MICRO HYDROPOWER AT LOW HEAD RIVER

Arutchelvi Thayanandan[1], Muhammad Fauzi Yaacub[2],
Muhammad Farhan Mohd Saifful[3], Luqman Nur Hakim Abdull Wahab [4]

[1,2,3,4] Civil Engineering Department Polytechnic Ungku Omar, Ipoh, Perak, Malaysia
E-mail: arutchelvi@puo.edu.my, muhdfauzi.1005@gmail.com, farhan25857@gmail.com, lhqeemm@gmail.com,

Abstract

This study investigates the potential of micro hydropower technology for electricity generation in Malaysia, focusing on low head river systems. Malaysia's increasing electricity demand, primarily met through fossil fuels, has led to significant greenhouse gas emissions, necessitating alternative energy solutions. Given Malaysia's abundant natural hydro resources, particularly its extensive river network, micro hydropower emerges as a promising renewable energy source. The project aims to design, construct, and evaluate a micro hydropower plant tailored to low head rivers. The design includes an Archimedes screw turbine to harness renewable energy from small-scale water resources. The turbine measures 1000 mm in length and features a helical structure optimized for converting water flow into rotational energy. The production of Archimedes turbine involves designing for location and power needs, selecting durable materials like PVC pipe and assembling the turbine with other components to complete the prototype. Prototype testing will take place at Ungku Omar Polytechnic. Initial findings highlight inherent inefficiencies in energy conversion and mechanical operation, with an initial turbine efficiency of 1.67% under clear weather conditions. Subsequent design optimizations, including enhancements to water flow concentration, significantly improved turbine efficiency to 4.07%. Challenges such as structural integrity and susceptibility to adverse weather were identified, emphasizing the need for continuous refinement. The successful prototype demonstrates the feasibility of generating electricity from low head rivers, marking a significant step toward sustainable energy solutions. The project's outcomes suggest that with ongoing design improvements, micro hydropower can play a crucial role in Malaysia's renewable energy landscape, offering a reliable and environmentally friendly alternative to traditional fossil fuel-based power generation.

Keywords *: environmental; generation; hydropower; low head river; renewable energy; turbine*

I. INTRODUCTION

A. Project Background

Recently, environmental concerns within energy policies, notably regarding global warming, have garnered unprecedented focus. The escalation in carbon dioxide (CO^2) emissions, primarily attributed to excessive reliance on fossil fuels, deforestation, and land degradation, has resulted in a doubled global average temperature compared to earlier projections. In Malaysia, a developing nation, the demand for electricity has consistently rise over the last twenty years. Presently, the country's electricity sector remains dominated by fossil resources. [1]. The largest portion of Malaysia's Greenhouse Gas (GHG) emissions comes from electricity generation. Being a developing nation, the increasing demand for energy has put significant pressure on the government to find for more cost-effective energy sources in power generation [2]. In Malaysia, the primary sources of electricity generation include coal (48.3%), natural gas (39.4%), hydropower (7.4%), diesel (2.8%), oil (1.9%) and a minimal contribution from other renewable energies (0.2%) [3]. The widespread use of coal skyrocketed global CO^2 emissions, particularly in Asian nations. Countries like China, India, United States and United Kingdom contributed to 85% increase in worldwide CO^2 emissions due to coal consumption. The prevalence of coal in energy production is primarily motivated by its abundance and cost-effectiveness. Many nations, including Australia, China, United States, Russia, India, Indonesia, Singapore, Thailand, Philippines and Malaysia, heavily rely on fossil fuels, constituting over 79% of energy mix for electricity generation. Conversely, countries such as Brazil, Canada, Norway and Sweden have transitioned to renewable energy sources in recent years for a significant part of their

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electricity production. Brazil, Canada and Norway generate 62.9%, 59.6% and 95.7% of their electricity from hydropower, respectively [1].

