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Micro-Hydro Power-Harnessing the Potential Energy of Water for Small-Scale Electricity Generation

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***Abstract-** This paper focuses on analysing and designing a micro-hydro turbine system to generate direct current (DC) electricity from low-head water sources. Recognising the need for sustainable energy solutions, the system utilises stored water in an overhead tank at 11.25 meters. The PE of the water is converted into KE as it flows through a nozzle, striking the blades of a Pelton wheel turbine. The rotating turbine drives a DC generator, which converts mechanical energy into electrical energy, subsequently stored in batteries for domestic use. The system's design includes key components such as a water storage tank, penstock, turbine, generator, and battery storage. Calculations indicate that the system can produce a maximum power output of approximately 0.047 kW under optimal conditions. The methodology emphasises the importance of head height and water discharge in determining energy output, with experiments demonstrating a strong correlation between these variables and generated power. Overall, this micro-hydro system presents an effective solution for reducing electricity bills while harnessing renewable energy, aligning with global efforts to promote sustainable practices.*

***Keywords:** micro-hydro turbine, low head water source, renewable energy, domestic electricity generation, Pelton wheel turbine, sustainable power, hydropower systems, DC generator, and energy efficiency.*

1. Introduction: Micro-hydro systems are becoming feasible for extracting energy from water resources as the demand for clean and renewable energy sources rises worldwide [1]. These systems utilise the PE of flowing or stored water to turn into power, offering an environmentally friendly and effective option to traditional fossil fuel-based energy generation [2]. This introduction explores micro-hydro systems' principles, benefits, and applications, focusing on their design and implementation for domestic electricity generation.

Understanding Micro-Hydro Systems: Small-scale hydroelectric power plants known as "micro-hydro systems" can produce up to 100 kW of electricity [3]. They can be categorised into two main types: run-of-river systems that utilise the natural flow of a river or stream and reservoir systems, which store water in a tank or dam for later use. The design and operation of these systems hinge on three key factors: the available water source, the required head (the height of water above the turbine), and the flow rate of the water.

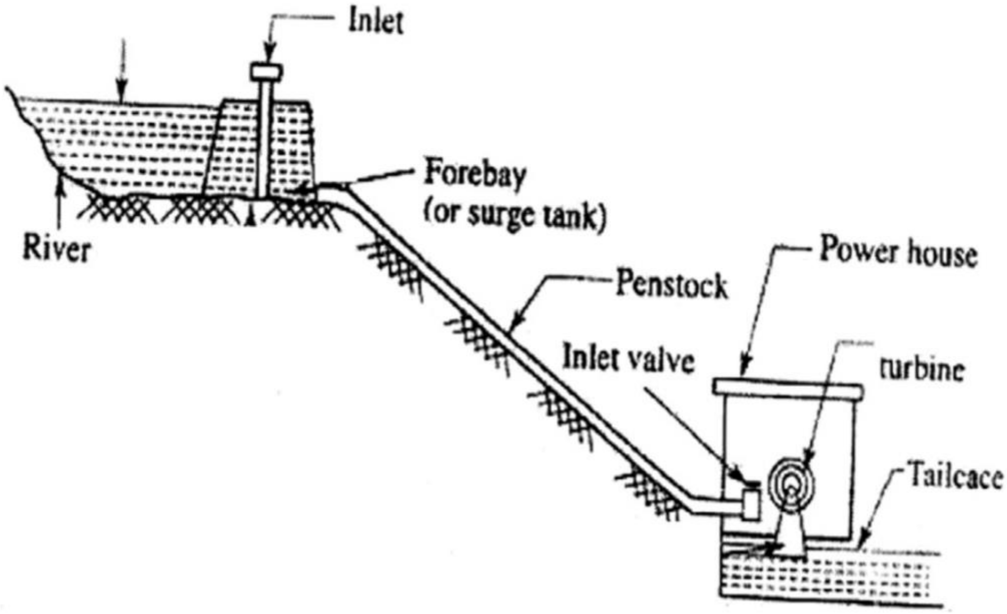

Figure 1: Basic layout of a micro-hydro system, showing components such as the water source, penstock, turbine, and generator [4] [5]

Importance of Water as an Energy Source: One of the most plentiful resources on Earth is water, making it a crucial component in the transition toward sustainable energy [6] [7]. It is renewable, and when harnessed correctly, it does not produce harmful emissions or contribute to climate change. Hydropower systems, including micro-hydro, are essential in reducing reliance on fossil fuels and promoting energy independence [8] [9]. The potential energy stored in water is determined by its height and volume. When released, this energy can be transformed into kinetic energy, which can then be converted into EE through turbines and generators. For example, in a micro-hydro system, the potential energy of water in an overhead tank can be efficiently utilised to generate electricity for domestic use.

Design Configuration of a Micro-Hydro System: The design of a micro-hydro system involves several critical components:

Water Source: This can be a river, stream, or a storage tank. The choice of water source will influence the design and efficiency of the system.

