



Modeling Design of Picohydro Power Generation System Using Crossflow Turbine

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ABSTRACT

The goal of this project is to learn how to use a Crossflow turbine to create a Picohydro power plant system modeling. The manufacturing process, from design to evaluation, is the methodology employed. The turbine type utilized is a crossflow turbine, measuring 26 cm in outer diameter, 17.3 cm in inner diameter of the blade runner, and up to 35 pieces of blades. The calculations show that the distance between the blades is 2.3 cm, the blade length is 8.5 cm, the blade width is 4.4 cm, and the radius of curvature of the blade is 2.8 cm. The test results without load obtained the highest turbine rotation of 421 Rpm produces a voltage of 7.29 V before going through the boost converter.

INTRODUCTION

Electrical energy is one of the most important energies for human life. It is needed for various human activities, such as industry, transportation, households, and others, and along with changes in people's lifestyles (Bandri et al., 2021; Pratama et al., 2021.). Limited power plants cannot advance the industrial or socio-economic conditions of a country. Then this infrastructure project is the most significant endeavor undertaken by the current government. On the other hand, the increase of electric power development for local areas, especially in rural areas is too expensive. The purpose of electricity development is to stabilize people's economy through equitable distribution of electricity development.

Picohydro power plant (PHP), a small-scale power plant that produces energy of about 5 kW or less. It is a remarkable technique to convert the kinetic energy from the height and release of water into electrical energy using turbines and generators (Bosowa et al., 2021; Juni Yanda et al., 2021; Saepul Uyun & Novianto, 2020). Before being converted into electrical energy, water energy can be used for mechanical purposes. Creating electrical energy with turbines using waterfalls or river water flow (Yusmartato et al., 2022; Saepul Uyun & Novianto, 2020).

In the utilization of hydropower, the type of water turbine is selected based on the water discharge and the height of the waterfall. One of the most efficient types of turbines for generating electrical energy is the crossflow turbine, which has an efficiency of up to 82%. This is due to the fact that crossflow turbines use twice the water energy, which produces water thrust on the blades as the water leaves the runner, indicating that this multistage water work increases the effectiveness and ease of the water output system on the runner (Putu Andrean Wiranata et al., 2020; Saleh et al., 2019). However, to determine the flow of water that has a water fall height is very difficult because the terrain is very far and heavy. So with this research made a model of picohydro power plant (Picohydro Power Plant) using crossflow turbine to determine the voltage generated.

THEORETICAL REVIEW

Literature Review

Several previous studies have investigated the power capacity of water to generate hydroelectricity. (Bandri et al., 2021; Suyanto et al., 2021) utilized an externally hinged blade kinetic turbine to generate electricity on a picohydro scale. The method used is a real experiment. The study looked at how increasing the number of blades on a kinetic turbine (e.g., a hinged turbine with hinges on the outside of the *runner*) impacts (Boedi et al., 2022). The design of a low-speed Picohydro power generation system involves the use of a screw turbine. *The performance of the screw turbine is influenced by bonded parameters and parameters that are important for design, such as blade pitch / period, tilt angle, rotation, and water discharge* (Suyanto et al., 2021). This research focuses on modeling a picohydro power plant (Picohydro Power Plant) using a crossflow turbine. The purpose of this research is to be a reference for the development of water potential for new renewable energy in power generation in the future (Bandri et al., 2021).

METHODOLOGY

This research was conducted at the Electrical Engineering Laboratory of Muhammadiyah University of Palembang. This research begins with the process of designing and manufacturing the Picohydro Power Plant frame and crossflow turbine, and continues with the process of testing the tool and collecting test data.

Type of Research Data

The data used in this study were obtained from the modeling of Picohydro Power Plant directly in the field. The results of the design calculation are in accordance with the planning parameter data, and the measurement results are directly obtained during the process of testing the Picohydro Power Plant model using a *crossflow* turbine during load and no load, and during battery charging.

Research Stages

The stages of this research were carried out in two stages which included:

Design and Manufacture of an Picohydro Power Plant Model

Data generated from the geothermal system planning and the *crossflow* turbine used in the geothermal system model (Tabel 1). Fig.1 and Fig.2 below show an design of the *Picohydro* power plant model using a crossflow turbine.

