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Determination of operating modes of photoelectric pump plants used in irrigation systems

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ABSTRACT: A methodology for calculating the maximum power of the photoelectric pump plant is proposed, taking into account the duration of irrigation and the volume of water supplied for it, the values of the pump's marginal effort and water delivery efficiency, the parameters of the pipeline system, and also the operating mode of the pump that corresponds to the values of the variable power of the photoelectric device during the day. A graphoanalytical method of determining the static pressure changes of the pump with the method of changing the frequency of wheel revolutions has been developed. The advantage of organizing the pump mode according to this methodology is shown by the example of the reduction of energy costs needed to collect 9000 m^3 of water in the reservoir for one irrigation.

KEY WORDS: photoelectric plant, pump plant, pump head, pump water supply efficiency, head characteristic, pump power, working point.

I. INTRODUCTION

Today, the world's energy needs are increasing by an average of 1% per year, 5% in developing countries, the reserves of hydrocarbons, the main energy resource, are decreasing, and the price of fuel and its harmful effects on the environment are increasing significantly, so renewable energy sources in the world energy, mainly the economic and environmental benefits of using solar energy are growing year by year [1]. As evidence of our opinion, it is possible to cite the fact that the energy costs of photoelectric pump devices in the irrigation system are 2...4 times lower than devices running on organic fuel [2,3].

According to the International Renewable Energy Agency, 56% of the world's irrigated land is now pumped, and in developing countries in Africa, India, the Middle East and other regions, solar energy is one of the most efficient and environmentally" clean" sources of pumped water recognized as one [4].

In the Republic of Uzbekistan, the size of irrigated areas to which water is supplied by pumping stations is 60 %, for this purpose 8 billion kWh of electricity is consumed every year. In the conditions of such a large amount of energy consumption, it is one of the important tasks to carry out research and development activities aimed at increasing the efficiency of pumping stations, achieving energy efficiency of equipment, and reducing operating costs.

II. SIGNIFICANCE OF THE SYSTEM

The main part of pumping devices used today is designed for the use of solar and wind energy, the choice of one or another type of energy, the determination of the parameters and components of the devices, the speed and amount of energy in the places, the requirements of the consumer, the parameters of water supply are determined. Taking this into account, in this work, a methodology for calculating the operating modes that takes into account the shortness and variability of solar energy radiation during the day and ensures optimal adaptation of the pump device to the power supplied from the photoelectric plant (PEP) was proposed. At the same time, the parameters of the operation modes of the photoelectric pump device, which take into account the variability of the power supplied to the pump device and the pressure values, in order to collect the necessary water volume in the reservoir and ensure the full use of solar energy in

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this process, in the conditions that the duration of irrigation (water consumption) and the duration of solar radiation do not completely match each other. a graphoanalytic method of calculation was developed.

III. LITERATURE SURVEY

Supplying pumping equipment with electricity using solar panels is common in Africa, South America, Middle Eastern countries, China, India and other countries [19,20]. Although the use of photoelectric pumping plant (PEPP) in the world began in the 70s of the last century, the development in this field was very low because of the high cost of solar panels at that time. For example, in 1977, the price of a 1-watt solar panel was $76, and by 2015 it had dropped to $0.3 [2].

One of the main factors ensuring the effectiveness of PEPP is the need to correctly select the components (parts) included in them, which was considered in the work [5]. DC pump motors can be very efficient in using solar energy, but it is suggested by [6] that this power is up to 80% efficient for motors up to 5 kW. The authors of this work came to the conclusion that it is appropriate to use alternating current in high-power electric motors.

Solar panels used for pumps can reduce energy potential by up to 16% [7]. The main reason for this is the absence of a maximum power tracker (MPT), the panels get dusty, and they overheat in the heat. As a result of using MPT, the capacity of pumps increases by 35% [8], and their water supply efficiency increases by 7.4% [9].

