Effect of Intake Variations on Vortex Hydro Turbine Performances

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Abstract. Pico hydro Power Plant (PLTPH) is a small-scale hydroelectric power plant that utilizes the conduit of water flow by converting potential energy into mechanical energy. The vortex turbine utilizes a whirlpool formed by the vortex turbine housing to push the blades to rotate. In this PLTPH prototype research, the vortex turbine was designed with a 2050 mm penstock head, a 6 inch input pipe with the use of a nozzle as an intake with a narrowing in size from 6 inches to 3 inches, a water discharging of 37.96 L/s, a vortex turbine housing with a diameter of 590 mm, a height of 470 mm, and an outtake of 4 inches. The runner design is equipped with 8 blades with a width of 220mm, a height of 225mm with a shaft diameter of 1 inch, and a shaft length of 1060mm. The design and manufacture of this prototype requires supporting components such as: a). hanging scales; b). vortex turbines; b). tachometers; c). permanent magnet generators; e). kiprok; f). avometer. Testing the prototype of the pico-hydro power plant is carried out by measuring the voltage produced by the generator, using variations in the opening of the water flow of 50%, 75%, 100% to find the maximum rotation, and tested without load, and when coupled generator, generator-load. Based on the results of the PLTPH performance test, the largest opening produces maximum performance. The results of the no-load test with a coupled generator, the voltage is 57.5 Volts DC obtained when the valve opening is 100%, at a discharging of 30.9 L/s, rotation N(1) 104.8 rpm, (N2) 499 rpm. The output of the generator with the battery connected to the load is 30.6 Volts DC, with rotation (N1) 78.2 rpm, (N2) 373 rpm, and a current of 38.3 A and has an efficiency of 58.5%.

Keywords: Energy, PLTPH, Vortex Turbine, Head, Vortex Intake, Permanent Magnet Generator

1 Introduction

Energy is a very important requirement for human life. One of the energy that humans need is electrical energy. Many human activities use electrical energy, as well as in the home environment, industry, schools, and others. The increasing population growth in Indonesia has a strong impact on the high demand for energy, especially

R. Andrie Asmara et al. (eds.), *Proceedings of the 5th Annual Advanced Technology, Applied Science, and Engineering Conference (ATASEC) 2023*, Advances in Engineering Research 229,
https://doi.org/10.2991/978-94-6463-358-0_12

electricity, which is increasing from year to year [1]. The potential of water as an alternative energy in Indonesia is very large, its utilization can be carried out in all regions, so that hydroelectric power plants are prioritized over wind power plants. One possibility is PLTPH. Most water turbines are designed to use strong currents and large drops of water. So that the flow of water that is not too heavy is not utilized properly. The idea was born to use the flow of river water to become a current or a vortex [2]. Therefore, we are utilizing PLTPH in the river area of Gunungrejo, Kec. Singosari, Malang Regency, East Java which has an average discharge of 0.95175 m3/s and has a height of 3.34 m which will be used to supply a 3-storey building at the Al-Ikhlas Yatim Dhuafa Islamic Boarding School (PPYD) in the Gunungrejo Area , Kec. Singosari, Malang Regency, East Java.

One of the factors that influences the performance of a vortex turbine is the intake design and also the influence of the openings in the penstock pipe which functions to regulate the capacity of water entering the turbine runner. Based on previous research, it is known that the design of the turbine intake and penstock opening affects the performance of the vortex turbine. Therefore, in this research, a design will be made to suit water resources and applied to PLTPH, so it is hoped that this research can improve turbine performance with the highest efficiency.

