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The need for Energy-Efficient automated Pumping Systems for Groundwater conveyance

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Abstract

The work of pumping units is the largest energy consumption in the process of groundwater extraction from wells and its transportation to consumers. Improper selection of pumps, lack of monitoring of ground water levels and lack of automation of control systems lead to increase in electrical energy consumption. The paper deals with problems of improving energy efficiency of groundwater supply systems and discusses the advantages of automated water level monitoring and pump control systems. As a practical case study, the Takhtakuprik groundwater intake facility of Kuva district of the Fergana region was chosen. According to the study results, the use of automated control systems can reduce energy consumption by 15-30%.

Keywords: Groundwater, pumping system, automation, energy efficiency, water tower.

Introduction

Today the use of groundwater is one of the most important sources of water supply. The increase of population and the expansion of industrial and agricultural demands necessitate the efficient utilization of water resources. Most of the energy consumption in the process of extracting groundwater from wells and transporting it to consumers is associated with pumping operations. Therefore, the introduction of energy-efficient technologies is an important factor in ensuring the economic and technical sustainability of water supply systems[1,2].

In conventional water supply systems, simplified control methods are frequently used, which results in non-optimal pump operation. As a result, a high consumption of electricity, an accelerated wear of equipment and a reduction in the reliability of the system[3] are observed. The objective of this article is to provide a scientific and practical rationale for the role of automated pump control systems in improving energy efficiency in groundwater conveyance systems[4].

Materials and Methods

The energy consumption in the case of groundwater extraction from wells and supply to consumers is mainly linked to the functioning of pumping units. The pump power depends on the hydraulic and mechanical losses, depth of groundwater and parameters of the pipeline network[5].

The theoretical pump power is given by the following expression[6]:

$$N = \frac{\rho * g * Q * H}{\eta} \quad (1)$$

where: ρ – water density (1000 kg/m³), g – gravitational acceleration (9.81 m/s²), Q – flow rate (m³/s), H – total head (m), η – pump efficiency.

The total head is the sum of the depth of the well, the height of the water tower and the hydraulic losses in the pipeline:

$$H = H_{well} + H_{tower} + h_{loss} \quad (2)$$

Hydraulic losses in pipelines are calculated using the Darcy–Weisbach equation:

$$h_{loss} = \lambda * \frac{L}{D} * \frac{v^2}{2g}, \quad (3)$$

where: λ – friction coefficient, L – pipeline length, D – pipe diameter, v – flow velocity.

These equations show that if the pipe diameter is wrong and the pump operating conditions are not optimized, the energy consumption can significantly increase[7,8].

Energy consumption in groundwater conveyance depends on a number of technical and hydraulic factors such as: i. dynamic water level, static water level, well depth; ii. performance of the pump; iii. pipeline length and diameter. iv. hydraulic losses; v. flow regime (laminar or turbulent); vi. degree of control and automation.

All these factors directly impact the total energy consumed by the pumping system. In particular, fluctuations in the groundwater level together with the lack of adaptive pump control result in a considerable increase in energy consumption.

Correct choice of water level measuring and monitoring methods is of great importance in efficient exploitation of groundwater resources[9]. Data received from water level measurements determine the operating regime of pumping units and directly affect energy consumption. In practice, the methods used can be conditionally divided into conventional and modern automated systems.

Continuous and accurate monitoring of the groundwater levels is necessary for stable system operation, pump protection and energy efficiency. The determination of the water levels is actually done through various techniques.

Water Level Systems with Float Control: Float based devices work by automatically turning the pump off or on at a certain water level. The main advantage of these systems is their structural simplicity and low price.

But the float-based systems cannot measure the real time water level changes accurately and continuously[9]. Such systems are negatively affected by seasonal factors. Surface freeze in winter may restrict the movement of the float mechanism.

The frequent water level change during summer may make the pump work repeatedly with stop and start, which increases mechanical wear and energy consumption. In spring and autumn, sediment and organic impurities can enter the well and cause jamming or malfunction of the float mechanism. This reduces the accuracy and reliability of the system.

Automated Pump Control and Level Monitoring: Hydrostatic pressure sensors, ultrasonic sensors and radar type level transmitters are widely used to determine the water levels in modern water supply systems. These devices allow for continuous and highly accurate measurement of changes in water level.

For the hydrostatic method the water level is obtained from the relation:

$$H = \frac{P}{p*g} \quad (4)$$

The data obtained are processed by a PLC (Programmable Logic Controller), which automatically controls the operating mode of the pumping units. Variable Frequency Drives (VFDs) regulate the rotational speed of pumps and enable the adjustment of the pump flow–head characteristic to suit the demand in real time.