A PEP with a power of 148 W and a PEPP with a water delivery capacity of 15 L/min, a power of 110 W and a pump that drives water into a water tank with a capacity of 1000 L were investigated in [10]. The price of the device is set at $410, which includes a battery, charger, inverter and other accessories. This system was able to irrigate 0.2 hectares of land between 1100 and 1500 during the day. The system uses a water reservoir to accumulate excess solar energy. Summarizing the results of all the reviewed studies, it can be seen that the battery-powered PEPP system is undoubtedly an effective system [11].

The analysis of the literature on this topic showed the need to research issues related to the adaptation of the pump operation mode to the variable power of solar panels during the day.

IV. METHODOLOGY

In order to maximize the use of the sun‘s energy in small energy plants used in the irrigation system, collecting the required volume of water in a special reservoir is considered the most optimal method of energy accumulation [12]. PEPP scheme for irrigation system intended to use this method is presented in Fig 1.
In order to effectively use PEPP, determining the daily amount of water required for irrigation and the amount of water collected in the reservoir based on it, the amount of electricity consumed for this purpose, and developing methods for adjusting the pump power according to the variable power of PEP are considered to be the main issues.

The daily amount of water required for irrigation is determined based on the irrigation rate, which is specific to the irrigation area, depending on the climate, soil type, location of groundwater and the type of crop.

$$V = m \cdot \omega, \ m^3 \tag{1}$$

where m is the irrigation rate (for one irrigation), m^3/ha; ω - land area designated for irrigation, ha.
The amount of energy required by the pump unit for pumping water of volume V into the reservoir is determined as follows.

$$Э_p = 9{,}81 \int_{t_1}^{t_2} Q(t)\, H(t) \eta^{-1}(t) dt; \tag{2}$$

where t_1 and t_2 are the start and end hours of the pump unit's operation (this time is determined by solar activity hours)
The value of the full power of the pump at time t is calculated by the following formula

$$H(t) = H_G(t) + \Delta H(t) \tag{3}$$

where $\Delta H(t)$ is the value of the pressure lost in the pipe system at the distance from the water source of the pump to the water reservoir, and this value is determined using hydraulic calculations.

$$\Delta H(t) = \left(\sum \xi + \lambda \frac{l}{d} \right) \frac{\vartheta(t)_i^2}{2g} \tag{4}$$

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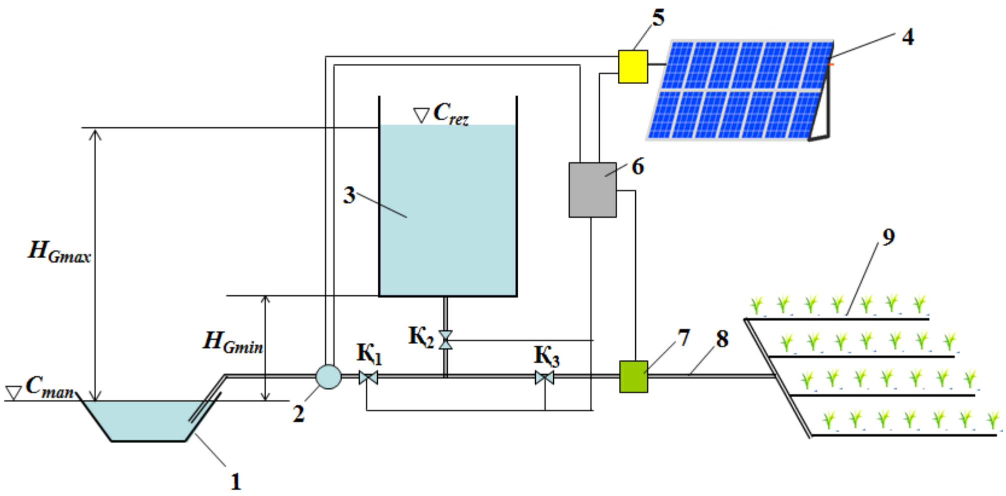
$\Sigma\xi$ – sum of coefficients of local resistances in pipes, λ – coefficient of hydraulic friction in pipes, l – length of pipes, d – diameter of pipes, ϑ(t) – speed of water in pipes.