2 Hydro Power Plant

Hydroelectric Power Plant (PLTA) is a power plant whose energy utilizes water as the driving force or main energy in the generation process. Utilization of energy from river flow that can be used is potential energy (when water falls) and also kinetic energy (when water flows). The amount of energy that is in the river can be known by the size of the moving fluid or commonly called the water discharge [3]. The output that can be generated from a Hydroelectric Power Plant (PLTA) is classified into several sections, the following is a table of differences in the output of a Hydroelectric Power Plant:

Table 1. TYPES OF HYDRO POWER GENERATION

No.	Type	Output Power (kW)
1.	Large-hydro	> 100 MW
2.	Medium-hydro	15 - 100 MW
3.	Small-hydro	1 - 15 MW
4.	Mini-hydro	> 100 kW and < 1 MW
5.	Micro-hydro	5 kW – 100 kW
6.	Pico-hydro	100 W – 5 kW

This research focuses on Pico-Hydro hydroelectric power plant that produces no more than 5 kW output power. Some advantages of this type of power plant are as follows [3][4][5]:

- Relatively cheap manufacturing cost for the turbine because it can be made from the remaining scrap metal sold in the market.
- Other components, such as generators, batteries, and turbines, are relatively inexpensive because they are easy to find in the market.
- This type of generation has very little impact on nature because it does not use fossil fuels.
- The water flow used to rotate the turbine can also be used as farming irrigation.
- Pico Hydro power generation is suitable for rural areas that far away from the electricity grid.

In this study using a vortex type turbine (vortex), namely a power plant that utilizes a whirlpool formed by the turbine house. A whirlpool vortex or spiral vortex is a meeting of two water currents that collide with each other simultaneously which then forms a spiral water loop. Vortex as a vortex which is the effect of rotational rotation where the viscosity affects it [4].

2.1 Turbine Dimensions

Some components must be taken into account in pyco hydro power generation, includes runner, bearing, and pulley. The first main component is called runner. This part is coupled with the turbine to produce rotation. Some equations related to runner are explained as follows:

1. Calculation of outside runner diameter (D1) [11]

$$D_1 = \frac{U_1.60}{\pi.n} \tag{1}$$

$$D_2 = D_1 \times 0{,}66 \tag{2}$$

Where, D_1: outside runner diameter (m); D_2: inside runner diameter (m); n: turbine rotation (rpm)

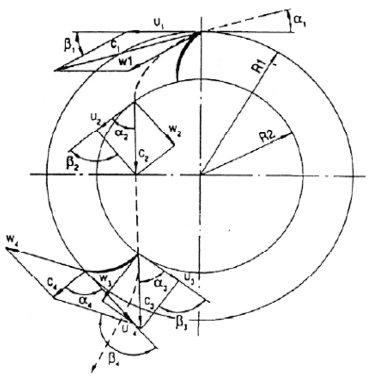

Fig. 1. Parameters of a Crossflow Turbine [12]

W1: relative speed of water entering the turbine house; C1: speed of water entering the turbine; β1: the angle of velocity of water entering the outside of the runner; U1: line speed (circumference); α1: the angle formed by absolute velocity and tangential; W2: relative speed of water coming out at level I blade; C2: speed of water coming out of the turbine; B2: the angle at which the water velocity exits on the outside of the runner; U2: speed of the line (circumference) when the water comes out of the blade; The parameters when water enters from the level II blade are C3, W3, α3, and U3. The parameters when the water comes out of the level II blade are, C4, W4, α4, and U4.

2. Calculation of Blade length
   The calculation of the blade length is based on the following equations [10]:

$$b = 0{,}006\,\frac{nQ}{kH} \tag{3}$$

   Where,
   n: turbine rotation (rpm); Q: flow capacity (m3 / s); k: coefficient of water burst thickness against runner diameter;
   H: height of falling water (m)

3. Calculation of Arc Length (LB)
   The calculation of arc length is as follows
   Calculating the value of C [10]:

$$C = \sqrt{{R_1}^2 + {R_2}^2 - 2R_1R_2\cos(\beta_1\beta_2)} \tag{4}$$

   Calculating ε:

$$\varepsilon = \sin^{-1}\left[\frac{R_2\sin(\beta_1+\beta_2)}{c}\right] \tag{5}$$