The extensive global reliance on non-renewable energy sources has imposed significant environmental harm. Consequences include global warming, acid rain, ozone layer depletion, air pollution and release of radioactive substances. Consequently, there's a growing necessity for environmentally friendly and sustainable renewable energy options like hydro, biomass, wind, solar and geothermal energies for future power generation. Renewable sources offer the cleanest energy with minimal environmental impacts, mitigating global warming effects, lowering secondary wastes. Among renewable sources, hydropower stands out as the most reliable and cost-effective, totalling 76% of all renewable electricity generation worldwide. Its adaptability to meet base-load requirements and high-capacity factor recognizes it. Consequently, run-of-river hydropower emerges as an ideal option for Malaysia due to its lower environmental impact and operational simplicity, proving beneficial sustainable development. Moreover, small-scale hydropower technology claims easy maintenance and operation, making it an affordable and adaptable solution tailored to local geographical, environmental and socio-economic conditions [3]. Small scale hydropower can be divided into 2 categories, which is Mini hydropower and Micro hydropower.

Malaysia possesses abundant potential in natural hydro resources [4]. This is primarily due to Malaysia's distinct geographical advantage, boasting 189 rivers with a combined length of approximately 57,300 kilometres [4,5]. With consistently high temperatures, year-round humidity, substantial rainfall and a rugged topography spanning the country's length and breadth, Malaysia boasts an extensive network of rivers that flow from foothills to mountainous regions. These geographical features, accounting for 41% of the country's total land area, contribute to Malaysia's significant hydropower potential. The country experiences heavy rainfall primarily during the southwest monsoon, registering an estimated average annual rainfall of 2450 mm, 2630 mm, and 3850 mm in Peninsular Malaysia, Sabah, and Sarawak, respectively. These figures surpass the global average annual rainfall of 750 mm, indicating Malaysia's considerable potential for small-scale hydropower generation.

Micro hydropower systems are installed along rivers with significant differences in elevation. Rivers with higher elevation gaps yield greater potential energy, enhancing the efficiency of micro hydro plants. Current investigations centre around turbine selection suitable for low head river settings. Although most turbines impose a static head of 10 meters or more, some can operate effectively within the 0-3meter range. This makes low head hydropower particularly practical in countries like Malaysia, where low head rivers are more prevalent, especially in densely populated areas [3]. Low head micro-hydropower is easily built, cheaper and leaves a small environmental and ecological impact compared to large hydropower. Power source for electricity generation, which is mainly coal can be minimized by the construction of micro-hydropower.

B. Problem Statement

Hydropower remains a key renewable energy source in the pursuit of the decarbonization of economy, though high potential impact of the hydro-morphological alterations may pose significant concerns for aquatic ecosystems. The overall effect of these innovations is sustainable in design and operation of hydropower, striking a better balance between the objectives of decarbonization and ecosystem protection [6]. Smaller waterways in lowland areas that have low heads have historically been overlooked due to efficiency issues with older, conventional turbine designs that require relatively high pressure to operate [7]. The characteristics of low head river topography greatly affect the complexity design of a turbine.

Hydroelectric turbines put fish at risk of severe injury during passage, which is in hydroelectric turbines that have been a persistent focus in hydropower impacts research [8]. Fish might get injured due to abrupt pressure changes, cavitation, shear forces, turbulence and mechanical contact with the turbine [9]. Injuries involve scale loss, bruising, amputation of body parts and death [8]. The severity of injuries primarily depends on turbine type and technical characteristics in relation to fish. Knowledge on the extent and mechanisms of fish damage caused by hydropower facilities is important for the ecological improvement. The design of micro hydropower must be fish friendly to minimize the ecological effects.

Hydroelectric power plant is usually located near a body of flowing water. The change in elevation and the volume of water flow from one point to another determine the amount of available energy in a body of flowing water. The electricity that a low head

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micro hydropower plant produces is lower than high head micro hydropower. In low head river the construction and configuration of the turbine may increase the electricity output.