1-water source; 2-pump unit; 3-water storage tank; 4- PEP; 5-inverter; 6-management blog; 7-water consumption measurement, distribution blog; 8-water supply pipe; 9-crop area.

Fig 1. PEPP scheme for irrigation system

We determine the value of $Q(t)$ based on the following relationship using the pressure characteristic equations of the pump and piping system

$$Q(t) = k[H_0 - H_G(t)]^{0.5} \tag{5}$$

where k - is a coefficient representing the values of hydraulic resistance in the water flow path of the pumping plant, including pipes

$$k = \frac{1}{(S_p+S_k)^{0,5}} \tag{6}$$

S_p is the coefficient of the pump effort characteristic, Sq is the coefficient of hydraulic resistance of the pipe system, H_0 - is the effort value when the pump water supply efficiency is zero (the valve is closed).
The value of S_k - is determined by the following formula [13]

$$S_k = \Delta H_{opt} / Q^2_{opt} \tag{7}$$

Q_{opt} - pump performance value corresponding to the maximum value of the pump efficiency. The value of ΔH_{opt} by Q_{opt} is determined using (4)

The values of Sp and H_0 are determined by the method of B.S. Leznov based on the pressure characteristic [14].
Thus, we determine the pump power at time t of the day based on the values of $Q(t)$ and $H(t)$ as follows

$$N_H(t) = 9,81 \cdot Q(t) \cdot H(t) \cdot \eta^{-1}(t) \tag{8}$$

Within N_H values, one can find the maximum power of PEP corresponding to $N_{Hmax.}$
The block diagram of calculations according to this method is given in Fig 2.

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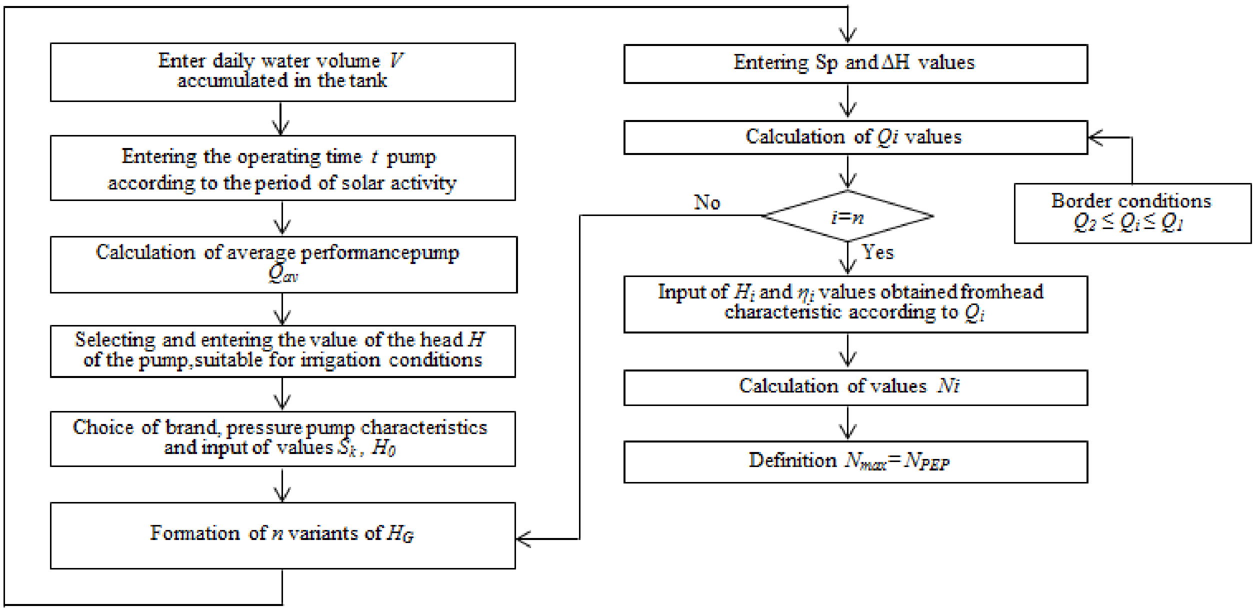

