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To the Issue of Determining Adaptively Energy- and Resource-Saving Operation Mode of a Pumping Station

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ABSTRACT: Energy efficiency and resource conservation are key aspects of modern technologies aimed at sustainable development. Pumping stations, an essential element of municipal and industrial infrastructure, consume significant energy. Implementing energy and resource-saving modes can significantly reduce operational costs and minimize environmental impact.

KEYWORDS: motor, centrifugal pump, energy efficiency, resource-saving, pumping station.

I. INTRODUCTION

Pumping stations are an important component of energy systems, providing coolant circulation, water supply, and other processes. With increasing demands for energy efficiency and sustainable development, there is a need to implement adaptive control systems for pumping stations. In this article, we focus on energy-saving technologies.
Constructive layout options for the "motor-pump" system with a pressure pipeline according to [1]:
Sequential layout scheme:
- "Motor-pump-pipeline" with identical and different types of pump units at one pump station.

Parallel layout scheme:
- Several identical centrifugal pumps (motor-pump) into a common pressure pipeline.
- Several different or identical centrifugal pumps with different parameters (trimming the pump impellers) into a common pressure pipeline.

The formulation of tasks for the selection of a mode and the identification of specific energy consumption standards.
Example of the operation of a pump station:
Installed ***m*** pump units with two pressure pipelines, connected equally in parallel pump units to each pressure pipeline.
The water supply schedule is compiled taking into account the performance of each of the ***m*** pump units, and the total volume of the pump station's performance increases from smaller to larger and vice versa.
Tasks for selecting the mode and indicators of specific energy consumption, as well as the composition of pump units and covering the consumption schedule for such and similar pump stations according to the three specified options [2, 3]:

1) Optimize the operation of the pump station to minimize the specific energy consumption in each stage of the water supply according to the water supply schedule, without special requirements for the accuracy of its maintenance and the number of pump unit switches.
2) Optimize the operation of the pump station to minimize the specific energy consumption in each given stage of the water supply schedule without special requirements for its maintenance accuracy and with a minimum number of pump unit switches.
3) Optimize the operation of the pump station to minimize the specific energy consumption in each given stage of the water supply schedule with an approximation to maintaining the water supply schedule (with accurate maintenance) without special requirements for the number of pump unit switches.
4) Optimize the operation of the pump station to minimize the specific energy consumption in each given stage of the water supply schedule with the maximum approximation to the required water supply schedule at each stage and a minimum number of pump unit switches.

5) Optimize the operation of the pump station for maximum water supply at each stage of the water supply schedule without special requirements for the specific energy consumption value and the number of pump unit switches.
6) Optimize the operation of the pump station for maximum water supply at each stage of the water supply schedule while maintaining the minimum specific energy consumption without special requirements for the number of pump unit switches.
7) Optimize the operation of the pump station for maximum water supply at each stage of the water supply schedule with a minimum number of pump unit switches without special requirements for the specific energy consumption value.
8) Optimize the operation of the pump station for maximum water supply at each stage of the water supply schedule with minimum specific energy consumption and the number of pump unit switches.

The tasks considered apply to pump stations where smooth regulation of the pump units' performance is not provided.
If the pump station can smoothly regulate the performance of the pump units, the task is reduced to solving the smooth transition between the stages of the water supply schedule.
Recommendations for the implementation of tasks:
- Task 1 is most rational to use when there are no special requirements for the accuracy of maintaining the water supply schedule at each stage (for example, filling reservoirs, the pump station operates not in a cascade of stations, etc.), and the pump motor does not have restrictions on the number of starts and stops per year, and the network allows starting without prior coordination with the power system.
- Task 2 should be implemented when there is a restriction on the number of motor starts.
- Task 4 is most acceptable for pump stations operating as part of a cascade of pump stations or in terminal pump stations, or in cases of ensuring a specified volume of pumped irrigation water.

The most energy-saving mode out of the four formulated tasks is the first task. As constraints are imposed, the implementation of the optimization work not on the minimum specific norms of consumption will be less than without restrictions on the number of starts and ensuring a strictly specified water supply schedule at each stage.

II. An analysis of existing approaches to energy-saving

Modern pumping stations are equipped with various control systems that reduce energy consumption. The main areas of energy saving include [4-7]:
- Use of highly efficient pumps and electric motors.
- Introduction of frequency converters to regulate the rotation speed of pumps.
- Optimization of hydraulic modes and reduction of hydraulic losses.
- Use of automated control systems (ACS) to monitor and regulate the operation of pumping stations.

