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Assessment of the Technical and Economic Efficiency of Using Free-Flow Micro Hydropower Plants in Energy and Water Management Systems

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ABSTRACT: This article examines the use of free-flow micro hydropower plants (micro-HPPs) in energy and water management systems. The study analyzes the hydropower potential of rivers, canals, and hydraulic structures in Uzbekistan. The advantages of free-flow micro-HPPs include low capital costs, simple installation on existing water facilities, and efficient use of water resources. Technical parameters such as water discharge, head, and installed capacity are considered, demonstrating the potential of micro hydropower for expanding renewable energy supply.

I. INTRODUCTION

One of the energy installations based on renewable energy sources in the Republic of Uzbekistan is micro-hydroelectric power plants. Their total hydropower potential is 3.314 tons of water. (or 2.32 t.n.e.) or 27.0 billion. exceeds kW·h. These include rivers and canals in water management and energy systems, free water flow and the difference in natural water levels, as well as micro-hydroelectric power plants installed in water intake structures, reservoirs, water outlet, transmission, and discharge structures [1,6,7].

One of the most important aspects of analyzing the hydropower potential of water management and energy facilities is the development of a method for determining water-energy indicators, i.e., hydro-energy parameters, taking into account their seasonal operating modes and purpose, due to the fact that the use of micro-HPPs at the above-mentioned facilities does not require the construction of expensive structures when using free flow of a river or canal, and the presence of a ready-made pressure front (basin) in water intake structures, reservoirs, water outlet, transmission, and discharge structures does not require large expenditures[2,6,8,].

A necessary condition for the use of free-flow micro-HPPs is its feasibility study, i.e., determining the technical and economic parameters of free-flow micro-HPPs installed on rivers and canals [94,95]. The technical and economic parameters of free-flow micro-HPPs installed on rivers and canals include the following indicators [94, 95], namely: water flow velocity, head, water consumption, capacity, annual electricity generated by free-flow micro-HPP, allocated capital expenditure, annual operating costs, income from generated electricity, amount of saved fuel resources, net profit, and payback period [2,3,5,7].

II. METHODS

Installation of free-flow micro-hydroelectric power plants in several sections of the hydropower plant is one of the effective options. This creates the possibility of utilizing the hydropotential of free water flow in any part of rivers and canals.

Free-flow water pressure in a river or canal:

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$$H_{\text{flow}} = \frac{\alpha_{flow} \cdot \vartheta_{low}^2}{2 \cdot g}, \text{[m]} \quad (1)$$

In this case, α_{flov} is the coefficient of kinetic energy of the water flow in the river or channel, or the Coriolis coefficient; ϑ_{flov} is the water flow velocity in the river or channel.
The pressure of a free-flow microHPP is determined as follows:

$$H_{\text{microHPP}} = \frac{\alpha_{\text{microHPP}} \cdot \vartheta_{\text{microHPP}}^2}{2 \cdot g}, \text{[m]} \quad (2)$$

where, α_{microHPP} - coefficient of kinetic energy of the water flow passing through the microHPP or Coriolis coefficient; $\vartheta_{\text{microHPP}}^2$ - the flow rate of water passing through a microHPP.

Power of the water flow at the installation point of a free-flow micro-HPP:

$$N_{flow} = 9{,}81 \cdot Q_{flow} \cdot H_{flow} = \frac{\rho \cdot g \cdot S_{flow} \cdot \vartheta_{flow} \cdot \frac{\vartheta_{flow}^2}{2g}}{1000} = \frac{\rho \cdot S_{flow} \cdot \frac{\vartheta_{flow}^3}{2}}{1000} = 0{,}5 \cdot S_{flow} \cdot \vartheta_{flow}^3, \text{[kW]} \quad (3)$$

where, S_{flow} - the cross-sectional area of a river or canal at the point of installation of a free-flow micro-HPP; ρ - water density, $\rho = 1000$ kg/m^3.
The total capacity of a free-flow micro-HPP is determined based on the following expression [9, 10]:

$$N_{\text{micro-HPP}} = 9{,}81 \cdot Q_{\text{micro-HPP}} \cdot H_{\text{micro-HPP}} = \frac{\rho \cdot g \cdot S_{shovel} \cdot \vartheta_{\text{micro-HPP}} \cdot \frac{\vartheta_{\text{micro-HPP}}^2}{2g}}{1000} =$$

$$= \frac{\rho \cdot S_{shovel} \cdot \frac{\vartheta_{\text{micro-HPP}}^3}{2}}{1000} = 0{,}5 \cdot S_{shovel} \cdot \vartheta_{mikro-HHP}^3, \text{[kW]} \quad (4)$$

where The blade is the blade surface of the free-flow micro-HPP impeller.

Free-flow micro-hydroelectric power plant capacity:

$$N_{\text{micro-HPP}} = 0{,}5 \cdot S_{shovel} \cdot \vartheta_{\text{micro-HPP}}^3 \cdot \eta_{ag}, \text{[kW]} \quad (5)$$

where $\eta_{га}$ - the efficiency of a free-flow micro-HPP hydraulic unit, determined by the following equality:

$$\eta_{ag} = \eta_{tur} \cdot \eta_{\text{gen}} \quad (6)$$

η_{tur} - efficiency of a free-flow micro-HPP hydraulic turbine, η_{tur} = (30÷55) %;
η_{gen} - free-flow microHPP generator efficiency, η_{gen} = (95÷97) %.
The efficiency of water flow utilization (EFU) at the installation point of a free-flow micro-HPP is determined as follows:

$$\text{EFU} = \frac{N_{\text{micro-HPP}}}{N_{flow}} \cdot 100, [\%] \quad (7)$$

The annual electricity generated by one free-flow micro-HPP is determined using this formula[]:

$$Э_{Э\text{micro-HP}} = N_{\text{micro-HP}} \cdot T_{prof}, \text{[kWh]} \quad (8)$$

where T is the operating time of the free-flow micro-HPP during the year, hours.
The coefficient of utilization of installed capacity(CUIC) of a micro-hydroelectric power plant with a free-flow is determined as follows [4,5,8,9,10]:

$$\text{CUIC} = \frac{Э_{\text{micro-HPP}}}{N_{\text{micro-HPP}}^{max} \cdot 24 \cdot 365} \cdot 100, [\%] \quad (9)$$

