MODELING OF HYDROELECTRIC POWER PLANT DEVICES IN THE MATLAB/SIMULINK ENVIRONMENT.

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Abstract. This article discusses mathematical models of hydroelectric power plant (HPP) devices and methods for modeling them in the MATLAB/SIMULINK environment. The main devices that make up the HPP - a hydroturbine, a synchronous generator, and automatic control systems - are developed as separate models. The physical properties, dynamic characteristics, and interactions of each device are represented in a digital environment, and their performance is analyzed. Based on the model, the behavior of the HPP in various operating conditions is studied, and the effectiveness of control strategies is evaluated. The results obtained indicate the importance of modeling in improving the stability of HPP systems and optimizing them. The results of the research can be used in practical engineering processes.

Keywords: Hydroelectric power station, hydroturbine controller, generator, asynchronous motor, Matlab/Simulink.

Annotatsiya. Ushbu maqolada gidroelektrostansiya (GES) qurilmalarining matematik modellari va ularni MATLAB/SIMULINK muhitida modellashtirish usullari yoritilgan. GES tarkibiga kiruvchi asosiy qurilmalar — gidroturbina, sinxron generator va avtomatik boshqaruv tizimlari alohida modellar ko‘rinishida ishlab chiqilgan. Har bir qurilmaning fizikaviy xossalari, dinamik tavsiflari va o‘zaro ta’siri raqamli muhitda ifodalanib, ularning ishlash samaradorligi tahlil qilingan. Model asosida GES’ning turli ish holatlaridagi xatti-harakatlari o‘rganilib, boshqaruv strategiyalarining samaradorligi baholangan. Olingan natijalar GES tizimlarining barqarorligini oshirish va ularni optimallashtirishda modellashtirishning muhimligini ko‘rsatadi. Tadqiqot natijalari amaliy muhandislik jarayonlarida qo‘llanilishi mumkin.

Kalit so‘zlar: Gidroelektrstansiya, gidroturbinali regulyator, generator, Asinxron dvigatel, matlab/simulink.

Аннотация. В данной статье рассматриваются математические модели устройств гидроэлектростанций (ГЭС) и методы их моделирования в среде MATLAB/SIMULINK. Основные устройства, составляющие ГЭС – гидротурбина, синхронный генератор и системы автоматического управления – разработаны в виде отдельных моделей. Физические свойства, динамические характеристики и взаимодействие каждого устройства

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представлены в цифровой среде, а также проведен анализ их работы. На основе модели изучено поведение ГЭС в различных режимах эксплуатации и оценена эффективность стратегий управления. Полученные результаты свидетельствуют о важности моделирования для повышения устойчивости систем ГЭС и их оптимизации. Результаты исследования могут быть использованы в практических инженерных процессах.

Ключевые слова: Гидроэлектростанция, гидротурбинный регулятор, генератор, асинхронный двигатель, Matlab/Simulink.

Introduction

Hydropower occupies an important place in the global energy market today. This sector, as one of the renewable energy sources, provides environmentally friendly and sustainable electricity generation. In particular, the Republic of Uzbekistan has a high hydropower potential and is one of the most important resources in Central Asia. The hydropower plants available in the country account for 10-12 percent of the total electricity generation.

Currently, more than 50 hydroelectric power plants of various capacities are operating in Uzbekistan, with a total installed capacity of about 2.2 gigawatts. As a result of the reforms being carried out in the energy sector, the share of the sector is increasing through the construction of small and medium-sized hydropower plants and the modernization of existing ones. It is planned to implement more than 30 new hydropower projects in the republic by 2030, which will increase the country's energy security.

In accordance with the Resolution of the President of the Republic of Uzbekistan No. PQ-252 dated July 12, 2024, in order to sustainably provide the population and sectors of the economy with energy resources, reduce the use of natural gas in the production of electricity, and further increase the effective use of the existing potential of the hydropower sector, the issue of providing the population with electricity was raised by developing this Resolution, which aims to localize the production of equipment and spare parts necessary for the construction and operation of hydroelectric power plants in our country, introduce international construction standards and advanced foreign technologies at each stage of the implementation of projects for the construction of existing hydroelectric power plants and the modernization of existing ones, and widely involve local entrepreneurs in the construction of micro and small hydroelectric power plants[1-3].