Fig 2. Block diagram of PED power calculation methodology

As can be seen from the formula (8) given above, the values of $Q(t)$, $H(t)$ and $\eta(t)$ should be adjusted accordingly to ensure $N_H(t)= N_{PV}(t)$. The mathematical model of this process for $H(t)$ is the pressure characteristic equation of the piping system from $H_p=H_G + s{\cdot}Q^2$, the maximum pump efficiency based on the use of the equation $\eta = c{\cdot}Q - d{\cdot}Q^2$ can be expressed by the following relation.

$$Q(t) = \frac{\sqrt{(N_{PV}(t){\cdot}d)^2 - 384{,}94{\cdot}s{\cdot}H_G(t) + 39{,}24{\cdot}N_{PV}(t){\cdot}c{\cdot}s} - N_{PV}(t){\cdot}d}{19{,}62{\cdot}s} \quad (9)$$

where, *d, c* pump efficiency graph coefficients, *s* - pipe system hydraulic resistance coefficient.

This equation allows us to model the water delivery performance of a pump pumping water to a height H_G using the capacity of PEP at time *t*.

To ensure the maximum use of solar energy, it is necessary to change (adjust) the power of the pump in accordance with the power of PEP, for this we choose the method of changing the number of revolutions of the pump shaft. We use the proposed equations to recalculate the change of parameters based on the laws of similarity of pumps when the number of shaft revolutions changes. Based on the results obtained in the calculations, we express the change of the pump operating mode graphically (Fig 3).

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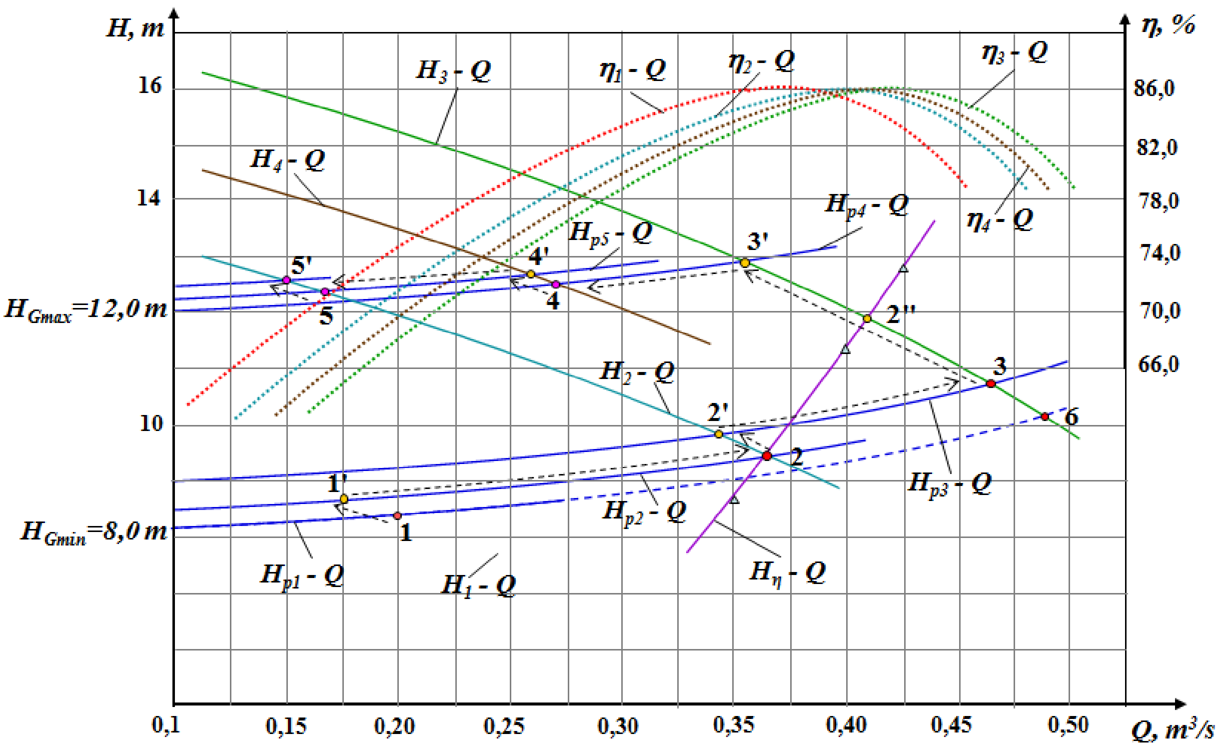