C. Objective

a. To design a micro hydropower plant at a low head river that can generate electricity.

b. To construct the prototype of micro hydropower system generation

c. To test the effectiveness of micro hydropower system generation

II. LITERATURE REVIEW

A. Low Head Hydropower Technology

The possibility to exploit low head micro hydro system is enormous in rural areas because there is where population is concentrated [10]. In general, turbines fall into two categories: impulse turbines and reaction turbines. The runners in impulse turbines (Pelton and Crossflow with various variants) are turned by high-velocity water jets directed onto them. The runner blades of reaction turbines rotate because of an upward hydrodynamic force produced by a water flow. Impulse runner type turbines work best in high head applications and reaction runner type turbines work best in low head hydroelectric sites. The literature offers different hydropower height classifications [11].

III. METHODOLOGY

A. Flow Chart

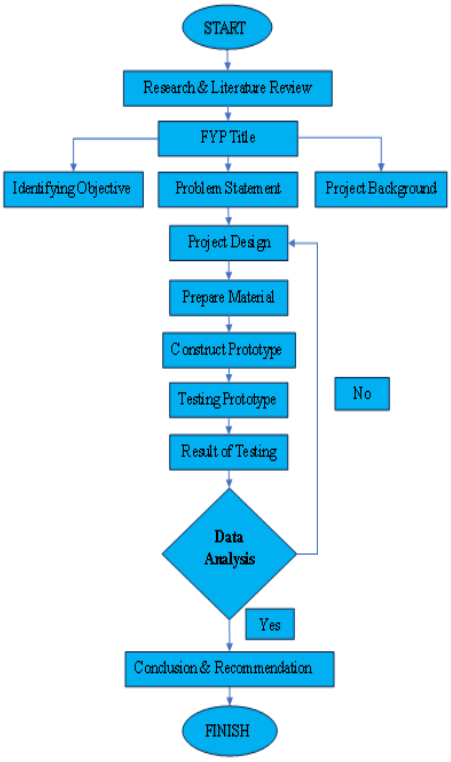

Figure 1 : Project Flow Chart

B. Project Design

Figure 2 represents Micro Hydropower Prototype design featuring an Archimedes Turbine housed within an Aluminium Hollow Square Tube. The structure measures 310 mm in width, 1000 mm in length, and 130 mm in height. Inside the tube, two Archimedes screw turbines are positioned 130 mm apart from each other, with an additional 60 mm gap between them, providing space to place generator and efficient space for water flow and debris passage. The screws extend the full 1000 mm length of the tube, ensuring maximum interaction with the water to generate electricity. The compact and robust design utilizes the spiral motion of the turbines to convert low-pressure water flows into mechanical energy, suitable for micro-hydropower applications. The front view indicates a width of 123mm for the internal space of turbines, optimizing the space within the tube. This setup demonstrates a practical approach to harnessing renewable energy from small-scale water sources.

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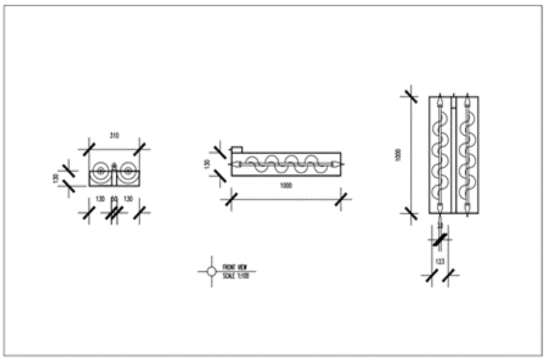

Figure 2: Prototype Design

In Figure 3 shows the finished prototype from the top, side and front view. The constructed Micro Hydropower Prototype, based on the original design, features an aluminium hollow square tube housing two Archimedes screw turbines. The prototype measures 310 mm in width, 1000 mm in length and 130 mm in height, with the turbines positioned 130 mm apart and a 60 mm gap. The top view shows the turbines' layout, ensuring optimal water flow and debris passage. The side view highlights the structural integrity and alignment of the turbines along the tube's length. The front view demonstrates the entry and exit points for water flow, allowing efficient conversion of water energy into mechanical energy. This design ensures continuous operation without clogging, suitable for low-pressure water sources. The prototype successfully embodies the intended design, offering a practical solution for small-scale renewable energy generation.