The stages of the algorithm of the automatic control usually are: i. real-time water level monitoring; ii. comparison with pre-defined minimum and maximum threshold levels; iii. Pump speed setting or start/stop control; iv. activation of alarm and protection modes on emergency situations.

Results and Discussion

Transformer substations are the main power source that provides uninterrupted work of water facilities. They supply electricity to the main water pump units, water treatment and disinfection equipment, and well pumps (Figure-2)[10].



(a)



(b)

Figure-1: Existing Transformers.

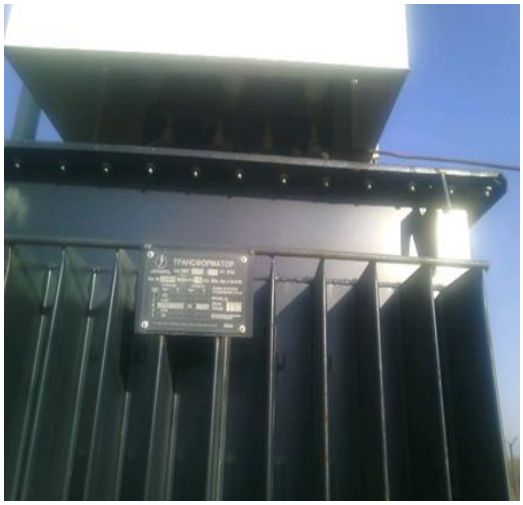


Figure-2: The major electricity consumer.

Thermographic Analysis of Electrical Equipment: The technical condition of the electrical equipment of water facilities was estimated using thermographic inspections. The transformer thermogram analysis showed local overheating of some contacts and connection points[11].



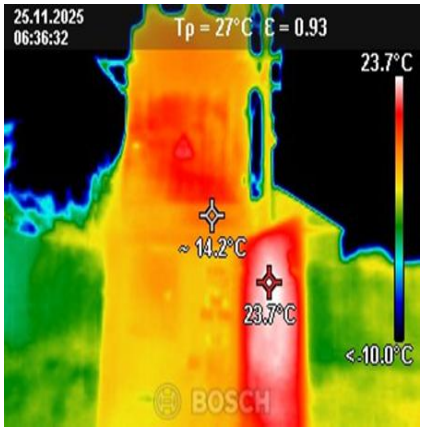
(a)



(b)

Figure-3: Thermogram of the power transformer.

The highest temperature during the measurements was 45.2°C and a few degrees less at neighboring points (about 41.4°C). 27°C which indicates that the temperature rise in some elements is high. This local heating may be caused by increased contact resistance, mechanical looseness, oxidation or uneven load sharing. Although the temperatures measured here are not yet critical, they may lead to further energy losses and lower equipment reliability in the future. The thermogram analysis of the whole transformer substation revealed some structural components with local heating zones that reached 33.5 °C (Figure 4). The temperature of the main part of the transformer surface was about 27–28 °C, which is within the normal limits of the general condition[10].



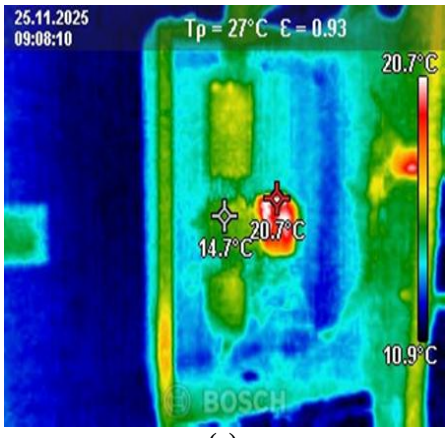
(a)



(b)

Figure-4: Thermogram of the complete transformer substation.

The state of electric motors and distribution panel: An uneven temperature distribution was also observed on the distribution panel supplying electricity to the water pump (Figure-5). Some contacts registered temperatures of 20.7°C, others around 14.7°C. This difference does not present an immediate danger but can result in energy losses during prolonged operation.



