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The Impact of Varying Water Turbine Blade on Performance of Pico Hydro Power Plants

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Abstract

This study has a purpose to determine the number of blades effect on a water turbine regarding flow rate and turbine rotation. The turbine utilized in this study is a Pelton-type impulse turbine, which harnesses potential energy and water pressure to enhance its rotational speed. Additionally, it examines how turbine rotation affects voltage, current, and electric power generated. This research is an experimental study focusing on a prototype mini-micro hydro water turbine. The testing involved varying the valve openings at angles of 36°, 54°, 72°, and 90°, as well as the number of blades, which were set to 6, 8, and 10. The output parameters were measured using instruments that met the specifications for the test equipment. The results indicated that the minimum water discharge required to drive the turbine prototype was 30 cm^3/s at a valve opening of 36°. The minimum power generated for each variation in the number of blades was as follows: 0.114 W for 6 blades, 1.426 W for 8 blades, and 1.672 W for 10 blades. At the maximum valve opening of 90°, a flow rate of 67 cm^3/s was achieved. Under these conditions, the turbine generated powers of 1.5 W for 6 blades, 7.593 W for 8 blades, and 8.16 W for 10 blades. These findings demonstrate that the performance of the micro-hydro power generation system is significantly influenced by water discharge, turbine rotation speed, and the specifications of the power generator used. This study provides valuable insights for developing renewable energy sources to supply electricity in remote areas with limited access to conventional energy. Furthermore, the results can serve as a foundation for designing more efficient and sustainable micro-hydro systems in the future. The results indicate that an increase in the number of turbine blades leads to greater kinetic energy in the water, which in turn raises the rotational speed of the turbine. This increase in kinetic energy enhances the conversion of water energy into mechanical energy, resulting in improved efficiency of the turbine.

Keywords: prototype; kaplan; pelton; voltage; current; power generator.

1. Introduction

Indonesia is primarily an agricultural country, with two-thirds of its territory covered by water and abundant renewable energy sources particularly from hydropower. Current data indicates that Indonesia has a potential for water energy of approximately 95 GW; however, only about 7%, or 6.7 GW has been harnessed so far [1]. This presents a significant opportunity for further research and development in utilizing water resources to meet the country's electricity needs. As an archipelagic nation, Indonesia is traversed by many large and small rivers [2]. Consequently, remote areas predominantly rely on river flows to power micro-hydropower plants to fulfill their electricity requirements [3]. Most micro-hydro power plants utilize Pelton turbines as the driving force for electric generators [4]. This preference is due to the advantages of Pelton turbines over other types; one key benefit is their ability to operate effectively with small water discharges, allowing them to remain functional even during dry seasons [5]. The exploration of micro-hydro power usage is expected to expand in alignment with the national energy policy for 2050, which has the purpose for renewable energy to comprise 31% of the energy mix, with micro-hydro energy accounting for 10% of this total [6]. This initiative intents to reduce dependence on fossil fuels, which are becoming increasingly scarce and to address the rise in greenhouse gas emissions caused by combustion [7]. Hydroelectric power plants can be classified based on various parameters, including generating capacity and waterfall height, as illustrated in Table 1 [8].

The government is actively working to increase the electrification ratio in Indonesia to ensure equitable development across the country. According to data from Perusahaan Listrik Negara (PLN), the electrification ratio is expected to reach 99.83% by December 2024 [9]. However, achieving a 100% electrification rate presents significant challenges, particularly due to the geographical and demographic diversity of the regions in Indonesia. To address these challenges, utilizing renewable energy sources, such as solar energy and micro hydropower plants, is a promising solution [10]. Numerous studies have been conducted on micro-hydropower plants utilizing various types of turbines. One notable research effort was led by Sudibyo et al. [11], who assessed the potential of micro-hydropower plants in Papua and Maluku. His findings revealed that the estimated water energy potential is 615 MW in Papua, 190 MW in Maluku, 24 MW in North Maluku, and 3 MW in West Papua. Additionally, a field study was conducted by Yulia et al. [12], focusing on the river hydrology in the Lhoong District of Aceh Besar Regency for hydropower generation. The results indicated that by employing the F.J. method, a constant discharge percentage of 85% was achieved, resulting in a flow rate of 0.24 m^3/s, an output power capacity of 27.914 kW, and a waterfall height of 13.63 m.