Table 1. Planning Data of the Geothermal System

Parameters	Value
Water tank	200 lt
Truss length	250 cm
Frame height	250 cm
Frame width	100 cm
Water discharge	0.0036 m /s ³

Table 2. Turbine Design Data

Item Name	Parameters	Value
Runner	Outside diameter	0,26 m
	Blade inlet angle	15°
	Blade outlet angle	45°
Power House	Housing Length	1 m
	Housing Width	0,50 m
	High Housing	0,70 m
Nozzle	Nozzle width diameter	0.025 m
DC Generator	Voltage	24 V
	Current	1 A
	Rotation speed	1500 Rpm

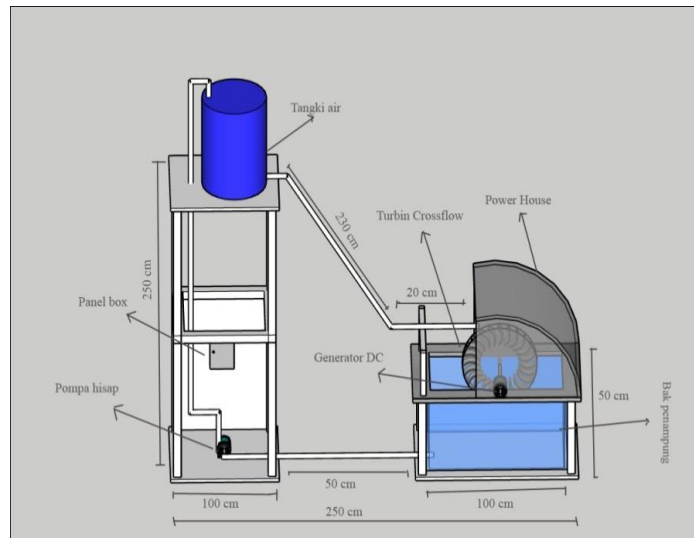


Figure 1. Prototype of the Geothermal Power Plant

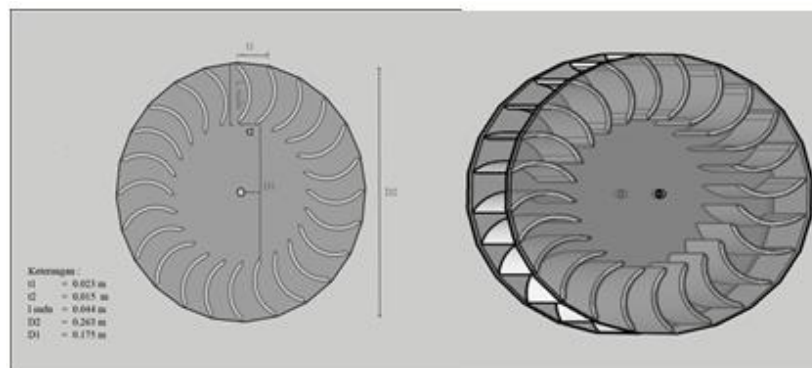


Figure 2. Crossflow Turbine Design

The flowcharts of the stages of how the picohydro power plant model works are Fig.3.

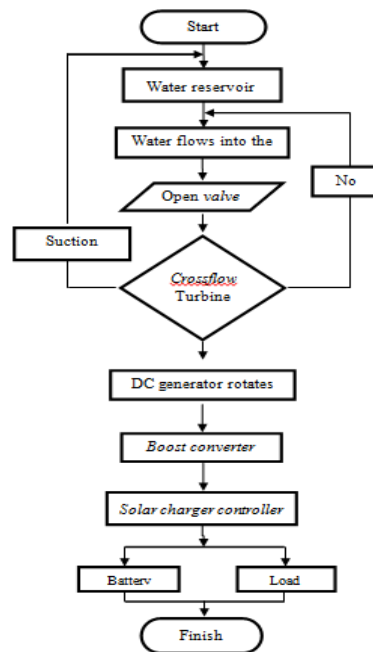


Figure 3. Tool Flowchart Picohydro Power Plant Model

Test on the Performance of the EHP Model

The following stages of testing the performance of the *crossflow* turbine on the Picohydro Power Plant model using loading or no load and testing the Picohydro Power Plant model in an OFF-Grid state when charging a 12 V 12 Ah battery can be seen in Fig.4, Fig. 5, and Fig. 6.

