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Portable Pico-hydro Power Plant with Archimedes Screw Turbine in Pelangi Reservoir of Universitas Islam Indonesia

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***Abstract*– Indonesia has a lot of potential to build hydroelectric power plants because of its size and abundance of water. As in the Islamic University of Indonesia, there is a Pelangi Reservoir which has the potential to develop a pico-hydro power plant. A portable pico hydro system is needed to generate electricity properly. In this study, the pico hydro generator system was designed starting from the turbine, pulley, generator, controller, battery to the load. In the process, the voltage and current generated by this portable pico hydro generator system will be observed. By using a screw turbine, the team designed the system to optimally utilize Pelangi Reservoir water flow. The DC generator was chosen as a converter of kinetic energy into electrical energy because with low rotation, and a stable DC generator produces direct electricity. Several changes from design to reality were made so that the system could work according to field conditions and not damage the ecosystem around Pelangi reservoir. According to the test results, the current pico-hydro system at Pelangi Reservoir UII can generate a maximum power of 8.544 watts and an average discharge of 7.1532 L/second. The power can increase if the water flow has a larger discharge. If the large discharge flow is balanced by the robustness of the turbine and system. At low conditions, the system can charge a battery with a capacity of 12 volts 4 Ah with a water flow rate of 4.807 L/second, which is 9.9 volts to 12.2 volts in 36 minutes. The efficiency of hydroelectric power generation (Pico-hydro) then increases to 16.71%. The system can generate 86.49 watts of electricity at 1500 rpm on the generator.**

Keywords: DC Generator, Pico hydro, Screw Turbine

I. INTRODUCTION

Electricity is currently still an essential requirement for the community, whether used for household needs or for industrial needs. The need for electrical energy in recent years in Indonesia has grown in line with the rapid population growth and improving economic growth [1]. Most electrical energy needs in Indonesia still utilize non-renewable energy sources, such as natural gas and coal. Meanwhile, the use of renewable energy sources can be utilized, including water, wind, and sun, is still very minimal, its utilization needs to be improved [2].

Indonesia's electricity needs are mostly met by Steam Power Plants. This Steam Power Plant runs on fossil fuels, specifically coal, where reserves of fossil energy sources are rapidly depleting. Coal combustion has the potential to emit greenhouse gases as well as harmful substances such as sulfur dioxide and carbon dioxide. Furthermore, steam power plants are Indonesia's largest source of carbon emissions. Waste from coal-fired power plant operations contains a variety of hazardous substances that continue to accumulate, wreaking havoc on environmental conditions [3]. The need for renewable energy development to replace fossil fuels in order to improve Indonesia's energy security. Based on [4] Indonesia's national energy in 2020 is 35.5% coal, 21.9% natural gas, 28.1% oil, and 14.5% new renewable energy.

A hydroelectric power plant is a type of electrical energy generator that uses water energy to power a turbine that is linked to a generator. Indonesia has a lot of potential to build hydroelectric power plants because of its size and abundance of water. Although the resource potential is very large (769.69MW), utilization remains low. This is evident from the installed capacity (228.89MW), which remains small in comparison to the total available potential [5]. As in the environment around the Islamic University of Indonesia which is passed by several small rivers. The Islamic University of Indonesia has two water dams that are still underutilized. The need for new ideas and innovations to improve the utilization of the University's reservoir. By utilizing the existing water flow, hydroelectric power plants are made on a small scale or we call it pico-hydro. The main components of a pico-hydro system can consist of a generator, turbine and battery. There are various types of turbines for pico-hydro, for example, gravitational vortex turbine, Archimedes turbine, Kaplan turbine, Crossflow turbine, Francis and propeller turbine [6][7].