   Calculating ζ:

$$\zeta = 180^\circ - (\beta_1 + \beta\varpi_2 + \varepsilon) \tag{6}$$

   Calculating ϕ:

$$\varphi = (\beta_1 + \beta_2) - (180^\circ - 2\zeta) \tag{7}$$

   Calculating d:

$$d = \frac{R_1\sin\theta}{2\sin(180^\circ - \zeta)} \tag{8}$$

   Calculating angle of complete blade (δ):

$$\delta = 180^\circ - 2(\beta_1 + \varepsilon) \tag{9}$$

   Calculating the radius of curvature of the blade (rb):

$$rb = \frac{d}{\cos(\beta_1 + \varepsilon)} \tag{10}$$

Calculate the radius of curvature of a pitch (blade) for a blade (rp):

$$rp = \sqrt{rb^2 + R_1 - 2rbR_1\cos\beta_1} \tag{11}$$

Calculate arc length (lb):

$$lb = 2\pi . rb\left(\frac{\delta}{360°}\right) \tag{12}$$

4. Calculation of Blades Number
   The calculation of blades number is based on the following equations [13]:

$$Z = \frac{\pi D_1}{t} \tag{13}$$

Where, t is the distance between the outer blades [11]:

$$t = \frac{s_2}{\sin \beta_1} \tag{14}$$

$$S_2 = k.D_1 \tag{15}$$

Where, k is a statute (0.075 - 0.10)

5. Calculation of a plate width
   By determining the plate width (t), the runner length is calculated as [13]:

$$B = b + 2t \tag{16}$$

6. Calculation of the axis
   The calculation of the punter is based on the following formula [13]:

$$T = 9{,}74 \times 10^5 \frac{Pd}{n} \tag{17}$$

Where, Pd is the planned power (kW):

$$P_d = f_c \times P_T \tag{18}$$

Where,
FC: correction factor; PT: turbine output power
Shaft diameter can be calculated by the equation:

$$d_S = \sqrt[3]{\frac{5{,}1}{\tau a} \times Kt \times Cb \times T} \tag{19}$$

Where,
τa: allowable voltage (kg / mm2); Ct: correction factor for twisting; Cb: flexural factor
T: moment of punter

2.2 Pico Hydro Power Plant Scheme

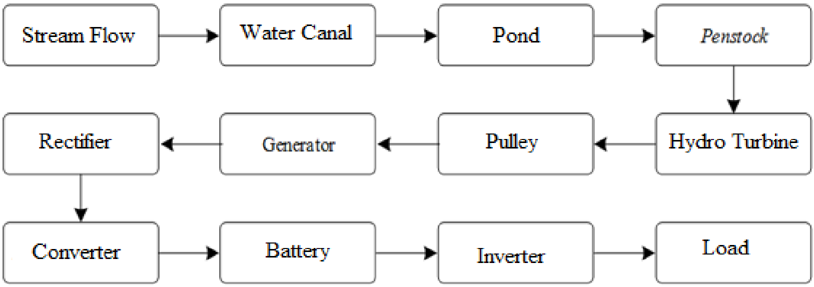

Fig. 2. PICO HYDRO POWER PLANT SCHEME

From the block diagram above, you can see the PLTPH working system until the load is connected. The potential energy of the river flow which is dammed by the dam is then channeled to the calming tank through the canal. Then from the calming tank, the water in the calming tank flows through the penstock to the turbine intake, so that the water flow hits the runner which makes the pulley rotate and the generator also rotates and produces a three-phase AC voltage, then it is rectified using a kiprok/bridge coverter to produce DC voltage, because The DC voltage output is high, then the voltage is reduced by the DC-DC Converter to 24 Volt DC for battery charging, then it is passed to the hybrid inverter to change the DC voltage to AC to supply the load.