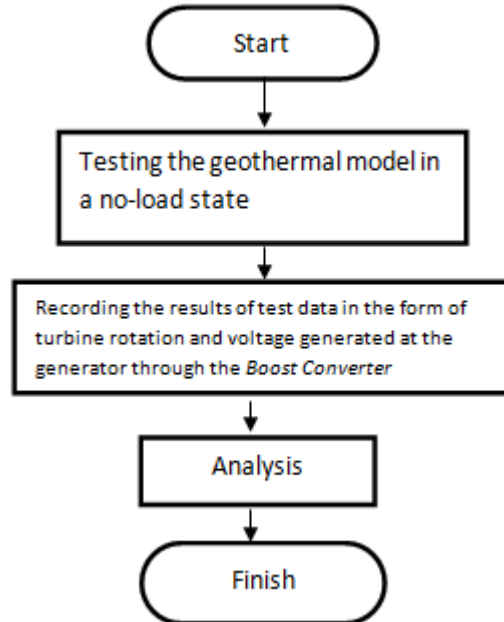


Figure 4. Flowchart of the Model Testing Using *Crossflow* Turbine Without Load

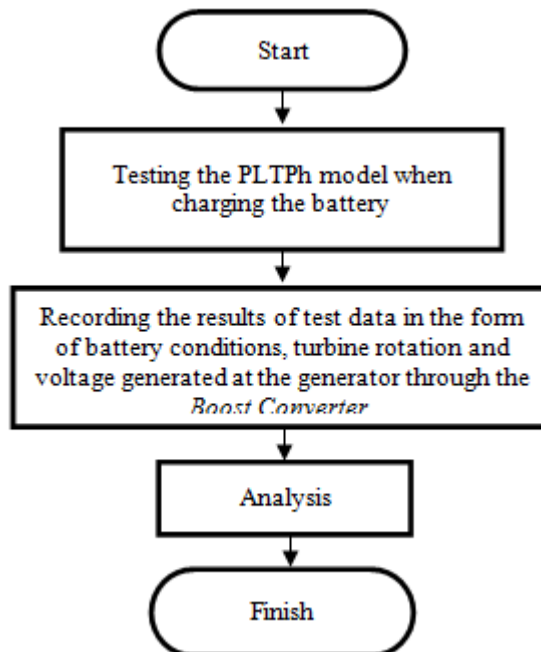


Figure 5. Flowchart of Testing Load Variations on the Model of Picohydro Power Plant

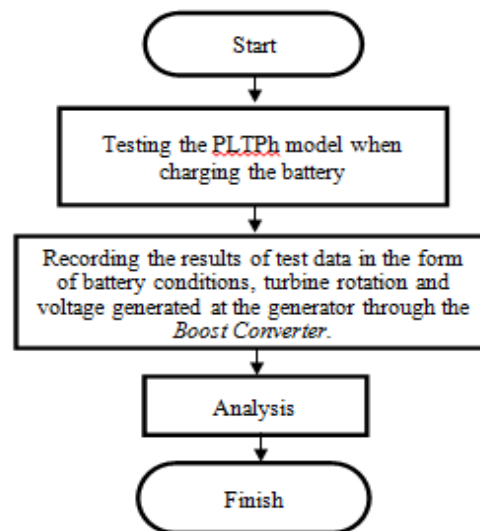


Figure 6. Flowchart of Testing the Model in the Battery Charging State

The no-load testing phase of the Picohydro Power Plant includes measuring the rotation of the turbine and the voltage produced by the generator through the *boost converter*, Voltage measurements are made using a multimeter when the generator is operating. This measurement is carried out for two minutes using a tachometer by placing the tip of the tachometer to the turbine shaft. The testing phase of load variation on Picohydro Power Plant begins with preparing the light source for testing. Variations in LED lamp power are carried out in stages, starting from 5 Watts, 10 Watts, and 15 Watts. The test results show the turbine rotation, current, voltage, and generator power generated through the *boost converter*. Test measurements are intermittent for two minutes until the water in the reservoir runs out and is refilled by the suction pump, measurements are made using a tachometer and multimeter.

