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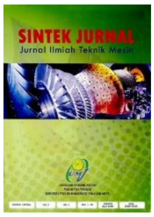

PUMP AS TURBINES (PATS) DESIGN OPTIMIZATION AS A RENEWABLE ENERGY SOURCE ALTERNATIVE

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ABSTRACT

One economical alternative to building a small-scale hydroelectric power plant is to use pumps as turbines, often referred to as PATs, which stands for Pump As Turbines. This research was conducted with an experimental method using a factorial experiment 22 After conducting research and data processing, Angle of Entry of Pump As Turbines and impeller tip angles Factors on turbines are equally influential to increase the speed of turning Pump As Turbines (PATs), but the variables the most influential in this study to increase the rotational speed of Pump As Turbines is the entry angle of PATs. Based on data processing to find the most influential variable using the Yates algorithm, if changing the PATs Entry Angle from 45° to 90° there will be an increase in Pump As Turbines rotational speed of 30.1 rpm while changing the impeller tip angles from 40° to 30° can only increase the Pump As Turbines rotational speed by 18.6 rpm. The alternator capacity that can be produced by Pump As Turbines is 100W, based on electrical power testing using a load of incandescent light bulbs. The electric power that can be generated by Pump As Turbines uses test samples at optimum conditions, namely the 90° Angle of Entry and the impeller tip angle 30° at the water pressure from the input pump 0.375 bar (g). The results of loading given using incandescent light bulbs with the power of 5 W, 10 W, 25 W, 40 W, and 100 W, there is the lowest voltage that is 194 V on a light bulb with 100 Watt power with alternator rotational speed of 855.7 rpm in the 3rd experiment.

Keywords: Pump As Turbines (PATs); impeller tip angles; factorial design; electrical energy.

1. INTRODUCTION

The field of Pump As Turbines (PATs) is not something new in the utilization of the potential energy of water into kinetic energy. Research on Pump As Turbines (PATs) has started since 1930. Since then several studies have been carried out and reported in several journals, such as research published in the journal "Review of Pump as Turbine (PAT) for Micro-Hydropower". Pump As Turbines (PATs) have been successfully tested by several researchers, but Pump As Turbines (PATs) still have relatively lower efficiency when compared to the efficiency of conventional turbines. Research to increase the efficiency of centrifugal pumps when operated as a turbine. The theoretical result (Computational Fluid Dynamics) shows the highest efficiency of 71%. This is a challenge in itself in operating Pump As Turbines (PATs) for larger capacities [1].

An experimental optimization of the blade curve type on a pump that functions as a turbine for a Picohidro power plant. Modifications made by changing the curve of the impeller blade made of Composite with variations in the inclination of the entry and exit angles (30°/30°; 30°/45°; 30°/60°;30°/75°; 45°/30°; 60°/30°; 75°/30°) The results of the optimization show an increase in the amount of shaft rotation and output power [2].

A study entitled the effect of rapid pipe angle on the efficiency of a Micro Hydro Power Plant (PLTMH). The research was conducted by using experimental methods, varying the angle of the pipe rapidly and the variation in flow rate (valve opening). The results of his research show that the angle of the pipe is very influential on the rotation of the turbine and the efficiency of the electricity generated [3-7].

The purpose of this research is to analyze the effect of the pump as turbines (PATs) entry angle and the impeller tip angle of the turbine on the performance of Pump As Turbines (PATs), as well as to analyze the capacity generated by the Pump As Turbines (PATs) alternator.

2. METHODS

Here are the variables determined in this study:

2.1. Input Variable

Factors that can affect the rotational speed of Pump As Turbines (PATs), include:

a. Pump As Turbines entry angle (PATs)
b. Impeller tip angle
c. Water pressure from the input pump
d. Number of blades
e. Pipe diameter

2.2. Fixed variables

The variables that are made fixed in this study are:

a. Water pressure from the input pump: 0.375 bar (g)
b. Pipe diameter : 3 inch
c. Number of blades : 4 pcs

2.3. Variable is not fixed

Variable variables are input variables that affect the rotation of Pump As Turbines (PATs) which are taken as a 2^2 factorial design model, including:

a. Angle of entry of PATs, coded with (SMP).
   - Number of level two (SMP = 2)
   - Maximum value : 90°
   - Minimum value : 45°
b. The angle of the impeller tip, coded with (SUI).
   - Number of level two (SUI = 2)
   - Maximum value : 40°
   - Minimum value : 30°

The sample of the experimental research study the optimization of the Pump As Turbines (PATs) design using the 2^2 factorial design method, can be seen in Figures 1, 2, 3 and 4.

