Analysis of the Characteristics of the Archimedes Screw Turbine Micro-hydro Power Plant with Variation of Turbine Elevation Angle

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Electrical energy has become a basic need of modern society, but the supply of electricity has not yet fully met the needs of the community. Many potential energy sources can be converted into electrical energy. One potential energy source is water flow which can be used for micro-hydropower plants in remote areas. This paper describes the results of research on micro-hydro power plants using Archimedes screw turbines. The purpose of this study was to study the characteristics of the Archimedes screw turbine micro-hydro power plant concerning variations in the elevation angle of the turbine. Determination of the characteristics was carried out on a prototype micro-hydropower plant using a BLDC generator and a 2-blade Archimedes screw turbine. The research variable was the turbine elevation angle, namely 20^0, 25^0, 30^0, 35^0, and 40^0 with a water discharge of 2.64 l/s. The results of determining the characteristics of the Archimedes screw turbine micro-hydro generator show that an increase in the turbine elevation angle from 20^0 to 40^0 will cause an increase in mechanical characteristics such as torque and rpm as well as electrical characteristics such as voltage, current and electrical power to reach a maximum at an elevation angle of about 30^0. Furthermore, increasing the elevation angle to more than 30^0 will cause a decrease in mechanical and electrical characteristics.

Keywords: Power plant, Micro-hydro, Archimedes screw turbine, Elevation angle

I. PENDAHULUAN

Electrical energy is a basic requirement for modern society. Every year there is an increase in the community's need for electrical energy. In many countries, the management of electrical energy has been carried out well. This management includes the generation, distribution, and marketing of electrical energy to the public [1]. Regarding the distribution of electrical energy, not all areas can be reached by the electricity network. These areas are usually remote areas that are difficult to reach by the electricity grid. Even though some remote areas have several potential sources of energy that can be converted into electrical energy. One example of a potential source of energy is a river flow that passes through this remote area.

Micro hydropower from rivers can be a solution for supplying electrical energy in remote areas [2]. There are various types of micro hydropower plants with their respective advantages and disadvantages [3 - 5]. One type of micro-hydro power plant is the Archimedes screw turbine power plant. The Archimedes screw turbine micro-hydro plant has several advantages, namely that it can be used on river currents that are not too swift [6], does not damage the environment around the river [7], does not interfere with fish life in the river [8], and others. Archimedes screw turbine micro-hydro plant has been widely researched and studied, both theoretically [9] and experimentally [10]. The results of these studies have shown that the Archimedes screw turbine has a fairly good performance. Several researchers have conducted analysis and design of Archimedes screw turbines to obtain optimal turbine performance [11, 12]. The utilization of river flow as a source of electrical energy can also be combined with the use of solar energy to obtain a more adequate supply of electrical energy for remote areas [13]. Several studies on the characteristics of Archimedes screw turbines on various factors have also been carried out. Some of these studies are research on the effect of the water (fluid) filling level of the turbine on the characteristics and performance of the turbine [14], research on the effect of water flow (fluid) through the turbine on the characteristics and performance of the turbine [15], research on the effect of slope and the amount of water flow (fluid) through the turbine blades on the characteristics and performance of the turbine [16], and so on.

This paper will discuss the results of research on the effect of turbine elevation on the characteristics and performance of Archimedes screw turbine micro-hydro generators. The results of this study will complement the various research results that have been conducted by other people. The novelty and uniqueness of this research are that the turbine and generator are analyzed as a single system. As a single combined turbine and generator system, there will be two kinds of system characteristics, namely mechanical characteristics and electrical characteristics. This paper will discuss the mechanical characteristics of the torque and rpm at various elevation angles of the turbine. The electrical characteristics of the voltage and current to get the generator power at various elevation angles of the turbine.

II. METHODOLOGY

2.1. Tools and Materials

The tools and materials used in this research are:

- Archimedes screw turbine as a propulsion turbine.