3 Results and Discussions

3.1 Spiral Vortex Turbine House

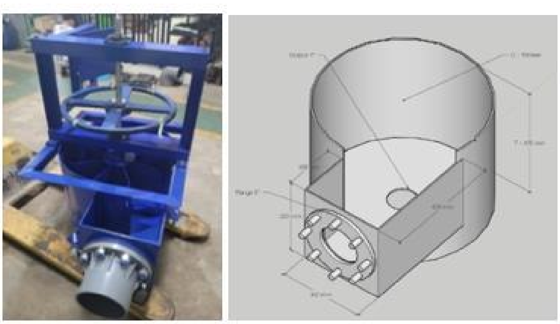

Fig. 3. SPIRAL VORTEX TURBINE HOUSE

The spiral vortex turbine house intake is connected to a 6" penstock pipe which comes from the stilling tank, while the outtake is connected to a 4" pipe, both of which are connected using a flange to make it easier to remove and install during maintenance. The outtake pipe will be reused to rotate the second turbine used in the system, namely the crossflow turbine. For the intake, an additional nozzle is given which reduces the diameter to 3", this aims to maximize the intake of the spiral vortex turbine house so that the vortex can be formed more perfectly, and the water pressure generated to rotate the runner will be higher. This uses the principle of continuity equation. The material used to make the spiral vortex turbine house uses an iron plate 6mm thick and for the intake uses an iron plate 5mm thick. All plates used use SUS 304 specifications because of the advantages of this plate being resistant to corrosive media.

3.2 Turbine Support Structure

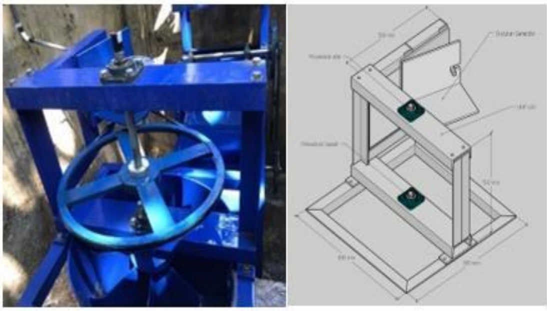

Fig. 4. TURBINE SPORT STRUCTURE

There are two blade/runner support structures using 120mm UNP iron, arranged at the top and bottom with a distance of 382mm. In each UNP, in the middle there is a hole for the runner shaft and a pillowblock is provided for support so that the runner can rotate. The frame holder attached to the spiral vortex turbine house uses angle iron measuring 50x50mm, the UNP iron support and the generator mounting frame also use angle iron of the same size. The generator mount is designed to have an adjuster hinge to make it easier to adjust the tension, remove and install the belt. The hinge adjuster is locked using a studbolt measuring M12x1.5.

3.3 Turbine Intake

There are two types of intake used for the system. The first design, the intake has an adjuster door which is used to direct the water to form a spiral vortex.

Meanwhile, in the second design, the intake type used uses a nozzle. The nozzle is used to direct water into the spiral vortex turbine house on the outside so that the vortex will form perfectly. Apart from that, the nozzle used is in a conical shape with a diameter that gets smaller at the end, from the initial diameter of the penstock measuring 6", tapering down to a size of 3 ” at the tip just before it hits the blade. The nozzle is made conical from 6 inches to 3 inches in size.

Fig. 5. Turbine Intake (a) Guide Plate (b) Nozzle

3.4 Runner

The runner is designed to have a curve at the end of each blade like the letter "L", this is intended to maximize the cross-section of the blade when pushed by a water vortex, and the selection of the number of blades of 8 refers to the results of previous research that has been carried out. The shaft used is 1060mm long. The length selection takes into account sufficient space to place the pulley and the location of the generator so that it is not too close to the water that rotates the turbine.

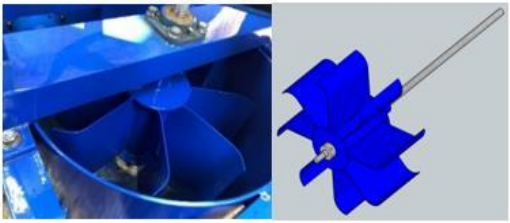

Fig. 6. Turbine Runner

The installation distance of the runner on the turbine house is around 20 cm from the base of the turbine house.