Figure 1. Entry angle Pump As Turbines (PATs) $\alpha = 90^0$

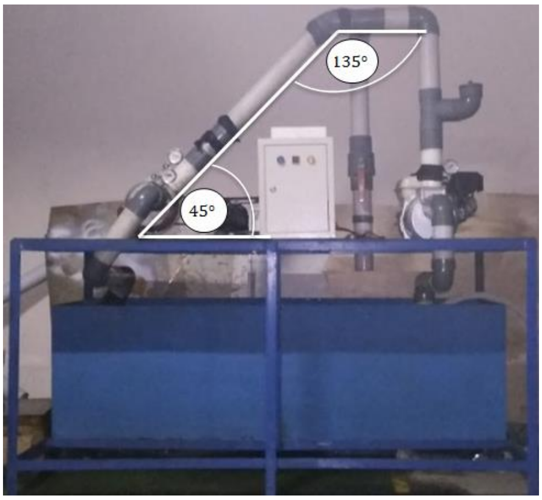

Figure 2. Entry angle Pump As Turbines (PATs) $\alpha = 45^0$

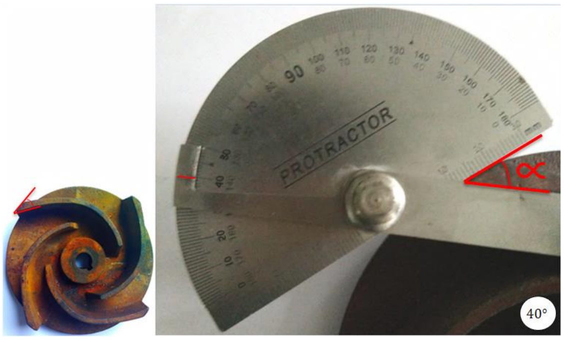

Figure 3. Angle of the impeller tip α = 40^0

Figure 4. Impeller tip angle α = 30^0

The water collected in the tub is sucked by the input pump to be circulated to the Pump As Turbines (PATs) through PVC pipes so that Pump As Turbines (PATs) can rotate due to the flow of water. The water flow from the Pump As Turbines (PATs) goes back into the reservoir to be sucked back in by the input pump, and so this process continues until it finishes operating. Pump As Turbines (PATs) are connected to the alternator using a V-belt so that the alternator can generate electrical energy.

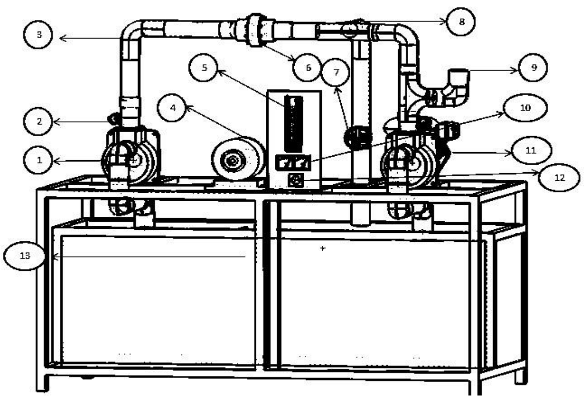

Figure 5. Schematic installation *Pump As Turbines* (PATs)

Pump As Turbines (PATs) installation scheme can be seen in Figure 5.

The details of the equipment used in this study are:

1. Pompa sentrifugal (pompa *input*)
2. *Pump As Turbines* (PATs)
3. Pipa PVC *(Polyvinyl Chloride)*
4. Weirmeter
5. Alternator
6. Baterai
7. Inverter
8. *Pressure gauge*
9. *Tachometer*
10. Multimeter
11. Bola lampu pijar
12. Mesin gerinda
13. Busur derajat

The electrical schemes used in Pump As Turbines (PATs), use three important components, namely the alternator, battery and inverter. Where the alternator functions as a generator of electricity which is then stored in the battery. The electrical energy in the battery is converted from a current 12V DC to 220V AC current using an inverter, the electrical system schematic can be seen in Figure 6.

