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Micro Hydro Power Plant (MHP) performance using breast-shot waterwheel with different electrical load to improve efficiency

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Abstract

The aim of this study is to investigate the performance of breast-shot waterwheel with different electrical loads to increase efficiency. The method used is to design a pinwheel blade using blade material with a supporting frame added to the top, middle, and bottom of the pinwheel blade. The blade material used a thickness of 1.5 mm with angle iron installed on the three sides of the blade with a size of 30 mm × 30 mm × 3 mm. Tests were carried out with variations in lamp load when the water flow rate and water velocity were constant. Parameters measured in this test are water flow rate (m^3/s), velocity of water (m/s), head of water (m), generator rotation (rpm), electric current (A), and generator output voltage (V). The results of the Hydro Power Plant (MHP) test with a waterwheel drive with the highest efficiency value at a water discharge of 0.267 m^3/s, a velocity of 5.069 m/s, a generator rotation of 940 rpm, and a load of 840 W, which is 10.74%.

Keywords:

Breast-shot water wheel, efficiency, electric load, generator power, specific water consumption.

1 Introduction

The increase in population causes the need for electrical energy to increase. Therefore, it is important for a region to be able to meet its electrical energy needs independently. Independence to produce electrical energy is important in the current era because it allows a region not to depend on energy sources from outside [1-4]. Micro Hydro Power (MHP) is one type of power plant that can be used as a form of energy independence.

One of them is the MHP, established in Surokonto Village, Pageruyung District, Kendal. This MHP, which was built in 2020, has a potential water flow discharge of 0.476 m^3/s and a potential hydraulic power of 2.477 kW, with a generated electrical power of 0.207 kW [1]. However, this Surokonto MHP has a weakness in the blade of the pinwheel, which causes the blade to come off easily when the flow discharge is large. Therefore, it is necessary to redesign the pinwheel blade by replacing the blade material which is stronger and waterproof, so that the Surokonto MHP can operate again and produce electrical energy that can be utilized by the surrounding community. By utilizing the existing construction, the re-planning is only done on the blade of the waterwheel by redesigning the blade so that it has a stronger construction framework. A stronger construction framework can be obtained by providing a layer of strip iron in the center of the blade and angle iron on the side of the blade. The layer is expected to be able to withstand the pressure due to the swift flow of water so that the blade is not easily separated and is able to operate again in over longer period of time.

MHP is a power plant that utilizes the potential energy of water to produce mechanical energy, which is used to rotate the generator [5-6], so that the generator can produce electrical energy. The term micro hydro is used to describe hydroelectric power plants that have a capacity of less than 100 kW. There are 3 general classifications of hydroelectric power plants [7-9], namely micro hydropower have a capacity of less than 100 kW, mini hydropower between 101 and 2 MW, and small hydropower have a capacity between 2 MW and 25 MW. MHP is a type of run of river plant, which is a scheme or system layout with or without a weir but does not use a reservoir [10-12]. Where the water head is obtained not by building a reservoir but by diverting the flow of river water or waterways directly to the waterwheel. MHP is usually built in an area that has sufficient capacity, water flow rate, head or height.

Micro hydro is a type of hydroelectric power plant that usually produces between 5 kW and 100 kW of electricity by utilizing natural water flows and is mainly used by remote towns or households that do not yet have electricity. The main differences between generator types are the height drop or head and the water flow rate before it enters the generator [13-15]. Water potential energy is in the form of a head or height difference between incoming water and outgoing water to produce energy. The greater the height difference, the greater the potential for water energy. Then the flowing water is used to drive the waterwheel. When the water flow hits the blades on the mill, the resulting force will make the mill shaft rotate. The rotation of the pinwheel shaft is then transmitted to the generator shaft so that the generator can rotate and produce electrical energy.

A waterwheel is a device for converting the kinetic energy of water into mechanical energy, namely the thrust of the water jet causing the mill shaft to rotate. The rotation of this wheel is used to drive an electric generator. Thus, electricity will be generated, which can be used for various needs. The flowing water power will mash the blades of the mill, so that the mill receives a number of forces that work to cause the mill to move [16].