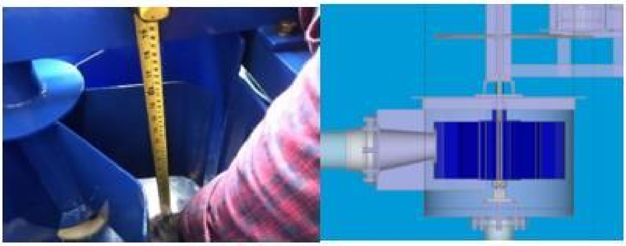

Fig. 7. Runner Position in Turbine House

3.5 Pulley System

In this system, the pulley design used is a non-stage or direct pulley design, but uses a pulley diameter comparison system that is large enough to maximize the rotation produced by the turbine and ensure that the rotation is sufficient to rotate the generator. The pulley diameter on the permanent magnet generator is 10 cm, and the pulley diameter on the turbine shaft is 50 cm, in other words the ratio used is 5:1. The belt used to connect the two pulleys uses type and size A-71.

Fig. 8. Pulley System

In power transmission on the pulley, there are rotational losses produced by the pulley. Where rotation losses in the pulley can be calculated using equations (2.13), (2.14), and (2.15). Data was obtained from turbine measurements when the generator was not connected with a turbine rpm value of 104.5 and generator rpm of 499.1.

The vortex turbine is installed in the turbine house, where the turbine body is also occupied by a crossflow turbine which is the second turbine in this PLTPH system. The turbine tub has a length of 2.6 meters and a width of 2.2 meters and has a depth of 1.5 meters in the vortex area and 2 meters in the crossflow turbine area.

3.6 Turbine Performance

3.6.1 Turbine with Guide Plate Shaped Intake

Measuring the flow of flowing water is based on the size of the river which will later be channeled to operate the turbine. From direct measurements in the field the following data was obtained.

Table 2. Water Discharge Measurement

No	Time (s)	Q (m3/s)	Q (L/s)
1	8,87	1,0118	1011,8354
2	10,97	0,8181	818,1386
3	9	0,9972	997,2200
4	9,16	0,9798	979,8013

The results of the turbine rotation test with the intake type with a guide plate showed the following results:

Table 3. THE TURBINE ROTATION WITH A GUIDE PLATE SHAPED INTAKE

No	Guide plate open	RPM		Voltage (V DC)	Hydro speed (m/s)	Q (m^3/s)	Remark
		Tur-bine	Generator				
1	100%	43	-	-	1,442	0,0262	not connect-ed to generator
2		39	-	-	1,343	0,0244	
3		40	-	-	1,489	0,0271	
1		40	225	25	1,353	0,2468	connected to generator
2		41	223	24	1,254	0,0228	
3		38	226	26	1,340	0,0244	
1	50%	60	-	-	1,580	0,0288	not connect-ed to generator
2		63	-	-	1,597	0,0291	
3		61	-	-	1,518	0,0277	
1		58	250	29	1,509	0,0275	connected to generator
2		56	247	27	1,506	0,0274	
3		57	249	28	1,605	0,0292	

The data marked with coloring is the highest data when carrying out the experiment. Discharge calculations are carried out by taking water speed data, then calculating. An example of the calculation process for experimental data number 1 in the table above with a recorded time of 10.54 s, the discharge calculation using equation (1) is as follows :

$$
\begin{aligned}
Q &= \left(\frac{1}{4} \times \pi \times (d)^2\right) \times \left(\frac{l}{t}\right) \\
&= \left(\frac{1}{4} \times 3{,}14 \times (0{,}1524)^2\right) \times \left(\frac{15{,}2}{10{,}54}\right) \\
&= 0{,}0182\ \mathrm{m}^2 \times 1{,}442\ \mathrm{m/s} \\
&= 0{,}0262\ \mathrm{m}^3/\mathrm{s}
\end{aligned}
$$

The highest output was 58 rpm on the turbine shaft, 250 rpm on the generator shaft, and an output voltage of 29 VDC. The following is a graph of the results of testing the guide plate shaped intake.