ANALYSIS AND RESULTS.

The essence of the science of small hydroelectric power plants (small HPPs) is a type of classical hydroelectric power plant, differing in one important

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difference - that they have a relatively small capacity. In different countries, the threshold value between the capacity of a small HPP and the capacity of a conventional HPP is different. The possible range of fluctuations in this limiting capacity is very wide. In domestic design practice, a HPP is considered small with a capacity of 30,000 kW or less. This value is indicated in the current GOST. According to the norm, plants that produce up to 500 kW of electricity are small HPPs. Studies have been conducted on the introduction of this type of HPPs in Uzbekistan for many years. Currently, it is impossible to do this with full technical capabilities. This problem can be solved by gradually localizing the experience of other developed countries, adapting it to our own [2-5].

Although MATLAB is primarily designed for numerical computation, an optional toolkit provides access to symbolic computation capabilities and uses the MuPAD symbolic engine. The Simulink add-on package adds graphical multi-domain simulation and model-based design for dynamic and embedded systems.

In this Hydroturbine Design and Calculation topic, we will model a small hydroelectric power plant in Matlab/Simulink. First, we will model the water flow entering the hydroturbine and then describe the flow in detail. This process is described below.

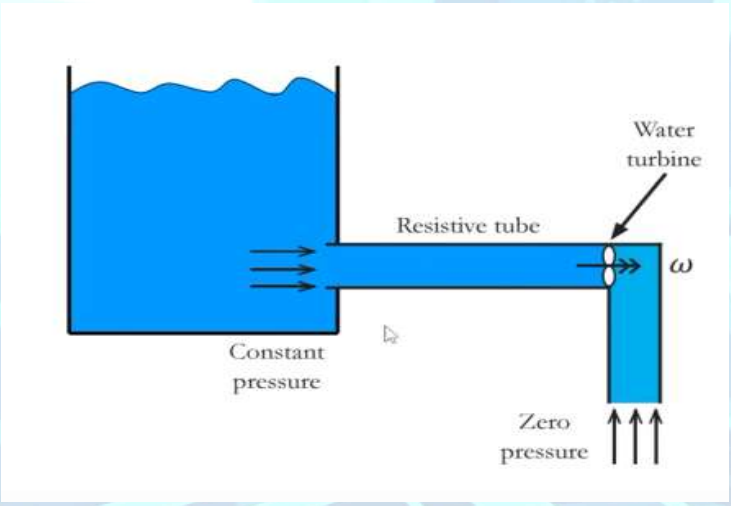


Figure 1. Fluid motion in a hydroturbine.

The custom hydraulic fluid block allows you to specify the type of hydraulic fluid used in a loop of hydraulic blocks. It provides hydraulic fluid properties such as kinematic viscosity, density, and bulk modulus for all hydraulic blocks in the loop. These fluid properties are assumed to be constant during the simulation. The custom hydraulic fluid block allows you to specify fluid properties such as kinematic viscosity, density, bulk modulus, and relative amount of entrained air as block parameters. The custom hydraulic fluid block has one port.

If the flow is assumed to be fully developed along the entire length of the pipe, the final effects are also not taken into account. To take into account local

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resistances, such as bends, fittings, inlet and outlet losses, etc., all resistances are converted to their equivalent lengths, and then the total length of all resistances is added to the geometric length of the pipe. The pressure loss due to friction is calculated by Darcy's equation, in which the losses are proportional to the friction coefficient and the square of the flow velocity, which depend on the flow regime. The friction coefficient in the turbulent regime is determined by the Haaland approximation. The friction factor in the transition from laminar to turbulent regimes is determined by linear interpolation between the extreme points of the regimes.

