Characteristics Analysis of Archimedes Screw Turbine Micro Hydro Power Plants with Variations in Water Discharge

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Abstract. Electrical energy has a very important role in human life, but the electricity supply still does not fully meet the needs of the community. Many potential energy resources can be converted into electrical energy. One of the potential energy resources is the flow of water that can be used for micro-hydropower plants for remote areas. This paper presents the results of research on micro-hydro power plants using Archimedes screw turbines. This power generation system has several advantages, namely low maintenance costs, does not damage the water ecosystem, does not require extensive land. The purpose of this research is to study the characteristics of the Archimedes micro-hydro power plant on variations in water discharge. These characteristics include mechanical characteristics such as the maximum torque and rpm and electrical characteristics such as voltage, current and electric power. The determination of characteristics is carried out on the prototype of the micro hydropower plant Archimedes screw turbine with the specifications of the turbine screw having 2 blades, the turbine elevation angle of 30º, 2.5: 1 gearbox ratio using four variations of water discharge, namely 1.18 l/s, 2.33 l/s, 2.55 l/s, and 2.64 l/s. The determination results of the micro hydropower plant Archimedes screw turbine characteristics show that an increase in water flow will cause an increase in mechanical characteristics such as large torque and rpm and electrical characteristics such as voltage, current and electric power. However, the increase in the magnitude of these characteristics is not directly proportional to the increase in water discharge.

1. Introduction
The community's need for electrical energy is very high and continues to increase every year. In many countries, the electrical energy generated by power plants has been well managed, starting from the generation, distribution, and marketing of this electrical energy to the public [1]. In connection with the distribution of electrical energy, not all areas, especially in remote and most remote areas, receive electricity supply. Even though in some remote areas there are several potential sources of energy that can be converted into electrical energy. One example of a potential source of electrical energy is river flows that pass through these remote areas.

For areas with such conditions, micro-hydropower plants can be a solution for electricity supply [2]. There are different types of micro hydropower plants. Each of these types has advantages and disadvantages [3-5]. One such type of plant is the Archimedes screw turbine power plant. Some of the advantages of Archimedes screw turbines are that they can be used in river flows that are not too heavy [6], do not damage the environment around the river [7], do not really interfere with fish life in the river [8], and so on.

Archimedes screw turbines have been widely researched and studied, both theoretically [9] and
experiments [10]. The results of this study indicate that the Archimedes screw turbine has a fairly good performance. Several analyzes and designs of Archimedes screw turbines have also been carried out to get better and optimal turbine performance [11, 12]. The advantages of Archimedes’ screw turbines, which can be used in less swift river flows in remote areas, can also be combined with the use of solar energy to obtain a more adequate energy supply [13].

Further research on the characteristics of Archimedes screw turbines on various factors has also been carried out. For examples research on the effect of water (fluid) filling levels in turbines on the characteristics and performance of turbines [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 the tilt and number of 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 water flow through the turbine on system characteristics and performance. The results of this study will complement the various research results that have been conducted by other people. The novelty of this research is that the turbine and generator are analyzed as a single system. Analysis of the turbine and generator as a single system is an advantage of this research. As a single combined system of turbines and generators, there will be two kinds of system characteristics, namely mechanical characteristics and electrical characteristics. The mechanical characteristics studied were the amount of torque and rpm at various variations of water discharge. The electrical characteristics studied are voltage and current to obtain the power characteristics of the generator at various water discharge variations.

2. Method

2.1. Tools and Materials

The tools and materials used in this research are:
- Water pump as a water discharge supplier
- Digital multi-meter to measure generator current and voltage
- The gearbox as a transmitter of energy from the turbine to the generator
- Turbines convert the energy of the motion of the water flow into energy to rotate the turbine wheels
- Turbine casing as a protective cover for the turbine
- 3-phase mini AC generator to convert the rotational energy of the generator wheels into electrical energy

The design of the Archimedes screw turbine Micro Hydro Power Plant (MHPP) can be shown in Figure 1.

![Figure 1. Archimedes Screw Turbine MHPP Design](image)

2.2. Flow Chart Diagram

In general, the stages in the research can be described in the flow chart in Figure 2.
In this study, the measurement of the mechanical and electrical characteristics of the Archimedes screw turbine generator at various water discharge variations was carried out. In this study, four variations of water flow were used, the turbine tilt angle of 30° and a gearbox with a ratio of 2.5:1. The measured mechanical characteristics are the maximum generator torque and rpm generated. The electrical characteristics measured are the voltage and electric current generated by the generator. Furthermore, based on the voltage and current values, the generator power can be calculated.