The hydro turbine type that is used to drive a generator for this pico-hydro generation is the Archimedes screw turbine. Archimedes screw turbines are designed for low heads ranging from 1 to 10 m and flow rates ranging from 0.1 to $15 m^3/s$ [7]. According to [7] and [8], the Archimedes screw turbine is a turbine that can operate at high and stable efficiency under the low head and high range discharge conditions. Another advantage is that it is simple to maintain and operate, and it does not harm the environment where it is installed. Because aquatic organisms such as fish can still swim through gaps in the turbine blades, Archimedes turbines are being considered. This can be used in remote and small areas. The Archimedes screw is a turbine that uses the Archimedes principle to convert water's potential energy into energy.

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This research aims to be able to utilize the flow of water in Pelangi Reservoir for small-scale electrical energy generation using screw turbines. By designing a pico-hydro power plant that is able to generate and store electrical energy in batteries. So, it is expected to provide benefits for the surrounding environment, such as being able to light the way around the dark UII Reservoir. The system design is expected to have a positive effect on the surrounding environment, especially in UII Reservoir, such as being able to provide lighting for road users and anglers around Pelangi Reservoir, and in general, it is expected that the system can assist the government in accelerating the transition of the energy system towards a sustainable national energy system.

The portable system is carried out because of the intermittent nature of the water flow in the UII reservoir, so it is hoped that the system can be adjusted according to the height of the water head. The system can also be saved when the dry season arrives and used when the water flow starts to flow again. The system will be designed with a simple and lightweight design to make it easier to move positions. In [9], designing and realizing the Archimedes screw turbine model for the low head in Indonesia to get the maximum possible output electrical power. Research by [10] produced a prototype of a pico-hydro power plant with the average power output for the generator at 0.178L/s water flow of 1.45 watts with an average voltage of 41 volts. With a water discharge of 0.178L/s generator is capable of turning on a load equivalent to 25 watts or 12 volts lamps. The design carried out by [11] resulted in an average value of the required water discharge of 0.7 meters in cross-sectional area and 0.50 meters in depth. The speed of an object floating on a trajectory is 0.527 m/s. and the power generated by the turbine is 19 to 26 watts. After getting the generated power, put it into the battery for 7 to 16 hours.

Based on the results of the literature study, it can be seen that in general all hydroelectric power plants will depend on the amount of water discharge that exists in the water flow source that will be placed in the hydropower plant. Then other factors that can affect the output voltage and current is the slope angle of the turbine placed on the generator, and the type of turbine used also plays an important role when determining the location of the water flow source. In this study, the Pico hydro generator system will be designed starting from the screw turbine, pulley, DC generator, controller, battery to the load. In the process, the voltage and current generated by this portable Pico hydro generator system will be observed to obtain the system performance.

II. METHODOLOGY

A. Design Method

The method applied in the system design process is to use the design thinking method. The use of the design thinking method is expected to produce an idea and the latest solution to a problem raised. There are five design thinking processes, namely empathize, define problems, ideate, prototype, and test. Figure 1 depicts the flow of each process.

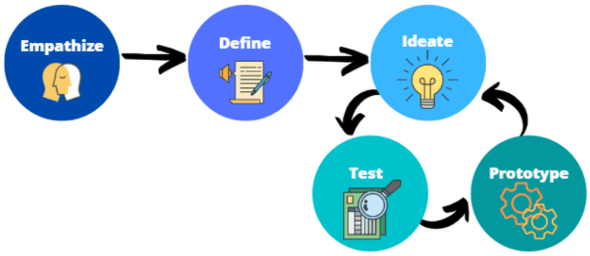

Figure 1. Design cycle of an engineering system

In the empathize process, observations were made by reading literature and conducting direct surveys of the Pelangi reservoir and also another reservoir owned by Universitas Islam Indonesia (UII). The second process is defined, and the problem formulation is obtained on how to reduce the use of non-renewable fuels as electricity producers by utilizing the UII reservoir and the surrounding water flow for electricity generation. This takes into account the water discharge, component specifications such as the type of generator, electrical energy storage area, frame shape, turbine type, and material in order to produce a prototype of a pico-hydro power plant that can produce the most electrical energy. Furthermore, whether the system has a negative impact on the environment is heavily considered during the ideate stage. In this stage, the team proposed several solutions to the problems raised, including the construction of a pico-hydro power plant using a screw turbine. Trials and the implementation of tools are carried out during the prototyping process.