The working process of the waterwheel power plant to the use of electricity occurs several energy changes. First is the change of potential energy in the flow of water into mechanical energy (motion) by the wheel. Second, this mechanical energy will rotate the generator, due to the rotation of the generator there is a jump of electrons [17]. This is what produces electric current. The next process of electric current is distributed to homes, rooms, factories, or anything that needs it. Here the electric current is converted depending on the need to be light energy for lamps or lighting converted into heat such as in irons or ovens, or converted into driving power for fans, and engines.

Based on the flow direction of the fluid shot waterwheels are divided into several types [18, 19]: (1) Undershot. An undershot type of water turbine is a type of water turbine where the propelling water flow hits the blades at the bottom of the turbine. The turbine wheel rotates only because of the impact of water in the form of water splashes on the wheel blades, which are straight in the radial direction. The potential head of the water is first converted into velocity head before the water strikes the turbine blades. (2) The breast-shot, the breast-shot type water turbine is a combination of overshot and undershot turbines in terms of the energy it receives. Breast-shot water turbines also require a height difference with water jets. The height of the fall does not exceed the diameter of the turbine, the direction of the water flow that drives the water turbine around the axis of the water turbine.

(3) An overshot, an overshot type water turbine is a type of turbine in which the propulsive water flow hits the blades at the top of the turbine, and due to the weight of the water, the turbine rotates. Overshot water turbines require a height difference with the water jet. Overshot water turbines are the most widely used water turbines compared to other types of turbines.

The potential electrical power generated by an MHP is influenced by several factors, including available water discharge, head, and system efficiency [20- 24]. Eq. 1 – Eq. 6 is used in calculating the potential electrical power of water [25-29]:

1. Velocity of water (Eq. 1)

$$v = \sqrt{2 \cdot g \cdot h} \tag{1}$$

where, velocity of water (m/s), gravity acceleration (m/s^2), h is head of the water (m).

2. Water flow rate (Eq. 2)

$$Q = v \cdot A \tag{2}$$

where, Q is flow rate (m^3/s), v is velocity of water (m/s), and A is cross-sectional area (m/s).

3. Hydraulic power (Eq. 3)

$$P_h = \rho \cdot g \cdot H \cdot Q \tag{3}$$

where, P_h is hydraulic power (W), ρ is density of water (kg/m^3), g is gravitational acceleration (m/s^2), H is height of water (m), Q is the flow discharge (m^3/s).

4. Electric power (Eq. 4)

$$P_l = V \cdot l \cdot \cos\theta \tag{4}$$

where, v is voltage (V), is ampere (A), cos θ is power factor.

5. Efficiency (Eq. 5)

$$\eta_s = \frac{P_l}{P_h} \times 100\% \tag{5}$$

where, η is an efficiency (%), P_L is electric power (W), P_h is hydraulic power (W).

6. Specific Water Consumption (SWC) [25, 26] (Eq. 6)

$$SWC = \frac{Q \times 3600 \times 1000}{P_l} \tag{6}$$

where, SWC is specific water consumption (m^3/kWh), Q is discharge (m^3/s).

Based on the above background, the purpose of this research is to redesign the waterwheel blade design that has been made by Herlambang et al. [1] using a breast-shot waterwheel type that has a stronger construction with a redesigned waterwheel blade and stronger construction, so as to increase the performance of the waterwheel.

2 Methods

In the manufacture of this waterwheel, a design selection has been made that has been adapted to the data that has been obtained during field survey measurements so that the characteristics of the waterwheel that will be made are obtained. The planning of the waterwheel design has criteria, including being strong, having the same size and shape in each of the blades, and being corrosion resistant. Based on these criteria, the iron plate material was chosen for the 2 mm waterwheel cover and the used drum for the 1.5 mm waterwheel blade because it met the existing criteria compared to other materials. The diameter of the waterwheel is 1100 mm, consisting of 12 blades with a width of 700 mm.