2.3. Measurement of Mechanical Characteristics

2.3.1. Torque measurement. The measurement of the torque on the turbine is carried out using a spring that is attached to the turbine shaft through a rope. The springs and ropes act as brakes on the turbine shaft. The turbine rotation will weaken and stop after a while due to the braking effect of increasing the length of the spring. Based on this principle, the torque value of the turbine is:

\[ \tau = k \Delta x \cdot r \]  

2.3.2. 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 was 60 seconds. Thus the amount of rpm is:

\[ \text{rpm} = \frac{\text{rotation}}{\text{time}} \cdot 60 \]
2.4. Measurement of Electrical Characteristics

2.4.1. Voltage and Current Measurement. Measurement of voltage and current is done by connecting the output of the AC generator to the diode and capacitor circuit so that it becomes DC electricity. The DC output is connected to the positive and negative probe cables of the digital multi-meter to each of the output poles of the circuit. Stress data collection was carried out on various variations of the water discharge used. Current data collection is done by using 5 variations of resistor loading on various variations of the water discharge used.

2.4.2. 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 the current and voltage data with 5 loading variations. Electric power is calculated by the equation:

\[ P = V \cdot I \]  

(3)

3. Results and Discussion

3.1. Measurement Result Data

The data from the measurement of the turbine generator mechanical characteristics, namely the amount of turbine torque are shown in Table 1 and the amount of turbine rpm is shown in Table 2.

| Water Discharge (l/s) | Torque (Nm)       |
|----------------------|-------------------|
| 2.64                 | 0.0293 ± 0.0001   |
| 2.55                 | 0.0278 ± 0.0001   |
| 2.33                 | 0.0221 ± 0.0001   |
| 1.18                 | 0.0150 ± 0.0001   |

| Water Discharge (l/s) | rpm               |
|----------------------|-------------------|
| 2.64                 | 880.50 ± 0.69     |
| 2.55                 | 858.50 ± 0.76     |
| 2.33                 | 843.20 ± 0.77     |
| 1.18                 | 475.05 ± 0.76     |

The data from the measurement of the turbine generator’s electrical characteristics, namely the generator voltage is shown in Table 3 and the generator current is shown in Table 4.

| Water Discharge (l/s) | Voltage (V) |
|----------------------|-------------|
| 2.64                 | 5.03 ± 0.06 |
| 2.55                 | 4.69 ± 0.07 |
| 2.33                 | 4.19 ± 0.05 |
| 1.18                 | 2.80 ± 0.03 |

| Water Discharge (l/s) | Electric Current (mA) for R = 1kΩ | R = 2kΩ | R = 3kΩ | R = 4kΩ | R = 5kΩ |
|----------------------|-----------------------------------|--------|--------|--------|--------|
| 2.64                 | 4.49 ± 0.04                      | 3.35 ± 0.03 | 1.74 ± 0.01 | 1.4 ± 0.01 | 1.19 ± 0.01 |
| 2.55                 | 3.70 ± 0.05                      | 1.99 ± 0.01 | 1.54 ± 0.01 | 1.26 ± 0.02 | 1.00 ± 0.01 |
| 2.33                 | 3.38 ± 0.07                      | 1.84 ± 0.01 | 1.46 ± 0.02 | 1.17 ± 0.04 | 0.92 ± 0.01 |
From the measurement data of the generator voltage and current, the generator power can be calculated. The results of the calculation of generator power are shown in Table 5.

**Table 5. The Power Generated by the Generator.**

| Water Discharge (l/s) | R = 1kΩ | R = 2kΩ | R = 3kΩ | R = 4kΩ | R = 5kΩ |
|----------------------|---------|---------|---------|---------|---------|
| 2.64                 | 19.25 ± 0.27 | 10.56 ± 0.17 | 8.08 ± 0.08 | 6.73 ± 0.07 | 5.85 ± 0.07 |
| 2.55                 | 12.98 ± 0.26 | 7.49 ± 0.06 | 6.15 ± 0.08 | 5.3 ± 0.13 | 4.54 ± 0.07 |
| 2.33                 | 10.73 ± 0.33 | 6.37 ± 0.07 | 5.5 ± 0.11 | 4.69 ± 0.17 | 3.8 ± 0.06 |
| 1.18                 | 4.01 ± 0.13 | 2.27 ± 0.05 | 1.93 ± 0.04 | 1.64 ± 0.02 | 1.3 ± 0.02 |

**3.2. Discussion**

In this study, the spring used has a spring constant of 28.245 N/m and the radius of the turbine shaft has a size of 0.006 m. It can be seen in Table 1, that the greater the water discharge used, the greater the torque produced. The resulting torque value is influenced by the water compressive force and the volume of the water bucket between the turbine helices. With the bucket volume between the turbine helices, the water flow can go down quickly so that it hits the side of the turbine blade. The more volume of the water bucket between the turbine helices causes more water to hit the turbine side so that the torque generated by the Archimedes screw turbine will increase.