- PVC pipe as a water penstock.

- Soothing tub to calm the flow of water.

- A reservoir to accommodate the flow of water.

- Generator as a converter of water flow energy into electrical energy.

- Pump water as a source of water flow.

2.2. Archimedes Screw Turbine Micro-hydro Plant Design

The design of the Archimedes screw turbine micro-hydro power plant is shown in Figure 1.

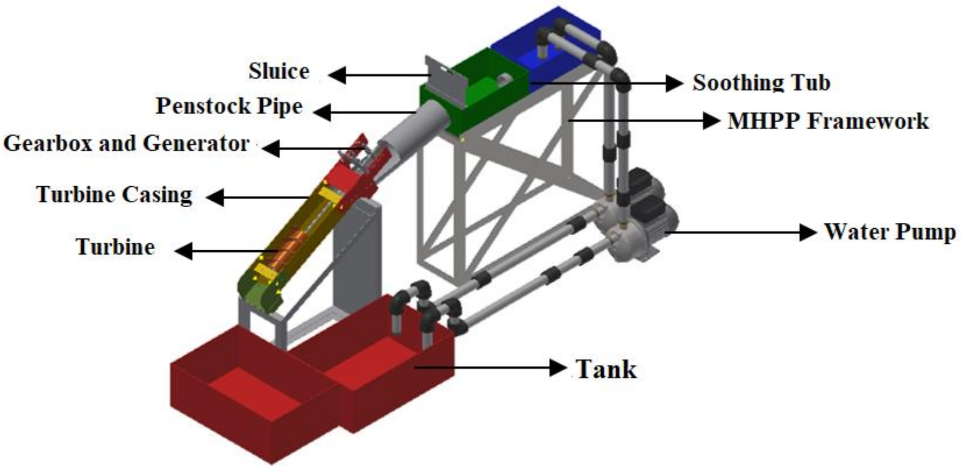

Figure 1: Archimedes screw turbine micro-hydro plant design

2.3. Characteristics Measurement

The measurement of the mechanical and electrical characteristics of the Archimedes screw turbine micro-hydro generator was carried out at various variations of the turbine elevation angle. In this study, five variations of the turbine elevation angle were used, namely 20^0, 25^0, 30^0, 35^0, and 40^0. The water discharge was fixed at 2.64 l/s and a gearbox with a ratio of 2.5: 1. The measurement of the mechanical characteristics consists of measuring the torque and the measurement of the rpm produced by the turbine. Measurement of electrical characteristics consists of measuring the voltage and measuring the electric current generated by the generator. Generator power is calculated based on the measurement of voltage and electric current.

1. Torque Measurement

The measurement of the torque on the turbine is done by using a spring that is attached to the turbine shaft through a rope. The springs and ropes will act as brakes on the turbine shaft. The rotation of the turbine will weaken and stop after a while due to braking by the force of increasing the length of the spring. The amount of torque from the turbine is equal to the torque by the spring force [8]:

$$\tau = -\, k\, \Delta x\;\; r \qquad (1)$$

2. Measuring rpm

The measurement of rpm in the turbine is done by counting the number of revolutions in a certain time interval. In this study, the time interval used is 60 seconds, so the rpm is:

$$rpm = \frac{rotation}{time}.60 \qquad (2)$$

3. Measurement of Voltage and Current

Measurement of voltage and current is done by connecting the output of the AC generator to a series of diodes and capacitors to convert DC electricity. Furthermore, the DC electricity connected is measured using a digital multi-meter. The measurement of the electric voltage is carried out at various variations of the turbine elevation angle. The measurement of electric current is carried out using 5 variations of resistor loading at various variations of the turbine elevation angle.

4. Calculation of Electrical Power

After obtaining the voltage and current data, the value of the electric power generated by the generator can be calculated. The value of the electric power generated by the generator is obtained from current and voltage data with 5 loading variations. Electric power is calculated by equation [9]:

$$P = V.I \qquad (3)$$

2.4. Research Flowchart

Broadly speaking, the stages in the study are stated in the flow chart in Figure 2.