Table 1. Classification of hydropower plants

Classification of power plants	Water drops high level (m)	Power plants capacity
Large hydroelectric power plant	> 250	> 100 MW
Medium hydroelectric power plant	71 – 250	15 – 100 MW
Small hydroelectric power plant	50 – 70	1 – 15 MW
Mini hydro power plant	15 – 50	100 kW – 1 MW
Micro hydro power plant	5 – 15	5 – 100 kW
Pico hydro power plant	< 5	< 5 kW

When selecting a turbine for hydroelectric power plants, there are several important factors to consider. One key consideration is the type of turbine, but the number of turbine blades is also crucial as it significantly impacts the overall performance of the hydropower plant [13]. Budiarsyah et al. analyzed the effect of the blade quantity in crossflow turbines for mini-hydropower plants, using variations of 15 and 30 blades [14]. The water discharges tested were 0.49 and 0.53 liters per second, respectively, along with varying loads of 0, 20, 30, 40, and 50 g. The results indicated that increasing the number of turbine blades led to greater torque and power output. Additionally, research by Hasibuan et al. investigated the number of blades impact in Kaplan turbines on the rotation speed and power generation for Pico hydropower plants [15]. In this study, turbine blades were varied to include 4, 6, and 8 blades. The results indicated that the highest turbine rotation occurred with 6 blades, which had a more significant impact on current, voltage, and generator power compared to both 4 and 8 blades. Additionally, the number of blades and the inclusion of baffle plates on the turbine blades contribute to increased turbine efficiency. The baffle plates help direct the water flow more effectively over the blades, thereby enhancing torque [16].

This research focuses on designing a water turbine prototype made from simple recycled materials and investigating on how the number of blades affects the turbine's performance. Although the turbine is classified as a Pelton turbine based on its inlet flow pattern, its blades are flat rather than bowl-shaped. For future tests, the blades will be redesigned to match the traditional shape of Pelton turbine blades to compare the performance differences between bowl-shaped and flat blades.

2. Experimental Methods

The research tool is designed as a Pico hydropower prototype, utilizing entirely recycled materials that are cost-effective and easy to source. This approach not only keeps investment costs low but also promotes environmental sustainability. The prototype's design, assembly and testing were conducted at the Automotive Mechanical Engineering Laboratory, part of the Automotive Engineering Education Study Program at the Faculty of Engineering, Makassar State University. The tools and materials required for this study include a multimeter, meter, flowmeter, saw, tachometer, pliers, screwdriver, ring wrench, scissors, glue gun, solder, water turbine, water pump, ½ inch pipe, tablespoon, 100l reservoir/water tank, electric generator, iron 12, step-up transformer (12–220 V), and 12 V battery. The schematic diagram illustrating the setup of the experimental tools is presented in Figure 1. To evaluate the performance of the Pico hydropower system, testing was carried out using three different variations in the number of spoons: 6, 8, and 10 spoons. Additionally, variations in water discharge were tested by adjusting the valves to openings on 36°, 54°, 72° and 90°. The initial opening angle of the valve is determined by the flow rate required to rotate the turbine rotor. Therefore, the valve opening is divided into four parts using a protractor. The turbine masses in this study were 0.582, 0.606, and 0.60 kg for the blade counts of 6, 8, and 10, respectively, while the runner radius is 0.1282 m and head (H) is 2 m. Data collection was conducted simultaneously for each valve opening and the different blade configurations.

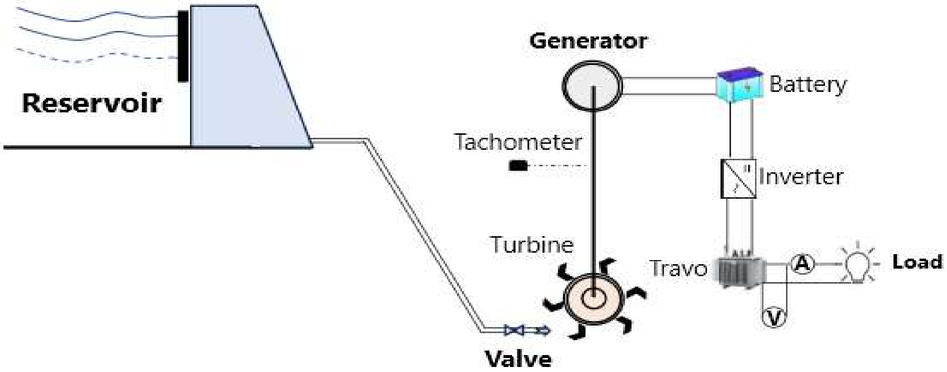

Figure 1. The schematic diagram illustrating the set-up experiment tools

All measurement parameters and data analysis results from each system performance parameter are calculated using the following equation:

1) Hydro Power

$$P_H = \rho g h Q \tag{1}$$

where ρ is density (1000 kg/m^3), g is gravitational acceleration (9.81 m/s^2), and h is head (m), Q is volumetric flowrate m^3/s.

