Optimize the cost of paying for electricity in the water supply system by using accumulating tanks

Alexei Kapanski[1,*], *Nadezhda* Hruntovich[1], *Siarhei* Bakhur[1], *Larisa* Markaryants[2], and *Leonid* Dolomanyak[3]

[1]Sukhoi State Technical University of Gomel, Prospect Octiabria, 48, 246746, Gomel, Republic of Belarus
[2]Federal State Budgetary Educational Institution of Higher Education «Moscow State Linguistic University» (MSLU), 119034, 38 Ostozhenka St. Moscow
[3]Kazan State Power Engineering University, str. Krasnoselskaya, 51, 420066, Kazan, Russia

Abstract. The article considers the method of optimizing the pumps in the water supply system of the first water rise station in the zones of the day, where there is a different system of payment for electric energy. To assess the regulatory capacity of pumps on a temporary parameter, the authors of the article propose to use existing water tanks in the water supply system, which act as a buffer, smoothing the unevenness of water consumption. The studies have revealed that the comprehensive optimization of pumps on the criterion of minimizing specific electricity consumption by lifting water and optimizing the operation of pumps in the zones of the day allows to significantly improve energy efficiency and reduce the cost of extraction and transportation of water to the consumer. In the article, the authors examine an algorithm that allows us to assess the economic potential of pump regulation in the real-world conditions of the system.

1 Introduction

Implementation of a set of organizational and technical measures aimed at reducing energy consumption is always a pressing task in the current conditions of the water and sewerage industry. Active introduction of modern energy-saving technologies, development of the system of assessment and forecasting of energy efficiency indicators, development of effective ways and methods to identify hidden reserves of energy savings leads to a reduction in energy intensity of products [1]. The importance of state control in the implementation of planned energy-saving measures is explained by the need to improve the system of tariff regulation of water utilities, which includes a unit energy component of which the share of which reaches 25% (Fig. 1) [2].

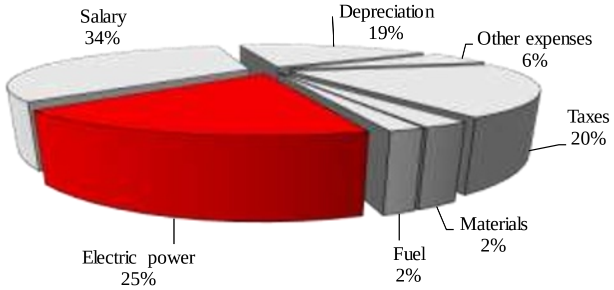

Fig. 1. Cost structure for water production and transportation.

Tariff regulation of drinking water contributes to the implementation of technical measures aimed at improving the energy efficiency of water utilities, as a result of which the monetary costs of extracting and transporting water to the consumer are reduced. Such measures include the introduction of modern energy-efficient equipment, regulation of the operating modes of pumping stations of the first and second rise, optimization of pressure schedules, reduction of water losses during transportation, construction of water reuse facilities, etc.

On the other hand, when planning the cost of water production, factors determining the change in the cost of energy resources should be taken into account: price change indices; payment for active electric power in the zones of the day [3, 4]. Under the current operating conditions of water utilities, the development of measures aimed at regulating the operating modes of pumping units to optimize electrical load schedules according to the criterion of minimum payment for energy carriers is relevant. The article presents the results of a study on the example of the water intake of one of the water intakes of the Republic of Belarus.

2 Electricity payment system

In the Republic of Belarus, the electricity tariff for industrial consumers with connected capacity above 750 kVA is determined by the formula:

$$C_p = a \cdot P_{\max} + b \cdot W, \tag{1}$$

where a – basic rate of a two-part tariff for electric capacity; $P_{\max}$ – the actual value of the largest half-hour combined active power for the billing period; b – additional rate of two-part tariff for electricity.

