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Preliminary Study on the Influence of Blade Shape and Quantity in Water Turbines using the INA219 Sensor

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ABSTRAK

Desain blade pada turbin air berperan penting dalam meningkatkan efisiensi konversi energi kinetik air menjadi energi listrik, terutama pada skala kecil. Penelitian ini bertujuan mengevaluasi pengaruh variasi bentuk dan jumlah blade terhadap performa turbin serta membandingkan akurasi pengukuran tegangan menggunakan sensor INA219 berbasis Arduino Uno dengan multimeter digital. Empat bentuk blade diuji: silinder, setengah silinder, cekung oval, dan plat datar, masing-masing dalam konfigurasi 4 dan 8 blade. Uji dilakukan pada tiga tingkat debit air (rendah, sedang, tinggi) untuk mengamati proses optimasi performa turbin. Hasil menunjukkan bahwa blade silinder dengan 8 blade menghasilkan tegangan tertinggi sebesar 1,03 V pada debit tinggi. Rata-rata selisih pengukuran sensor dan multimeter sebesar ±0,015 V, menunjukkan akurasi baik dan terbukti bahwa blade silinder paling efisien sehingga sensor INA219 berbasis Arduino layak digunakan dalam sistem monitoring tegangan turbin air mikro.

Kata kunci*: Arduino, Blade, INA219, Optimasi, Tegangan, Turbin*

ABSTRACT

The design of turbine blades plays a crucial role in enhancing the efficiency of converting the kinetic energy of water into electrical energy, particularly on a small scale. This study aims to evaluate the influence of blade shape and number on turbine performance, as well as to compare the accuracy of voltage measurements using an INA219 sensor based on Arduino Uno with a digital multimeter. Four blade shapes were tested: cylindrical, semi-cylindrical, concave oval, and flat plate, each configured with 4 and 8 blades. Tests were conducted under three water flow rate conditions (low, medium, and high) to observe the optimization process of turbine performance. The results showed that the cylindrical blade with 8 blades produced the highest voltage of 1.03 V at high flow rate. The average measurement difference between the sensor and the multimeter was ±0.015 V, indicating good accuracy. These findings confirm that the cylindrical blade is the most efficient, and the INA219 sensor based on Arduino is suitable for use in micro-hydro turbine voltage monitoring systems.

Keywords*: Arduino, Blade, INA219, Optimization, Voltage, Turbine*

1. INTRODUCTION

Indonesia has significant potential in harnessing water energy, particularly from river flows that are widely distributed across its archipelagic regions **(Taufiqurrahman & Windarta, 2020)**. This potential supports the development of renewable energy through (HPP) Hydroelectric Power Plants and (MHPP) Micro-Hydro Power Plants. The utilization of water energy as a renewable energy source is also in line with government policies aimed at reducing greenhouse gas emissions and decreasing dependence on fossil fuels **(Allifah & Wijayanti, 2022)**. Moreover, the process is relatively simple and cost-effective **(Rumbayan & Rumbayan, 2023)**. One of the key components in hydroelectric power systems is the water turbine, which functions to rotate the generator and produce electricity at a certain speed **(Gorgulu, 2023).** The working principle is based on the conversion of the water's potential energy into mechanical energy, which is then converted into electrical energy through the generator **(Saleh et al., 2019)**.

The efficiency of the turbine is strongly influenced by the design of the blades used. Blade designs that are not well-suited to the characteristics of the water flow may result in reduced turbine performance, lower electrical output, and accelerated wear of turbine components. Previous studies have highlighted the importance of blade design in improving efficiency. For instance **(Edi et al., 2024)** demonstrated that optimizing blade shapes can significantly enhance power output, while **(Biantoro et al., 2021)** emphasized the critical role of water flow rate in the performance of waterwheels. In addition to blade shape, the number of blades also plays a vital role in system efficiency, as shown in the experimental results of **(Assefa & Tesfay, 2025),** which indicated that an appropriate blade count is key to maximizing energy conversion efficiency. This study presents a more comprehensive approach to evaluating the performance of micro-hydro turbines by simultaneously examining two key variables: blade shape and blade count, which have typically been studied separately in previous research. In addition, the study utilizes the INA219 sensor integrated with an Arduino Uno for real-time voltage monitoring—an approach that has seen limited application in similar studies. By conducting experimental tests across various water flow rates (low, medium, and high), the research provides a more realistic and practical depiction of turbine performance under diverse flow conditions. The combination of blade design optimization and the validation of a low-cost monitoring system offers a novel contribution to the development of efficient, adaptable, and cost-effective micro-hydro turbine systems.

