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Performance Analysis of Micro-Hydro Plants Using Crossflow Turbines at Varying Water Fall Heights

Arum Kusuma W.*, Dezetty Monika, M. Rasyid Lubis, Rafi Ariansyah, M. Arifin, A. Damar Aji
Program Studi Teknik Listrik, Jurusan Teknik Elektro – Politeknik Negeri Jakarta
Depok, Indonesia
*arum.kusumawardhany@elektro.pnj.ac.id

Abstract – *Hydropower plants have limitations in scalability and location, as they require large water flows and complex infrastructure. One solution to overcome these drawbacks is portable hydroelectric power plants, which are more flexible and adaptable to variations in water level. Portable geothermal power plants allow the regulation of water fall height to optimise their performance, especially in remote areas that are not reached by conventional power grids. This research aims to develop the performance of portable geothermal power plants by utilising variations in water level to analyse the performance of the effect of water fall height on the performance of portable geothermal power plants with crossflow turbines. This research uses an experimental method, which involves collecting and analysing data from the height of (variation 1) and (variation 2) to determine the performance of the Pico Hydro Power Plant (PLTPh). The research was conducted at Mahogany Lake, University of Indonesia. The data collected includes measurements of voltage, current, power, and rotation speed of the turbine and generator at different altitude variations to determine the effect of water fall height on the performance of PLTPh with crossflow turbines. The results showed that the height of the water fall can affect the performance of the Pico Hydro Power Plant (PLTPh). At the height (variation 1), the power and output voltage generated are higher than the height (variation 2). In addition, the output voltage is also greater when the generator is operating without load. This difference shows that variations in altitude, flow speed and water discharge entering the turbine cross section greatly affect the rotation of the generator and the amount of electrical power generated by the PLTPh.*

Keywords – *Crossflow Turbine; PLTPh; Variation; Water Discharge; Water Fall.*

I. INTRODUCTION

ONE type of hydropower is the Pico Hydro Power Plant (PLTPh), which is a power plant that utilises mechanical energy from the potential energy of water. Energy from the flow of water, which is used to rotate the turbine connected to the generator for energy absorption, occurs by rotating the turbine to move the generator so as to produce electrical power [1]. PLTPh does not cause damage to the ecosystem. PLTPh is designed to produce power around 100W to 5KW and utilise water as the driving force. Because our country is located in the tropics, new energy in Indonesia is very abundant. For example, solar energy is available every day. In addition, high rainfall in the tropics results in a high amount of water, so hydro energy is a huge source of electrical energy [2].

Micro-hydro, also known as small-scale power generation, uses water energy such as irrigation canals, rivers, or natural waterfalls by utilising the head and amount of water discharge [3]. Technically, picohydro consists of the words ‘Piko’, which means ‘small’, and ‘hydro’, which means ‘air’. Technically, a picohydro consists of three main parts: water (as the energy source), a turbine, and a generator. Picohydro derives energy from the flow of water of different heights. Basically, it utilises the potential energy of falling water (head) [4]. The higher the water fall, the more water energy can be converted into electricity [5].

The use of crossflow turbines provides more advantages when compared with the use of waterwheels or other types of picohydro turbines [6]. A crossflow turbine with its high efficiency is due to the use of water energy in this turbine occurring twice. The crossflow turbine’s high efficiency is attributed to its unique design, allowing water to interact with the runner twice [7]. Recent studies have shown that efficiencies of 88-90% can be achieved through proper nozzle and runner design [8]. The use of double noz-

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zles can double power output without compromising efficiency [9, 10]. Key factors influencing efficiency include water entry angle, diameter ratio, blade number, flow-stream spreading, runner aspect ratio, and blade exit angle [11]. Computational fluid dynamics and experimental studies have been used to optimize turbine design [12, 13]. The crossflow turbine's simple design makes it economical and suitable for small hydropower plants in developing countries [7]. Ongoing research aims to further improve efficiency and adapt the turbine for variable flow rates [13, 14]. First, the impact energy of water against the turbine blade where water flows in, then the second is the thrust of water against the blade when the water passes out of the runner. The following gradual water performance conditions cause advantages in terms of good effectiveness and ease in the water output system from the runner [15].