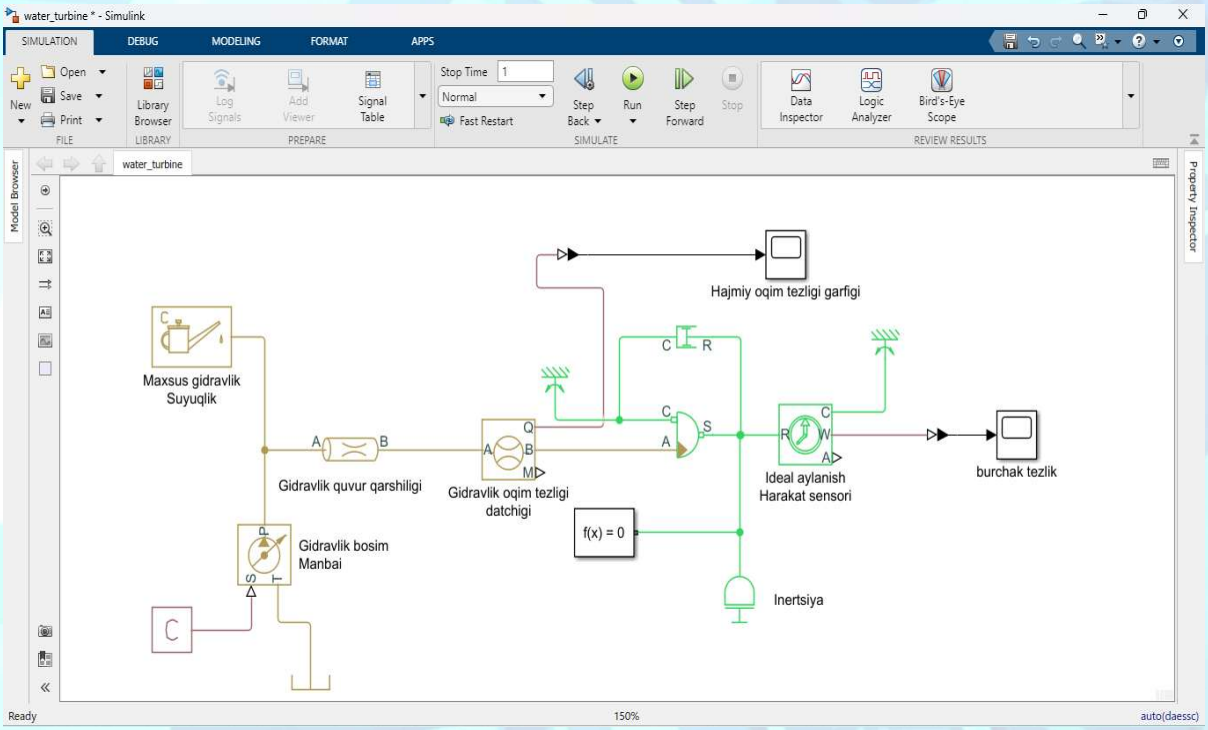


Figure 2. Fluid movement in a hydroturbine.

The Rotary Hydromechanical Converter block models an ideal transducer that converts hydraulic energy into mechanical energy in the form of rotational motion of the converter shaft and vice versa. Physically, the converter represents the main component of a single-acting rotary vane actuator. The compression option allows the converter to account for dynamic changes in fluid density. Using this block as a basic element, you can build a wide variety of rotary actuators by adding application-specific effects such as leakage, friction, hard stops, and more.

After modeling the flow velocity and fluid movement in the hydroturbine, we modeled the current generated in the hydroelectric generator. You can see this process below[5-9].