2) Mechanical Power

$$P_M = T.\ \omega \tag{2}$$

$$T = F.r \tag{3}$$

$$F = \frac{mv^2}{r} \tag{4}$$

$$\omega = \frac{2\pi n}{60} \tag{5}$$

$$\nu = \frac{2\pi n r}{60} \tag{6}$$

where T is torque (Nm), F is centrifugal force (N), ω rotation speed (rad/s), ν is linear speed (m/s), r is radius of turbine (0.1282 m), m is mass of turbine (kg),

3) Generator Power

$$P_G = V.I \tag{7}$$

4) Turbine Efficiency

$$\eta_T = \frac{P_M}{P_H} \times 100\% \tag{8}$$

3. Results and Discussion

3.1. Performance of Turbine using 6 Blades

The results of testing variations in flow rate and number of turbine blades will produce output data in the form of voltage, current, and DC power on the electric generator as shown in Table 2.

Table 2. Results of performance measurements for 6 turbine blades

Valve opening	Q (cm^3/s)	Rotation (rpm)	Generator output			Hydro power (W)	Mechanical power (W)	Efficiency (%)
			Voltage (V)	Current (A)	Power (W)			
36°	30	36.3	1.14	0.1	0.114	5.89	0.43	7.37
54°	50	58.7	2.93	0.1	0.293	9.81	1.89	19.26
72°	60	73.1	4.37	0.2	0.874	11.77	3.52	29.87
90°	67	84.2	7.05	0.2	1.411	13.14	5.21	39.63

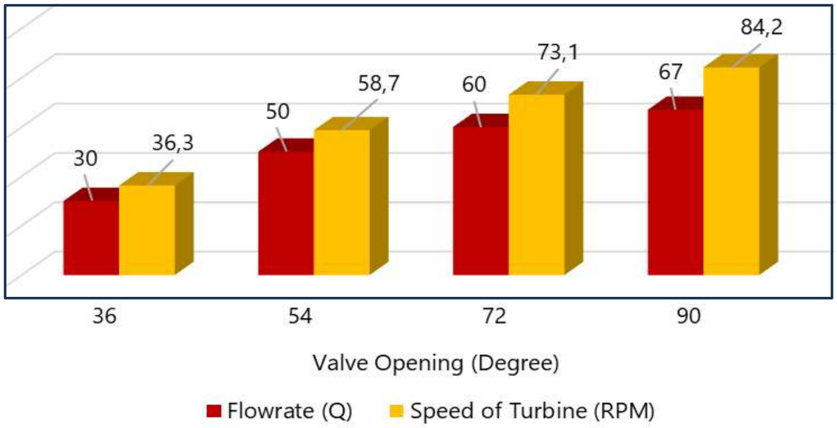

Figure 2. Effect of valve opening on volumetric flowrate and the speed of the turbine with 6 blades

The study's results indicated that a wider valve opening led to an increase in volumetric flow, which in turn, caused the turbine rotation to rise from 36.3 to 84.2 rpm, as illustrated in Figure 2. Consequently, the increase in flow rate and turbine rotation resulted in higher current and voltage outputs from the electric generator. However, it was observed that changes in turbine rotation had a minimal impact on the increase in electric current produced by the generator. Meanwhile, the generator voltage consistently increased, as demonstrated in Figure 3.