Figure 3 Micro Hydropower Prototype

C. Archimedes Turbine Design

Figure 4 illustrates the design of a key component in the Micro Hydropower Prototype. The turbine measures 1000 mm in length and features a helical structure optimized for converting water flow into rotational energy. The side view shows the screw's length and spacing between its helical blades, 100 mm. The end view displays the turbine's circular cross-section with an outer diameter of 123 mm and internal shaft diameter of 33 mm. This design ensures efficient energy conversion and allows water to pass through smoothly, minimizing the risk of clogging by debris. The Archimedes Screw Turbine's efficient structure is critical for the overall performance of the micro hydropower system, particularly in low-pressure, low-flow conditions.

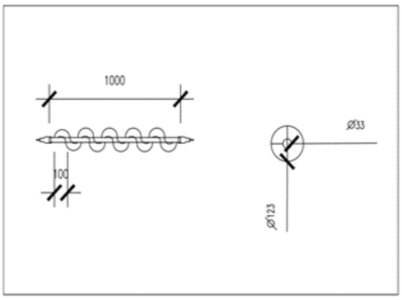

Figure 4: Archimedes Screw Design

Figure 5 illustrates the finished Archimedes Screw Turbine production. The turbine measures 1000 mm in length and features a helical structure optimized for converting water flow into rotational energy. The side view highlights the screw's overall length and the 100 mm spacing between its helical blades. The end view shows the turbine's circular cross-section, with an outer diameter of 123 mm and an internal shaft diameter of 33 mm. As shown in the figure, the finished component exhibits a very unequal blade angle. This irregularity is due to the heat applied during the molding process to shape the helical structure and the uneven pulling forces experienced while the material was still pliable.

Figure 5 Archimedes Screw Prototype

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Figure 6 shows the finished Micro Hydropower Frame from the design. The design of the Micro Hydropower Frame emphasizes a compact yet robust structure capable of supporting the necessary components for efficient micro hydropower generation. The detailed dimensions and the central slot feature indicate thoughtful planning to facilitate both stability and functionality, making this frame an integral part of a micro hydropower system.

Figure 6 Micro Hydropower Frame

E. Project Production Techniques

Materials used in constructing this project are sourced diversely, incorporating elements of sustainability by utilizing construction waste items alongside procured materials. This intentional blend forms the foundational components essential for the project's realization. The project plan entails conducting multiple rounds of testing.

F. River Assessment

River data is essential for planning hydropower stations. It helps assess flow rates, select suitable sites, and design infrastructure. Understanding water resources and environmental impacts ensures efficient, sustainable energy generation.

a. Location

Prototype testing took place at Ungku Omar Polytechnic, which is close to the Electrical Engineering Department, due to the low head river environment as shown in Figure 7.

Figure 7 Location of testing area in PUO via Google Map

b. Float Method

The Float method is a practical technique employed for measuring river flow velocity. Initially, a suitable site within the river is chosen, prioritizing areas with consistent flow patterns and minimal obstructions. A buoyant object, often marked for visibility, is then introduced upstream from the measurement point. Flow velocity is then calculated by dividing the distance travelled by the float by the time taken. These measurements provide valuable data for understanding river dynamics, including flow rates and discharge. While the float method offers simplicity and accessibility, caution is advised in challenging environments and the method may not be suitable for all conditions [16]. Figure 8 shows the set-up of float method at testing location.

Figure 8 Float Method Set-up

Figure 9 Float method conducted in the river.

