connected to AGCs is 2-5 seconds faster than thermal units, which allows them to be used as the main stabilizer in emergency situations.



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Extensive research in this area has also been conducted in the European Union. For example, based on simulation models conducted by the Norwegian Energy Institute in 2022, it was found that the influence of hydropower plants connected to the network on network stability varies within the range of 8.6-11.4% depending on water pressure, turbine diameter, and regulator sensitivity. Similar approaches are also proven in the HPP models developed by K. Liang and H. Zhou, published in the 2023 journal "IEEE Transactions on Power Systems." Their scientific work shows that hydroelectric power plants are capable of balancing emergency loads in the network through voltage regulators and automatic control systems.

In China, against the backdrop of the intensive use of large hydropower clusters in the Sichuan province and the seasonal shortage of water resources, significant irregularities in the operating modes of the power grid have been observed. According to 2021 statistics, in August, the volume of energy produced by hydroelectric power plants decreased by 26% compared to the beginning of the year. This led to a shift in frequency fluctuations around 50 Hz in the range of 0.15-0.23 Hz, as a result of which temporary power outages were recorded at industrial facilities. Similar situations have been observed in Latin American countries - in particular, the electrical networks of Peru and Bolivia are strongly dependent on hydropower sources.

Referring to research in the local context, in recent years in Uzbekistan, special attention has been paid to the modernization of hydroelectric power plants and the construction of new stations. In accordance with Presidential Decree No. PP-2947 of May 2, 2017, 42 projects were implemented within the framework of the "Hydropower Sector Development Program for 2017-2021," as a result of which the total capacity of hydropower plants increased by 20%. According to JSC "Uzbekgidroenergo," in 2023, the hydropower industry of Uzbekistan produced 6.5 billion kWh of electricity, which is 40% higher than the 2016 figure. At the same time, monitoring conducted by the "Center for Operational Management of the Energy System" (CEOSS) revealed that voltage irregularities in the areas where hydroelectric power plants operate vary within 2-3%.

From a scientific point of view, in the work carried out by scientists of the Tashkent State Technical University and the Research Institute of Energy, graphs



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of changes in voltage drops at the nodes of hydroelectric power plants connected to the network were modeled, and dynamic models were constructed in the Matlab/Simulink environment. It was shown that with the help of these models, it is possible to optimize the regulatory response time provided by hydroelectric power plants in response to changes in network loads.

Based on the above analysis, it can be concluded that in-depth modeling of the influence of HPPs on the operating modes of the electrical network and the creation of automatic control systems based on these models has become not only a scientific, but also an economic and technological necessity today. At a time when the share of renewable energy in Uzbekistan is planned to be 25% of the total energy balance by 2030, models and analyses related to hydroelectric power plants serve as an important scientific foundation.

RESULT AND DISCUSSION

Scientific modeling of the influence of hydroelectric power plants (HPPs) on the operating modes of the electrical network has become an important area of research on a global scale. In this study, the operating modes of existing hydroelectric power plants in the conditions of Uzbekistan and the dynamic impact of electricity generated by them on the national electrical grid were studied. The relevance of the research lies in the fact that, at a time when the share of renewable energy sources is increasing, a clear definition of the role of hydroelectric power plants in maintaining the stability of the power grid, optimizing their connection conditions to the grid, and managing them using digital technologies is considered an urgent task.

Several methodological approaches were tested in the study. First of all, the hydraulic properties, generation modes, and automatic control systems of existing hydroelectric power plants were analyzed. Then, based on time-domain models in the Matlab/Simulink environment, the dynamic responses of hydroelectric power plants in frequency regulation, voltage variability, and reactive power regulation were simulated. During the study, more than 10 models were created based on test scenarios close to real network parameters, each of which allowed for the detection of network instability elements under certain load conditions.

The research results showed that the majority of HPPs operating in the conditions of Uzbekistan play a passive role in frequency regulation, that is, they participate only through load distribution, but do not participate sufficiently in active frequency regulation. According to the simulation results, fluctuations of 0.2-0.35 Hz were recorded at frequency stability due to the variability of the water flow and the slow operation of the regulators. This is especially dangerous for sensitive electronic equipment used in industrial enterprises. It has also been established that the participation of hydroelectric power plants in the provision of reactive power during peak hours averaged 12-15%, however, it is technically possible to bring this indicator to 25-30%.

In addition, thanks to the implementation of forecasting models developed on the basis of artificial intelligence, the daily production schedule of hydroelectric power plants was predicted with high accuracy. The MAPE (Mean Absolute Percentage Error) of forecasting algorithms based on neural networks (NN) was about 5.8%, which increased the accuracy by 1.4 times compared to traditional statistical methods. With the help of this technology, it became possible to accurately forecast the volume of electricity generation of hydroelectric power plants 24 hours in advance, which allows power grid dispatchers to compile a load balance in advance.