The design parameters that affect the picohydro power plant turbine (PLTPh) are the point of water fall, the number of angles, the shape of the angle, and the diameter of the turbine [16]. This study will analyse several important aspects related to the effect of variations in water fall height on the performance of the Pico Hydro Power Plant (PLTPh) with a crossflow turbine. This study examines the effects of water fall height variations on Pico Hydro Power Plant performance using crossflow turbines. Research shows that increasing water fall height generally improves turbine efficiency and power output [17, 18]. Blade design, including depth and number, significantly impacts turbine performance [19, 20]. Optimal nozzle positioning and waterfall thickness are crucial for maximizing efficiency [18, 21]. Crossflow turbines are suitable for low-head applications with high water discharge, making them ideal for rural or isolated areas [22, 23]. However, efficiency may decrease with load power increases [24]. Overall, crossflow turbines offer a simple, easily maintainable solution for pico-hydro power generation, with potential efficiencies reaching up to 68% under optimal conditions [23].

First, this study will analyse the difference in output power generated at two different heights (variation 1 and variation 2), to determine the extent to which the height of the water fall affects the amount of electric power generated [25]. In addition, this study will also look at how the height variation affects the output voltage, both under load and no-load conditions, and observe the effect of height on the rotation speed of the turbine. The relationship between water fall height and water discharge [26] will be analysed to understand its impact on the overall efficiency of the geothermal system.

Furthermore, this study will also examine how altitude variations affect the output voltage and current of the system [27]. The results of this study are expected to provide an overview of the performance of the PLTPh in utilising variation 1 for a height of 30 cm and variation 2 for a height of 50 cm from the legs of the turbine frame to the point of water fall that will produce efficient electrical energy.

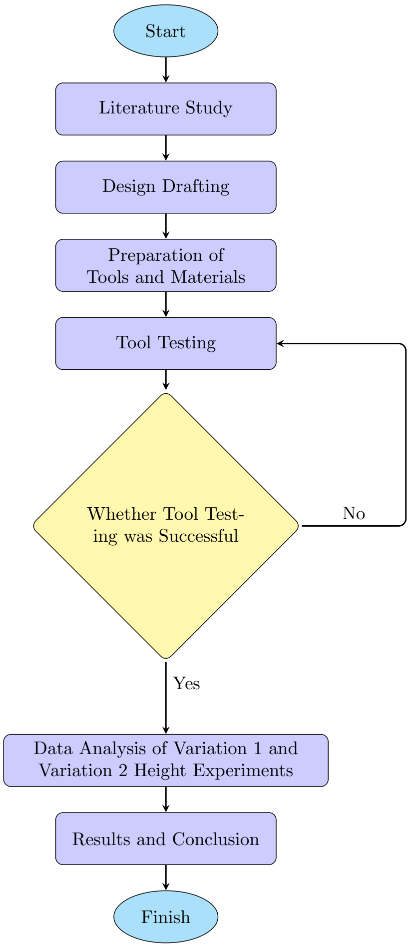

Figure 1: Research flow scheme

II. Research Methods

This research was conducted using the experimental method, in which the height variation of the geothermal power plant frame was set to adjust the water falling point. There were two height variations tested: 30 cm (variation 1) and 50 cm (variation 2). This difference in height aims to evaluate the effect of water fall height on the performance of the PLTPh, so that the optimal efficiency and power generated by the turbine can be found. The following is a schematic of the flow of research conducted in Figure 1.

i. Testing Methods

Tests were conducted with several variations, including variations in water fall height, variations in loaded and unloaded conditions, and variations in water discharge and flow velocity. At each variation, data was collected for further analysis.

The water drop height is set at two points, 30 cm (variation 1) and 50 cm (variation 2), to see the difference in turbine performance in generating electrical power.

Tests were conducted on the turbine with load and without load conditions. In the no-load condition, measurements were taken to determine the voltage and current generated without external resistance. While in the loaded condition, the output power of the generator is measured based on the current and voltage values at a given load.

The test points were also carried out at locations that have different water discharge and flow velocities. This is done to see how changes in water discharge and velocity affect the power generated by the geothermal plant.