The components of the breast-shot waterwheel as show in Fig. 1: (1) Blade holder plate with a thickness of 2 mm for holding the waterwheel blade; (2) Fan belt B115 type for waterwheel rotation transmission; (3) Pulley 6 inches to transmit the mechanical power of the waterwheel to the gear transmission mechanism; (4) Generator asynchronous type to generate electrical energy; (5) Fan belt B77 type to transmit power from the gear transmission mechanism to the generator; (6) Pulley 3 inches to transmit mechanical power from the gear to the generator pulley; (7) Pulley 8 inches to transmit mechanical power; (8) Pillow block with a size of 3/4 inch; (9) UNP 100 mm × 50 mm × 5 mm as a frame for waterwheel support; (10) Shaft 20 mm in the gear transmission; (11) Sprockets Z16 type to support transmission using chains; (12) Gear as a transmission to transmit mechanical power to an electric generator; (13) Sprockets Z40 type to support transmission using chains; (14) Pulley 16 inches to transmit the mechanical power of the waterwheel to the gear mechanism; (15) Shaft 50 mm for transmitting mechanical power through the pulley; (16) Arm with a length of 1100 mm to hold the waterwheel and to adjust the height of the waterwheel; (17) Threads for the waterwheel up and down mechanism; (18) Waterwheel blades to transmit the kinetic energy of water into mechanical energy in the form of waterwheel rotation; and (19) Belt holder for holding the waterwheel arm mechanism.

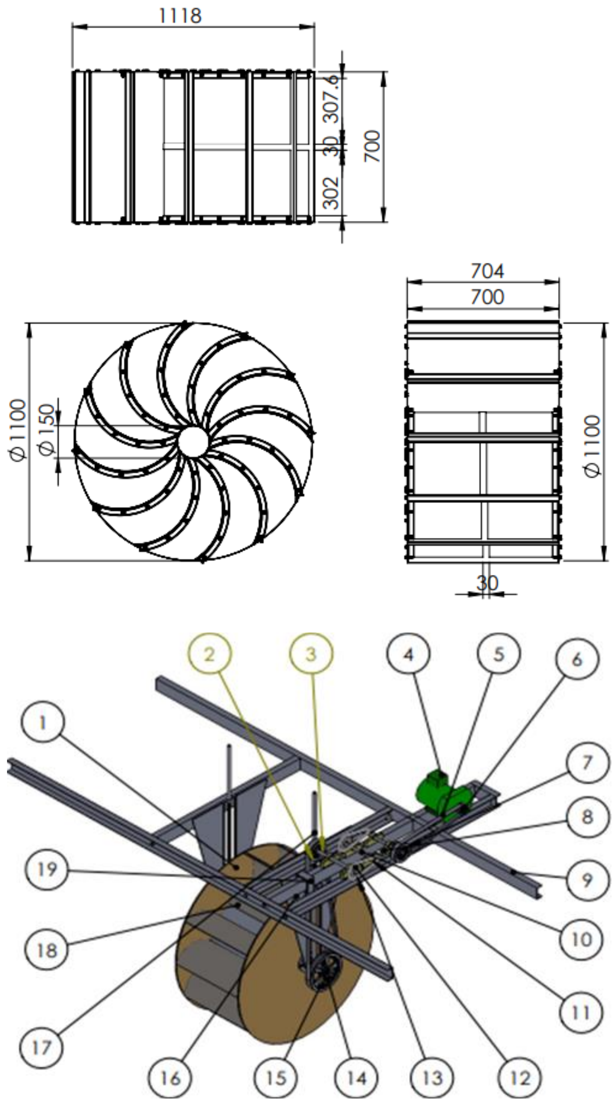

Fig. 1. Design of breastshot waterwheel with chain transmission mechanism to drive an electric generator: (1) blade holder plate; (2) fan belt B115; (3) pulley 6 inch; (4) generator asynschronous; (5) fan belt B77; (6) pulley 3 inch; (7) pulley 8 inch; (8) pillow block; (9) UNP; (10) shaft; (11) sprocket Z16; (12) gear transmission; (13) sprocket Z40; (14) pulley 16 inch; (15) shaft 50 mm; (16) arm; (17) thread mechanism; (18) blade.