B. Pico-Hydro Generation

Pico-scale hydroelectric power plants, in principle, utilize the difference in height and the amount of water discharge per second that exists in the flow of water from irrigation canals, rivers or waterfalls. This water flow will rotate the turbine shaft to produce mechanical energy. This energy then drives the generator, and the generator produces electricity which will be stored in the battery.

Water discharge (Q) is the flow rate of a liquid per unit of time that passes through a cross-section or can be accommodated in a place. Discharge is dependent on time (t) and volume (V) and is typically measured in litres per second mathematically expressed in Equation (1).

$$Q = \frac{V}{t} \quad (1)$$

Hydropower generation is the conversion of energy from hydropower and the height of the water fall (H) and certain water discharges (Q) into electric power via water turbines and generators. The other parameters are water density ($\rho = 0.998\ g/cm^3$) and the acceleration of gravity (g= 9.807 m/s^2) which also plays a role. The resulting power (P_H) can be calculated using the Equation (2). This Power is the maximum power that can be obtained.

$$P_H = \rho \times Q \times g \times H \quad (2)$$

While the power generated by the generator (P_G) can be expressed by using Equation 3. This power is the product of the generator's voltage (V) and current (I).

$$P_G = V \times I \quad (3)$$

The turbine speed will be transmitted to the generator. For torque can be calculated by using Equation 4.

$$P = T \times 2\pi \frac{n}{60} \quad (4)$$

System efficiency is the ability of the generator to convert the kinetic energy of flowing water into electrical energy. The efficiency value, is calculated by using Equation 5. The mathematical calculation of the efficiency of electric power generation ($\eta_{Picohydro}$) is calculated by using Equation 6.

$$\eta = \left(\frac{P_{out}}{P_{in}}\right) \times 100\% \quad (5)$$

$$\eta_{Picohydro} = \left(\frac{P_g}{P_H}\right) \times 100\% \quad (6)$$

C. System Design

The first stage of the design is the manufacture of the turbine. The initial design and calculation of component dimensions must be considered when modelling the screw turbine. The screw turbine component is made up of two major parts: the shaft and the blade. The turbine is made using PVC pipe material and with a cylindrical iron as its axis. Screw turbines made of PVC pipes have the advantage of being more economical than those made of metal. In addition, it is lighter than metal. The manufacturer of portable pico-hydro power plants will certainly pay attention to the dimensions and weight of the components. The lighter the components used, the better.

At first, the pipe is heated using an oven, and then the pipe is shaped in such a way as to form a turbine blade. After getting the blade according to the size, then the blade is glued to the turbine shaft. The specifications of the turbine are shown in Table 1. The second stage is the frame's construction. The frame is made of 2mm hollow iron material. Legs on the frame can be raised and lowered to accommodate different heights. This is done so that the system can efficiently adjust the tilt angle of the turbine based on the height of the water head. Turbine and frame construction can be seen in Figure 2.

Table 1. Turbine specifications

Parameter	Value	Unit
Blade angle	28	degree
Turbine length	1	m
Turbine diameter	0.26	m
Screw width	0.10	m
Turbine shaft diameter	0.06	m
Turbine Weight	2.90	kg