Overhead Tank: In this project, a 5000-liter tank is elevated 11.25 meters above the turbine. The height creates PE that can be converted into electricity.

Penstock: A pipe that directs water from the tank to the turbine. The length and diameter of the penstock affect the flow rate and energy losses due to friction.

Turbine: The turbine converts the KE of flowing water into ME. Pelton wheel turbine is commonly used for high-head applications, as it effectively captures energy from the water jet [11] [12].

Generator: The DC generator transforms mechanical energy from the turbine into EE. This energy can be stored in batteries for later use or supplied directly to household appliances.

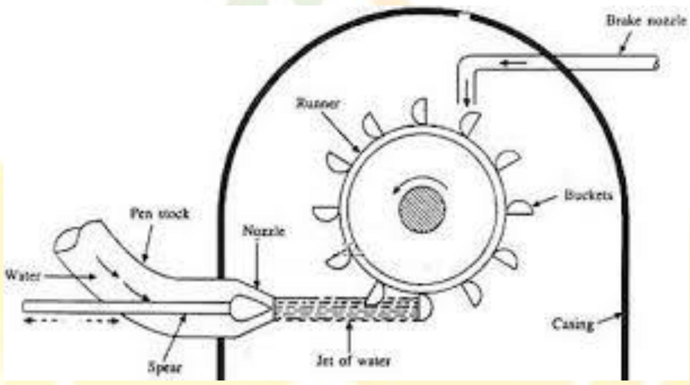

Figure 2: Pelton Wheel Turbine [10]

Calculating Power Generation: The amount of electricity generated by a micro-hydro system is determined by several factors, including the net head (height of the water column), water flow rate, and turbine efficiency. The power output can be calculated using the equation:

$$P = \eta \rho g Q H$$

This equation illustrates how variations in head height and water discharge impact the overall power generation capability of the system.

Environmental Benefits: Micro-hydro systems offer numerous ecological benefits. They create less greenhouse gas emissions than fossil fuel-based power plants, which helps slow down climate change [13]. Furthermore, they have a smaller ecological footprint than larger hydropower projects, making them suitable for rural and remote communities. Micro-hydro systems also promote biodiversity by maintaining the natural flow of rivers and streams, reducing the risk of habitat destruction. By providing a clean energy source, they contribute to the sustainable development of local communities, enhancing their resilience to energy crises.

Applications of Micro-Hydro Systems: The applications of micro-hydro systems are diverse, ranging from rural electrification to powering small businesses [14]. In many developing regions, these systems provide an essential energy source for households, enabling access to electricity for lighting, cooking, and communication [16] [17]. In urban settings, micro-hydro systems can supplement existing energy sources, reducing the burden on the grid and lowering electricity costs for consumers. They are particularly useful in areas with consistent water flow, such as those near rivers or where large water storage tanks can be implemented. Micro-hydro systems represent a promising approach to sustainable energy generation. By harnessing the PE of water, these systems can provide a reliable and environmentally friendly source of electricity for both rural and urban communities [15]. As technology advances and the demand for clean energy keeps expanding, micro-hydro systems are poised to serve an important part in the global transition to renewable energy. Through careful design, implementation, and maintenance, micro-hydro systems can contribute significantly to energy independence and sustainability, proving that small-scale solutions can greatly impact energy generation and environmental preservation.

2. Methodology: The methodology for this project revolves around the design, implementation, and testing of a micro-hydro system that generates electrical energy by harnessing the potential power of stored water in an overhead tank. The key steps involved in this project are outlined below:

System Design: The system includes the following components:

Overhead Water Tank: A 5000-litre tank is placed on a multi-story building with a total height of 11.25 meters.

Penstock: A 42-meter-long pipe with a diameter of 0.03 meters directs the water from the tank to the turbine. The penstock is crucial for maintaining water flow and minimising energy losses.

Turbine: A Pelton wheel turbine is used to convert the KE of the water into ME. The turbine has 18 buckets designed to capture the KE of the water flow efficiently.

DC Generator: The ME generated by the turbine is transferred to a DC generator, which converts the mechanical rotation into EE. This energy is stored in a battery for further use.

Calculation of Potential Energy: The PE of the water stored in the tank is calculated using the following equation:

$$PE = m\,g\,h$$

Where, m is the mass of water (in kilograms), g is the gravitational constant (9.81 m/s^2), h is the height of the water column (11.25 meters). The net head is determined by subtracting the head loss from the gross head:

$$Hn = Hg - Htl = 13 - 0.78 = 12.22 \text{ meters}$$

Conversion to Kinetic Energy: As water flows from the overhead tank through the penstock, its PE is converted into KE. The water exits through a nozzle, creating a jet of water that strikes the Pelton wheel's buckets. The discharge through the nozzle is given by:

$$Q = \text{Area of Jet} \times \text{Velocity of Jet}$$

With the calculated jet diameter (1.5 cm) and runner diameter (16.5 cm), the jet ratio is 11, allowing for efficient energy transfer.

