MATHEMATICAL MODEL OF THE OPTIMAL CONTROL SYSTEM FOR THE ELECTRIC DRIVE OF WATER DISCHARGE DEVICES

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ABSTRACT
This article examines the mathematical model of a control system for the electric drive of water discharge devices using a frequency converter. The model substantiates optimal control strategies that enable the maintenance of specified parameters during operation by regulating the speed of the electric drive. This approach also aims to achieve energy efficiency in the system.

Keywords: Water discharge device, frequency converter, optimal control, electric drive, energy efficiency, mathematical model.

INTRODUCTION
In the context of modern economic relations, it is becoming increasingly necessary to improve the efficiency of all types of energy resource usage and to widely implement energy-saving technologies. One of the key approaches to achieving this goal is reducing energy consumption at industrial facilities through the use of electric drives with automatic control. Among these, centrifugal-type motion mechanisms (CTMMs) are some of the most common and energy-intensive consumers of electric energy.
Currently, there is a global trend toward replacing uncontrolled electric drives of centrifugal pumps (CPs), compressors, and fans with controlled systems. The main goal of managing the operating modes of pump stations is to maintain constant pressure or flow rate at a specified point in the pipeline, or to adjust these parameters in accordance with technological requirements and external factors. This control can be achieved by deliberately changing certain parameters of the pump or pipeline.
At present, there are four known methods for operational control of pump operation modes:
- Control via recirculation (Bypass technology): redirecting a portion of the pump's output back to its input;
- Control by serial (parallel) connection of pumps;
- Control through throttling the pipeline;
- Control by varying the rotational speed of the pump impeller.

Based on the requirements for the pump's electric drive, squirrel-cage asynchronous motors are most commonly used, though synchronous motors may also be employed in some cases. The speed of squirrel-cage asynchronous motors can be controlled using the following methods:

a) **Changing the number of pole pairs** in the stator winding (limited step-wise control);
b) **Changing the supply voltage** (control using an autotransformer);
c) **Changing the supply frequency** (control using a frequency converter).

In a water discharge system, optimal control is implemented to achieve the following:
a) **Reducing energy consumption** – by adjusting the motor speed according to load demand.
b) **Reducing wear and tear** on the pump and pipeline system – by ensuring soft start and stop operations.
c) **Automation and flexibility** – by enabling real-time system control and monitoring of water flow and pressure.

Below is a block diagram illustrating automatic control with feedback between pressure and flow, aimed at maintaining stable pressure in the water supply system, as well as monitoring power consumption of the pump's electric drive.

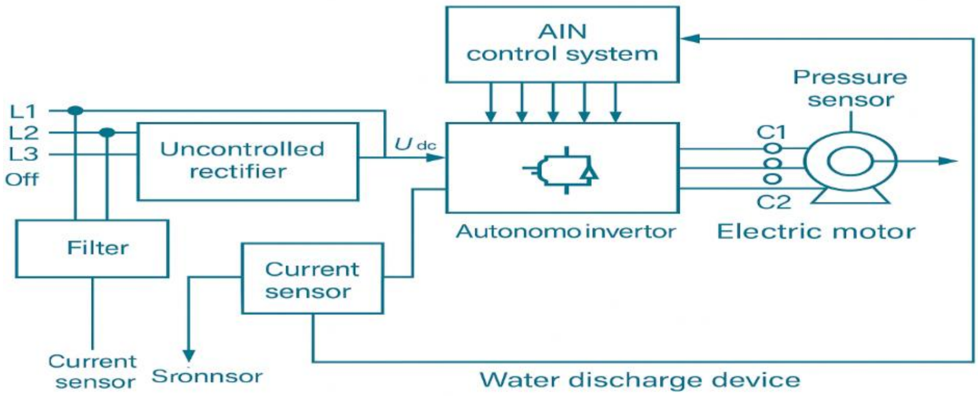

Figure 1. Block diagram of the automatic control system for the pump unit.

In optimal control, the condition $Q_{\text{required}} \leq (n)$ is accepted to minimize energy consumption. This means determining the rotational frequency of the electric drive that provides the required flow rate while consuming the least amount of energy.

The general mathematical model of the pump electric drive system allows for the study of different flow rates under various operating modes of the drive being analyzed. In this mathematical model, it is necessary to take into account the **resistance torque** of the pumps. To do this, a **block diagram** can be used along with an expression that accounts for how torque varies with speed.