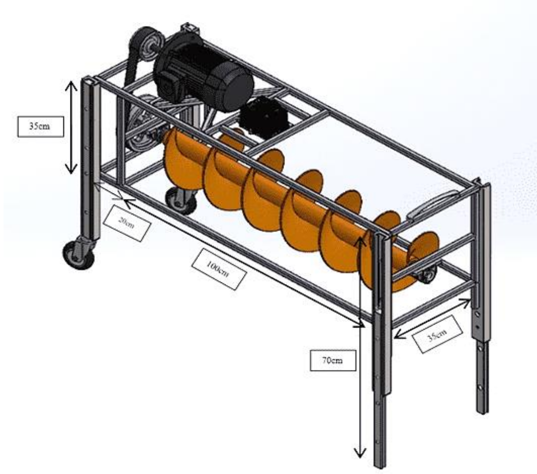

Figure 2. Design cycle of an engineering system

Table 2. System specifications

Parameter	Value	Unit
Volume	147	L
Weight	15.35	kg
Length	1.25	m
Width	0.35	m
Pipe diameter	0.02	m

The next stage is the manufacture of electronic devices. This electronic device consists of cables, a charge controller, a buck converter, a switch, a volt-ampere meter, a voltmeter bar, a battery and also a DC lamp. The electronic device is designed to charge a 12V 4Ah battery in the system. Figure 3 is a block diagram of the designed system with their specification. This design system can generate direct current (DC) electrical energy by using a 200 watts DC generator which is rotated using a screw turbine driven by the flow of water. Then the 3-inch and 2-inch pulley sets are used to transmit the rotational motion of the turbine which is then connected to the generator. When the generator shaft rotates, there will be a change in kinetic energy into electrical energy (DC). Direct electricity generated by the generator is then supplied to the battery charge regulator. The battery charge regulator's purpose is to automate the charging of the battery and convert the high-voltage DC current generated by the generator into a low-voltage current with a maximum voltage of 12 volts in accordance with the battery specifications (accumulator SMT Power 12V 4Ah). Furthermore, when the battery is fully charged, it serves to reduce the charging current. When the turbine rotation is low, the resulting voltage is lower than the battery, and this prevents backflow from the battery to the generator. The battery charge regulator can be set to cut off the current flowing to the load when the battery voltage is at a certain nominal value.

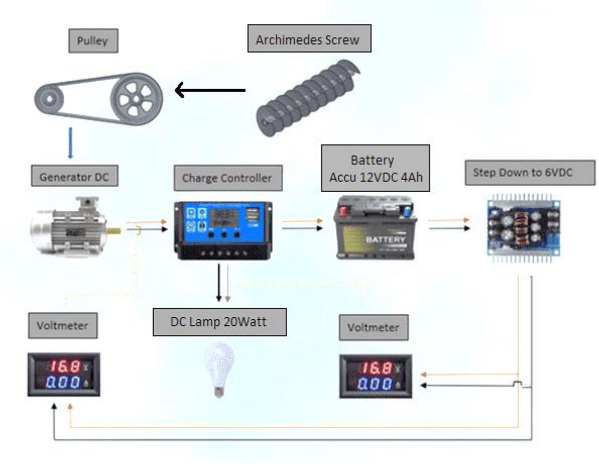

Figure 3. System block diagram

The system is made up of several components, including a DC generator, a pulley, electronic devices consisting of cables, DC lamps, a buck converter, a voltmeter and amperemeter in the form of a monitor screen, and also a battery. Then there is a screw turbine and a frame made of hollow iron. The system's final dimensions are 120cm × 35cm × 35cm, and the full specifications are shown in Table 2. Figure 4 depicts an image taken during system testing at Pelangi UII Reservoir

Figure 4. The experiment processes

III. Results and Discussion

The test is initiated by measuring the average discharge from the Pelangi Reservoir's small dam, which will be used as a test site. Following that, several tests are performed based on the designed system, including testing the best variation of the turbine's slope against the water surface and the system's performance. A turbine and battery resistance tests are performed to determine the system's resistance to water flow.

A. *Water flow measurement*

The purpose of the water discharge test is to determine how much water flows in the unit of volume per time. In this study, water flow in the pico-hydro power plant modelling is measured by dividing the volume of the vessel per time to fill the vessel, allowing the flow rate to be calculated. Data were collected over five days at various times, and the results are shown in Table 3 and Figure 5. Table 3 shows that the discharge from the UII reservoir's water flow is not always constant or intermittent. The measured discharge ranges from 4.63 to 11.9 L/s, with an average of 7.15 L/s.