The steps of data collection are: (1) Prepare all the test equipment that will be used in the test, namely the pitot tube, voltmeter, ampmeter, meter, hand tachometer, AC synchronous generator, and light load; (2) Measure the width of the water flow that hits the blade using a ruler; (3) Measure the water level in the cross-section channel with a ruler; (4) Measure the speed of water flow using a pitot tube; (5) Make a load circuit for lights, ampmeters, voltmeters and AC synchronous generators with spade and crocodile cables.

Testing performance for variations in electrical load and generator rotation with the components is shown in Fig. 2.

Fig. 2. Testing performance for variations in electrical load and generator rotation with the components: (1) tachometer; (2) load of 100 W; (3) v-belt; (4) ampere meter; (5) load of 40 W.

(6) Turn on the generator by pressing the switch on the generator, which is connected to the test load circuit; (7) Start the test with a load of 0 W; (8) Measure the rotation speed of the generator shaft using a hand tachometer and record it in the test data table; (9) Read the value of the current flowing in the ammeter measuring instrument and record it in the test data table; (10) Read the voltage value on the voltmeter measuring instrument and record it in the test data table; (11) Repeat steps 8 to 11 for each other load variation; (12) After a load variation of 1000 W, turn off all lights and generator loads, and then tidy up the equipment after testing and tidy up the test results data table, process data, and analyze data in Table 1 shows the results of the undershot waterwheel test with test parameters including electrical loading, wheel rotation, generator rotation, electric current, voltage, water flow rate, and water velocity.

3 Results and Discussion

The test results were obtained by carrying out the research procedure, namely measuring the water head at the sluice using a ruler, measuring the speed of water flow using a flow watch, making a series of ammeters, V meters, generators with spade and crocodile cables, lowering the position of the wheel to the maximum, and turning it on generator, starting the test with a load of 0 W, measuring the speed of rotation on the generator shaft using a hand tachometer, reading the current flowing using an ampere meter at each loading, reading the voltage at the generator output using a voltmeter at each loading, recording the results of the generator current, generator voltage, and the rotational speed of the generator shaft, tidying up the equipment after completing the test, processing the data, recording the results in a table, and making a figure of the characteristics of the waterwheel.

Based on the graph in Fig. 3, it can be seen that the higher the value of the installed load, the lower the value of the generator rotation produced. At a load of 40 W, the generator rotation generated is 1750 rpm, while at a load of 1000 W, the generator rotation generated is 835 rpm. The data obtained in 2020 also shows the same trend value. When the lowest load value results in a high generator rotation value, a high load value results in a low generator rotation value.

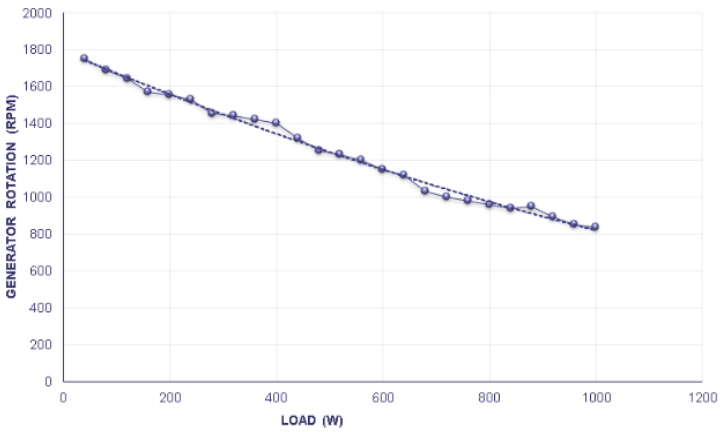

Fig. 3. The characteristics of load of the lamp (W) toward generator rotation (rpm).

As the load value increases, the electric power generated will increase and then decrease after the maximum condition. This is because an increase in the load value causes a decrease in the generator rotation value and the voltage produced, as shown in Fig. 4. The maximum value on the trendline is an electric power of 372 W at a lamp load of 656 W. In this condition, a lamp load of 656 W is 139.53 V. When the lowest load value produces a high voltage value, a high load value produces a low voltage value. The voltage value affects the value of the electrical power generated.