This study aims to evaluate the performance of a water turbine based on variations in blade shape and blade count through an experimental approach. By testing several blade configurations such as flat, oval, cylindrical, and semi cylindrical shapes and varying the number of blades, the study seeks to identify the most optimal design for maximizing rotational speed and power output. Furthermore, the research intends to align turbine characteristics with the typical water flow conditions found in small-scale microhydro systems, so that the outcomes can be practically applied and contribute to the development of more efficient and sustainable renewable energy technologies.

1.1 Generator Working Principle

A generator is a tool used to transform mechanical power into electrical power This form of mechanical power may originate from multiple sources, including heat, water, or steam. The generated electricity can be either AC or DC, based on the generator’s category and design applied in power plants. Its working principle follows Faraday’s Law, where a conductor rotating within a magnetic area intersects magnetic flux lines, generating an electromotive force (EMF) at its ends, which is measured in volts **(Haryanti et al., 2023)**. In the process of generating electromotive force (EMF), in addition to depending on the rotation of the turbine, an excitation current or booster current is required to form a magnetic field in the field coil in the generator rotor. The excitation current regulation in a generator influences the output voltage level. An increase in excitation current results in a higher generated voltage **(Rimbawati et al., 2019)**.

1.2 INA219

The INA219 sensor is used to measure current and voltage. By using I2C communication, this sensor can be connected to several devices through only two cable lines **(Moranain, 2018)**. The use of the INA219 sensor facilitates power analysis without the need for many additional components. In addition, high measurement accuracy helps evaluate the influenceof various factors.

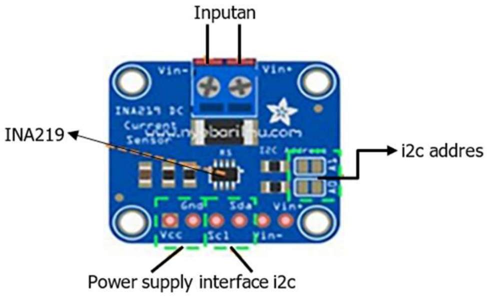

Figure 1. INA219 Sensor (Alam & Hariyadi, 2020)

1.3 Arduino Uno

Figure 2. Arduino Uno

Arduino Uno is a microcontroller development board that uses the Atmega328P as its base. This board is specifically designed to support the microcontroller circuit prototyping process, making it easier to develop various electronic projects. The Arduino Uno features 14 digital input/output (I/O) pins, with 6 of them supporting PWM output. Additionally, it includes 6 analog input pins, a 16 MHz crystal oscillator, a USB port, a power jack, an ICSP header, and a reset button. These components enable the fundamental operations of a microcontroller. To use it, the Arduino Uno can be connected to a computer via a USB cable or powered using an AC-DC adapter or a battery **(Sokop et al., 2016)**. In an effort to obtain the most effective results of the optimization test of the shape and number of blades from various different water discharges. So in this study, the design, testing and development of this was carried out by utilizing microcontroller technology. Monitoring is carried out using the INA219 sensor and the results will be compared with manual measurements.

2. METHODS

This study uses 4 variations of blade shapes, namely cylindrical, half-cylinder, oval concave and flat plate. The variation of blade shape can be seen in Figure 3. With the size of eac blade in Table 1.

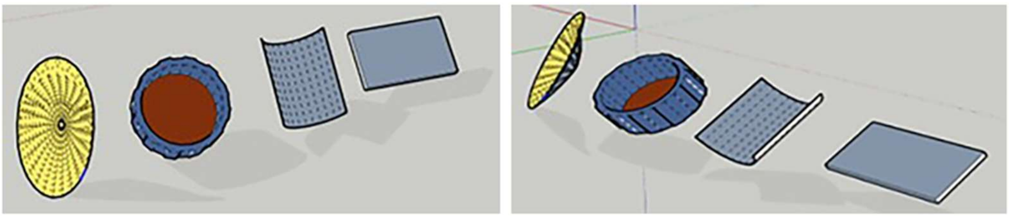
(a) (b)