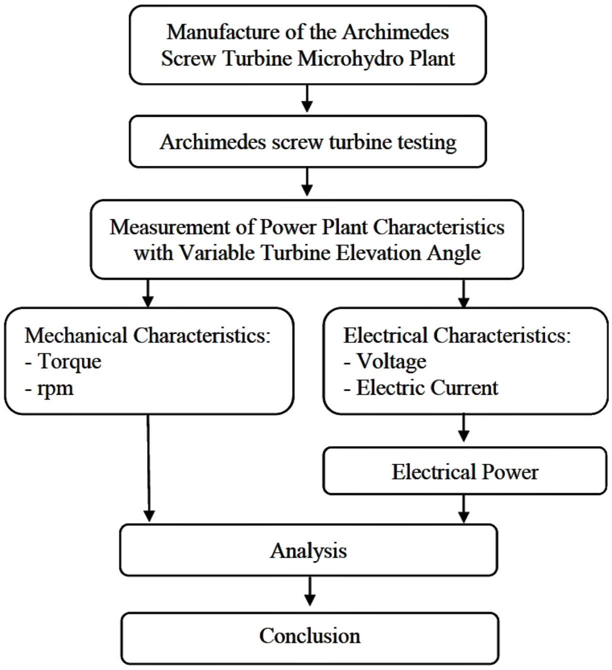

Figure 2: Research flowchart

III. RESULTS AND DISCUSSION

3.1. Torque Measurement Results

Torque measurements are made using a spring with a spring coefficient of 28,245 N / m on a turbine with a shaft radius of 6 mm. The amount of torque at various elevation angles of the turbine is calculated using Eq. (1). The results of determining the torque are presented in Table 1.

Table 1. The results of determining the torque at various elevation angles of the turbine

Angle	Torque (Nm)
20^0	0.0211
25^0	0.0222
30^0	0.0237
35^0	0.0225
40^0	0.0191

Furthermore, based on the data in Table 1, a graph of the torque vs. turbine elevation angle can be made (Figure 3).

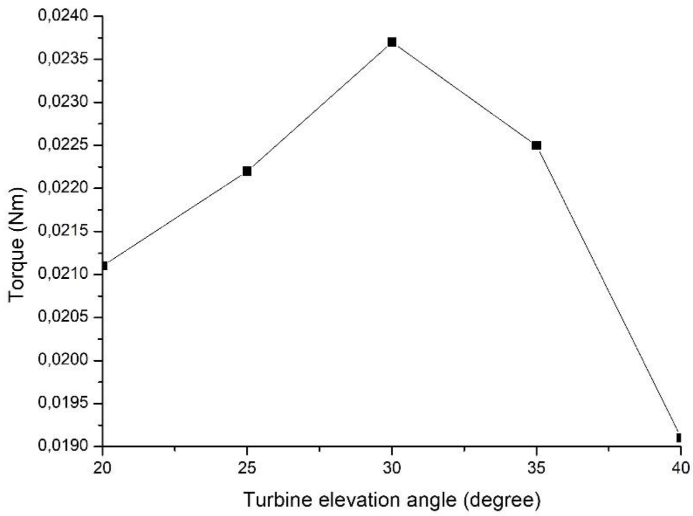

Figure 3: The graph of torque vs. turbine elevation angle

In Figure 3, it can be seen that the amount of torque generated by the turbine at various angles from 20^0 to 30^0 is that the greater the elevation angle of the turbine, the greater the torque produced. This is because the greater the elevation angle, the greater the difference in height between the two ends of the turbine. Furthermore, increasing the height difference will cause an increase in the amount of hydrostatic force, thus increasing the torque in the turbine. However, at the angle variation from 30^0 to 40^0 the opposite happens. The greater the turbine elevation angle, the smaller the torque generated. This is because the higher the elevation angle will cause the water flow to get closer to one point on the blade so that only part of the water hits the turbine and causes a decrease in torque in the turbine.