The testing phase of the Picohydro Power Plant model in the battery charging state includes the condition of the battery from the beginning to the end of charging, turbine rotation, voltage, current and power produced by the generator through the *boost converter*, the length of the battery charging test lasts for approximately two minutes until the water reservoir runs out and is refilled by the suction pump so that the turbine can work again, this test was carried out 10 times using measuring instruments tachometer, multimeter and SCC. The battery used in the test is a 12 V 12 Ah battery.

RESULTS AND DISCUSSION

Model Design of a Thermal Power Plant System Using a Crossflow Turbine

In this model, the design is divided into two parts: the geothermal system design and the *crossflow* turbine design. The flow used in this geothermal system uses a closed flow, namely PVC pipes of different sizes. In the design of the Picohydro Power Plant system model using a water fall height of 2.5 meters, which has a water discharge of $0.0036 \text{ m}^3 / \text{s}$ and a water velocity in section 1 of 1.80 m/s , the water velocity in section 2 of 7.2 m/s . Assuming a nozzle coefficient of 0.98, a nozzle width of 0.26 meters, and a water inlet angle of 15° . The following

are the results of data from the design of the Picohydro Power Plant system, which can be seen in Table 3.

Table 3. Data on the Design of the Geothermal System

Parameters	Value
Water tank	200 Lt
Capacity Water discharge	0.0036 m /s ³
<i>Nozzle</i> coefficient (C)	0,98
<i>Nozzle</i> width (L) _n	0,26 m
Water entry angle (α)	15°
<i>Head</i>	2,5 m
Water velocity of cross section 1	1.80 m/s
Water velocity of cross section 2	7.2 m/s

The design of the crossflow turbine obtained design data from the height of falling water and other parameters, obtained a large turbine outer diameter of 0.26 m, an inner diameter of 0.173 m, a runner width of 0.085 m and a total of 35 blades. For the overall design data of the crossflow turbine used in the geothermal power plant system model can be seen in Table 4 below.

Table 4. Crossflow Turbine Design Data

Parameters	Value
Outside diameter	0,26 m
Inside Diameter	0,173 m
<i>Runner</i> width	0.085 m
Distance between outer blades	0,023m
Distance between inner blades	0,015 m
Blade width	0.044 m
Blade curvature	0,028 m
Number of blades	35 blades

Here is an overall picture of the design of modeling *picohydro* power generation systems (Picohydro Power Plant) using crossflow turbines, which are obtained from the results of the data obtained in the tables above. Can be seen in Figures 7 and Figure 8.



Figure 7. Overview of the Whole Thermal Power Plant System



Figure 8. Model of 35-bladed *Crossflow* Turbine

Performance Testing of Modeling of an Picohydro Power Plant System Using a Crossflow Turbine

The performance testing on picohydro power plant modeling includes three steps:

Testing of no-load Thermal Power Plant

The parameters of this test are the measurement of turbine rotation and the maximum voltage produced by the generator before going through the *boost converter*. The results of the average measurement of parameters in the picohydro power plant test in a no-load state are presented in Table 5.

Table 5. Test Results of No-Load Geothermal Power Plant

Turbine rotation (Rpm)	Generator Voltage (V)
419	7,24
421	7,29
415	6,92

In Table 5, which shows the average results of the Picohydro Power Plant system modeling test in a no-load state, the highest turbine rotation is 421 Rpm and the highest voltage produced by the generator before going through the *boost converter* is 7.29 V, also obtained the lowest turbine rotation of 415 Rpm which produces a generator voltage of 6.92 V.

Testing of the Geothermal System Under Load Variation Conditions

This test measures turbine rotation, voltage, current, and power through the *boost converter*. The measurement results for testing the modeling of the geothermal system under load variation conditions are presented in Table 6.

Table 6, which shows the test results of the Picohydro Power Plant system in a state of load variation, shows that the highest turbine rotation is 426 Rpm with a load variation of 5 Watt LED lights, and the highest voltage is 12.96 V. Table 6 also shows that the 10 Watt LED lamp load variation test at 425 Rpm also produced the highest turbine rotation of 12.89 V. In the test on the variation of the 15 Watt LED lamp load, the highest turbine rotation was obtained at 423 and the resulting voltage was 12.86 V.