Figure 3. (a) Blade Shape Variations Seen From Left (b) Blade Shape Variations Seen From Right

Table 1. Blade Dimensions Based on Shape Variations

Blade Shape	Size (cm)
Oval Concave	$6 \times 3{,}5$
Cylinder	$3{,}1 \times 1{,}5$
Half Cylinder	$2{,}2 \times 2{,}8$
Flat Plate	3×2

The blade design greatly affects how effectively water energy can be converted into mechanical energy. This research stage is divided into 2 broadly, namely system design and testing. The system design consists of mechanics and electronics. The mechanical part is the design of the blade and turbine that will be used. Each type of blade will be mounted on the turbine shaft via the blade arm, which is 3.5 cm long from its axis. The electronic part in this system functions to monitor the current and voltage values generated by the turbine, thus allowing further analysis of turbine performance based on the variation of blades used.

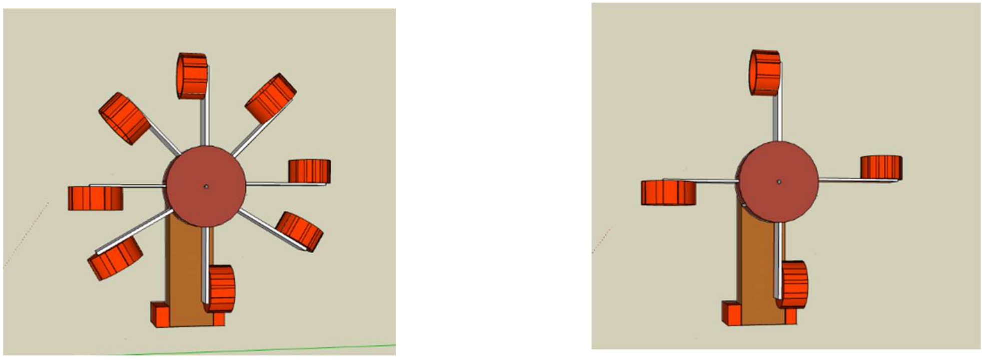
(a) (b)

Figure 4. (a) Design of Water Turbine with Variations in the Number of Blades 8 (b) Design of Water Turbine with Variations in the Number of Blades 4

In this study, the INA219 sensor is used to measure the voltage and current from the generator, which is the output of the water turbine. The generator (Figure 5) converts mechanical energy from the turbine into electricity, then the INA219 sensor (Figure 5) detects the voltage and current values to calculate the power generated. The measurement results of the INA219 sensor will be further processed by the microcontroller. The type of microcontroller used is Arduino Uno (Figure 5). The INA219 sensor is connected to Arduino via I2C communication, so that it only requires two cable lines to send data. Arduino (Figure 5) then processes the data and displays the measurement results digitally. With this system, monitoring turbine performance becomes more practical and real-time. The water discharge used to test the blades on the water turbine is varied into 3 types, namely $1.04247\text{x}\ 10^{-4}\text{m}^3/s$, $5.19825\text{x}10^{-5}\text{m}^3/s$, and $3.86089\text{x}\ 10^{-5}\text{m}^3/s$. The INA219 sensor circuit connected to the Arduino with the input voltage from the water turbine generator can be seen in Figure 5.