Figure 9 illustrates the float method conducted at the river. In this setup, the river is operated using a simple dam constructed from recyclable plastic bags and river stones. The primary purpose of the dam is to control and direct the natural flow of the river. Recyclable plastic bags are filled with sand or gravel, making them heavy enough to stay in place against the current. These bags are arranged strategically along the riverbed, creating a barrier that channels water flow towards the desired

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location. River stones are then placed around and on top of the bags to reinforce the structure, ensuring it remains stable and effective in diverting the water. This method of constructing a dam is both environmentally conscious and resource efficient. Using recyclable materials minimizes the environmental impact, while the river stones provide natural reinforcement without disrupting the ecosystem. The combination of these materials forms a vigorous yet flexible dam that can be easily adjusted or removed as needed.

IV. DATA ANALYSIS AND RESULT

A. Data - Sunny Day

Table 4.1 presents detailed measurements and observations from a river on a sunny day, encompassing various physical characteristics and flow dynamics. The measured distance between two points along the river is 3.0 meters, with the stream's width at Point 1 and 2 being 2.5 meters and 2.3 meters. Depth measurements at ten points across the stream's width at both locations ranging from 2 cm to 7.5 cm at Point 1 and 1 cm to 8.5 cm at Point 2. The table also includes the time taken for an object to travel from Point 1 to Point 2, measured at four depth points over three trials, with times ranging from 9 to 18 seconds, indicating variations in flow velocity. Furthermore, the elevation at the study site is recorded as 0.4 meters. This data provides a full view of the river's physical properties and flow behavior, necessary for understanding its hydrological dynamics and supporting ecological, engineering and water management applications.

Table 4.1 River Data for Sunny Day

Measured Distance (m)	3.0									
Width of Stream (m)	Point 1		2.5							
	Point 2		2.3							
Depth of Stream (cm)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Point 1	2	2.5	3.0	4.5	6.9	7.3	5	3.8	3.2	2
Point 2	1	2.2	3	4.8	6.5	8.5	5.5	4.3	3.8	3.2
Time Required for Object to reach from point 1 to point 2 (s)										
Trial 1	Depth Point		D3		D4		D5		D6	
	Time (s)		18		10		9		12	
Trial 2	Depth Point		D3		D4		D5		D6	
	Time (s)		17		11		11		14	
Trial 3	Depth Point		D3		D4		D5		D6	
	Time (s)		14		10		10		14	
Elevation (m)	0.4									

B. Data - Rainy Day

Table 4.2 presents detailed measurements and observations from a river on a rainy day, highlighting its physical characteristics and flow dynamics under these conditions. The measured distance between two points along the river remains 3.0 meters, with the stream's width at Point 1 being 2.5 meters and 2.3 meters at Point 2. Depth measurements at ten points across the stream's width at both locations show variability, ranging from 2 cm to 7.5 cm at Point 1 and 1.25 cm to 8.9 cm at Point 2. The table also includes the time taken for an object to travel from Point 1 to Point 2, measured at four depth points over three trials, with times ranging from 8 to 15 seconds, indicating changes in flow velocity compared to a sunny day. Additionally, the elevation at the study site is recorded as 0.4 meters.

Table 4.2 River Data for Rainy Day

Measured Distance (m)	3.0									
Width of Stream (m)	Point 1		2.5							
	Point 2		2.3							
Depth of Stream (cm)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Point 1	2	3	3.5	4.5	6.9	7.5	4.7	3.9	3.5	2
Point 2	1.25	2.6	3	5.5	7.2	8.9	5.5	4	4	3
Time Required for Object to reach from point 1 to point 2										
Trial 1	Depth (m)		D3		D4		D5		D6	
	Time (s)		15		10		9		14	
Trial 2	Depth (m)		D3		D4		D5		D6	
	Time (s)		14		11		9		8	
Trial 3	Depth (m)		D3		D4		D5		D6	
	Time (s)		12		9		9		10	
Elevation (m)	0.4									

C. Sunny Day Data (Upgraded Prototype)

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Table 4.3 provides detailed measurements and observations from a river on a sunny day, using an upgraded prototype for data collection. Measured distance between two points along the river is 3.0 meters, with the stream's width at Point 1 and 2 being 2.5 and 2.3 meters. Depth measurements at ten points across the stream's width at both locations reveal variability, ranging from 2 cm to 7.5 cm at Point 1 and 1 cm to 8.5 cm at Point 2. The table also includes the time taken for an object to travel from Point 1 to Point 2, measured at four depth points over three trials, with times ranging from 9 to 18 seconds, indicating variations in flow velocity.