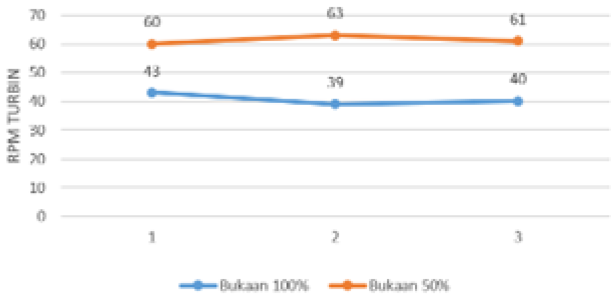

Fig. 9. Turbine is not connected to generator

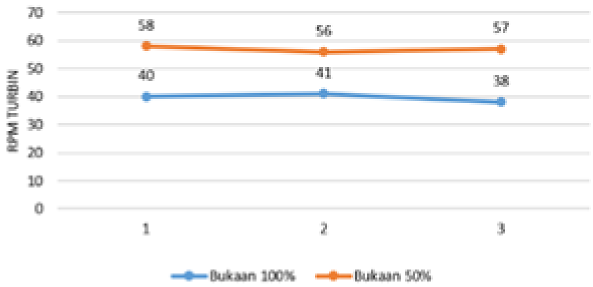

Fig. 10. Turbine is connected to generator

3.6.2 Turbine with Nozzle Shaped Intake

The results of the turbine rotation test with the intake nozzle type were obtained as follows:

Table 4. THE TURBINE ROTATION WITH A NOZZLE SHAPED INTAKE

No	RPM		Voltage (V DC)	Water velocity (m/s)	Q (m3/s)	Remark
	Turbine	Generator				
1	108	-	-	1,842	0,0335	not connected to generator
2	106,6	-	-	2	0,0364	
3	107	-	-	2,202	0,0369	
4	108,4	-	-	1,924	0,0350	
5	106,8	-	-	1,909	0,0348	
1	103	497	56,1	1,694	0,0308	connected to generator
2	103,4	498,2	55,4	1,811	0,0330	
3	104,8	499	57	1,679	0,0306	
4	103,9	498,5	54	1,813	0,0330	
5	104,5	499,1	57,5	2,079	0,0379	

The data marked with coloring is the highest data in conducting the experiment. From the experimental results above, it can be concluded that the rotation of the blade/runner gets a maximum rotation of 108.4 rpm when the generator is not coupled. Then when the generator is coupled/connected, the maximum output is when the turbine rotates at 104.5 rpm and the generator rotates at 499.1 rpm with an output voltage of 57.5 VDC. The following is a graph of the results of testing the intake nozzle type.

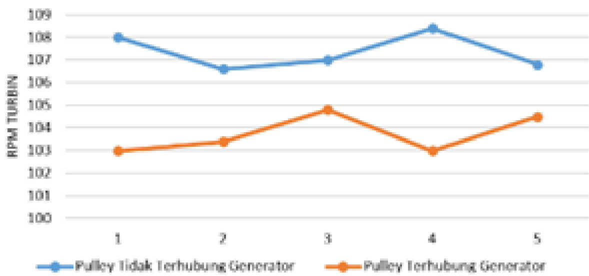

Fig. 11. Turbine with Nozzle Shaped Intake

The following is a graph of the comparison of test results between the adjustable intake door and nozzle.

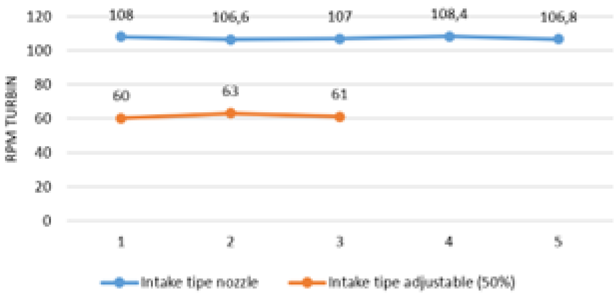

Fig. 12. Comparison Between Guide Plate and Nozzle Shaped Intakes

3.7 Speed Settings to Get Maximum Output

The rotational speed of the turbine depends on the period of the water flow hitting the turbine blades. In this experiment, the highest turbine output was sought by varying the closing of the penstock hole. The penstock hole is closed using a 6" cap or pipe cap. The variations given are opening the penstock hole 50%, 75% and 100%. The following is a table of the results of the penstock pipe intake test at 50% opening for the value of the water debit flowing in the penstock pipe and the value of the rotation of the turbine and generator.