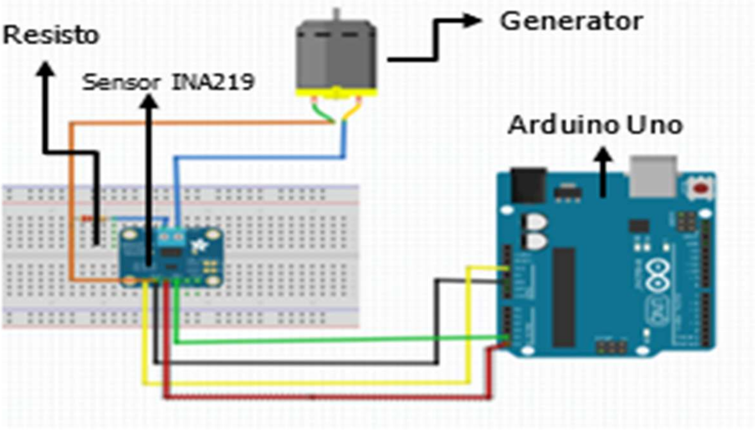

Figure 5. Power Meter with INA219 Sensor

Figure 6 shows the steps taken in testing blade optimization on a water turbine. This process begins with the creation of a water turbine system designed to test the impact of the variations in the shape and number of blades on the voltage produced. The turbine is made with two variations in the number of blades, namely 4 and 8, with the blade shape as in Figure 4. From the voltage results, the amount of power produced can be known through Equation 1. The electrical power generated by the system can be calculated based on the relationship between current and voltage, as shown in Equation 1. This equation indicates that power is directly proportional to the product of the current and the voltage flowing through the circuit.

$$p = i \times v \tag{1}$$

With the following provisions:

p: Power (P) in Watt (W)
i : Current (I) in amperes (A)
v: Voltage (V) in volts (V)

Each variation of water discharge is applied to the turbine, and the resulting voltage data is recorded systematically. After the data is collected, the next step is data analysis and processing. The data obtained is compared between variations in the number of blades to see which one gives the highest and most stable voltage output. The results of this analysis are then used to draw conclusions about the effectiveness of the blade shape in increasing the efficiency of the water turbine. Testing the blade shape optimization on the water turbine turbine as shown in Figure 6. Testing according to the flow diagram is repeated for the next blade shape test conditions, so that it can be known which blade shape produces the optimal voltage.

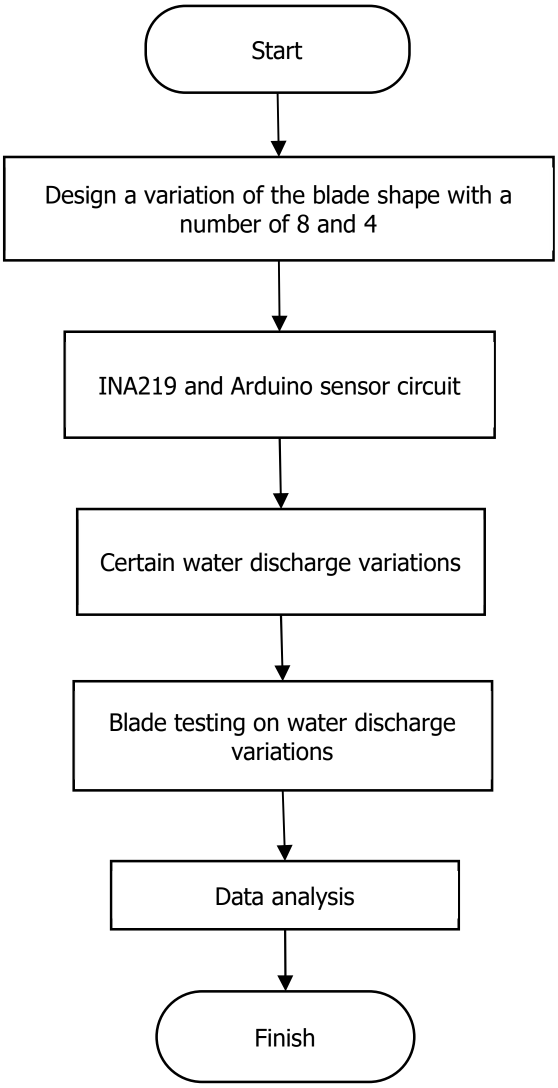

Figure 6. Flowchart of Blade Shape Optimization on a Water Turbin.

3. RESULTS AND DISCUSSION

The following is a graph of the voltage measurement data produced by the turbine. In Figure 7, it can be seen that testing with 8 blades always produces a higher voltage compared to 4 blades. This occurs for each test at different water discharges. The highest voltage occurs when the water discharge is $1.04247\times 10^{-4}m^{3}$, namely an average voltage of 1.03 Volts (Figure 9). While the small water discharge occurs when the water discharge is $5.19825\times 10^{-5}m^{3}$. with an average voltage of 0.75 Volts (Figure 8).