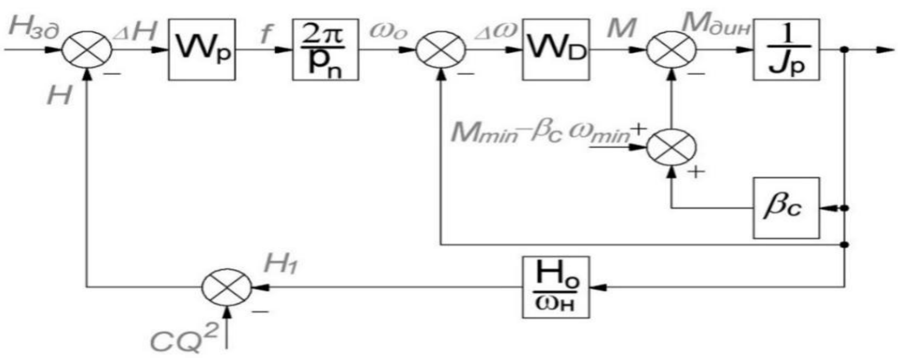

Figure 2. Structural diagram of the control system for the electric drive of a pump unit to maintain constant pressure within the operating range.

To mathematically express the control of a centrifugal pump system using a frequency converter, the following expressions are used:

1) The hydraulic characteristic of the pump is expressed by the following relation."

$$\begin{cases} H = H_0 \cdot \left(\frac{n}{n_0}\right)^2 \\ Q = Q_0 \cdot \left(\frac{n}{n_0}\right) \end{cases}$$

2) The power and torque of the pump's electric drive

$$P = \rho \cdot g \cdot Q \cdot H \cdot \eta$$

$$J\frac{d\omega}{dt} = M_{el} - M_{nasos} \quad \text{yoki} \quad J\frac{d\omega}{dt} = k_m \cdot \frac{U}{f} \cdot I - k_M \cdot \omega^2$$

3) The frequency converter's correlation (or connection) coefficient"

$$\frac{U}{f} = \text{const}, \qquad n_{ayl} = k_{uz} \cdot f_1$$

4) Optimal control parameters"

$$\begin{cases} P_{min} = \int_0^{\infty} P(t)dt = \rho \cdot g \cdot Q(t) \cdot H(t) \cdot \eta \cdot dt \rightarrow \min \\ Q_{talab}(t) \leq Q(t) \\ n_{min} \leq n_t \leq n_{max} \end{cases}$$

Below we will examine the mathematical description of the static and dynamic modes of a centrifugal pump based on its mathematical model. The mathematical model for optimal control of the centrifugal pump's electric drive via a frequency converter is assembled in MATLAB Simulink according to the block diagram shown in Figure 3. The differential equations developed for the static and dynamic modes of the pump were solved using the Runge-Kutta numerical method."

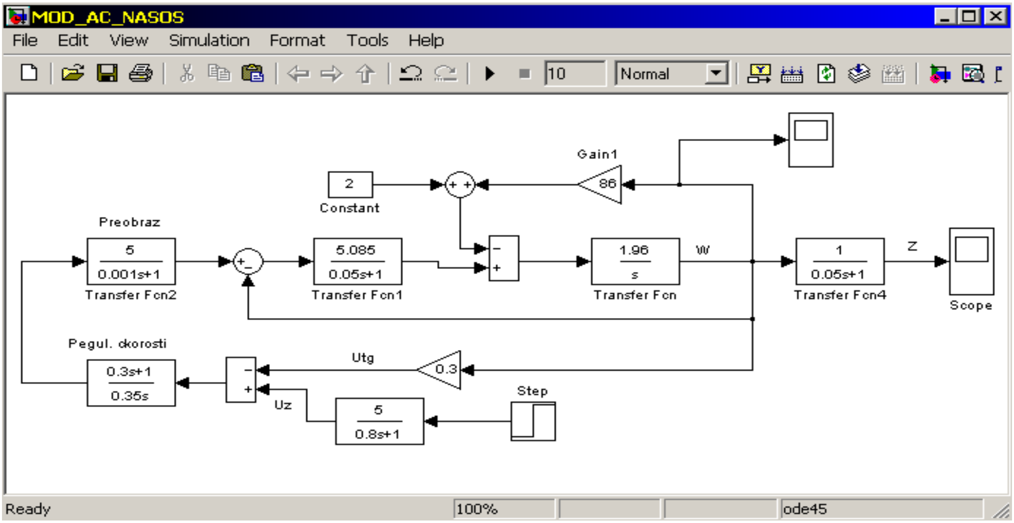

Figure 3. The structural diagram of the pump as represented in MATLAB Simulink (taking into account the transmission coefficients)

CONCLUSION

Based on the results of the pump system's computational scheme in MATLAB/Simulink, the following conclusions can be drawn. Due to a decrease in water demand, the power consumption of the motor and pump significantly decreases according to the power variation law. Energy consumption can be reduced by up to 40–50% compared to the nominal condition. The frequency converter ensures a smooth start of the motor during startup, gradually increasing the torque without causing overload. The transient process stabilizes within 4–6 seconds. The flow rate and pressure errors, ΔQ and ΔH, do not exceed 5%.

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