Table 4.3 River Data for Sunny Day (Upgraded Prototype)

Measured Distance (m)	3.0									
Width of Stream (m)	Point 1	2.5								
	Point 2	2.3								
Depth of Stream (cm)	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10
Point 1	2	2.5	3.0	4.5	6.9	7.3	5	3.8	3.2	2
Point 2	1	2.2	3	4.8	6.5	8.5	5.5	4.3	3.8	3.2
Time Required for Object to reach from point 1 to point 2 (s)										
Trial 1	Depth Point	D3	D4	D5	D6					
	Time (s)	18	10	9	12					
Trial 2	Depth Point	D3	D4	D5	D6					
	Time (s)	17	11	11	14					
Trial 3	Depth Point	D3	D4	D5	D6					
	Time (s)	14	10	10	14					
Elevation (m)	0.4									

D. Velocity and Discharge Calculation

The velocity at which water travels down a river is known as its rate of travel. Discharge (Q) can be calculated using the formula [17]:

$$Q = A \times V \text{ [17]}$$

Where A is the cross-sectional area and V is the average velocity of the water flow.

Table 4.4 Velocity and Discharge Data

	Sunny Day	Rainy Day	Sunny Day Improved
Velocity (m/s)	0.231	0.273	0.231
Discharge (m3/s)	0.023	0.0284	0.023

E. River Potential Energy (Power Input)

The energy that water gains from being at an elevation is known as its potential energy. To put it simply, potential energy is the outcome of the head differential of water. Thus, the relationship between the potential energy per unit volume of water and its height can be stated as follows [19]:

$P = \rho gQh$ [18]

where:
P is the power (W)
ρ is the density of fluid (kg/m^3)
Q is the flow rate (m^3/s)
g is the acceleration due to gravity (m/s^2)
h is height difference between two points of the fluid flow (m)

Table 4.5 Power Input (w) Data

	Sunny Day	Rainy Day	Clear Day Improved
Power Input (w)	90.25	111.44	90.25

a. Data Table

Table 4.6 illustrates the electricity output from a micro hydropower prototype under three different conditions: a clear day, a day after rain and a clear day using an upgraded prototype. On a clear day, the electricity output ranges from 5.04 volts to 7.04 volts, representing the baseline performance under normal flow conditions. After rain, the output significantly increases to a range of 10.24 to 11.97 volts, likely due to the higher flow velocity and discharge enhancing the turbine's electricity generation. On a clear day using the upgraded prototype, the electricity output further increases, with values ranging from 14.24 to 15.08 volts. This substantial improvement indicates that the upgraded prototype is much more efficient at converting the river's kinetic energy into electrical energy.

Table 4.6 Micro Hydropower Prototype Electricity Output.

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Electricity (v) / Day	Min	Max
Sunny Day	5.04	7.04
Rainy Day	10.24	11.97
Sunny Day Improved	14.24	15.08

b. Power Output

The power output from generator is calculated using the following formulas. First, calculate the average voltage output (V) by the mean of the recorded values. Next, determine the current (I) from the generator specifications using $I = W/V$. Finally, find the power output (P) with P $= I \times V$ [20].