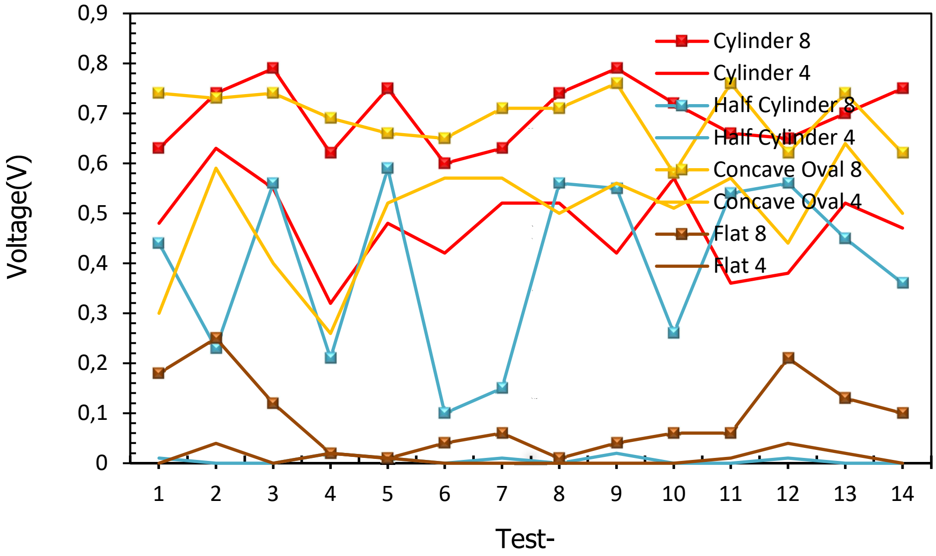

Figure 7. Turbin Test Result With Water Discharge of 3.86089$\times 10^{-3} m^3/s$

Figure 7 illustrates the output voltage generated by the turbine using various blade shapes and quantities over 14 experimental trials. Under relatively low water discharge conditions, the voltage output exhibited noticeable fluctuations. The cylindrical blade configuration with eight blades produced the highest and most consistent voltage, followed by the concave oval blade. In contrast, the semi-cylindrical blade showed less stable performance. The lowest voltage outputs were observed in the semi-cylindrical and flat blade configurations with only four blades.

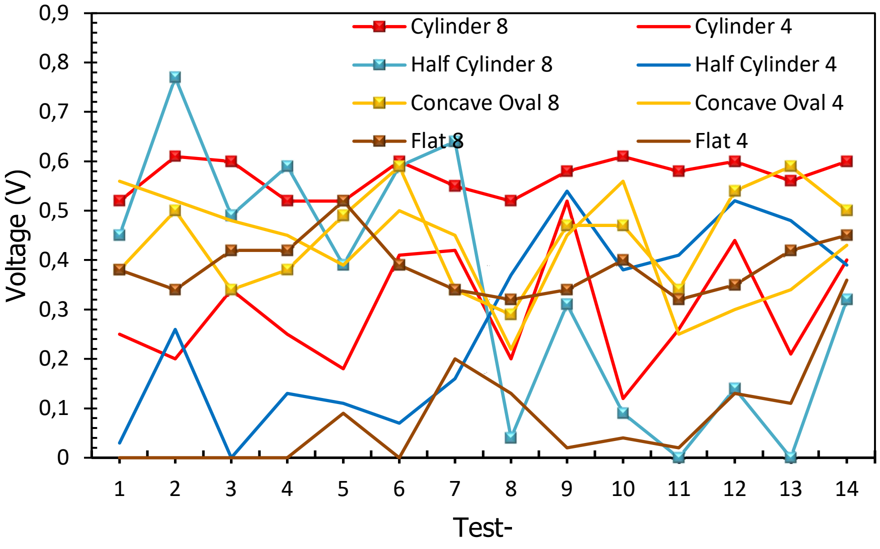

Figure 8. Turbin Test Result with Water Discharge of 5.19825$\times 10^{-5} m^3/s$

Figure 8 shows that the semi-cylindrical blade with eight blades produced relatively higher voltage, although the output was unstable. Similarly, the voltage generated by the concave oval blade was also unstable and less optimal. In contrast, the cylindrical blade with eight blades produced a more stable voltage output, although the voltage level was moderate rather than high. Compared to the results in Figure 7, the voltage generated at a water discharge rate of 3.86089 × 10^{-5} m^3/s was significantly more optimal.