Table 3. Water flow test

Date	Time	Debit (L/second)
29th June 2022	02.00 PM	11.90
29th June 2022	04.30 PM	11.23
2nd July 2022	11.00 AM	8.93
2nd July 2022	04.00 PM	7.35
3rd July 2022	10.00 AM	7.30
3rd July 2022	01.00 PM	4.72
4th July 2022	01.00 PM	5.32
4th July 2022	04.30 PM	4.92
5th July 2022	02.00 PM	5.22
5th July 2022	05.00 PM	4.63

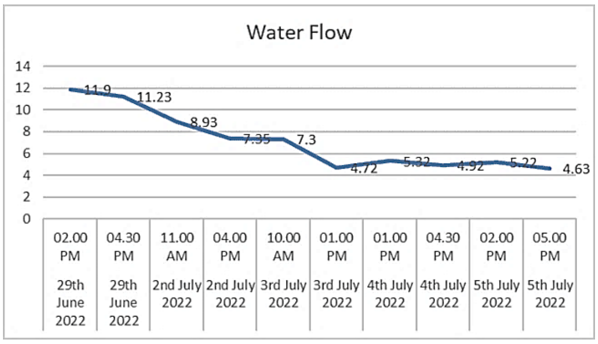

Figure 5. Water flow test

B. *Turbine Angle Variation Test*

The performance of this screw turbine is influenced by several parameters, one of which is the tilt angle of the turbine. This parameter greatly affects the rotation of the turbine, which affects the rotation of the generator and has an impact on the output power of the generator itself. In this research, the tilt angle of the turbine is varied to achieve the most efficient angle. The inclination test is carried out at the same water flow rate as the system when it is not loaded. The height of the water head has a significant impact on the turbine's tilt angle. The inclination angle of the turbine with respect to the water surface can be changed by adjusting the height of the forefoot. The illustration of the turbine angle variation test can be seen in Figure 6. Several variations of the inclination angle are obtained by using the sine ratio. The data from the test results are shown in Table 4 and the graph is shown in Figure 7. The best inclination angle is obtained from the variation of the angle, particularly at an angle of 17.16°. When compared to other inclination angles, this angle causes the turbine to have the highest speed. The next data collection is executed at an angle of 17.16°. After obtaining the most efficient turbine tilt angle, the next test is to measure the output of the system (current and voltage). Data collection was carried out several times within a certain time span.

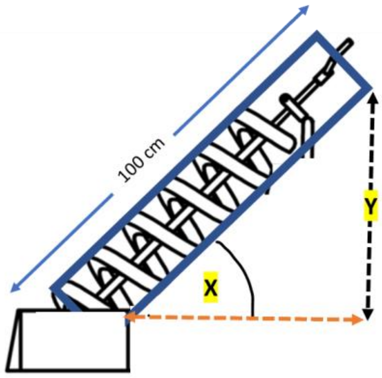

Figure 6. Illustration of turbine angle variation test

Table 4. Result angle variation test

Y (cm)	X (degrees)	Turbine speed (rpm)
17.00	9.21	113
21.00	11.54	145
24.90	13.83	224
27.00	15.07	275
30.50	17.16	289
33.00	18.66	184