Table 5. INTAKE OPEN VARIATION AT 50%

No	RPM		Voltage (V DC)	Mass (kg)	Torque (Nm)	Water velocity (m/s)	Q (m3/s)	Remark
	Turbine	Generator						
1	76,2	-	-	4,2	23,46	2,563	0,0467	not connected to generator
2	75,8	-	-	4,2	23,48	2,607	0,0475	
3	73,7	-	-	4,1	22,92	2,671	0,0487	
4	70,2	-	-	4,2	23,48	2,748	0,0501	
5	72,1	-	-	4,0	22,36	2,576	0,0469	
1	63,9	321	35,4	-	-	2,620	0,0477	connected to generator
2	64,1	333,6	37	-	-	2,680	0,0488	
3	63,6	330	36,2	-	-	2,491	0,0454	
4	62,3	328,8	34,5	-	-	2,571	0,0468	
5	62,5	325,2	34,9	-	-	1,571	0,0268	

From the table data above it can be seen that the highest value with a variation of the penstock opening of 50% is obtained by a turbine rotation of 76.2 rpm with a torque of 23.46 Nm when the generator is not coupled. Meanwhile, when the generator is coupled, it produces 64.1 rpm on the turbine, 330 rpm on the generator with an output voltage of 37 V.

The following is a table of the results of the penstock pipe intake test when the opening is 75% on the value of the water debit flowing in the penstock pipe and the value of the rotation of the turbine and generator

Table 6. INTAKE OPEN VARIATION AT 75%

No	RPM		Voltage (V DC)	Mass (kg)	Torque (Nm)	Water velocity (m/s)	Q (m3/s)	Remark
	Turbine	Generator						
1	89,2	-	-	5,7	31,84	2,390	0,0436	not connected to generator
2	88,4	-	-	5,5	30,75	2,077	0,0379	
3	88,5	-	-	5,6	31,31	2,105	0,0384	
4	86,4	-	-	4,9	27,39	1,872	0,0341	
5	87,4	-	-	5,1	28,51	1,531	0,0279	
1	89,1	438,2	48,42	-	-	1,842	0,0336	connected to generator
2	90,4	434,6	47,18	-	-	1,577	0,0287	
3	88,5	434	46,8	-	-	1,725	0,0315	
4	89,8	436	48	-	-	2,099	0,0383	
5	89,2	437,3	48,3	-	-	1,934	0,0353	

From the table data above, it can be seen that the highest value with a penstock opening variation of 75% is that the turbine rotation is 89.2 rpm with a torque of 31.84 Nm when the generator is not coupled. Meanwhile, when the generator is coupled, it produces 89.1 rpm on the turbine, 438 rpm on the generator with an output voltage of 48.42 V.

The following is a table of test results for the intake penstock pipe when it is 100% open regarding the value of the water flow flowing through the penstock pipe and the rotation value of the turbine and generator.

Table 7. INTAKE OPEN VARIATION AT 100%

No	RPM		Voltage (V DC)	Torque (Nm)	Water velocity (m/s)	Q (m3/s)	Remark
	Turbine	Generator					
1	108	-	-	38,58	2,024	0,0369	not connected to generator
2	107	-	-	38,02	2,000	0,0365	
3	107	-	-	38,02	1,842	0,0336	
4	106,6	-	-	37,46	1,924	0,0351	
5	106,8	-	-	38,02	1,910	0,0348	
1	103	497	56,1	-	1,695	0,0309	connected to generator
2	103,4	498,2	55,4	-	1,812	0,0330	
3	104,8	499	57	-	1,680	0,0306	
4	103,9	498,5	54	-	1,814	0,0331	
5	104,5	499,1	57,5	-	2,079	0,0379	

From the data in the table above, it can be seen that the highest value with a 100% variation in the penstock opening is that the turbine rotation is 108.4 rpm with a torque of 38.54 Nm when the generator is not coupled. Whereas when the generator is coupled it produces 104.5 rpm on the turbine, 499.1 rpm on the generator with an output voltage of 57.5 V.