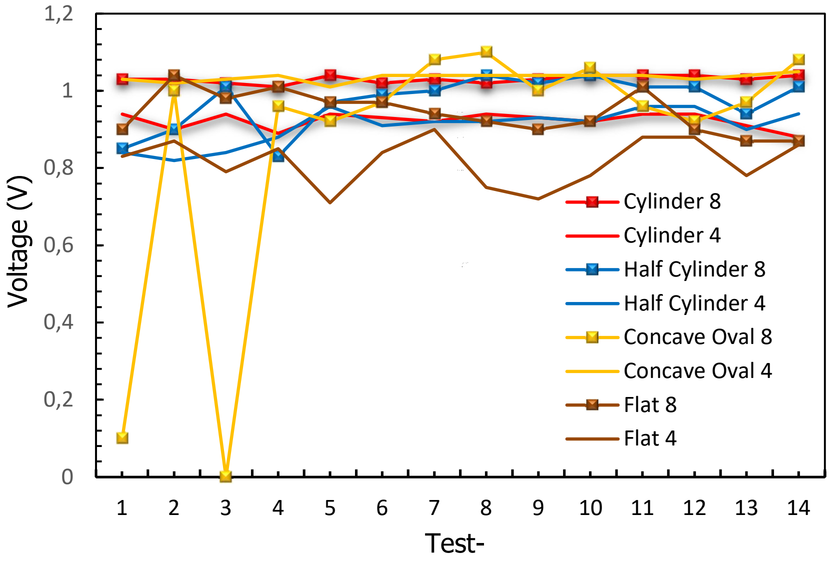

Figure 9. Turbine Test Result with Water Discharge of 1.04247$\times 10^{-4} m^3/s$

Figure 9 shows that cylindrical, concave oval, and semi-cylindrical blade shapes with both 8 and 4 blades produced relatively stable and optimal average voltage outputs. However, the concave oval blade with 8 blades exhibited less stable voltage performance compared to the others.

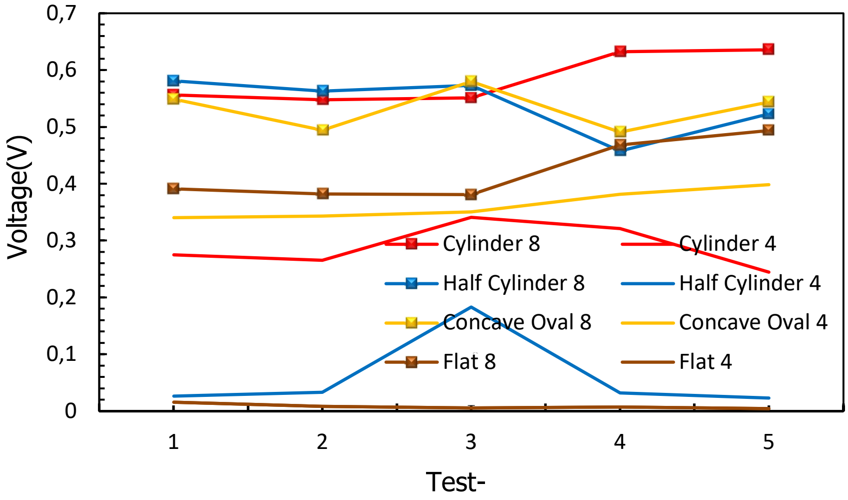

Figure 10. Turbine Test Result Using a Multimeter with a Water Flow Rate of 5.19825$\times 10^{-5} m^3/s$

Figure 10 is the result of a comparison of graphic data between a water turbine measured using an Arduino and one measured using a multimeter with a cylindrical blade showing some differences in the graphic pattern. However, based on the analysis of the average data, both methods still show the same conclusion regarding the most optimal cylindrical blade to use. This shows that even though there are differences in graphic details, the use of Arduino can still provide a fairly accurate picture in determining the best performance of a water turbine blade.