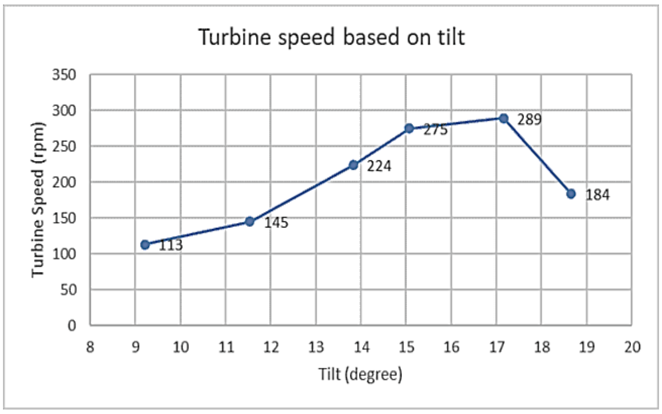

Figure 7. Turbine speed based on turbine tilt

C. System testing

After determining the best turbine tilt angle, system testing is performed using the best inclination angle. The output of the system is measured in the form of turbine rotation speed, current (I), and voltage during system testing (V). Data was collected several times over a particular period of time. The experiment was conducted in two conditions: no-load and system conditions with a 20-Watt DC lamp load. From the experiment on micro-hydro power plant without a load as shown in Table 5 and Figure 8, it can be seen that the turbine rotation speed is between 190–299 rpm. The voltage generated by the generator follows the turbine speed, which is 14.1–19.2 volts. The higher the turbine rotation speed, the higher the generated voltage. The measurement results of a micro hydro power plant using a 20-Watt DC lamp load, as shown in Table 6 and Figure 9, showed that the turbine rotation speed slightly decreased from the results of the no-load experiment. The power generated by the system under load conditions during the experiment is in the range of 4.248-8.544 Watts after recording the voltage and current values when the system is working. The maximum efficiency of the system that can be obtained is the ratio of the maximum power generated by the generator (8.544 Watts) and the maximum power that can be obtained by the system (51.12 Watts). Equation 6 can be used to get the value of the system efficiency, which is 16.71%.

Tests were also carried out using a rotating machine at a speed of 1500 rpm. The turning engine is connected directly to the generator shaft. This test is intended to determine the ability of the system to charge at high speed. The system can produce 86.49 watts of power. If this speed is used to charge the battery, it will reach the maximum charging duration.

Table 5. System with no load test

Date	Time	Speed (rpm)	Voltage (VDC)	Current (A)
29th June 2022	02.00 PM	289	18.1	0
29th June 2022	04.30 PM	268	17.8	0
2nd July 2022	11.00 AM	299	19.2	0
2nd July 2022	04.00 PM	265	17.1	0
3rd July 2022	10.00 AM	252	16.8	0
3rd July 2022	01.00 PM	258	17.0	0
4th July 2022	01.00 PM	205	16.4	0
4th July 2022	04.30 PM	203	16.0	0
5th July 2022	02.00 PM	204	16.2	0
5th July 2022	05.00 PM	190	14.1	0

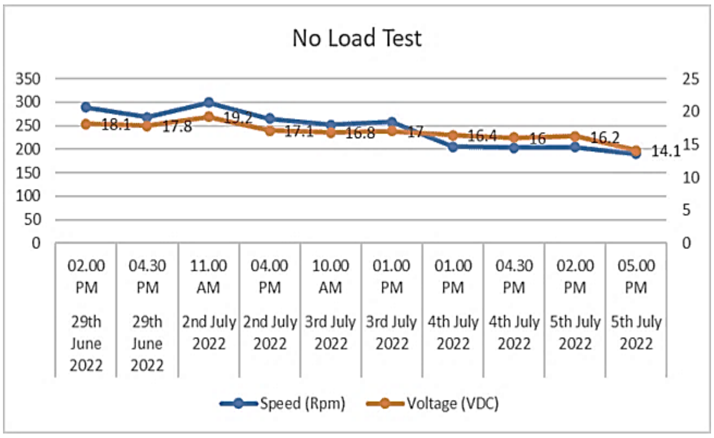

Figure 8. System with no load test

Table 6. System with load DC lamp 20 Watt

Date	Time	Speed (rpm)	Voltage (VDC)	Current (A)
29th June 2022	02.00 PM	269	9.6	0.89
29th June 2022	04.30 PM	268	9.0	0.91
2nd July 2022	11.00 AM	252	9.9	0.82
2nd July 2022	04.00 PM	250	9.5	0.82
3rd July 2022	10.00 AM	248	9.6	0.80
3rd July 2022	01.00 PM	172	11.8	0.36
4th July 2022	01.00 PM	203	9.7	0.48
4th July 2022	04.30 PM	215	10.1	0.38
5th July 2022	02.00 PM	224	9.4	0.47
5th July 2022	05.00 PM	231	11.0	0.34