Capital expenditure allocated for the installation of n free-flow micro-HPPs installed on a river or canal of length L

$$\Sigma K \text{ micro} - \text{HPP} = \Sigma N \text{ micro} - \text{HPP} \cdot k_{сол}, \text{[AQSH doll]} \quad (10)$$

The net profit from the use of annual free-flow micro-HPPs is determined as follows:[94, 95, 96,99]:

$$Ф = S \text{ micro} - \text{HPP} + Э_{\text{fuel}} + Э_{KD} - X \text{ micro} - \text{HPP}, \text{[AQSH. doll]} \quad (11)$$

The comparative economic efficiency coefficient (CEEC) for free-flow micro-HPPs is determined as follows.[1, 3, 6,8]:

$$\text{CEEC} = F / \Sigma K \text{ micro} - \text{HPP} \quad (12)$$

The payback period or payback period of capital investments allocated to a free-flow micro-HPP is determined by this equation.[10]:

$$T_{pp.} = 1/\text{CEEC [year]}$$

(13)

III. RESULTS

Based on the developed method, the technical and economic parameters of a free-flow micro-hydroelectric power plant were determined based on various water flow rates, head, water consumption, and capacity.[1, 5, 9,10].

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Figure 1 shows the characteristic of the dependence, reflecting the change in pressure, power, and payback period based on the results obtained by the method for determining the technical and economic parameters of a free-flow micro-hydroelectric power plant in relation to the flow rate of water entering the installation.

According to Figure 1, it can be seen that with an increase in the flow rate of water entering the free-flow micro-HPP, the pressure of the free-flow micro-HPP increases, and as a result, the capacity of the free-flow micro-HPP increases, which depends mainly on two parameters (water flow rate and pressure).

As a result, an increase in the flow rate of water entering a free-flow micro-hydroelectric power plant indicates an increase in its pressure and, as a result, an increase in its power, which depends mainly on two parameters (water flow rate and pressure). With an increase in the power of a free-flow micro-hydroelectric power plant, its technical and economic indicators increase, and with a water flow velocity of more than 1.2 m/s, the power of a free-flow micro-hydroelectric power plant reaches a value of more than 3.0 ÷ 3.5 kW, and its payback period averages from 4 to 4.5 years..[2, 5, 6,9,10]:

The conducted research and calculations allow not only to recommend approaches to the selection of free-flow micro-hydroelectric power plant parameters, but also to justify their application in the specific conditions of rivers and canals of the region and to determine a number of technical and economic indicators.[4, 5, 6,8].

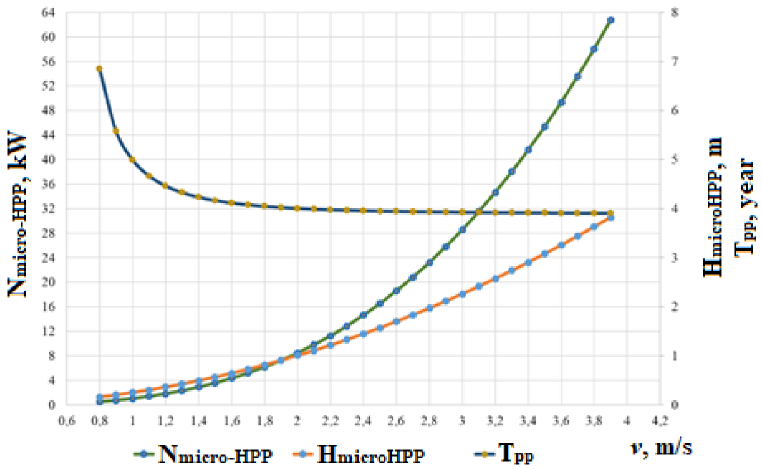

Figure 1. Characteristic of the dependence of the pressure, power, and payback period of a free-flow microHPP on the water flow velocity

From the conducted research on determining the technical and economic parameters of free-flow micro-hydroelectric power plants in rivers and canals of hydropower and water management systems, it can be concluded that a high capacity of a free-flow micro-hydroelectric power plant leads to a shorter payback period and, accordingly, to a higher economic efficiency. This indicates that the use of a free-flow micro-hydroelectric power plant is economically efficient and has a low payback period of 30 kW.[4, 5, 6,7,9].

The energy hydropower potential of natural watercourses, rivers, and canals within the republic's hydropower plants is sufficient for improving the electricity supply of individual and farms, small industrial enterprises, through the use of free-flow micro-hydroelectric power plants. [1, 4, 5,6].

IV. CONCLUSION

The use of free-flow micro-hydroelectric power plants in natural watercourses, rivers, and canals of hydropower plants is of great importance in meeting the needs of electricity consumers located in remote areas and without a centralized power supply system, saving fuel resources by generating electricity without the use of fuel resources, and as a result, generating environmentally friendly electricity without releasing greenhouse gases into the atmosphere within the framework of the "green energy" policy, which is currently relevant in the energy sector, and solving other issues.[3, 6, 9,10].

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