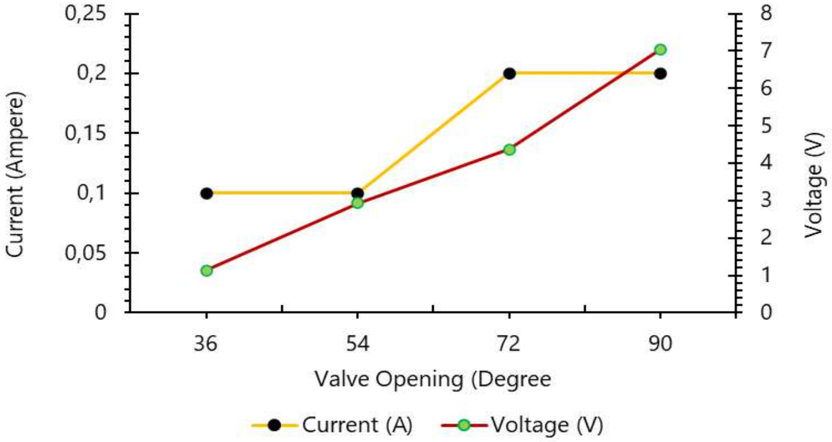

Figure 3. Effect of valve opening on voltage and current of generator output with 6 blades

3.2. Performance of Turbine using 8 Blades

The results of testing an 8-blade water turbine are shown in the Table 3 and Figure 4.

Table 3. Results of performance measurements for 8 turbine blades

Valve opening	Q (cm^3/s)	Rotation (rpm)	Generator output			Hydro power (W)	Mechanical power (W)	Efficiency (%)
			Voltage (V)	Current (A)	Power (W)			
36°	30	50.2	7.13	0.2	1.426	5.89	0.88	14.91
54°	50	63.4	11.83	0.2	2.366	9.81	2.33	23.78
72°	60	71.1	14.28	0.3	4.284	11.77	3.52	29.91
90°	67	86.5	18.98	0.4	7.592	13.14	5.82	44.27

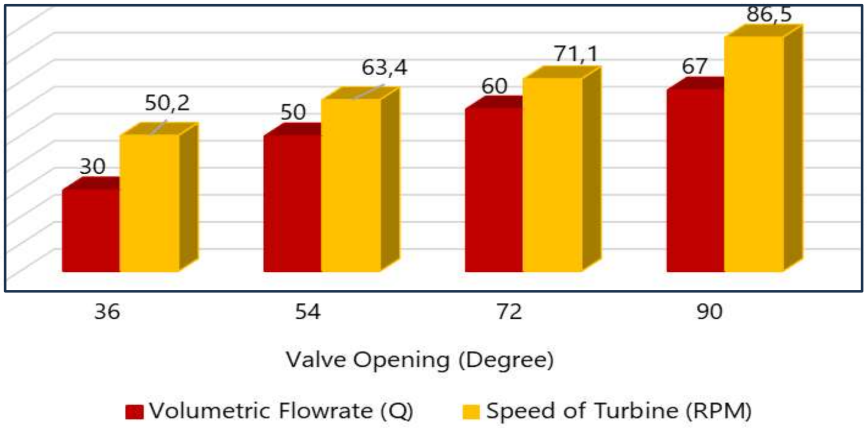

Figure 4. Effect of valve opening on volumetric flowrate and the speed of the turbine with 8 blades

Adding blades to the water turbine design affects the turbine's rotation speed. This is because the blades create more space for the water to collide, allowing the potential energy from the water discharge to be maximized, as illustrated in Figure 4. Utilizing eight blades in the turbine design, the turbine's rotation speed increased by an average of 7.49%, rising from 50.20 to 86.50 rpm when compared to the turbine with 6 blades. The increase in turbine rotation will also cause the generator to rotate faster, leading to a simultaneous increase in voltage and current at the generator output. Increasing the turbine's rotation can enhance the generator's current and voltage by an average of 83 and 237%, respectively, compared to a turbine with six blades.