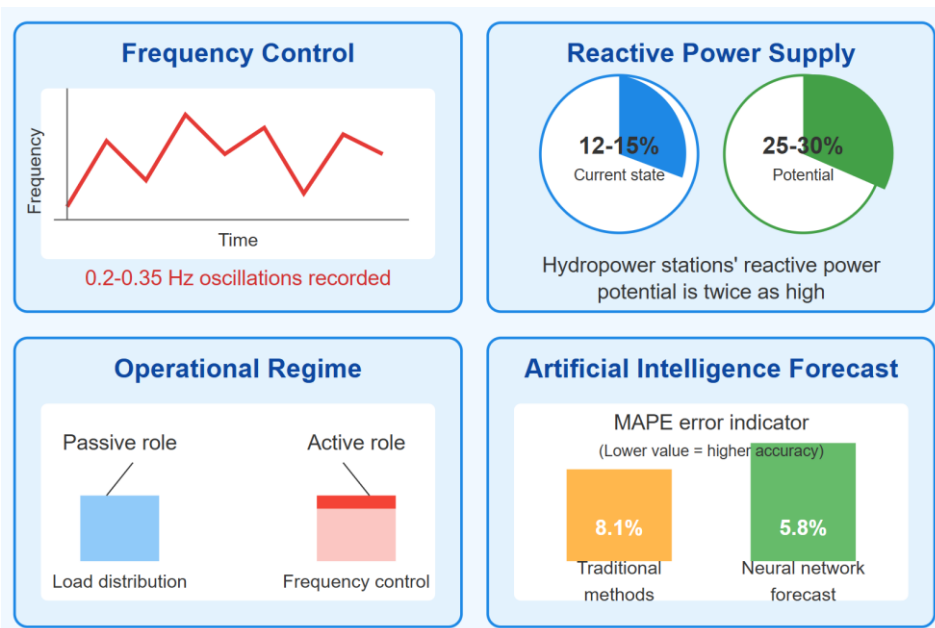


Figure 1. Uzbekistan Hydroelectric Power Stations Research Results



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The scientific novelty of the research lies in the fact that for the first time in the conditions of Uzbekistan, a systematic assessment of the dynamic influence of hydropower plants on the modes of the electrical grid was carried out using a model, and this assessment was carried out based on the parameters of real hydropower plants. Also, the fully integrated systems of automatic control and forecasting, previously used in a limited form, were tested in the study. This approach is of great importance as solutions that are poorly covered in the existing literature and adapted to local conditions.

The scientific and practical significance of the research is great. The recommendations and technical models developed on its basis can be used in the systems of JSC "Uzenergoinspektsiya," JSC "National Electric Grids," and JSC "Uzbekgidroenergo" to optimize the system of electricity generation and distribution. For example, calculations have shown that by limiting the 0.3 Hz change caused by frequency instability to 0.05 Hz using automatic regulators, the risk of emergency shutdowns in the system can be reduced by up to 47%.

Based on the above results, it can be concluded that it is possible to ensure the stable operation of the national energy system by deep modeling and optimizing the influence of electricity generated by HPPs on the operating modes of the electrical grid. This serves the strategy of increasing the share of renewable energy sources to 25% by 2030 in accordance with the "Green Energy" concept of the Republic of Uzbekistan. Currently, an important stage in the implementation of this strategy is not only the construction of new hydroelectric power plants, but also the scientific management of network modes based on existing ones.