Fig 3. Pump operating mode graphs

$H_3 – Q$ – nominal head characteristic of the pump; $\eta_3 – Q$ – nominal efficiency characteristic pump; $H_1 – Q$, $H_2 – Q$, $H_4 – Q$ are the characteristics of effort that occurred when the frequency of rotation of the pump was changed; $H_{p1} – Q$, $H_{p2} – Q$, $H_{p3} – Q$, $H_{p4} – Q$ and $H_{p5} – Q$ are pressure characteristics that occur when the geometric pressure H_G values of the piping system change; $\eta_1 – Q$, $\eta_2 – Q$, $\eta_4 – Q$ - efficiency characteristic pump that occurred when the frequency of pump rotations changed; 3-point operating point of the pump at the nominal frequency of rotations; 1, 2, 4 – working points of the pump when the rotation frequency changes; 1', 2', 3', 4' - operating points that occur when the H_G values of the pump change; 6 – the initial operating point when the number of point pump revolutions does not change; $H_\eta – Q$ is an equal value pump efficiency graph.

A pump corresponding to the maximum power of the pump plant, determined by the method shown in the block diagram in Fig 2, is selected, and its operating characteristics ($H_3 – Q$ and $\eta_3 – Q$) are constructed. In times of low solar activity, the number of pump shaft revolutions is reduced to use the PEP power, and the parameters of the pump corresponding to this power are determined and its operating point is found, for example, operating point 1 corresponds to this situation. At this operating point, when the pump runs for a while, the water level in the upper reservoir rises, so the pump head increases and the operating point moves to 1‘. During this time, the power of PEP also increases, and accordingly we increase the number of revolutions of the pump shaft, increase the power of the pump and get the 2nd operating point, and then the 2‘ point due to the increase in pressure. When the solar activity is maximum, the pump takes the operating point 3, when the reservoir is full, it takes the position 3‘. In the afternoon, when the activity of the sun decreases, the number of pump shaft revolutions is reduced again, and operating points 4 and 4' and 5 and 5' are created. In this way, the pump operation mode is adapted to the PEP operation mode, where the variation of the pump operation mode between the operating points is indicated by the arrow-dotted line.

V. RESULTS

As an example, we determine the advantage of organizing the pump operation mode according to this method through the energy costs needed to collect 9000 m3 of water in the reservoir for one irrigation. If a non-adjustable pump (with the same rotation frequency) is used, then the pump will work depending on the change of H_G only between the

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Vol. 10, Issue 8, August 2023

operating points 6 and 3‘of the graph $H_3 - Q$ in Figure 3, that is, at point 6 59.4 kW, at point 3‘ It has a capacity of 54.9 kW and consumes 368 kWh of electricity to collect 9000 m^3 of water for 5^{50} hours, and the maximum power of PEP in generating this energy is N_{PV} = 96.3 kW (Fig 4).