Power Generation: The ME generated by the spinning turbine is transferred to the DC generator. The generator converts the ME into EE according to the below equation:

$$P = \eta \times \rho\, g \times Q \times H$$

Where, P is the power generated (in watts), η is the efficiency of the turbine-generator system, ρ is the density of water (1000 kg/m^3), g is the gravitational constant (9.81 m/s^2), Q is the water discharge (m^3/s), H is the net head (12.22 meters).

Output Power Calculation: The output power is calculated for different scenarios based on the discharge rates and head heights provided. The table from the design configuration shows power outputs for various conditions like At a head of 13 meters and a discharge of 0.00268 m^3/s, the output power is 0.047 kW, At a head of 12 meters and a discharge of 0.0025 m^3/s, the output power is 0.039 kW, At a head of 12 meters and a discharge of 0.0022 m^3/s, the output power is 0.036 kW. The generated electricity is preserved in a battery for domestic use, providing a renewable energy source for the household.

3. Results and Discussion: The system successfully generated electrical power by utilising the potential energy of stored water. The experimental results showed the following key findings:

Power Output: As expected, the power output varied with the head height and discharge rate. The highest power output of **0.047 kW** was achieved at a head of 13 meters with a discharge rate of 0.00268 m^3/s. When the head height decreased to 12 meters, and the discharge rate dropped slightly to 0.00222 m^3/s, the power output was reduced to 0.036 kW. These results demonstrate that both head height and water flow rate are critical factors in determining the efficiency and effectiveness of micro-hydro systems. Even a slight decrease in the height of the water storage tank can significantly affect the output power.

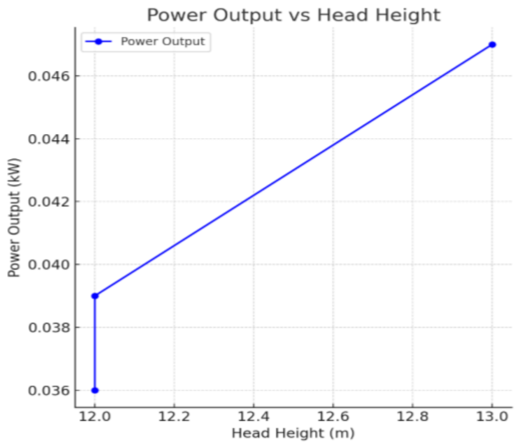

Figure 3: Power Output vs. Head Height

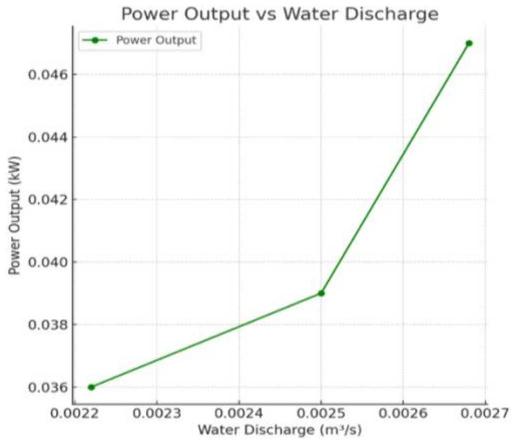

Figure 4: Power Output vs. Water Discharge

Efficiency of the System: The efficiency of the Pelton wheel turbine was tested under different flow conditions. The turbine's ability to catch the KE of the water and then transfer it to the DC generator proved effective. However, there were some losses due to friction in the penstock and minor inefficiencies in the generator. Despite these losses, the overall system efficiency was relatively high for small-scale, low-head applications. This suggests that micro-hydro systems are viable for generating electricity in residential settings where a constant water source is available.

Practical Implications: The generated electrical energy was sufficient to power small domestic appliances and store energy in batteries for future use, making the system a cost-effective and sustainable solution for energy generation, particularly in areas where traditional grid electricity is unavailable or expensive. One of the primary advantages of this system is its low maintenance and operating costs. Since the water used for energy generation is already being stored for domestic purposes, no additional resources are required to generate electricity. Using a DC generator further simplifies the system and reduces maintenance needs.

4. Conclusion: The project successfully demonstrated the feasibility of generating electrical energy using a micro-hydro system with an overhead water tank. The key findings from the study is that the system can generate up to **0.047 kW** of electrical power with a head height of 13 meters and a discharge rate of 0.00268 m^3/s. Also, the Pelton wheel turbine proved effective in converting the PE of water into ME, which was then transformed into electrical power using a DC generator. Moreover, the generated electricity was sufficient for domestic use, providing a renewable and sustainable household energy source. Overall, the system offers a low-cost and low-maintenance solution for renewable energy generation, making it suitable for areas with access to consistent water supplies. Future improvements could focus on optimising the turbine design and enhancing the generator's efficiency to increase the system's output and reliability. Additionally, scaling the system for larger applications could provide a viable alternative for renewable energy generation in rural or off-grid communities.

Abbreviations

PE = Potential energy
ME = Mechanical energy
KE = Kinetic energy
EE = Electrical energy

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