* Corresponding author: kapanski@mail.ru

Thus, the consumer pays for energy not only for consumed electricity, but for participating in the maximum electrical loads of the energy system [1]. With the availability of automated metering systems that allow recording the values of electric loads with 30-minute discretization, the consumer has the opportunity to switch to a differentiated payment system in which the tariff for electricity is determined by the formula:

$$C_d = a \cdot k_a \cdot P_{\max} + b \cdot \left(k_n \cdot W_n + k_{hp} \cdot W_{hp} + k_p \cdot W_p\right), \quad (2)$$

where k_a – decreasing coefficient to the basic rate of the two-part tariff, set at 0.5; k_n, k_{hp}, k_p – respectively night, half-peak and peak tariff coefficients; W_n, W_{hp}, W_p – energy costs in the night, peak and half-peak zones.

The rate coefficient is $k_{hp} = 1$. The coefficient k_n, k_p determined on the basis of the calendar number of days and established time zones (night t_n, peak t_p and half-peak t_{hp}):

$$k_\text{n} = 1 - \frac{a \cdot \left(1 - k_\text{a}\right) \cdot \left(4 \cdot t_\text{p} - t_\text{n}\right)}{b \cdot d \cdot \left(t_\text{n}^2 - \text{t}_\text{p}^2\right)}; \quad (3)$$

$$k_p = 1 + \frac{a \cdot \left(1 - k_a\right) \cdot \left(4 \cdot t_n - t_p\right)}{b \cdot d \cdot \left(t_n^2 - \text{t}_p^2\right)}, \quad (4)$$

where d – calendar number of days in the billing period.

The energy system has identified the following time zones: from 23:00 to 6:00 h - night zone; from 6:00 to 8:00 h and from 11:00 to 23:00 h the half-peak zone and from 8:00 to 11:00 h the peak zone.

In addition, the evening peak load $P_{e.\max}$ (from 18:00 to 21:00) is highlighted, which should not exceed the morning maximum $P_{m.\max}$ (from 08:00 to 11:00) in the billing period. Otherwise, the payment for electricity is not differentiated by the zones of the day and is calculated by the formula 1.

Thus, the choice of a system of payment for electricity and the possibility of gradation by day zone increases the motivation of energy personnel to regulate electric loads in order to reduce payment for electricity [2, 3, 4].

Analyzing the formula 2, it can be noted that the main ways to reduce the cost of electricity are:

- reduction of total energy costs by increasing the energy efficiency of equipment;
- reducing the maximum electrical load due to the optimal distribution during the work shift and the optimal distribution of electrical loads in time zones [5].

The results of comparing the average daily payment for electricity under real operating conditions of the water utility in the city of Zhlobin (Republic of Belarus) are shown in the Table 1.

Later, when comparing the economic efficiency of the transition from a two-part tariff to a differentiated tariff, the formula was used:

$$\Delta C = \left(C_p - C_d\right) / C_p \cdot 100\,\%. \quad (5)$$

Fig. 2 shows a graph of the electrical load of the studied water intake, indicating tariff zones.

Table 1. Comparison of the average daily cost of electricity for various payment systems.

Index	Designation	Units rev.	Value	
Rate type	–		№1	№2
Base rate	a	\$/kW	0.43	0.43
Additional rate	b	\$/kWh	0.11	0.11
Maximum power	$P_{\max}$	kW	152.0	152.0
Tariff coefficients	k_a	–	–	0.5
	k_n	–	–	0.76
	k_{hp}	–	–	1
	k_p	–	–	2.2
Electricity consumption by tariff zones	W_n	kWh	–	384
	W_{hp}	kWh	–	1902
	W_p	kWh	–	380
Total electricity consumption	W	kWh	2666	2666
Payment for maximum power	C_P	\$	64.8	32.4
Electricity payment	C_W	\$	311.5	349.5
Total	C	\$	376.3	381.9
In Table 1 tariff № 1 is two-part; tariff № 2 – two-part differential				

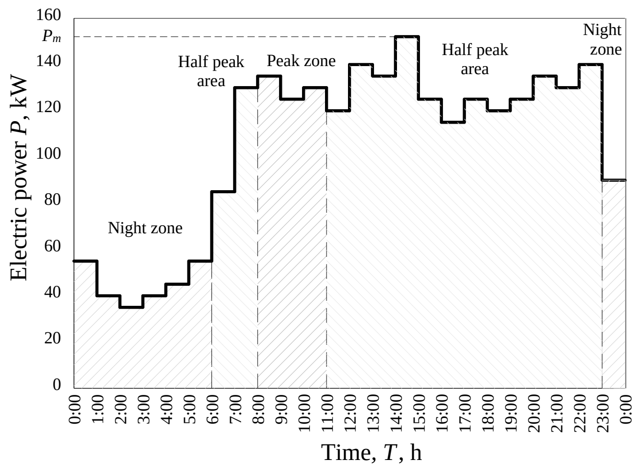

Fig. 2. Chart of daily electric power water intake.