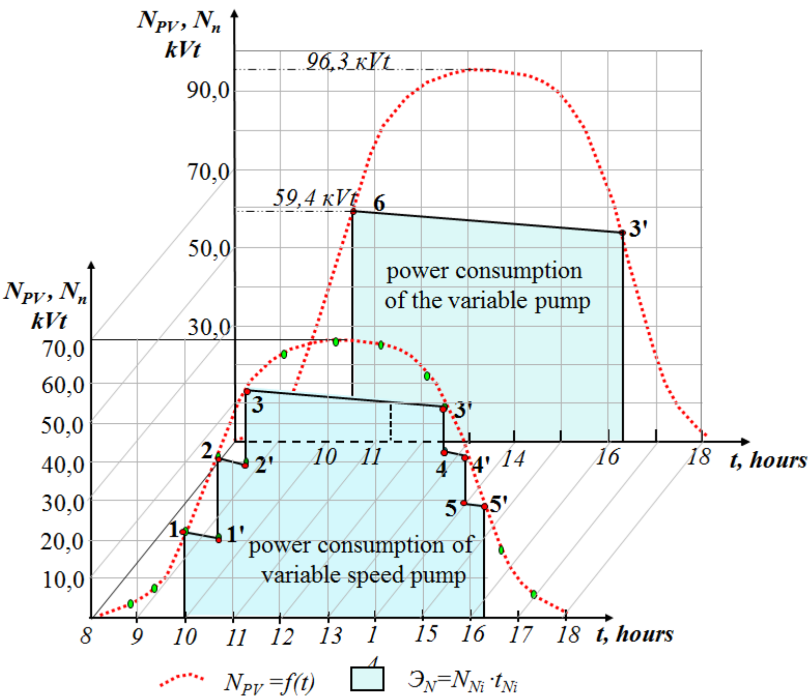

Fig 4. Graph of pumping unit and PEP capacities

It can be concluded that almost 40 % of PEP electricity remains unused by the pumping unit. If the method of changing the frequency of pump cycles is used, 314.5 kWh of electricity is needed to collect 9000 m^3 of water by adjusting the pump power to NPV, and the maximum power of the PEP in producing this energy is 70 kW, which is 81% of the energy utilization of the PEP allows.

Indicators of two options, i.e. pump device with variable rotation frequency – option 1 and pump device with constant rotation frequency – option 2 are presented in Table 1.

Table 1. The results of the comparison of indicators

No	Indicator name	Option 1	Option 2
1	Volume of collected water, m ^{3}	9000	9000
2	Number of pumps	1	1
3	Pump brand	D2000-21	D2000-21
4	Pump head, m	10.2 - 12.8	8.4 - 12.8
5	Pump performance, m^3/s	0.36 - 0.42	0.15 – 0.467
6	Pump operation time, hours	5 ^{50}	6 ^{20}
7	Electric energy consumption of the pump, kWh	368.0	314.48
8	Power of photoelectric plant, kW	96.3	70.0

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Vol. 10, Issue 8, August 2023

VI. CONCLUSION

1. The method of determining the power of the photoelectric plant was developed based on the maximum power required to supply the volume of water required for the pump plant to the tank.
2. A graphoanalytic method of calculating the parameters of adjusting the main parameters of the photoelectric pump plant with a water (energy) storage tank by changing the frequency of shaft rotations of the pump operating mode corresponding to the amount of variable energy of solar radiation was proposed.
3. The results of calculating the parameters of the photoelectric pump plant in the irrigation system with a pump power of 58.3 kW and PEP power of 70 kW. When using the method of adjusting the pump operation mode, the maximum power of PEP is 26.3% less required compared to the mode when the pump worked in constant mode, pumping from solar energy showed that the utilization rate of the device reaches 81%.

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