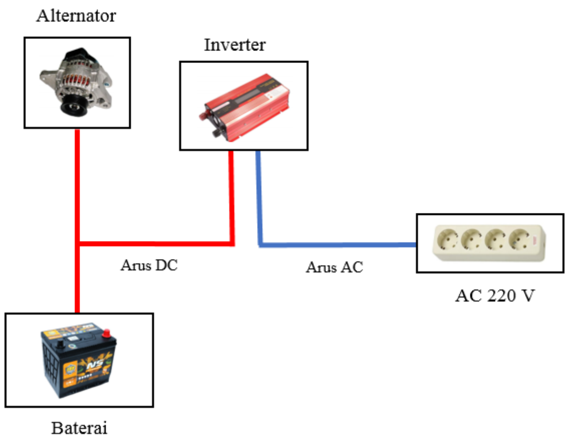

Figure 6. Schematic of the Electrical System Used In Pump As Turbines (PATs)

3. RESULTS AND DISCUSSION

In table 1 it can be seen that the test results, the total tests carried out in this study were 4 experiments by carrying out 3 times taking data at the same water pressure at 0,375 bar (g).

Table 1. Test Results *Pump As Turbines* (PATs)

Entry Angle PATs (SMP)	Impeller Tip Angle (SUI)	Water pressure from the input pump (bar (g))	Inlet water pressure PATs (bar (g))			Rotating speed PATs (rpm)			Alternator rotating speed (rpm)			Water level on weirmeter (m)		
			1	2	3	1	2	3	1	2	3	1	2	3
90°	**40°**	0.375	0.250	0.250	0.250	967.5	970.4	969.9	2110	2128	2119	0.06	0.06	0.06
90°	**30°**	0.375	0.250	0.250	0.250	999.1	998.4	996.8	2260	2251	2237	0.06	0.06	0.06
45°	**40°**	0.375	0.250	0.250	0.250	947.1	946.0	955.2	2072	2067	2092	0.05	0.05	0.05
45°	**30°**	0.375	0.250	0.250	0.250	983.8	978.8	979.9	2158	2153	2157	0.05	0.05	0.05

3.1. Analysis of variance

Data from the Pump As Turbines (PATs) test results need to be known whether there is a significant difference or not, to find out it is necessary to do an Analysis of variance with the help of Microsoft Excel. The processing of test data using the help of Microsoft Excel can be seen in table 2.

Table 2. Data Processing Analysis of Variance Test

Testing number	Rotating speed (rpm)	Rotating speed (rpm)	Rotating speed (rpm)	Rotating speed (rpm)
	SMP 90°, SUI 40°	**SMP 90°, SUI 30°**	**SMP 45°, SUI 40°**	**SMP 45°, SUI 30°**
I	967.5	999.1	947.1	983.8
II	970.4	998.4	946	978.8
II	969.9	996.8	955.2	979.9
N =	3	3	3	3
Average =	969.27	998.10	949.43	980.83

Variation between treatment **(between grup)**

Grand Average =	974.41				
Delta^2 =	26.44	561.30	623.75	41.28	
DF =	2.00				
SS =	79.31	1683.89	1871.25	123.84	3758.29
ST =	1879.14				

Information:

1. SMP = Entry angel PATs
2. SUI = Impeller Tip Angle

Variation within treatment **(inside grup)**

	A	B	C	D	TOTAL
SS =	4.81	2.78	50.49	13.81	71.88
DF =	2	2	2	2	8
SR =	8.99				

Information:

ST > SR = samples are considered to come from the same population

ST > SR = sample is considered to come from the same population

From the results of the Analysis of variance test, it can be seen that the value of ST> SR (the ST value is greater than the SR value), it can be concluded that there is a difference in the influence caused by the pump as turbines (PATs) entry angle and the angle of the impeller tip to the pump rotation. As Turbines (PATs) are generated.