Of particular interest is the change in the cost of electricity with a shift in the graph of electrical load [10, 11, 12, 13]. For the studied water utility, in Fig. 3, the boundaries of economic efficiency are marked with the shift of the electric load 2 hours ahead and 3 hours ago. For the studied water utility, in Fig. 3, the boundaries of economic efficiency are marked with the shift of the electric load 2 hours ahead and 3 hours ago.

In real conditions, changing the electrical load by shifting the production cycle is not possible, since the operating modes of the equipment are determined by the needs of the population and industry for water supply.

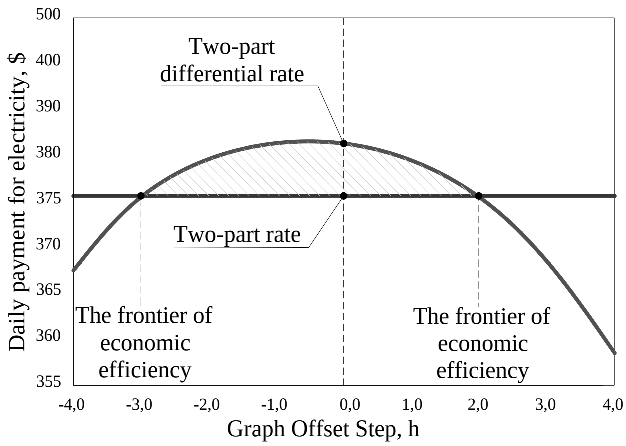

Fig. 3. Change in the cost of electricity at various tariffs and the shift of the electrical load.

Under existing conditions, the transition to a differentiated payment system is impractical $\Delta C = -1.5$ %. In this connection, a search for new methods for regulating the schedule of electric load is required.

3 Storage tanks as a tool for regulating electrical load

To regulate the supply of water to the city and preserve the fire reserve of water, three reinforced concrete control tanks are provided for the studied water intake. The capacity of each tank is 6000 m^3. The tanks are tied with the following pipelines: water supply from the deferrization station to the tanks; water supply from the tank to the pumping station of the 2nd lift; overflow pipe to prevent overfilling of the tank; full discharge pipe. All pipelines are equipped with shut-off and control valves.

The water level in the tanks ranges from $h_{\min} = 2.0$ m to $h_{\max} = 3.75$ m (Fig. 4).

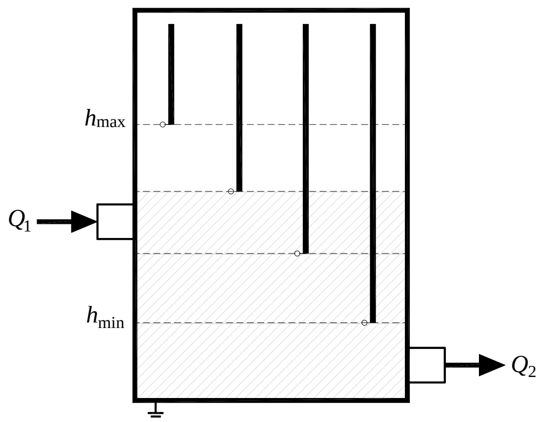

Fig. 4. Accumulation tank with location levels for water level sensors.

The minimum level is due to the need for a fire reserve, when the maximum level is reached, water enters the overflow pipe. To control the water level in each tank, sensors are installed (measuring pressure transducer), the signal from which is output to the pumping station of the second rise. Water level control is carried out by the pumping unit operator. Consider the ability to control the water level in the tank [6].

It is necessary to build a system that maintains a given level of water in the tank h_0. We assume that water is pumped into the tank continuously. To control the water level h, we can change the volume of water Q_1 raised from the wells. Thus, the water level h is an adjustable quantity. The change in the water level in the tank depends on the difference in the volumes of water raised by Q_1 and supplied to the network Q_2 and the area of the tank. The area of all tanks is $S = 3600$ m^2.