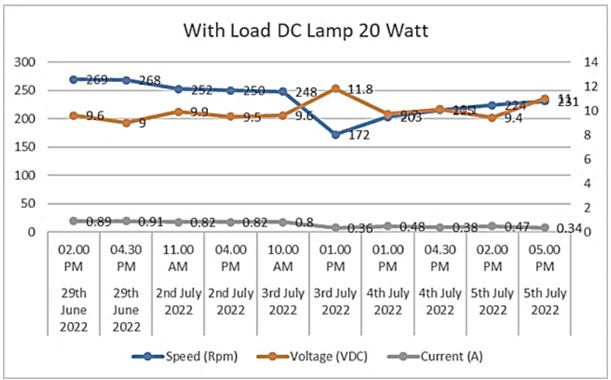

Figure 9. System with no load test

A. *Battery Test*

The battery installed in the system is connected to the charge controller to adjust the voltage generated by the generator. As shown in Figure 3, if the load requires power from the battery in the system, it must go through the charge controller first to adjust the use voltage. The 12V 4Ah battery charging test was carried out at a discharge of 4.807 L/second and an inclination angle of 17.157°. At that time the generator produces electricity of 16.1 volts. The electricity generated by the generator is supplied to the battery charge regulator, so that charging the battery uses a voltage of 12.1 volts. The condition of the battery is low when it has not been connected to the battery charge controller, which is 9.9 volts. Charging this battery lasts for approximately 36 minutes, it can be charged up to 12.2 volts. Battery voltage before and after charging test can be seen in Figure 10.

Figure 10. Battery voltage before and after charging

B. *System Endurance*

This test is focused on turbine resistance, electronic box tightness and generator housing protection against water. Tests were carried out on different discharge variations with various test durations ranging from 35 to 240 minutes. The condition of turbine blades and shafts, electronic box and generator protection in the form of a generator housing will be observed based on the tests obtained as shown in Table 7.

The condition of the electronic box and generator housing was safe during testing in various discharge variants. The electronic box and generator protector can be considered safe if water does not enter and hit the generator and electronic devices. The condition of the turbine can be considered safe when the turbine blade cannot be separated from the turbine shaft. Turbine conditions can be said to be safe, only at the discharge of 11.90 L/s at the time of entry for 170 minutes, the turbine blade on the front is slightly open. However, after repairing the turbine, further testing the turbine can survive. The tests have been carried out with a total time of ±725 minutes and with an average water discharge of 8.0984 L/s

Table 7. System with load DC lamp 20 Watt

Debit (L/s)	Duration (minutes)	Turbine	Box	Housing
5.22	±240	Safe	Safe	Safe
5.32	±180	Safe	Safe	Safe
8.93	±90	Safe	Safe	Safe
9.12	±35	Safe	Safe	Safe
11.90	±180	Unsafe*	Safe	Safe

IV. Conclusion

The portable pico-hydro generator system uses a Archimedes turbine which is designed can produce a maximum power of 8,544 watts at Pelangi Reservoir UII with average discharge of 7.1532 L/second. The power can increase if the water flow has a larger discharge. If the large discharge flow is balanced by the robustness of the turbine and system. At low conditions, the system can charge a battery with a capacity of 12 volts 4 Ah with a water flow rate of 4.807 L/second, which is from 9.9 to 12.2 volts in 36 minutes. If the flow rate increases, the resulting voltage can be greater and the charging process can be faster. The system can run well with an efficiency of 16.67%. Frame design can be improved further in terms of flexibility and water and flow resistance materials. The system will be made more compact, easier to carry everywhere, and more portable.

Acknowledgement

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