(a)



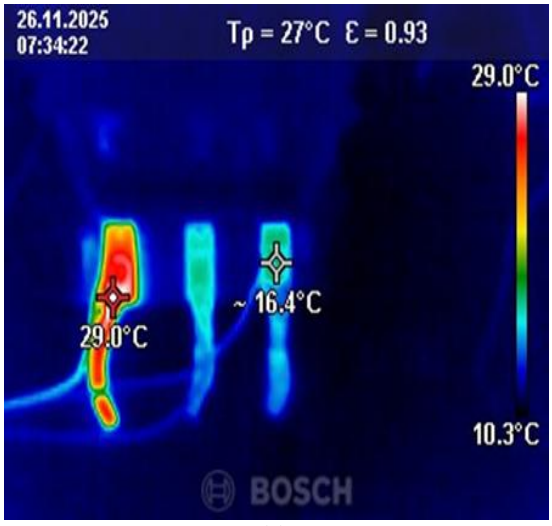
(b)

Figure-5: Thermogram of the distribution panel that powers the water pump.

Local overheating was also found on the distribution board feeding the water facility. The maximum temperature at some connection points was 29.0 °C, while in other phases it was about 16.4 °C, i.e. ΔT about 12–13 °C (Figure-6).

Thermographic inspections of the asynchronous electric motors did not reveal any critical overheating of the motor casings. However, in some cases local heating zones of up to 30.1 °C were observed at the connection points of the cables that supplied electricity to the motors (Figure-7).

Further inspection results showed that the temperature field was uniformly distributed in some asynchronous motors and the maximum temperature was not higher than 21.1 °C (Figure-8). This indicates that the technical state of the motors complies with operational demands.

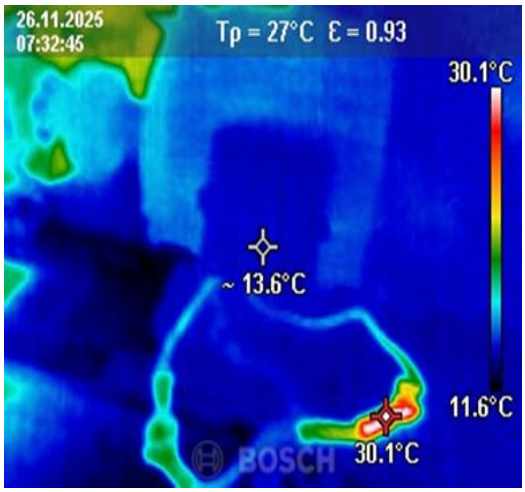


(a)



(b)

Figure-6: Thermogram of the electrical supply distribution panel of the water facility.

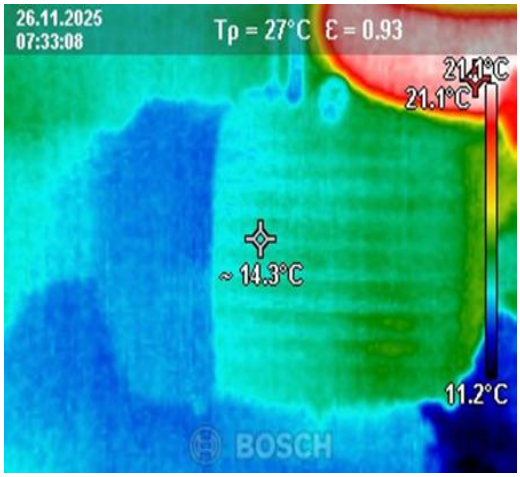


(a)



(b)

Figure-7: Asynchronous motor thermogram.



(a)



(b)

Figure-8: Thermogram of the asynchronous machine.

Analysis of seasonal electricity consumption: The analysis shows that the use of electricity in Kuva district is not evenly distributed to different areas. In particular, the load is greater in areas with a dense concentration of water pump units. This is explained by the developed water supply infrastructure and the large number of consumers[12-14]. The seasonal analysis shows that electricity consumption was highest in the months of July and August. In particular, in the district centre in July were consumed 30,620 kWh, in August - 30,060 kWh. In summer months, consumption in the Takhtakuprik NCA zone also increased sharply, to 5,150 kWh in July and 9,960 kWh in August.

In winter and spring months (January-March and November-December) electricity consumption is relatively low and stable, which is connected with reduced water use. In some zones the electricity consumption drops to zero in some periods of the year this reflect the seasonal operation of the pump units. Overall, the results confirm the seasonality of the electricity consumption and the main load is related to water lifting and transmission processes.

The main purpose of the research object is to provide the population and other consumers of the district with high-quality drinking water and wastewater services. The population of Kuva district is estimated to be around 300,000 people at the beginning of 2025. The population connected to the centralized water supply system is about 65–70%, consumers are households and legal entities, including industrial enterprises, social facilities and budgetary organizations.

The district has a network of drinking water pipelines with total length of about 600–700 km including main and internal distribution pipelines. Several pumping stations pump water out of the wells, supply it to the main pipelines, and maintain the necessary pressure in the network. Water towers and reservoirs for storing clean water are used to regulate pressure, to create reserves of water, to ensure hydraulic stability of the network. These reservoirs have a total capacity of several thousands of cubic meters.