For the measurement procedure, trials and data collection were carried out which can be described as follows:

1. **Preparation Before Testing**: Ensure all equipment is installed properly, the IoT system is working, and the water flow is stable.
2. **PLTPh Framework Height Setting**: Set the PLTPh frame at the first height, which is 30 cm, with the water flow right into the turbine.
3. **System Testing at 30 cm Height**: Start the test by flowing water from a height of 30 cm while monitoring the IoT system recording data.
4. **Data Capture at 30 cm Height**: Record voltage, current, generator RPM, turbine RPM, and water discharge every 10 minutes.
5. **Second Height Setting**: Raise the height of the PLTPh frame to 50 cm and ensure that the water flow remains stable.
6. **System Testing at 50 cm Height**: Repeat the test by flowing water from a height of 50 cm and monitor the IoT system.
7. **Data Capture at 50 cm Height**: Record the voltage, current, generator RPM, turbine RPM, and water discharge at a height of 50 cm every 10 minutes.
8. **Data Analysis**: Compare the data from both height variations to calculate the power and efficiency of the geothermal system.

III. RESULTS AND DISCUSSION

The purpose of this test is to measure the basic performance of the PLTPh system in the absence of additional loads, in order to determine the maximum voltage and turbine rotation that can be achieved without resistance from external loads.

i. Variation 1 Without Load

At a height of 30 cm, the water velocity varied between 1.2 m/s to 1.6 m/s, while the water discharge stabilized at 0.03 to 0.04 m³/s. Turbine rotation ranged from 444 rpm to 498 rpm, with higher generator rotation, reaching 529 rpm to 585 rpm. The voltage generated also showed higher values, ranging from 16.15 V to 17.23 V, as shown in Table 1.

Table 1: Variation 1 Without Load

Velocity (m/s)	Discharge (m³/s)	Turbine RPM	Generator RPM	Voltage (V)
1.2	0.03	444	529	16.15
1.4	0.03	467	557	16.85
1.5	0.04	483	570	17.10
1.6	0.04	498	585	17.23

The relationship between water velocity and voltage is shown in Figure 2.

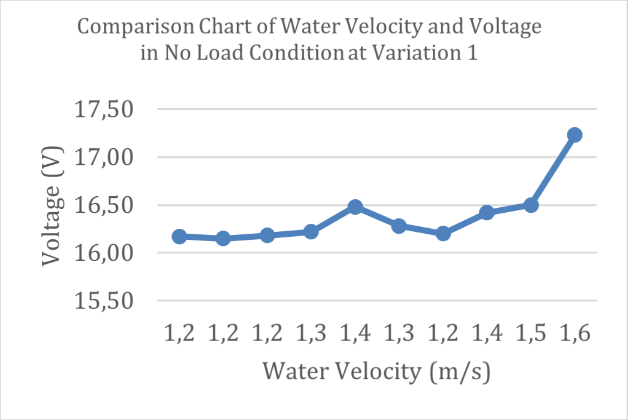

Figure 2: Comparison of Water Velocity and Voltage in No-Load Condition at Variation 1

Figure 2 indicates the influence between the water flow velocity and the voltage generated. In general, both trends show an increase in voltage as the water flow velocity increases.

ii. Variation 2 Without Load

In contrast, Table 2 shows the results for a height of 50 cm. Although the water discharge remains constant at 0.03 m³/s and the water velocity is more stable between 1.1 m/s to 1.2 m/s, the turbine and generator rotations are lower than the 30 cm height variation. Turbine rotation only reached 381 rpm to 435 rpm, and generator rotation ranged from 435 rpm to 481 rpm. The voltage produced is also lower, with values ranging from 13.85 V to 14.66 V.

Table 2: Variation 2 Without Load

Velocity (m/s)	Discharge (m³/s)	Turbine RPM	Generator RPM	Voltage (V)
1.1	0.03	381	435	13.85
1.15	0.03	398	452	14.12
1.18	0.03	415	469	14.33
1.2	0.03	435	481	14.66

The graphical comparison between water velocity and voltage is illustrated in Figure 3.