Suppose that at time $t = 0$ the water level in the tank is equal to a predetermined value, and the input Q_2 and output Q_1 volume are equal to each other, so that the water level does not change. This mode determines the nominal water level in the tank. In the calculations, we assume the nominal level equal to $h_0 = 3.0$ m. Then the control system model can be described by an equation that determines the change in water consumption:

$$h(t) = \frac{1}{S}\int_0^t (Q_1(t) - Q_2(t))dt. \tag{6}$$

The resulting equation can be represented in differential form:

$$\frac{dh(t)}{dt} = \frac{1}{S}\left(Q_1(t) - Q_2(t)\right). \tag{7}$$

Target function minimizing the cost of cash for electricity when using a differentiated tariff:

$$\begin{aligned} C_d &= a \cdot k_a \cdot w_{\text{sp}} \cdot Q_{h.\max} + \\ &+ b \cdot \left(k_n \cdot W_n + k_{hp} \cdot W_{hp} + k_p \cdot W_p\right) \to \min \end{aligned} \tag{8}$$

where w_{sp} – specific consumption of electricity for rising water, kWh / m^3; $Q_{h.\max}$ – maximum hourly water consumption, m^3 / h.

To implement the system, it is necessary to fulfill a number of conditions. Firstly, the daily volume of water rise should not be lower than the volume supplied to the pipeline network [7].

The system of linear constraints takes the form in the optimization function takes the form:

$$\begin{cases} Q_{1.d} \ge Q_{2.d}; \\ Q_{1.h} \le V_{t.\max}; \\ Q_{1.h} \le Q_{h.wf}; \\ Q_h \ge 0; \\ P_{m.\max} \ge P_{e.\max}; \\ h \ge h_{\min}; \\ h \le h_{\max}, \end{cases} \tag{9}$$

where $Q_{1.d}$, $Q_{2.d}$ – daily volume of raised and supplied water, m^3;

$V_{t.\max}$ – total tank volume, m^3;

$Q_{1.h}$ – hourly flow rate, m^3/h;

 https://doi.org/10.1051/e3sconf/202017801065

$Q_{h.wf}$ – hourly maximum volume of water production, m^3/h;

$h_{\max}$, $h_{\max}$, h – minimum, maximum and actual water level, m.

Secondly, the hourly rise in water cannot be greater than the maximum volume of the tank. Thirdly, it is necessary to fulfill the condition in which the minimum value of the 30-minute power of the morning maximum will be less than the maximum value of the 30-minute power of the evening maximum of loads $P_{e.\max}$.

Also, in the system of linear restrictions, it is necessary to include the boundaries of the change in the water level in the tank.

In Fig. 5 shows the results of optimizing the schedule of electric load minimizing the cost of paying for electricity.

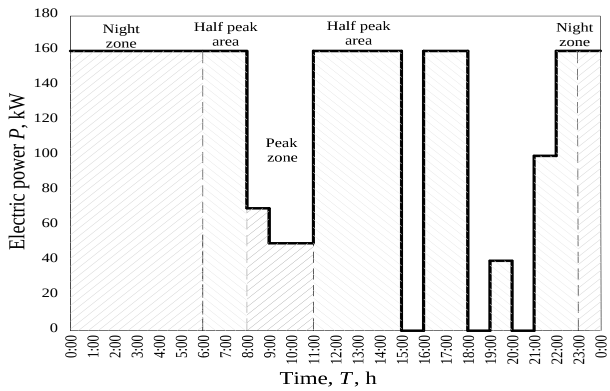

Fig. 5. Chart of daily electric power water intake after optimization.

The economic efficiency after the measures was ΔC = 10.2%, which is a very significant indicator.

4 Conclusions

Maneuvering the load schedules does not directly lead to a decrease in power consumption, however, due to a reduction in the cost of purchasing electricity, the electric power component of the cost is reduced. When using a differentiated payment system by day zones, it becomes possible to significantly increase the economic efficiency of water utilities. In the peak zone, where the maximum payment for electricity, shutdown of the well pumps is supposed, while the consumer will be provided with water filled in the tanks. The implementation of such an event in practical conditions allows reducing the cost of paying for electricity by more than 10%.

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