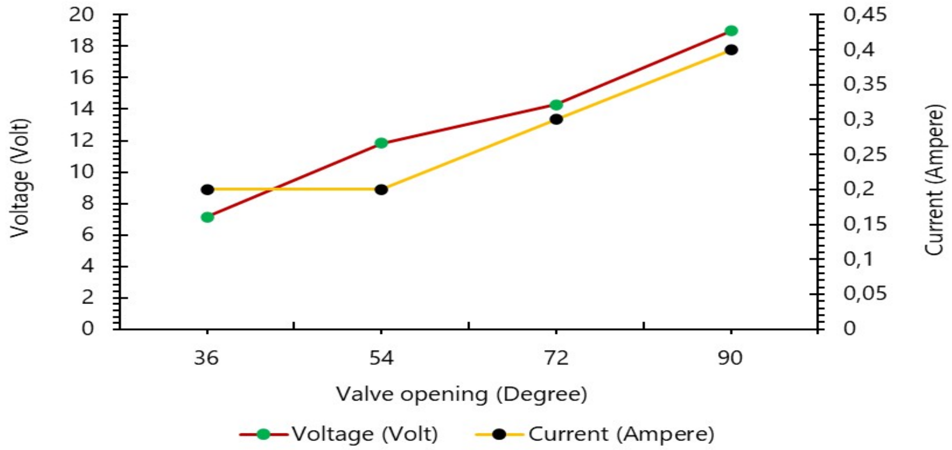

Figure 5. Effect of valve opening on voltage and current of generator output with 8 blades

3.3. Performance of Turbine using 10 Blades

The data from the test results for designing a water turbine blade with ten blades is presented in Table 4 and Figure 6 as well as Figure 7.

Tabel 4. Results of performance measurements for 10 turbine blades

Valve opening	Q (cm^3/s)	Rotation (rpm)	Generator output			Hydro power (W)	Mechanical power (W)	Efficiency (%)
			Voltage (V)	Current (A)	Power (W)			
36°	30	66.3	8.36	0.2	1.672	5.89	1.61	27.44
54°	50	78.1	13.11	0.3	3.933	9.81	3.74	38.08
72°	60	84.7	19.23	0.4	7.692	11.77	5.27	44.79
90°	67	98.1	20.4	0.4	8.116	13.14	7.89	60.08

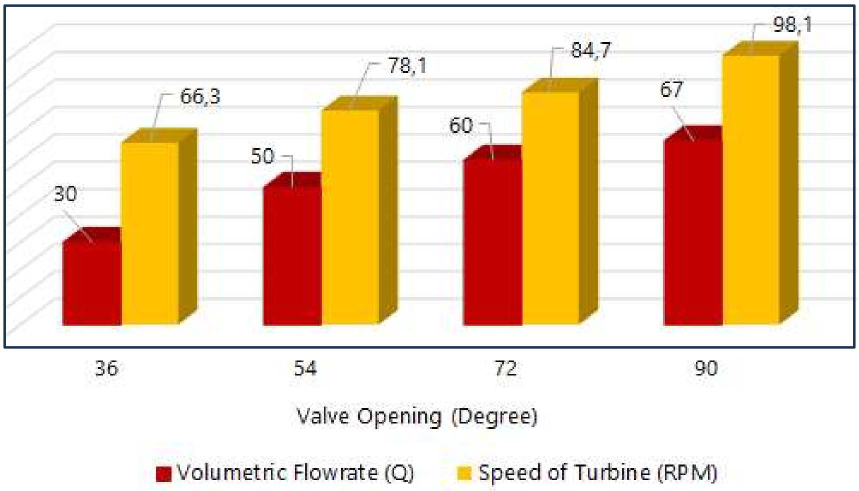

Figure 6. Effect of valve opening on volumetric flowrate and the speed of the turbine with 10 blades

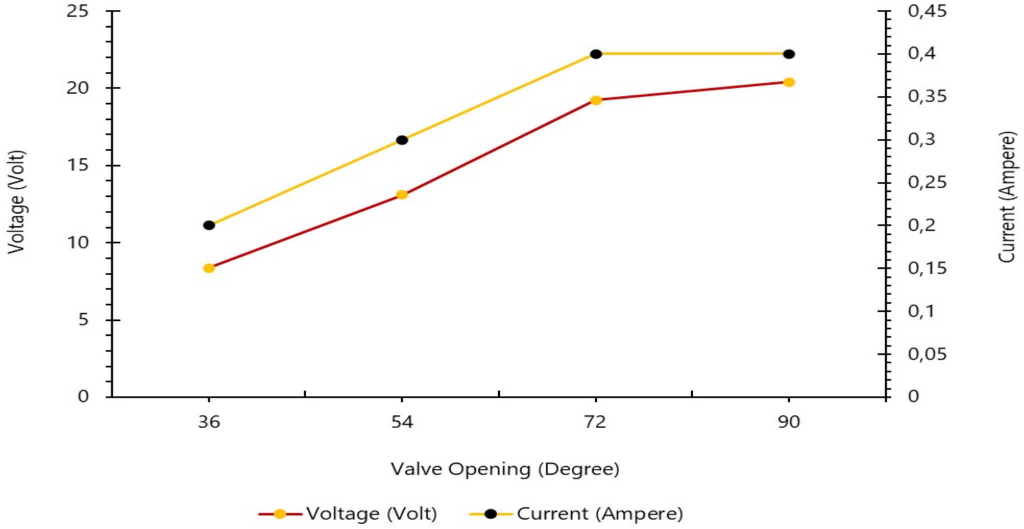

Figure 7. Effect of valve opening on voltage and current of generator output with 10 blades