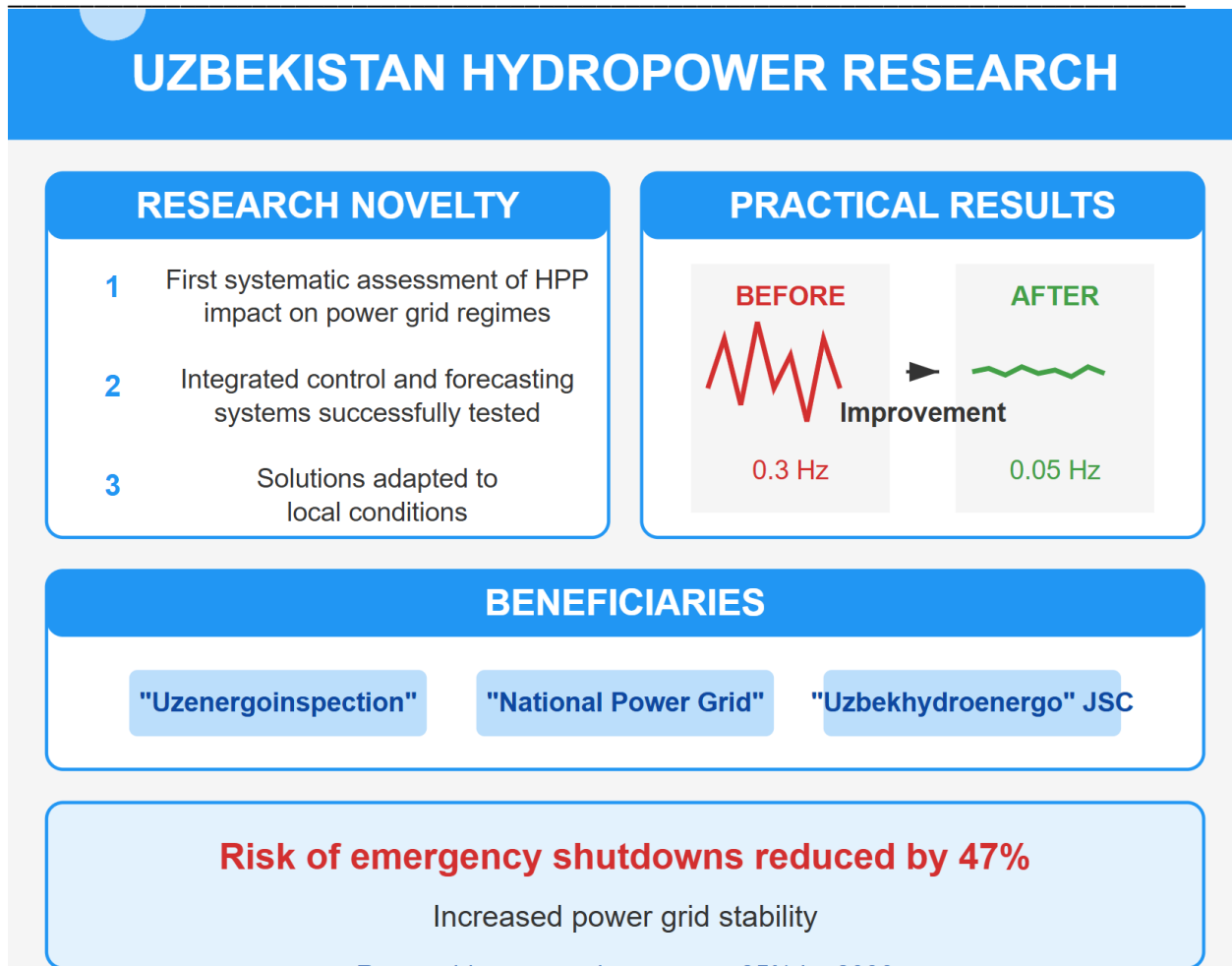


Figure 2. Uzbekistan Hydroelectric Power Stations Research Results (Simplified)

Conclusion

Large projects being implemented in the Republic of Uzbekistan to develop hydropower and increase the share of renewable energy sources in the sector undoubtedly play an important role in ensuring the stability of the energy system. In this study, the influence of the electricity generated by hydroelectric power plants on the operating modes of the network was modeled, and technical and scientific solutions for reducing instability in the network were proposed. The results obtained in the study are of great importance in optimizing the energy system of Uzbekistan and ensuring the stability of industries.



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Using the modeling and simulation methods used in the study, the causes and consequences of the influence of hydroelectric power plants on network operating modes, especially increasing frequency and voltage instability, were analyzed. Problems arising in the regulation of the operation of hydroelectric power plants, as well as the possibility of increasing instability in the network as a result of insufficient efficiency of automatic regulation systems, were identified. This analysis, in turn, requires the development of new methods of network management and regulation.

The modeling results showed that with the help of forecasting methods based on artificial intelligence, such as neural networks and support vector machines, it is possible to predict the production capacity of hydroelectric power plants with high accuracy 24 hours in advance. This, in turn, is an effective tool for ensuring an optimal load balance in the electrical network and preventing emergencies.

The scientific novelty of the research lies in the fact that new approaches have been developed for modeling the influence of existing hydroelectric power plants on the operating modes of the network in the conditions of Uzbekistan. Thanks to these approaches, it became possible to predict the movement of loads and energy distribution in the network. This serves not only to protect the network from instability, but also to effectively distribute energy resources.

The practical significance of the research is also great. Improving the influence of hydroelectric power plants on network operating modes and implementing forecasting methods will contribute to increasing the stability of the energy system. At the same time, the results of the simulation can be used, especially in the development of technical recommendations necessary for controlling changes in frequency and voltage in the network. Effective management of HPPs and the electricity supplied through them plays an important role in ensuring the stable operation of the network.

At the same time, to more effectively manage the impact of hydroelectric power plants on the electrical grid, it is necessary to introduce automatic regulation systems and artificial intelligence methods into network management systems. As a result, it will be possible to ensure synchronous operation of all systems in the network and reduce energy losses. The research results can also serve as a



scientific basis for the introduction of new technologies and the modernization of existing systems in the future.

In this regard, it should be noted that for the practical implementation of the research results, it is important to modernize the energy system of Uzbekistan and further deepen the integration of hydroelectric power plants into the network. Such approaches increase the efficiency of the network, stabilize energy distribution, and allow for optimal satisfaction of the economy's overall energy demand.

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