3.2. Results of Measurement rpm

Measurement of turbine rpm is done by counting the number of turbine revolutions in one minute. The results of the rpm measurement are presented in Table 2.

Table 2. Turbine rpm measurement results at various turbine elevation angles

Angle	rpm
20^0	748.50
25^0	825.60
30^0	839.85
35^0	705.30
40^0	581.25

Furthermore, based on the data in Table 2, a large graph of turbine rpm vs. turbine elevation angle can be made (Figure 4).

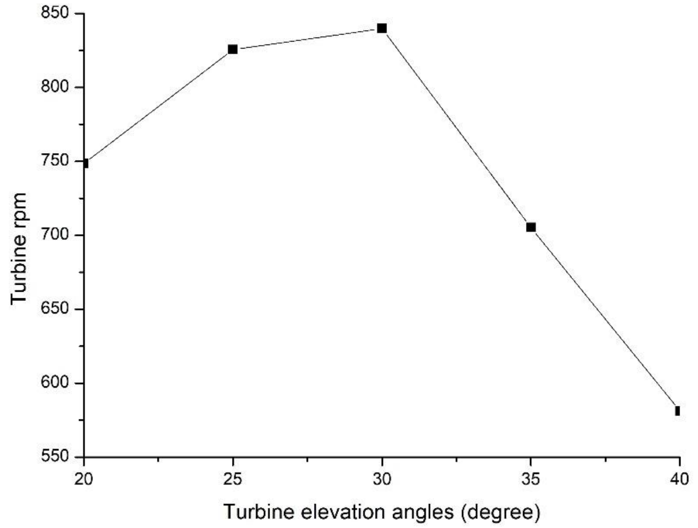

Figure 4: The graph of turbine rpm vs. turbine elevation angle

In Figure 4, it can be seen that an increase in the turbine elevation angle from 20^0 to 30^0 will cause an increase in turbine rpm. Furthermore, increasing the turbine elevation angle from 30^0 to 40^0 will cause a decrease in turbine rpm. There is a relationship between the amount of torque in the turbine and the rpm that arises so that the pattern of changes in the amount of turbine torque to changes in elevation angle will be the same as the pattern of changes in the size of turbine rpm with changes in elevation angle.

3.3. Voltage and Electric Current

Measurement of the voltage and electric current generated by the generator is done using a digital multi-meter. The results of measuring the electric voltage at the generator without loading are presented in Table 3.

Table 3. The results of measuring the generator voltage at various elevation angles of the turbine

Angle	Voltage (V)
20^0	5.16
25^0	5.36
30^0	5.57
35^0	4.44
40^0	3.58

Furthermore, based on the data in Table 3, a graph of the generator voltage vs. turbine elevation angle can be made (Figure 5).