Table 4.8 Micro Hydropower Prototype Efficiency (%)

	Sunny Day	Rainy Day	Sunny Day Improved
Efficiency (%)	1.67	2.49	4.07

c. Efficiency Vs Flowrate Graph

Figure 4.1 illustrates the relationship between efficiency of micro-hydropower system and river's discharge rate under two conditions: "After Rain" and "Clear Day." The horizontal axis represents discharge rates from 0 to 0.06 m³/s, while the vertical axis shows efficiency from 0% to 6%. The blue line, labelled "After Rain," indicates higher efficiency with increased water discharge post-rainfall, starting at (0,0) and rising to 5% efficiency at 0.05 m³/s. The green line, labelled "Clear Day," shows lower efficiency with less water discharge, starting at (0,0) but increasing to 1.5% at 0.02 m³/s. This graph demonstrates the micro-hydropower system operates more efficiently with higher water flow, which is more common after rainfall. On clear days with lower discharge rates, the efficiency increases at a slower pace. Thus, the system performs better with higher discharge rates, highlighting the importance of water availability for optimal micro-hydropower performance.

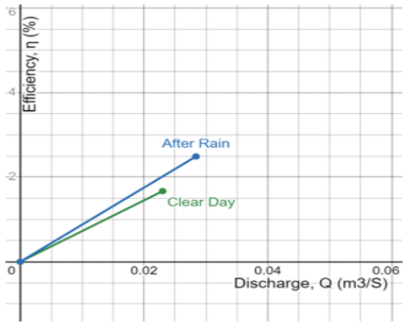

Figure 4.1 Efficiency, η Vs Flowrate, (m3/s) graph (Sunny and Rainy-Day Data)

Figure 4.2 graph illustrates the efficiency of a micro hydropower system under two scenarios: "Clear Day" and "Clear Day Upgraded," with efficiency (η) on the y-axis and discharge (Q) in cubic meters per second on the x-axis. The green line shows that on a clear day, efficiency increases linearly with discharge, reaching about 2% at 0.02 m³/s. In contrast, the purple line for "Clear Day Upgraded" indicates that with system improvements, efficiency also rises linearly but at a higher rate, achieving approximately 4% at the same discharge and about 6% at 0.04 m³/s. This significant efficiency boost demonstrates that the upgrades effectively double the energy conversion rate for a given water flow. Both lines starting from the origin suggests no efficiency without discharge. The graph underscores the substantial benefits of upgrading micro hydropower systems, showing that enhancements can lead to better utilization of water resources and increased energy production.

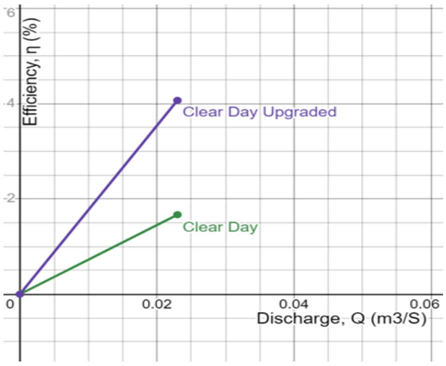

Figure 4.2 Efficiency, η Vs Flowrate, Q (m^3/s) graph

(Sunny and Sunny Upgraded Data)

d. Findings and Discussion

The analysis of the micro hydropower system's performance sheds light on several critical factors

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influencing its efficiency and effectiveness. Firstly, under clear weather conditions, the system attempted to generate significant power output despite an optimal flow rate of 0.023, resulting in a turbine efficiency of only 1.67%. This discrepancy suggests inherent inefficiencies in energy conversion, potentially stemming from the turbine's inability to harness kinetic energy efficiently from the river current. The prototype weight is not designed to a certain weight, hence there was challenges in the testing procedure. The prototype tends to be swept away with the current of river. The prototype's insufficient weight exacerbates this challenge, particularly in high-flow scenarios, further limiting its performance.

Secondly, the comparison between pre- and post-upgrade conditions reveals significant improvements in turbine efficiency following modifications to address water dispersal issues. Before the upgrade, the system exhibited low electricity output despite adequate power input, indicating a turbine efficiency of only 1.67%. However, after implementing measures to concentrate water flow near the turbine, turbine efficiency increased to 4.07%, underscoring the importance of design enhancements in optimizing energy conversion and overall performance.