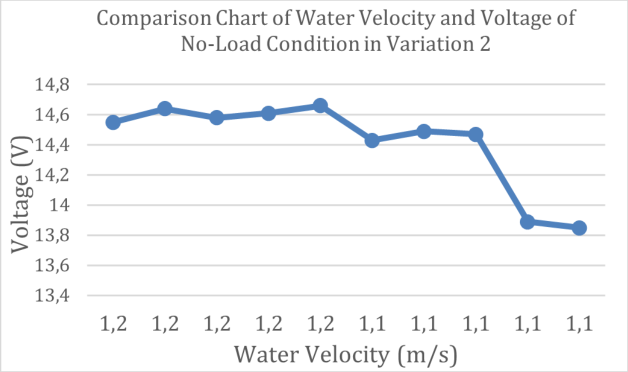

Figure 3: Comparison of Water Velocity and Voltage in No-Load Condition at Variation 2

Figure 3 illustrates the relationship between water flow velocity and voltage under certain conditions, namely when there is no additional load. The graph shows a downward trend in voltage along with a decrease in water flow velocity. This means that when the water velocity decreases, the voltage generated is also lower. Although there is a downward trend, there are minor variations in the voltage values. This could be due to factors such as instability of the water flow or external influences affecting the measurement.

From these results, it can be concluded that a height of 30 cm is more efficient in generating higher voltage and turbine rotation speed, making this height more optimal for a no-load PLTPh system. Variation 1, with a lower height, provides better performance in terms of electrical power generation, demonstrating the impact of water fall height on system performance. This test is essential to understand how changes in water discharge and velocity affect the power output of the hydroelectric system.

iii. Results of 1-Lamp Load Testing

This test aims to evaluate the performance of the system when given one lamp as a load, focusing on how the turbine and generator respond to the load, as well as observing changes in voltage and rotation generated.

Variation 1 with 1 Lamp Load. Table 3 shows the results for variation 1 with a load of 1 lamp at a height of 30 cm. The water velocity is stable at 1.3 m/s, with the highest water velocity recorded at 08:40, reaching 1.6 m/s, while the water discharge remains constant at 0.03 m³/s. Turbine rotation ranged from 460 rpm to 491 rpm, while generator rotation reached 551 rpm to 578 rpm. The resulting voltage varied between 8.89 V to 9.15 V, with a current between 0.20 A to 0.28 A, producing a power between 1.78 W to 2.58 W.

Table 3: Variation 1 with 1 Lamp Load with WV: Water Velocity, WD: Water Discharge, TR: Turbine Rotation, GR: Generator Rotation, V: Voltage

Time	**WV (m/s)**	**WD (m³/s)**	**TR (rpm)**	**GR (rpm)**	**V (V)**
08:00	1.3	0.03	460	551	8.89
08:20	1.4	0.03	472	563	9.02
08:40	1.6	0.03	491	578	9.15

The relationship between water velocity and voltage is shown in Figure 4.

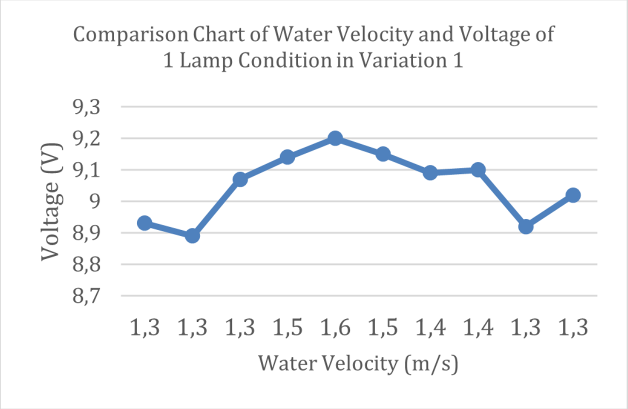

Figure 4: Comparison Chart of Water Velocity and Voltage of 1 Lamp Condition in Variation 1

Figure 4 shows the comparison of the relationship between water flow velocity and voltage under load conditions with one lamp. The graph shows a fairly significant voltage increase, even though there is a rising trend at a water velocity of 1.4-1.5 m/s. When compared to the previous graph of the no-load condition, it is evident that the presence of the load results in a greater voltage condition. This demonstrates that the electrical load affects the system's performance and the relationship between water flow velocity and voltage.