From the three tables above, conclusions can be drawn in the table below. That the average value of the turbine rpm speed works optimally when the pipe opening is 100%, namely the rotation value (N1) 104.5 rpm (N2) 499.1 rpm with the generator output voltage after passing the kiprok the voltage is 57.5 VDC. So the appropriate variation to use for the system is an intake using a nozzle type with a penstock opening of 100%. The following is a comparison graph of test results based on penstock opening.

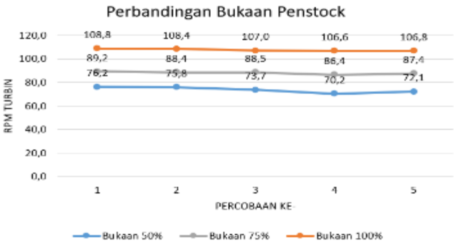

Fig. 13. IMPACT OF INTAKE OPEN VARIATION

3.8 Vortex Turbine Performance and Efficiency

To determine the level of efficiency of a vortex turbine, it is divided between turbine power and water power from variations in the number and percentage of intake openings. Previously, it is necessary to calculate the turbine torque and turbine angular speed. This is done both when the turbine is connected with pulleys and without pulleys.

To get these data it is necessary to do the following calculations:

- Calculating the power of flowing water (Pa) using equation (2) is as follows:

$$
\begin{aligned}
P_{hydro} &= \rho \times Q \times H \times g \\
&= 997{,}13 \times 0{,}02691 \times 2{,}05 \times 9{,}81 \\
&= 539.419 \text{ watt}
\end{aligned}
$$

- Calculating the force to find the vortex turbine torque using equation (3) is as follows:

$$
\begin{aligned}
F &= m \times g \\
&= 6.9\text{kg} \times 9.81\text{m/s}^2 \\
&= 67.689 \text{ N}
\end{aligned}
$$

- Calculating the torque produced by the vortex turbine using equation (4) is as follows:

$$
\begin{aligned}
T &= F \times l \\
&= 67{,}689 \times 0{,}57 \\
&= 38{,}58 \text{ Nm}
\end{aligned}
$$

- Calculate the turbine angular speed (ω) using equation (5) as follows:

$$
\begin{aligned}
\omega &= \frac{2\pi n}{60} \\
&= \frac{2 \times 3{,}14 \times 108}{60} \\
&= \frac{680{,}752}{60} \\
&= 11.304 \text{ rad/s}
\end{aligned}
$$

- Calculate turbine power (Pt) using equation (6) as follows:

$$
\begin{aligned}
P_t &= T.\omega \\
&= 38.58 \times 11.304 \\
&= 436.108 \text{ watt}
\end{aligned}
$$

- Calculating turbine efficiency (η) using equation (7) is as follows:

$$
\begin{aligned}
\eta &= \frac{P_t}{P_a} \times 100\% \\
&= \frac{436{,}108}{539{,}419} \times 100\% \\
&= 0{,}8085 \times 100\% \\
&= 80{,}85\%
\end{aligned}
$$

4 Conclusion

Based on the results of the design, testing and analysis of the PLTPH, conclusions were obtained, including:

- In testing two intake turbine designs using a nozzle type and an adjustable door with a 100% penstock intake pipe opening, the highest turbine rotation using a nozzle design was 108.4 rpm when the turbine was not connected to the generator and the turbine rotation when the generator was connected was 104.5 rpm. Whereas when testing using the intake adjustable door, the turbine rotation decreased, namely 43 rpm when the turbine was not connected to the generator and 41 rpm when the generator was connected.
- In testing the vortex turbine to the generator with an intake opening of 50%, the output voltage reaches 37 VDC, while when the intake opening is 75%, the voltage generated is 48.42 VDC, and the average output voltage generated at 100% aperture is 31.25 VDC when the generator is connected to the battery with a charging current of 0.53 ADC and when the battery is connected to a load the average voltage that can be output is 30.28 VDC with a current of 2.02 A and a power of 61.17 Watt.
- The efficiency of the vortex turbine with nozzle shaped intake is 80.85%

5 Acknowledgment

This work was supported by the State Polytechnic of Malang through Innovative Development Research Funding (2022-2023).

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