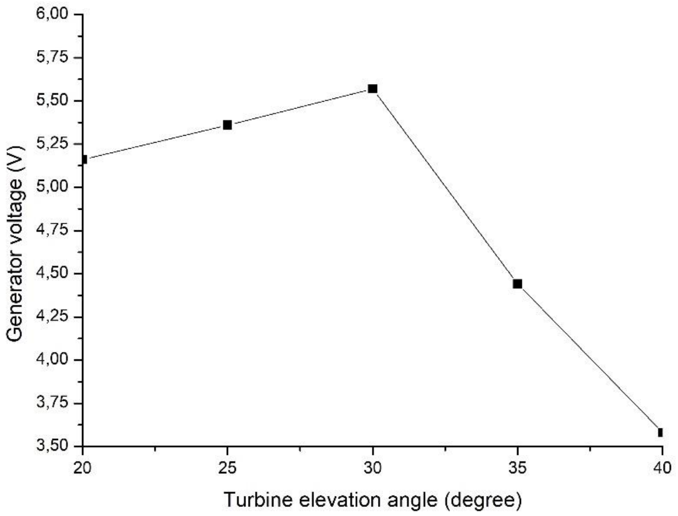

Figure 5: The graph of generator voltage vs. turbine elevation angle

In Figure 5, it can be seen that an increase in the turbine elevation angle from 20^0 to 30^0 will cause an increase in the generator voltage. Furthermore, increasing the turbine elevation angle from 30^0 to 40^0 will cause a decrease in the generator voltage. There is a relationship between the amount of rpm in the turbine with the amount of voltage that arises in the generator so that the pattern of changes in the amount of turbine rpm to changes in elevation angle will be the same as the pattern of changes in the magnitude of generator voltage with changes in elevation angle.

Measurement of electric current and voltage is also carried out on various variations of resistor loading, namely 1 kΩ, 2 kΩ, 3 kΩ, 4 kΩ, and 5 kΩ. The results of measurements of current and electric voltage are presented in Table 4.

Table 4. The results of measuring electric currents and voltages at various resistor loadings and various elevation angles

Angle	Currents (mA)					Voltage (V)				
	1 kΩ	2 kΩ	3 kΩ	4 kΩ	5 kΩ	1 kΩ	2 kΩ	3 kΩ	4 kΩ	5 kΩ
20^0	4.77	2.41	1.64	1.26	1.03	4.66	4.71	4.82	4.95	5.08
25^0	4.65	2.40	1.63	1.27	1.03	4.56	4.58	4.62	4.64	4.74
30^0	5.34	2.71	1.85	1.41	1.16	5.22	5.29	5.34	5.39	5.44
35^0	4.02	2.08	1.45	1.45	0.93	3.93	3.96	4.03	4.05	4.09
40^0	3.09	1.52	1.11	0.77	0.71	2.74	2.97	3.00	3.10	3.24

Figure 6 is an example of one of the generator loading curves at a turbine elevation angle of 300. Based on the graph in Figure 6, it can be seen that the increase in the value of the resistor loading causes a decrease in electric current and a slight increase in electric voltage.

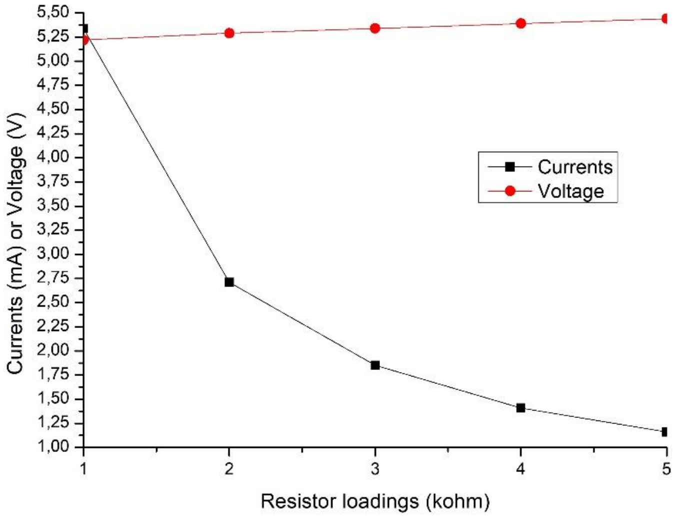

Figure 6: The graph of generator loading at turbine elevation angle 30^0

3.4. Electrical power

From the measurement results of voltage and electric current, it can be calculated the amount of electric power generated by the generator. The amount of electric power is calculated using Eq. (3). The amount of generator power is calculated at various variations of resistor loading, namely 1 kΩ, 2 kΩ, 3 kΩ, 4 kΩ, and 5 kΩ. The results of the calculation of electric power are presented in Table 5.