The major sources of water are over 10 artesian wells in the centre of Kuva district and adjacent areas. The depth of these wells varies usually from 100 to 250 m. According to the sanitary and epidemiological standards, the water from the wells is checked and disinfected by chlorination and ultraviolet (UV) treatment if necessary. Treated water is stored in special clean water reservoirs (water towers or above-ground reservoirs) and is pumped out to consumers through distribution networks in the city and district. The continuous and energy-efficient operation of pumps in these processes is crucial for the stable operation of the water supply system.



(a)



(b)

Figure-9: General view of the Takhtakuprik water tower.

This system consists of a well, submersible pump and a water tower built by classical method and provides the local population with drinking water. The water tower is 25 m high (H) and the pressure it develops is calculated:

$$P = p * g * H = 1000 * 9.81 * 25 = 245\ 000\ Pa = 2.5\ bar\ , \quad (5)$$

The reservoir is cylindrical and the volume is determined by the formula:

$$V = \pi * r^2 * h = 3.14 * (1.5 * 1.5) * 4 = 28.3\ m^3, \quad (6)$$

The following technical parameters determined the average mode of operation of the pump:
Water flow rate: Q=0.01 m³/s (36 m³/h);
Total head: H=60 m;
Efficiency: η=0.65.

The pump power is calculated as follows:

$$N = \frac{\rho * g * Q * H}{\eta} = \frac{1000 * 9.81 * 0.01 * 60}{0.65} = 9.06\ kW, \quad (7)$$

If the pump works for 10 hours per day on an average, then the annual consumption of electricity is:

$$E_{annual} = 9.06 * 10.365 = 33.069 \frac{kWh}{year}, \quad (8)$$

Daily water consumption is erratic. The peak water use times are 6:00–11:00 in the morning and 16:00–20:00 in the evening. This makes it necessary for the pumps to be working all the time in their optimum regime. At present, the process of water transmission is under manual control and continuous surveillance.

Identified problems and proposed solutions: The paper analyzes the current state of the system based on regulatory and legal requirements adopted in the Republic of Uzbekistan in the field of water supply and energy efficiency. The following problems were found in the existing system: i. Pump units work at full load constantly; ii. Control does not adapt to water level; iii. High losses in water and electricity.

It is assumed that the implementation of an automated control system will control the pumps with a variable frequency drive, which will lead to an average power consumption reduction of approximately 25%:

$$N_{auto} = 0.75 * 9.06 = 6.8\ kW\ , \quad (9)$$

Annual energy usage:

$$E_{auto} = 6.8 * 10.365 = 24.820\ kWh/year\ , \quad (10)$$

Yearly energy savings:

$$\Delta E = 33.069 - 24.820 = 8.249\ \frac{kWh}{year}, (25\%). \quad (11)$$

This indicator confirms the high economic efficiency of automated systems. Furthermore, in the Resolution PQ–250 of the President of the Republic of Uzbekistan, adopted in August 2025, on approval of the program for the management of water resources and the development of the irrigation sector for 2025–2028 [7], the following are defined: i. Modernization of pumping stations[15]; ii. Implementation of energy efficient pumping units[9,16]; iii. Installation of digital monitoring and accounting devices on more than 5,200 pumps; iv. Automation of 18 755 hydraulic structures.

In order to solve the above problems, it is proposed to introduce an automated pump control system in accordance with the above presidential resolution. Application of electronic level sensors, PLC, SCADA and variable frequency drives allows to optimize the mode of operation of the pump, to save water and energy resources. Improving energy efficiency is possible through the optimization of the pump operation by electronic level sensors and frequency converters[17].

Conclusion

The research and calculations performed show that the application of automated control systems of pumps in the transmission of groundwater allows substantially improve the energy efficiency. Adjusting the pump power to the actual water level and flow rate can reduce electricity consumption by 15–30%.

Although float-based level control systems have a simple structure, they can only detect limit states and cannot be used for continuous monitoring. Therefore, it is recommended to use automated systems in modern water supply systems, which are based on electronic level sensors, PLCs and frequency converters.

The analysis of the practical object – the water intake facility "Takhtakuprik" – confirmed the fact that automation improves the technical reliability, energy efficiency and convenience of operation of the water supply system. Automation of pump control in groundwater transmission can lead to substantial gains in energy efficiency. Float systems are only recommended as an auxiliary or backup device. The practical example shows that an automated water supply system improves its reliability and economic efficiency.

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