3.2. Determining the Main Effect with the Yates Algorithm

The results of the experiment were then carried out by a data processor looking for the main effect using the Yates algorithm, to find the most influential variable directly from the two experimental variables, such as the pump as turbines (PATs) entry angle and the impeller tip angle. To find out this, data processing was carried out with the help of Microsoft Excel, the results of data processing can be seen in table 3.

Table 3. Determining the Main Effect With the Yates Algorithm on the Results of the Pump As Turbines Test (PATs)

Entry angle PATs (SMP)	Impeller Tip Angle (SUI)	Rotating speed PATs (rpm)			Average	I	II	DIVIDER		Information
		1	2	3						
90°	**40°**	967.5	970.4	969.9	969.3	1967.4	3897.6	4	974.4	Average
90°	**30°**	999.1	998.4	996.8	998.1	1930.3	-60.2	2	-30.1	Entry angle PATs (SMP)
45°	**40°**	947.1	946.0	955.2	949.4	-28.8	37.1	2	18.6	Impeller Tip Angle (SUI)
45°	**30°**	983.8	978.8	979.9	980.8	-31.4	2.6	2	1.3	Entry angle PATs+ Impeller Tip Angle

Based on the two variables, namely the PATs Entry Angle (SMP) and the Impeller Tip Angle (SUI) both have an effect on increasing the rotational speed of Pump As Turbines (PATs), but the most influential variable for increasing the rotational speed of Pump As Turbines (PATs) is the angle enter PATs (SMP). Based on data processing looking for the most influential variables using the Yates algorithm, if you change the Angle of Entry of PATs (SMP) from 45 ° to 90°, there will be an increase in the rotational speed of the Pump As Turbines (PATs) by 30.1 rpm while changing the Angle of the Impeller Tip (SUI) from 40 ° to 30 ° can only increase the rotational speed of Pump As Turbines (PATs) by 18.6 rpm. This means that increasing the PATs Entry Angle (SMP) will increase the rotational speed produced by the Pump As Turbines (PATs), whereas increasing the Impeller Tip Angle (SUI) can actually decrease the rotational speed of the Pump As Turbines (PATs).

3.3. Response Surface Methodology

Response Surface Methodology is used to find the optimum value from a test using the two most influential variables, such as the pump as turbines (PATs) entry angle and the impeller tip angle with the water pressure from the pump input of 0.375 bar (g). The following are the steps carried out in the response surface methodology analysis.

a. Initial First Order Design

The first step is to determine the variables and levels to be used, while the variables and levels to be used can be seen in table 4.

Table 4. First-Order Experimental Design

Faktor	Level	
	+	-
Entry angle PATs (SMP)	90°	45°
Impeller Tip Angle (SUI)	45°	30°

The results of the experiment with the variables and levels used in the first order can be seen in table 5.

Table 5. First-Order Experimental Results

Sudut Masuk PATs (SMP)	**Sudut Ujung *Impeller* (SUI)**	**Putaran PATs (rpm)**			**Rata-rata**
		1	**2**	**3**	
90°	**40°**	967,5	970,4	969,9	969,3
90°	**30°**	999,1	998,4	996,8	998,1
45°	**40°**	947,1	946,0	955,2	949,4
45°	**30°**	983,8	978,8	979,9	980,8

The mapping of the two variables can be seen in Figure 8 which shows the results of the experiments that have been carried out. If observed in a graph, the higher the rotational speed of the Pump As Turbines (PATs) obtained is the combination of the higher PATs inlet angle (90°) and the lower angle of the impeller tip (30°).

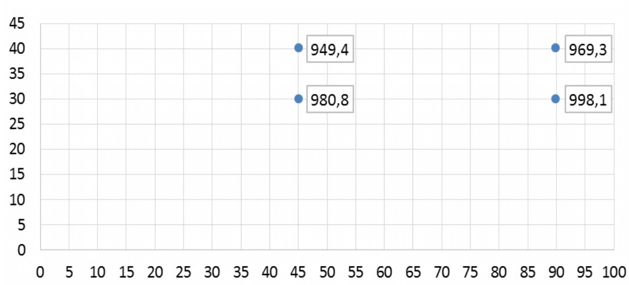

Figure 7. Pump As Turbines (PATs) rotational speed as a function of the angle of the impeller tip and the angle of entry of the PATs

The next stage is to make a combination of variables and levels taken from the midpoint value of the variable value and the first order level, with the aim of finding the optimum value. The combination of variables and levels can be seen in figure 7 and table 6.