Table 5. The calculation results of electrical power at various resistor loadings and various elevation angles

Angle	**Power (mW)**				
	1 kΩ	**2 kΩ**	**3 kΩ**	**4 kΩ**	**5 kΩ**
20^0	22.269	11.343	7.936	6.284	5.275
25^0	21.301	11.001	7.542	5.899	4.901
30^0	27.873	14.371	9.915	7.652	6.321
35^0	15.811	8.274	5.842	4.573	3.804
40^0	8.511	4.540	3.349	2.407	2.299

In Table 5, it can be seen that the greatest electric power occurs at the turbine elevation angle of 30^0 and the resistor loading is 1 kΩ with a power of 27.873 mW. Table 5 also shows that the value of the load resistor also affects the amount of power generated by the generator.

3.5. Discussion

From the measurement results of the mechanical and electrical characteristics of the Archimedes screw turbine micro-hydro generator at various variations of the turbine elevation angle from 20^0 to 40^0, the results show that the turbine elevation angle of 30^0 produces the maximum mechanical and electrical characteristics. At an elevation angle of 30^0, the maximum torque, rpm, voltage, current, and electrical power are obtained. Increasing the elevation angle of the turbine from 20^0 to 30^0 will cause a large increase in the hydrostatic force that rotates the turbine, increasing torque and rpm of turbine rotation. The faster the turbine rotation will cause an increase in the voltage, current, and electrical power that occurs in the generator. On the other hand, an increase in the elevation angle of the turbine from 30^0 to 40^0 will cause the flow of water not entirely to the turbine, causing a decrease in torque, rpm of turbine rotation. Decreasing turbine rotation will cause a decrease in voltage, current, and electrical power that occurs in the generator.

Regarding the turbine elevation angle that produces maximum characteristics, the results of this study can be compared with the theoretical results of Muller and Senior's research. Muller and Senior have formulated a simple theory that can be used to calculate the effect of the number of blades on turbine efficiency. The results of Muller and Senior's study show that the use of more turbine blades can improve turbine efficiency [9]. Ten years later, Delinger et al experimented to measure the effect of the number of turbine blades on the efficiency of Archimedes screw turbines. Delinger et al examined the relationship between the number of turbine blades and the turbine elevation angle which resulted in maximum characteristics. The results of Dellinger’s research show that the use of more blades can reduce the elevation angle of the turbine which results in maximum characteristics. This is because increasing the number of blades in the turbine will maximize the flow of water hitting the turbine [16]. Next, Rorres made an optimal design of the Archimedes screw turbine micro-hydro generator by including the number of turbine blades as one of the parameters for optimizing the generator characteristics [12].

The results obtained from this study are still limited to the range of elevation angles from 20^0 to 40^0 and the magnitude of the change in elevation angle is 5^0. To obtain a more complete measurement of the mechanical and electrical characteristics of the screw turbine micro-hydro generator, then further research needs to be carried out at various angle ranges outside the range of 20^0 to 40^0. Likewise, to obtain a more detailed measurement of the mechanical and electrical characteristics of the screw turbine micro-hydro generator, then it is necessary to do further research on the turbine elevation angle range from 20^0 to 40^0 with a change in the elevation angle of less than 5^0.

IV. CONCLUSION

The results showed that the maximum mechanical characteristics, namely the amount of torque and maximum rpm, occurred at an elevation angle of 30^0 with a torque of 0.0237 Nm and an rpm of 839.85 rpm. The maximum electrical characteristic is the voltage, current, and the maximum power also occurs at an angle of 30^0 with a voltage of 5.44 V, a current of 5.34 mA, so that the electric power is 27.873 mW with a loading of 1 kΩ. Increasing the elevation angle of the turbine from 20^0 to 30^0 will cause a large increase in the hydrostatic force that rotates the turbine. On the other hand, an increase in the elevation angle of the turbine from 30^0 to 40^0 will cause the flow of water not entirely to the turbine.

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