![Figure 3](image1.png)

**Figure 3.** Graphs of (a) torque and (b) rpm vs. water discharge

In Table 2, it can be seen that the value of the turbine rpm at various variations of water discharge. The amount of rpm indicates the angular speed of an object rotating on its axis. In this Archimedes screw turbine, there is a relationship between the turbine rotational speed and the volume of water buckets between the turbine helices. The greater the water discharge used, the greater the resulting rotation value per minute. This is due to the influence of the water bucket volume between the helices. The more the volume of the water bucket between the helices, the stronger the water on the blade side of the turbine, so that the rotation speed of the turbine is faster.

In Figure 3, two graphs are presented, namely the graph of the results of measuring turbine torque versus water flow in Table 1 and the graph of the results of measuring turbine rpm versus water flow in Table 2. In Figure 3 (a) it can be seen that the increase in turbine torque versus the increase in water flow is not directly proportional. Likewise in Figure 3 (b), it can be seen that the increase in turbine rpm versus the increase in water flow is not directly proportional.
In Table 3, it can be seen that the voltage has decreased along with the decrease in water discharge. Thus the higher the discharge used, the greater the voltage generated. In this study, to measure the electric current in the generator, data collection was carried out using loading with a variation of 5 resistors. The resistors used are 1 kΩ, 2 kΩ, 3 kΩ, 4 kΩ, and 5 kΩ. Table 4 shows the results of measuring the electric current. It can be seen that the value of the electric current is greater when using a smaller resistor loading. In Table 4, it is also seen that the value of the electric current has decreased along with the decrease in water discharge.

![Figure 4. Graphs of (a) Voltage and (b) Electric Current vs. Water Discharge](image)

In Figure 4, a graphical form of the measurement results for generator voltage versus water discharge is presented in Table 3, and a graphical form of the measurement of electric current at various load resistors versus water discharge shown in Table 4. In Figure 4 (a) it can be seen that the increase in voltage generator due to the increase in water discharge was not linearly proportional. Likewise, in Figure 4 (b) it can be seen that the increase in the amount of electric current at each load resistor due to the increase in water discharge is also not linearly proportional.

The results of the calculation of electric power are shown in Table 5. It can be seen that resistor loading affects the value of the power produced. It can be seen that the smaller the resistor value, the greater the power value generated by the Archimedes screw turbine generator. Regarding the variation of water discharge, it was found that the higher the water discharge used, the greater the value of the power generated. In Figure 5, a graphical form of the calculation of electric power versus water discharge is presented in Table 5. In Figure 5, it can be seen that the increase in generator power due to the increase in water discharge is not linearly proportional. In Figure 5 it can also be seen that the smaller the value of the load resistor, the greater the electric power produced.

![Figure 5. Electric Power vs. Water Discharge](image)
The mechanical characteristics of the Archimedes screw turbine generator used in this study tend to change the value of its mechanical magnitude which is uncertain to the increase in water discharge. This trend of change can be accelerated or it can be slower. Unlike the mechanical characteristics, the electrical characteristics of the Archimedes screw turbine generator used in this research always tend to change rapidly with changes in water discharge.

The results of this study can be compared with the results of research by Saroinsong and colleagues, who used a large Archimedes screw turbine generator, to produce electric power in the order of Watts. Saroinsong and colleagues also examined the relationship between electric power and generator rpm in the range from 0 to 400 rpm. The results of the research by Saroinsong and friends showed that there was a large generator rotation capable of producing optimum electrical power. The rotation which is lower or higher than the amount of rotation will cause a decrease in the electric power of the generator [15]. In this study, using a small Archimedes screw turbine generator with electrical power in the order of milliwatts, the amount of rotation that produces optimum power is not seen in the rotation range of 500 rpm to 900 rpm (Table 2 and Table 5). Therefore it is necessary to carry out further research to measure the characteristics of this turbine generator at various other rotation ranges.

4. Conclusions and Recommendations
The determination results of the micro hydropower plant Archimedes screw turbine characteristics show that an increase in water flow will cause an increase in mechanical characteristics such as large torque and rpm and electrical characteristics such as voltage, current and electric power. However, the increase in the magnitude of these characteristics is not directly proportional to the increase in water discharge.

Further research needs to be carried out to study the characteristics of the Archimedes screw micro-hydropower plant at various ranges of other water flow variations.

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