Adding turbine blades significantly impacts the increase in turbine rotor rotation, even with the same discharge when compared 6 and 8 blades to 10 blades, as illustrated in Figure 6. The average increase in turbine rotation from 6 blades to 10 blades is 237%, while the increase from 8 blades to 10 blades is 20%. Additionally, Figure 7 indicates that a greater number of turbine blades leads to a more stable and consistent increase in turbine rotation (rpm). Similarly, an increase in the turbine's rotation results in a corresponding increase in the generator's output current and voltage, as illustrated in Figure 7. The increase in generator current and voltage from 6 and 8 blades to 10 blades is 117, and 294%, as well as 18 and 17% respectively.

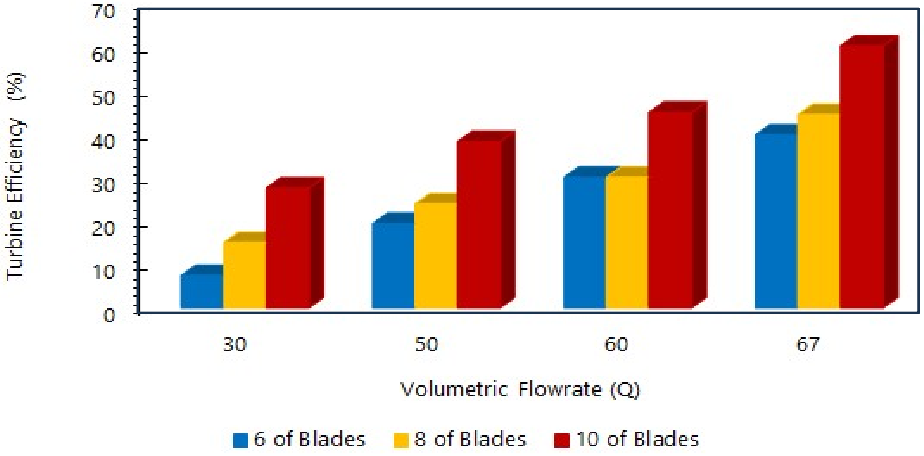

Figure 8. Effect of number of blades on turbine efficiency

The impact of the number of turbine blades and the flow rate on turbine efficiency are illustrated in Figure 8. The figure demonstrates that as the flow rate increases, turbine efficiency also improves. Similarly, an increase in the number of blades positively affects turbine efficiency at the same flow rate. The results indicate that an increase in the number of turbine blades leads to greater kinetic energy in the water, which in turn raises the rotational speed of the turbine. This increase in kinetic energy enhances the conversion of water energy into mechanical energy, resulting in improved efficiency of the turbine. Similarly, as the number of turbine blades increases, the torque generated by the turbine also rises. However, it is important to note that adding more blades can also lead to greater energy losses due to friction and increased moment of inertia.

4. Conclusion

This research attempts to design a simple prototype for a Pico hydropower plant. The design of this tool results in a minimum turbine discharge of 30 cm^3/s and a rotation speed of 36.3 rpm, achieved with a blade count of 6. In contrast, the maximum rotation speed of 98.1 rpm is reached with a flow discharge of 67 cm^3/s and a turbine blade count of 10. The Pico hydropower plant tool generated a minimum current of 0.1 amperes and a minimum voltage of 1.14 V, achieved at a water discharge rate of 30 cm^3/s and a turbine rotation speed of 36.3 rpm. In contrast, the maximum current and voltage recorded were 0.4 A and 20.4 V, obtained at a water discharge rate of 67 cm^3/s and a turbine rotation speed of 98.1 rpm. The study's results indicate that increasing the number of turbine blades reduces waterpower loss, thereby enhancing turbine power output. Furthermore, more turbine blades result in greater generator power and improved turbine efficiency. The findings of this research serve as initial guidance for students to create similar tools that can be directly implemented in other remote areas.

5. Acknowledgments

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