Variation 2 with 1 Lamp Load. In contrast, Table 4 presents the results for variation 2 at a height of 50 cm. Although the water velocity and water discharge remained stable at 1.3 m/s and 0.03 m³/s, the turbine rotation only reached 450 rpm to 463 rpm, and the generator rotation ranged from 522 rpm to 555 rpm.

The voltage produced was lower, between 8.46 V to 8.98 V, with a current between 0.15 A to 0.22 A, and the power produced varied from 1.27 W to 1.98 W.

Table 4: Variation 2 with 1 Lamp Load. WV: Water Velocity, WD: Water Discharge, TR: Turbine Rotation, GR: Generator Rotation, V: Voltage

Time	WV (m/s)	WD (m³/s)	TR (rpm)	GR (rpm)	V (V)
08:00	1.3	0.03	450	522	8.46
08:20	1.3	0.03	457	540	8.76
08:40	1.3	0.03	463	555	8.98

The graphical comparison between water velocity and voltage is illustrated in Figure 5.

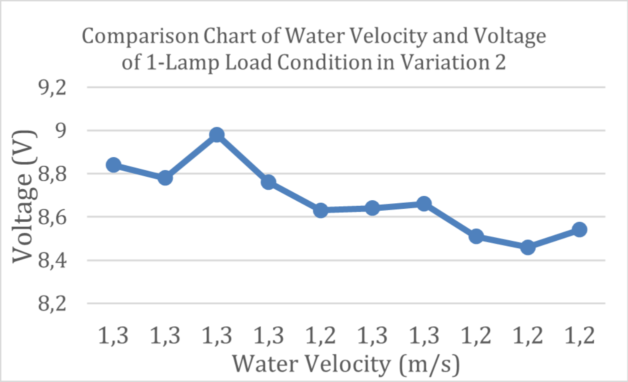

Figure 5: Comparison Chart of Water Velocity and Voltage of 1-Lamp Load Condition in Variation 2

Not much different from Figure 4, Figure 5 also shows a decrease in voltage caused by the increase in load. From Table 4 and Figure 5, it can be concluded that the height of 30 cm is more efficient in producing higher voltage, current, and electrical power. Thus, this height is more optimal for the loaded PLTPh system. Variation 1, with a lower height of 30 cm, performs better in terms of electrical power generation, further emphasizing the impact of the water fall height on performance.

iv. Results of 2-Lamp Load Testing

This test aims to evaluate the comparative performance of the system when given two lamps as a load, focusing on how the turbine and generator respond to the load, as well as observing the changes in voltage and rotation generated.

Variation 1 with 2 Lamps. Table 5 presents the results for variation 1 at a height of 30 cm. The water velocity stabilises at 1.2 m/s with a constant water discharge of 0.03 m³/s. Turbine rotation ranged from 438 rpm to 450 rpm, while generator rotation reached 521 rpm to 542 rpm. The voltage produced varied between 8.48 V to 8.62 V, with a current between 0.37 A to 0.43 A, producing power between 3.04 W to 3.71 W.

Table 5: Variation 1 with 2 Lamps with WV: Water Velocity, WD: Water Discharge, TR: Turbine Rotation, GR: Generator Rotation, V: Voltage

Time	WV (m/s)	WD (m³/s)	TR (rpm)	GR (rpm)	V (V)
08:00	1.2	0.03	438	521	8.48
08:20	1.2	0.03	445	530	8.55
08:40	1.2	0.03	450	542	8.62

The comparison of the relationship between water flow velocity and voltage under load conditions with two lamps is shown in Figure 6.