Table 1. Test results data on the breast-shot waterwheel

Load (W)	Generator rotation (rpm)	Output voltage (V)	Output current (A)	Velocity of water (m/s)	Flowrate (m^3/s)
0	1850	336	0	5.069	0.267
40	1750	315	0.24	5.069	0.267
80	1690	297	0.52	5.069	0.267
120	1640	285	0.68	5.069	0.267
160	1570	276	0.84	5.069	0.267
200	1557	273	1	5.069	0.267
240	1530	230	1.32	5.069	0.267
280	1450	225	1.46	5.069	0.267
320	1440	220	1.44	5.069	0.267
360	1420	219	1.58	5.069	0.267
400	1400	207	1.7	5.069	0.267
440	1320	189	1.94	5.069	0.267
480	1250	180	2.04	5.069	0.267
520	1230	165	2.1	5.069	0.267
560	1200	156	2.2	5.069	0.267
600	1150	150	2.3	5.069	0.267
640	1120	138	2.55	5.069	0.267
680	1030	124	2.6	5.069	0.267
720	1000	122	2.65	5.069	0.267
760	980	121	2.85	5.069	0.267
800	960	120	2.95	5.069	0.267
840	950	119	3.1	5.069	0.267
880	940	111	3.2	5.069	0.267
920	890	108	3.25	5.069	0.267
960	850	105	3.15	5.069	0.267
1000	835	96	3.3	5.069	0.267

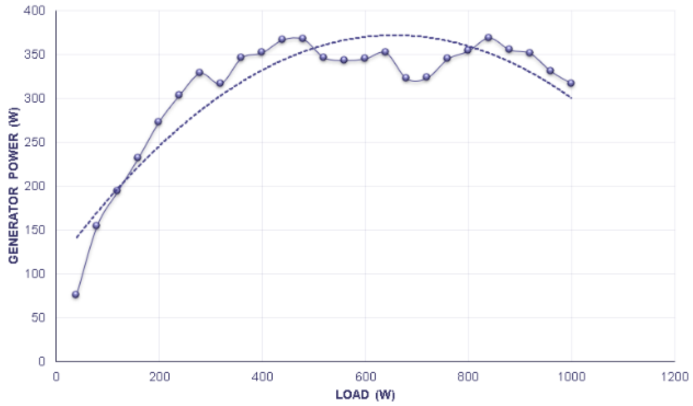

Fig. 4. The characteristics of load of the lamp (W) toward generator power (W).

The greater the rotation of the generator, the electric power generated will increase for a moment, and then when it reaches the optimal point, it will decrease in Fig. 5. The maximum point of the trendline is obtained at an electric power of 372 W with a generator rotation of 1142 rpm.

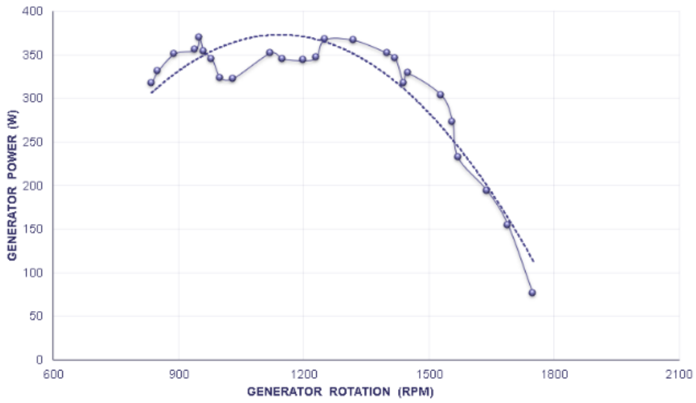

Fig. 5. The characteristics of generator rotation (rpm) toward generator power (W).