Furthermore, data recorded after heavy rain highlights the system's susceptibility to extreme weather conditions. Despite an increased flow rate and power input, the system's electricity output remains relatively low, resulting in a turbine efficiency of 2.49%. This marginal increase compared to clear weather conditions suggests that while the system can handle higher flow rates, its performance is compromised under adverse weather scenarios, necessitating additional measures to enhance stability and resilience.

e. Summary

In summary, the comprehensive analysis of the micro hydropower system's performance provides valuable insights into its operational dynamics and challenges. The findings emphasize the multifaceted nature of factors influencing system efficiency and effectiveness, ranging from mechanical inefficiencies to environmental vulnerabilities. Despite optimal flow rates during clear weather conditions, the system struggles to achieve significant power output, indicating inherent inefficiencies in energy conversion. Mechanical challenges, such as turbine rotation lag, further exacerbate these inefficiencies, highlighting the need for meticulous optimization and fine-tuning of system components. However, the comparison between pre- and post-upgrade conditions reveals promising improvements in turbine efficiency following design enhancements. Measures to address water dispersal issues significantly increase efficiency, underscoring the pivotal role of design modifications in optimizing energy conversion and overall system performance.

Moreover, the data highlights the system's vulnerability to extreme weather conditions, with heavy rain compromising performance despite increased flow rates. This underscores the importance of robust design considerations to enhance system stability and resilience in adverse environmental scenarios. Structural integrity concerns, such as the bending of M8 threaded rods, further contribute to energy transfer inefficiency, necessitating proactive measures to reinforce system components and maximize overall performance. By addressing identified challenges and leveraging emerging technologies, stakeholders can unlock the full potential of micro hydropower as a sustainable energy solution, paving the way for a greener and more resilient future.

f. Conclusion

In conclusion, the successful testing of generating electricity from low head rivers using Micro Hydropower technology marks a significant milestone in renewable energy innovation. The prototype showcased remarkable potential to harness sustainable energy despite the inherent challenges associated with low head conditions. The observed variations in system efficiency under different weather conditions underscore the importance of continuous refinement and optimization. From an initial efficiency of 1.67% in clear weather to a notable increase of 2.48% after rainfall and a significant improvement to 4.13% post-prototype upgrade, these findings highlight the iterative nature of design and the potential for further enhancement.

Although specific numerical calculations are not provided, fluctuations in power input and output measurements over time indicate delays in turbine rotation and subsequent decreases in rotation speed. These delays, likely attributed to factors such as friction or turbulence, contribute to energy losses and overall reduced efficiency, emphasizing the need for mechanical optimization and fine-tuning. Recommended to fabricate the turbine as accurately as possible to prevent significant delays.

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In essence, the project's success underscores the immense potential of Micro Hydropower technology in contributing to the global transition towards renewable energy. With continued refinement and innovation, Micro Hydropower systems hold promise as sustainable, reliable sources of electricity, offering a viable solution to meet the growing energy demands while mitigating environmental impacts.

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AUTHOR'S INFORMATION

Arutchelvi Thayanandan 	Civil Engineering Department, Polytechnic Ungku Omar, Ipoh, Perak, Malaysia E-mail: arutchelvi@puo.edu.my
Muhammad Fauzi Bin Yaacub 	Civil Engineering Department, Polytechnic Ungku Omar, Ipoh, Perak, Malaysia E-mail: muhdfauzi.1005@gmail.com
Muhammad Farhan Mohd Saifful 	Civil Engineering Department, Polytechnic Ungku Omar, Ipoh, Perak, Malaysia E-mail: farhan25857@gmail.com
Luqman Nur Hakim Abdull Wahab 	Civil Engineering Department, Polytechnic Ungku Omar, Ipoh, Perak, Malaysia E-mail: lhqeemm@gmail.com

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