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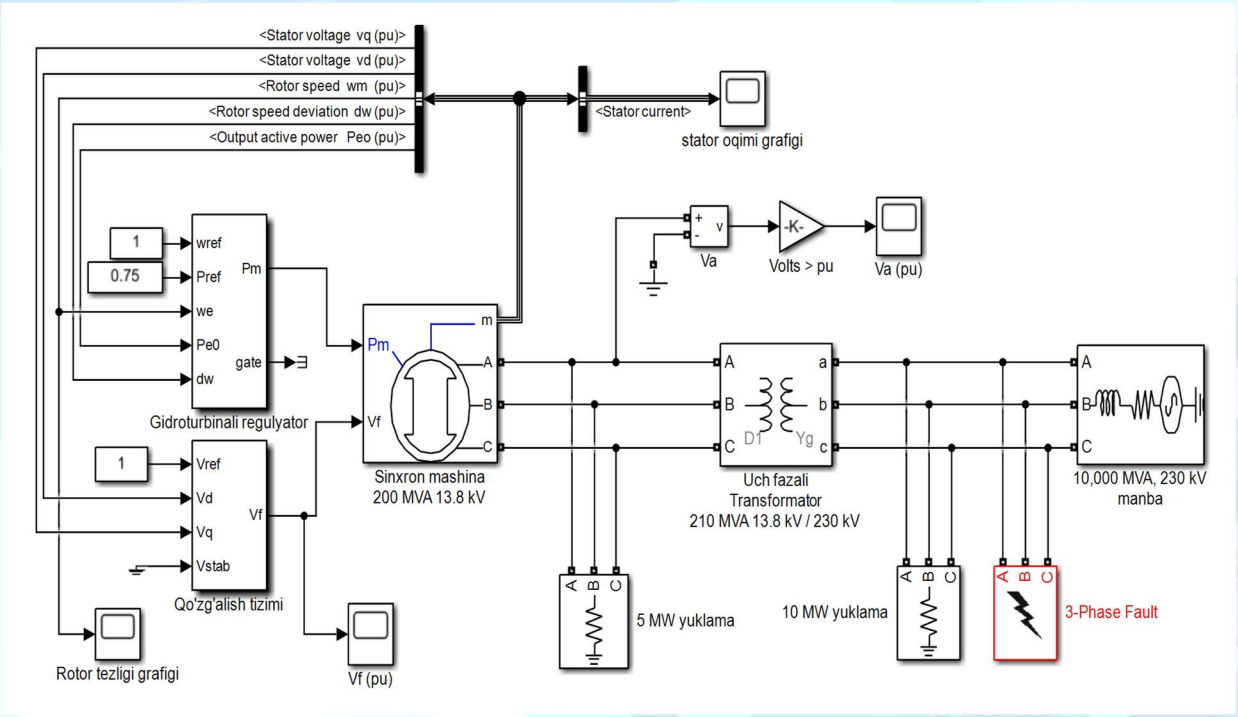


Figure 3. Simulink model of a hydroelectric power plant.

ANALYSIS AND RESULTS.

This study demonstrates the effectiveness of modeling hydropower plant (HPP) equipment using the MATLAB/SIMULINK environment. The simulation of essential components such as hydro turbines, synchronous generators, and automatic control systems allows for in-depth analysis of the dynamic behavior of hydropower systems. By developing accurate mathematical models and implementing them in Simulink, it becomes possible to evaluate system performance under different operating conditions and disturbances. These models not only help in predicting the system's response but also enable optimization of control strategies to improve operational efficiency and system stability.

Simulation results show that digital modeling can significantly aid in identifying critical operational parameters and avoiding potential failures. The use of MATLAB/SIMULINK provides flexibility in testing various configurations and control schemes without physical experimentation, saving both time and cost. Moreover, it supports real-time simulation, making it a powerful tool for the design and development of advanced control algorithms.

As a recommendation for future work, the integration of artificial intelligence (AI) and machine learning (ML) techniques is encouraged to enhance predictive maintenance, fault detection, and adaptive control within hydropower systems. AI-based models could learn from historical data and optimize system performance more effectively than conventional methods. Additionally, expanding the models to include grid-connected scenarios would allow researchers to assess

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the interaction between HPPs and the larger electrical power system, especially under fluctuating load demands and renewable energy integration.

Another key recommendation is the development of user-friendly simulation tools based on these models to aid engineers in training, system design, and decision-making processes. Overall, the use of MATLAB/SIMULINK for modeling HPP equipment presents a scalable and effective approach to modernizing hydropower technology and enhancing energy system resilience.

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