The test results show that different blade shapes produce varying output voltages. Of the four types of blades tested at varying water discharges, the most optimal blade used is a cylindrical blade with 8 blades, with an average highest voltage of 1.03V. In each test, the variation in blade shape produced the same current value, which was $3.8\times \mathbf{10^{-5}}$A. This can be explained through the concept of inertia, where cylindrical blades can accommodate more water mass, thereby increasing the moment of inertia of the system. As a result, even though the initial acceleration is smaller, the turbine tends to rotate more stably and maintain rotational energy longer. This will convert kinetic energy into mechanical energy more efficiently, resulting in greater torque, and more optimal voltage compared to other blade shapes. This is reinforced by **(Oktariani, 2022)** statement which states that the greater the load given, the torque produced will also increase. Based on Equation 1, the amount of power produced is $3.9\times \mathbf{10^{-2}}\mathrm{Watt}$.

In the variation of the number of blades of 4, the one that produces the most optimal voltage is the oval concave blade with the highest average voltage of 1.03V. In contrast to the way the cylindrical blade works, the oval concave blade is superior because the balance between the moment of inertia is small enough for acceleration and the water catchment area is large enough to produce high torque. The oval concave blade works based on the principle of impulse and momentum change. If there are too many blades, there is a possibility that the water that has hit one blade will interfere with the next blade. In contrast to the cylindrical blade which actually collects the falling water, the oval concave blade actually reflects or deflects the water so that efficiency is reduced. The amount of power produced by the oval concave blade is 3.9×10^{-2}Watt.

The variation of the blade with a half-cylinder shape is optimal at a water discharge variation of $1.04247\times 10^{-4}\ m^3/s$. The voltage produced by the half-cylinder blade is the second highest voltage after the cylindrical blade, the highest average voltage is $9{,}72\times 10^{-1}$V, with a power generated of 3.69×10^{-2}Watt. However, when tested at different water discharge variations, the half-cylinder blade shape did not show optimal performance. On the contrary, the oval concave shape is more optimal. This is because the half-cylinder shape is less efficient in accommodating water compared to cylindrical and oval concave blades. Half-cylinder blades tend to have a smaller area, making it difficult for water to enter or be accommodated properly. It is possible that this blade can be more optimal if its size is enlarged.

In the first water discharge variation, namely with the largest water discharge of $1{,}04247\mathrm{x}10^{-4}\ \mathrm{m}^3/s$, the flat plate blade with 8 blades is in third place with a fairly large voltage of $9{,}4\times 10^{-1}\mathrm{V}$, after the cylindrical and half-cylinder blades, with a power output of $3{,}61\times 10^{-2}\mathrm{Watt}$. However, the voltage generated does not have a significant difference compared to the oval concave blade. In other water discharge variations, the voltage generated by the flat plate blade is less than optimal. This is due to its limited ability to accommodate water as a load to drive the turbine. With a flatter shape, the plate blade tends to be less efficient in flowing or accommodating water, resulting in decreased thrust and turbine efficiency at smaller water discharges. Possibly, the flat plate blade will be more optimal if its size is adjusted to the variation of water discharge, so that it can be more effective in capturing energy from the water flow.

Variations in water discharge directly affect the voltage generated. The greater the water discharge flowing into the turbine, the higher the voltage generated by the system. This statement is supported by **(Agato et al., 2023)** who stated that blade efficiency increases with increasing water discharge. This shows that increasing water flow can improve generator performance, as long as other factors such as turbine design and generator efficiency remain optimal. This is also reinforced by the statement of **(Dewangga et al., 2022)** the more blades on the turbine, the greater the voltage generated by the hydroelectric generator. In addition, generator output is also influenced by the amount of water flow entering the generator. System efficiency depends on how optimally the flowing water can be utilized in the energy generation process.

4. CONCLUSION

Based on the experimental results, the cylindrical blade configuration with 8 blades demonstrated the highest performance, generating a maximum voltage of 1.03 V and an average power output of 3.9×10^{-2} watts at the highest water discharge rate. Cylindrical blades produced the highest voltage compared to other blade shapes, and using 8 blades significantly improved the generator’s rotation compared to 4-blade configurations. Water discharge was also found to have a direct impact on turbine energy output, with higher flow rates yielding greater power. Additionally, the INA219 sensor effectively measured current and voltage during all tests, with an average measurement deviation of ±0.015 V compared to a digital multimeter. These findings indicate that combining 8-cylinder blades with INA219-based monitoring offers an efficient and cost-effective solution for optimizing micro-hydro turbine systems.

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