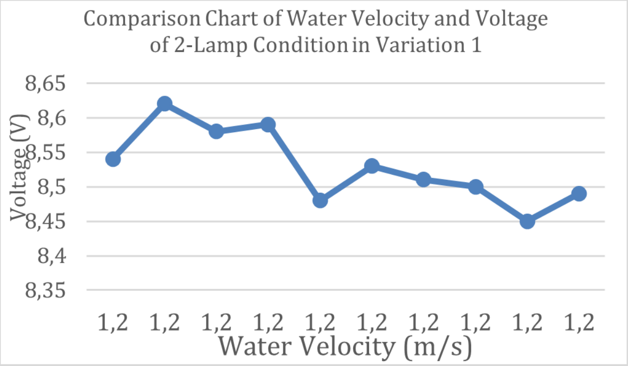

Figure 6: Comparison Chart of Water Velocity and Voltage of 2-Lamp Condition in Variation 1

Figure 6 shows the comparison of the relationship between water flow velocity and voltage under 2-lamp load conditions. The graph indicates a significant decrease in voltage compared to Figure 4, which represents the 1-lamp load condition. There is also a tendency for a decrease in water velocity, which can affect the voltage drop factor.

Variation 2 with 2 Lamps. In contrast, Table 6 presents the results for variation 2 at a height of 50 cm. Although the water velocity and water discharge remained stable at 1.3 m/s and 0.03 m³/s, the turbine rotation only reached 429 rpm to 460 rpm, and the generator rotation ranged from 516 rpm to 545 rpm. The voltage produced was lower, between 8.34 V to 8.88 V, with a current between 0.34 A to 0.45 A, and the power produced varied from 2.84 W to 4.00 W.

Table 6: Variation 2 with 2 Lamps with WV: Water Velocity, WD: Water Discharge, TR: Turbine Rotation, GR: Generator Rotation, V: Voltage

Time	WV (m/s)	WD (m³/s)	TR (rpm)	GR (rpm)	V (V)
08:00	1.3	0.03	429	516	8.34
08:20	1.3	0.03	445	532	8.65
08:40	1.3	0.03	460	545	8.88

The relationship between water velocity and voltage in variation 2 with two lamps is illustrated in Figure 7.

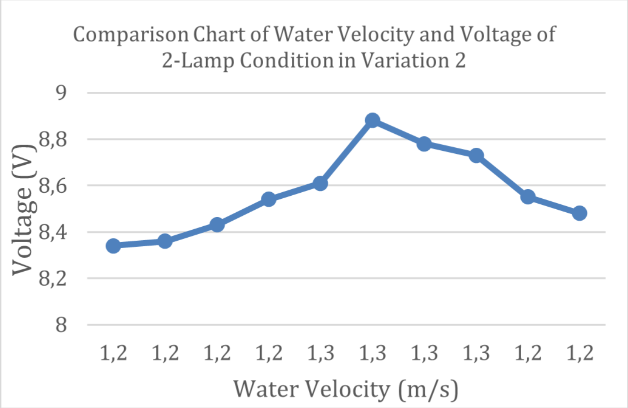

Figure 7: Comparison Chart of Water Velocity and Voltage of 2-Lamp Condition in Variation 2

Based on Figures 6 and 7, the 2-lamp load test results show a decrease in rotation due to the load. Both turbine and generator rotations decrease when the applied load increases, indicating additional resistance, which causes the generator rotation to be slower than in a no-load condition. This happens because the torque required to produce additional electrical energy cannot be fully met by the generator.

IV. CONCLUSION

Based on the results and discussion previously presented, it can be concluded that the effect of water fall height on the performance of the PLTPh is very significant. Specifically, a height of 30 cm (variation 1) is more efficient than a height of 50 cm (variation 2) in producing voltage, turbine rotation, and generator rotation, both in no-load and load conditions. Furthermore, under no-load conditions, the 30 cm height produces higher voltage and turbine rotation speed, with the highest voltage reaching 17.23 V and turbine rotation up to 498 rpm. In addition, the 1-lamp load test indicates that the 30 cm height generates more power, with the highest recorded output of 2.58 W, compared to the 50 cm height which only achieves a peak power of 1.98 W. Similarly, the 2-lamp load test also demonstrates that the 30 cm height results in greater power output, with a maximum of 3.71 W, whereas the 50 cm height reaches a maximum power of only 4.00 W at higher currents. Therefore, it can be stated that the lower water fall height (30 cm) consistently provides more optimal performance of the geothermal system in terms of voltage, turbine rotation, and electrical power generated, under both no-load and lamp-loaded conditions.

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