Fig. 6 reveals the resulting efficiency characteristics: the lamp load will increase, then at a load of 840 W, they will decrease. This is because the efficiency value is influenced by the value of the hydraulic power and the electrical power generated. In this graph, the maximum efficiency value is 10.72% with a load of 645 W. If the equation in graph 4.7 is used, the voltage obtained at a lamp load of 645 W is 141.52 V. The data obtained in 2020 also shows the same trend value. When the lowest load value produces a high electrical power value, a high load value it produces a low electrical power value. Where the value of electric power affects the amount of efficiency produced.

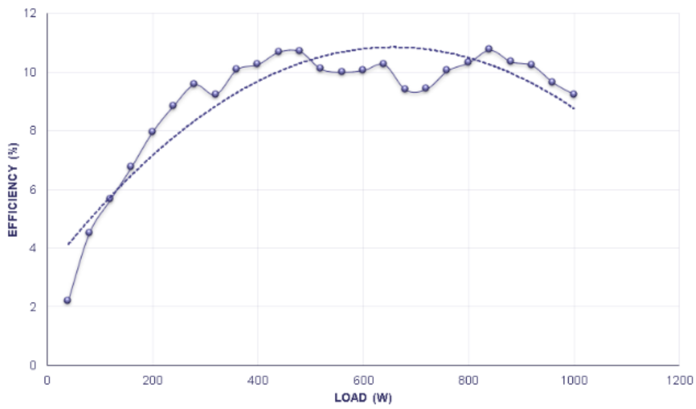

Fig. 6. The characteristics of load of the lamp (W) toward system efficiency (%).

Based on the graph in Fig. 7, it can be seen that the relationship between generator rotation and efficiency is that the greater the generator rotation, the greater the efficiency will increase for a moment. The efficiency on the trendline has a maximum point of 10.86% at a generator rotation of 1142 rpm, so if the equation used in graph 4.8 is obtained, the voltage at a generator rotation of 1142 rpm is 149.58 V. Specific Water Consumption (SWC) is a parameter in determining the efficiency of converting water potential energy into electrical energy. SWC is expressed in m^3 of water usage per kWh of electrical energy produced by the hydropower generator (m^3/kWh). Based on the graph in Fig. 8, it can be seen that increasing the load will result in a smaller SWC value, and then at the optimal point it will increase again. The characteristic results obtained show that the lowest SWC value on the trendline is 2474.665 m^3/kWh at a loading of 656 W.

Based on the graph in Fig. 9, it shown that the greater the load borne by the generator, the smaller the voltage will be. When the installed load is 40 W, the resulting voltage is 315 V, and when the installed load is 1000 W the resulting voltage is 96 V. And from the trendline equation, the load obtained when the working voltage is 220 V is 318.99 W.

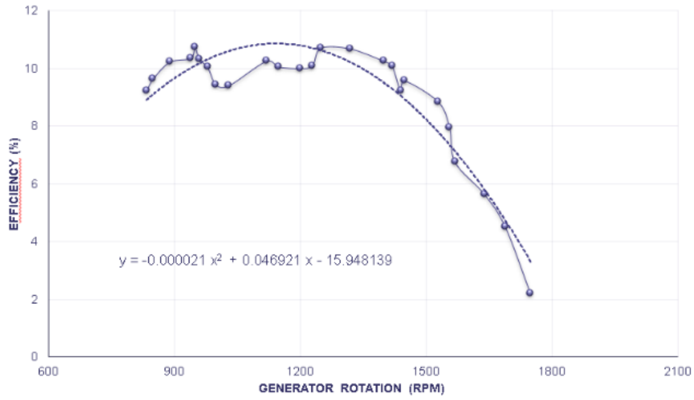

Fig. 7. The characteristics of generator rotation (rpm) toward system efficiency (%).