Table 6. Variables And Second-Order Levels

Entry angle PATs	Impeller Tip Angle	Rotating Speed (rpm)			Average
		1	2	3	
90°	40°	967,5	970,4	969,9	969,3
90°	30°	999,1	998,4	996,8	998,1
45°	40°	947,1	946,0	955,2	949,4
45°	30°	983,8	978,8	979,9	980,8
67,5°	35°				

Experiment samples of PATs Entry Angle (SMP) 67.5° and Impeller Tip Angle (SUI) 35°, the pipe installation can be seen in Figure 8.

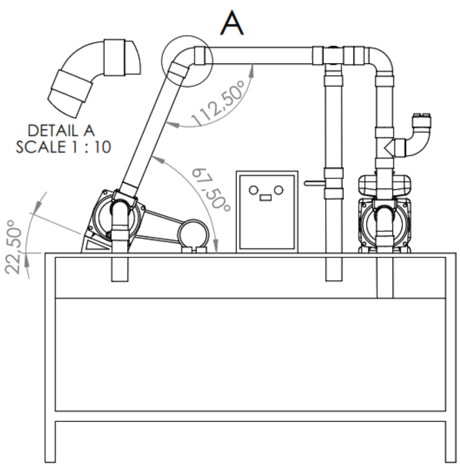

Figure 8. Pipe Installation Angle Entry PATs (SMP) 67.50°

The implementation of sample tests for PATs Entry Angle (SMP) 67.5° and Impeller Tip Angle (SUI) of 35° could not be carried out, because during the preparation of the pipe installation test sample preparation the PATs Entry Angle (SMP) 67.5° required an elbow pipe. 112.5° which turned out that the elbow pipe was not available in the market. PATs (SMP) entry angle pipe installation of 67.5° and the need for elbow pipe 112.5°, can be seen in figure 8.

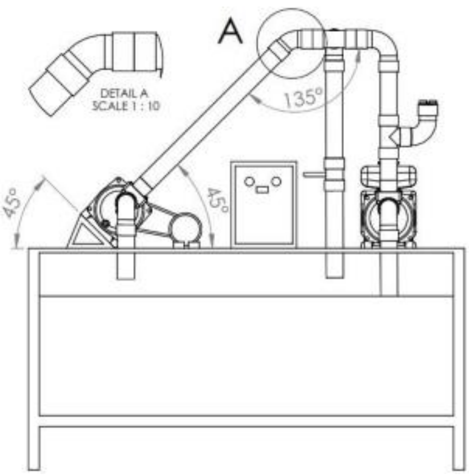

Figure 9. Pump As Turbines Intake Angle Pipe Installation

These limitations make the implementation of finding the optimum value from an experiment using the Response Surface Methodology unable to be carried out further, unlike the 45° PATs (SMP) Entry Angle pipe installation which requires a 135° elbow, because the pipe needs are available in the market. can be done. Installation of pipe entry angle of 45° PATs (SMP) and 135° elbow pipe requirements, can be seen in figure 9.

b. Path of Steepest Ascent

The path of steepest ascent step taken is to determine the slope gradient angle of the line which can be formed using the equation tg α = Δy / Δx, to simplify the calculation process, mapping is done first as shown in figure 10, here is the calculation process.

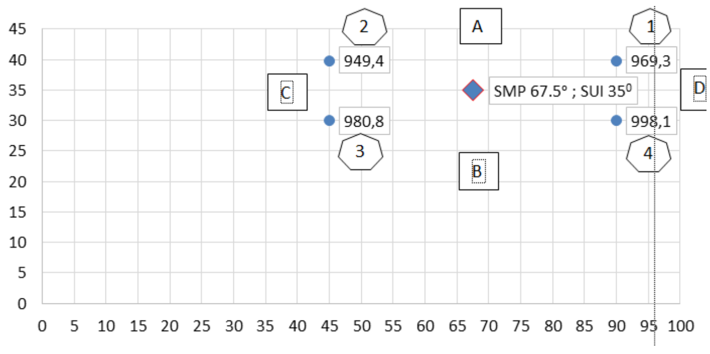

Figure 10. Mapping Slope Gradient Determination

The calculation process for determining the slope gradient uses equations $= \frac{\Delta y}{\Delta x}$, for the calculation process as follows:

a. find the x-axis delta (Δx):