Table 6. Test Results of Picohydro Power Plant State of Load Variation

Lamp power (W)	Turbine rotation (rpm)	Output		
		V (V)	I (A)	P (W)
5	426	12,96	0,26	3,36
	425	12,94	0,26	3,36
	418	12,87	0,26	3,34
10	425	12,89	0,43	5,54
	421	12,86	0,43	5,52
	415	12,77	0,43	5,49
15	422	12,86	0,52	6,68
	423	12,86	0,52	6,68
	417	12,79	0,52	6,65

However, the measurement results of the 15 Watt LED lamp load variation showed a current of 0.52 A and a power of 6.68 Watt. In this test, it was found that increasing the load applied to the generator causes a decrease in the voltage produced, and the armature reaction causes a *drop* at the generator terminals. Increased generator torque due to anchor reaction and increased load current will increase the generator output current and power.

Testing of the Picohydro Power Plant System in Battery Charging State

In this battery charging test, a battery with a capacity of 12V 12 Ah is tested, where the battery is charged with electrical energy generated by the turbine and it will be seen how much the voltage increases on the battery during charging. Every 5 minutes the battery capacity will be recorded some increase in battery voltage using a multimeter. The measurement data is seen in the following Table 7. Based on the table above, this is the data of the first test results of Picohydro Power Plant in a state of battery charging, also obtained the highest rotation generated in the generator of 12.98 V, also obtained the highest rotation generated by the turbine of 428 rpm, and the current at the time of charging the battery is 0.535 A, the initial battery capacity of 12.04 until the first test is completed, the final battery capacity is 12.15 V. Based on the table is also the data of the second test results of Picohydro Power Plant in the battery charger state, obtained the highest voltage generated by the generator of 12.98 V, also obtained the highest rotation generated by the turbine 428 rpm and the current at the time of battery charge battery of 0.53 A, the initial battery capacity of 12.15 until the first test is completed obtained the final battery capacity of 12.25 V.

Table 7. System Testing of Picohydro Power Plants Under Battery Charging Conditions

Testing	Turbine Speed (rpm)	Volt (V)	I (A)	Initial Battery	End Battery
1	428	12,98	0,54	12,04	12,06
	430	13,11	0,54	12,06	12,11
	425	12,89	0,54	12,11	12,15
2	425	12,90	0,54	12,15	12,19
	428	12,98	0,54	12,19	12,22
	422	12,87	0,54	12,22	12,25
3	430	13,09	0,54	12,25	12,27
	419	13,81	0,54	12,27	12,29
	423	12,85	0,54	12,29	12,31

Based on the table is also the data of the third test results of battery charging, obtained the highest voltage generated by the generator of 13.09 V, also obtained the highest rotation generated by the turbine 428 rpm and the current at the time of battery charge battery of 0.53 A, the initial battery capacity of 12.25 until the first test is completed, obtained the final battery capacity of 12.31 V. From the test above, it can be seen that the battery only increases from the beginning to the end by 0.06 - 0.11, due to the turbine rotation that is not too long and there is a time lag for recharging the reservoir. It takes 21 hours for Picohydro Power Plant to charge the battery from empty to full.

CONCLUSIONS AND RECOMMENDATIONS

The following are the conclusions that can be drawn from the research that has been done:

1. The design of Picohydro Power Plant modeling using a crossflow turbine with a height of 2.5 meters in a closed channel obtained a water discharge of 0.0036 m³/s. Based on the results of the calculation of crossflow turbine parameters, the size of the outer diameter of the runner is 0.263 m, the inner diameter of the runner is 0.175 m, with a distance between blades of 0.023 m, blade width of 0.044 m and the number of blades is 35 pieces.
2. The test results of Picohydro Power Plant when unloaded produce an average turbine rotation of 415.6 rpm and a maximum generator output voltage of 7.11 V, also obtained test results when the load produces a turbine rotation of 415.6 - 426.1 rpm, and the voltage generated through the boost converter is 12.74 V - 12.87 V.
3. The results of the Picohydro Power Plant test when the 12V 12Ah battery charge produces an average voltage of 12.78 V during battery charging with an average turbine speed of 420.96 rpm, it takes 21.42 hours to charge.

FURTHER STUDY

Still conducting further research to find out more about Modeling Design of Picohydro Power Generation System Using Crossflow Turbine.

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