III. The principles of adaptive control

Adaptive control of pumping systems is based on dynamic adjustment of pump operating parameters in response to changing operating conditions. The most important principles of adaptive management are:

1) Data collection and analysis

The basis of adaptive control is the continuous collection and analysis of data on the state of the system. Sensors are installed at key areas of the pumping system to measure parameters such as:
- Pressure, measuring fluid pressure at various points in the system allows you to determine whether pump adjustments are necessary.
- Flow, controlling the volume of pumped liquid helps adapt pump operation to current needs.
- Temperature, measuring the temperature of the fluid and the environment allows you to take into account heat loss and overheating of equipment.
- Liquid Level, monitoring liquid levels in reservoirs and tanks helps prevent emergencies and optimize flow.

2) Data processing and decision making

Once the data is collected, it is transmitted to a central controller or computer, which uses various algorithms for analysis and decision-making:
- Machine learning algorithms, allow you to identify patterns and predict future system states based on historical data.
- PID controllers, provide proportional, integral, and differential control to stabilize system operating parameters.

- Optimization algorithms**,** can be used to find the best operating modes for pumps that minimize energy consumption while meeting all requirements.

3) Implementation of control actions

The decisions made are converted into control actions on the equipment of the pumping station:

- Frequency converters, regulate the rotation speed of pumps to maintain optimal operating conditions.
- Valves and gate valves, control fluid flows to provide the required pressure and flow.
- Pump controllers, turn pumps on and off, and switch between different operating modes.

IV. Algorithms for Adaptive Control of Pumping Systems

Adaptive pump control uses advanced algorithms to dynamically adjust pump operation based on current operating conditions and system needs. The main adaptive control algorithms include machine learning algorithms, PID controllers, and optimization algorithms. This section details how they work and the benefits they provide.

Machine learning (ML) [8] is a class of algorithms that permits systems to evolve and adapt autonomously based on accumulated experience. In the context of pumping systems, machine learning algorithms can be employed to analyze large volumes of data and make decisions that enhance energy efficiency. The principal types of machine learning algorithms utilized in pumping systems include:

Classification and Regression Algorithms: These algorithms are employed to predict and classify system parameters. For instance, they can forecast future fluid flow based on historical data and the prevailing circumstances.

Neural networks are another type of machine learning algorithm that can be used in pumping systems. Deep neural networks (DNNs) are capable of analyzing complex nonlinear relationships between system parameters, thereby enabling the accurate prediction of energy needs and the regulation of pumps [9].

Clustering methods These algorithms are employed to identify typical operating modes of a pumping system, thereby enabling the optimization of control by the prevailing circumstances.

For example, a machine learning system was implemented at a water pumping station to predict water flow at various times of the day and night. Based on these predictions, the system automatically adjusted the pumps, resulting in a reduction in energy consumption of 20%.

Proportional-integral-derivative (PID) controllers [10] are one of the most prevalent control algorithms in pumping systems. The provision of precise and stable control is achieved through the utilization of three principal components.

The proportional (P) component is defined as the direct correction based on the current error, which is the difference between the setpoint and the actual value of a parameter.

The integral component is defined as considering the accumulated error over a while, thereby eliminating any permanent offsets.

The differential component (D) is defined as the component that responds to the rate of change of the error, providing a rapid response to dynamic changes.

In most practical cases, traditional controllers are employed: PI in electromagnetic circuits, P or PI in speed control circuits, and I or PI in pressure control circuits. Fuzzy logic and neural networks are more effectively used not for constructing such controllers, but for developing automatic tuning blocks for the controllers [11, 12]. These blocks act as regulators within the self-tuning parameter loops. Using methods for synthesizing fuzzy control algorithms, it is possible to perform conditional optimization of complex control loops without adequate knowledge of their mathematical models.

Optimization algorithms [13] are employed to identify the optimal operational modes for the pumping system, while simultaneously minimizing energy consumption and ensuring compliance with all operational requirements. The most fundamental optimization methods include:

Linear and non-linear programming are two of the most commonly used optimization algorithms. These are employed to resolve optimization issues where the objective is to minimize or maximize a function while taking into account a set of constraints.

Evolutionary algorithms include genetic algorithms and particle swarm methods, which simulate natural processes of evolution and collective behavior to identify optimal solutions.

Stochastic methods and Monte Carlo methods are employed to assess and optimize systems characterized by a high degree of uncertainty.

V. CONCLUSION

The application of individual frequency-controlled electric drives to pumping stations, along with the enhancement of information and automation levels, enables high-quality regulation of technological variables through the adjustment of mechanical and electromagnetic variables of electric drive systems. This ensures optimal operating modes for both the pumps and the pumping stations.

Various algorithms and types of regulators can be used to control variables, including pressure in the pumps, such as traditional PID, PI, and I controllers; fuzzy logic controllers; neural network controllers; and combinations of these controllers. Based on these insights, adaptive control of pumping stations is a promising direction that can significantly enhance their energy efficiency and extend the equipment's service life. The implementation of modern automation and monitoring technologies is a key factor in achieving high efficiency and sustainable development. Examples of successful application of adaptive systems in the energy sector demonstrate significant potential for energy savings and increased reliability of pumping station operations.

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