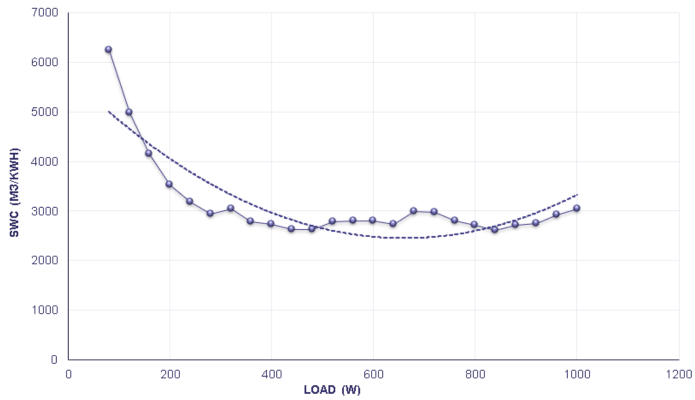

Fig. 8. The characteristics of load of the lamp (W) toward SWC (m^3/kWh).

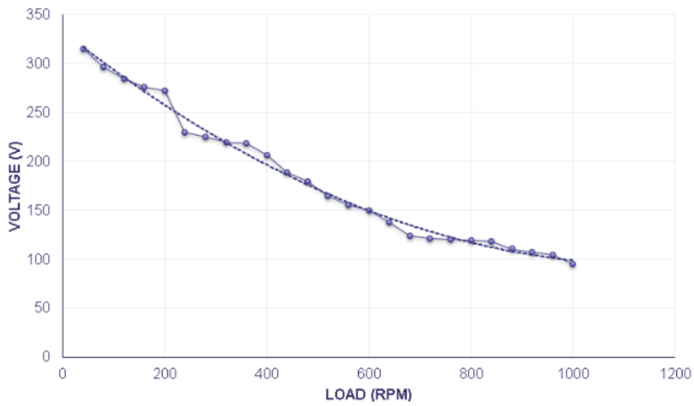

Fig. 9. The characteristics of load of the lamp (W) toward voltage (V).

Based on the graph in Fig. 10, it shown that the greater the rotation of the generator, the greater the voltage produced. When the voltage is 315 V, the rotation is 1750 rpm and when the voltage is 96 V the rotation is 835 rpm. From the trendline equation, it is also obtained that the rotation when the working voltage is 220 V is 1431.67 rpm.

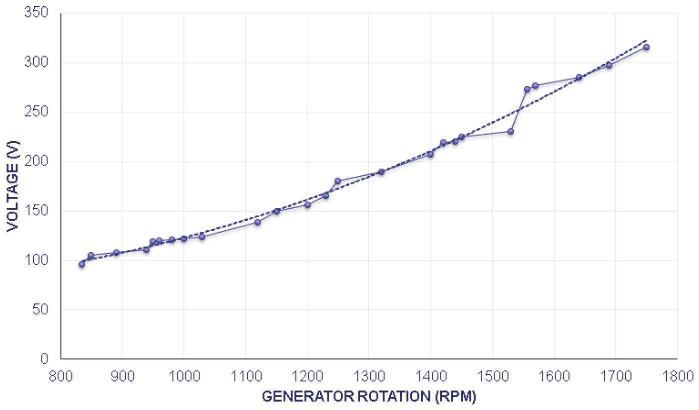

Fig. 10. The characteristics of generator rotation (rpm) toward voltage (V).

4 Conclusion

The breast-shot waterwheel in this study has specifications of 12 pieces, with a thickness of 1.5 mm equipped with angle iron with dimensions of 30 mm × 30 mm × 3 mm. The diameter of the wheel is 1100 mm, and the shaft diameter is 50.8 mm. The working principle of MHP with waterwheel drive is that water flow through the channel to the waterwheel. Then the water will hit the waterwheel so that it can move. In this condition, there is a change from hydraulic power to mechanical power. The rotation of the waterwheel is then channeled or transmitted through the transmission system in the form of v-belt transmission and chain transmission to the generator. The generator will rotate and then produce electrical power to be utilized. The highest efficiency value obtained was 10.74% at a discharge of 0.267, a water flow rate of 5.069, a generator rotation of 940 rpm, and a loading of 840 W. In this test, the lowest specific water consumption was 2474.665 m^3/kWh at a loading of 656 W and 139.53 V. The operating voltage of 220 V obtained was the generator rotation, and generator power produced 1431.67 rpm and 318.99 W, respectively.

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