A=1-2

=969.3-949.4

=19.9

B=4-3

=998.1-980.3

=17.8

$\Delta x = \frac{A+B}{2} = \frac{19.9+17.8}{2} = 18.85$

b. find the x-axis delta (Δy):
C=3-2
=980.8-949.4
=31.4
D=4-1
=998.1-969.3
=28.8
$\Delta y = \frac{A+B}{2} = \frac{31,4+28,8}{2} = 30.1$

Substitute the x-axis and y-axis values into the following equation:

$$tg\ \alpha = \frac{\Delta y}{\Delta x} = \frac{30.1}{18.85} = 1.596$$

$$\alpha = 57.930°$$

The slope gradient that can be formed from the Input Angle variable PATs (SMP) = 67.5 and Impeller Tip Angle (SUI) = 35^0 are α =57.930°, then for the drawing of the slope gradient line can be seen in Figure 11.

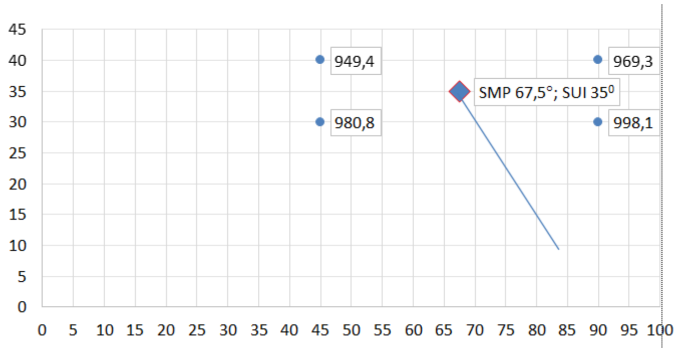

Figure 11. Determination of the Slope Gradient

3.4. Electrical power based on test results

To find out the electrical power that can be generated by Pump As Turbines (PATs), it is necessary to experiment with the Pump As Turbines (PATs) installation. Based on the previous test, it was found that the combination of variables that was the highest on the results of the rotational speed produced by (PATs) was obtained. The electric power test at the highest variation is the PATs Entry Angle (SMP) 90 ° and the Impeller Tip Angle (SUI) 30°, while the results of the electric power test can be seen in Table 7.

Table 7. The Results of The Pump As Turbines Electric Power Test (Pats)

Electrical Power (W)	1		2		3	
	Alternator Rotation Speed (rpm)	Electrical voltage (V)	Alternator Rotation Speed (rpm)	Electrical voltage (V)	Alternator Rotation Speed (rpm)	Electrical voltage (V)
0	895.0	218	896.4	218	895.8	218
5	872.1	204	872.7	204	873.6	204
10	883.5	210	882,9	210	883.4	210
25	888.9	212	888.4	212	889.1	212
40	879.9	208	879.7	208	878.6	208
100	858.3	194	856.5	194	855.7	194

From the test results by carrying out 3 measurement experiments, the electric power that can be generated by Pump As Turbines (PATs) uses a test sample of 90° inlet angle and 30° of impeller tip at the water pressure of the input pump of 0.375 bar (g). the results of loading the electric power given using a light bulb, get the lowest voltage, which is 194 V. There is a light bulb with 100 Watt power with the lowest alternator rotational speed of 855.7 rpm in experiment 3. So the electrical energy that can be generated by Pump As Turbines (PATs) are 100 Watts.

4. CONCLUSION

Based on the results of data analysis in the research process that has been carried out on the experimental study of the optimization of the design of pump as turbines (PATs) using the 2^2 factorial design method, the following conclusions are obtained:

The PATs Angle of Entry (SMP) and the Impeller Tip Angle (SUI) on the turbine both have an effect on increasing the rotational speed of Pump As Turbines (PATs), but the variables that have the greatest influence in this study are to increase the rotational speed of Pump As Turbines (PATs). is the entry angle of the PATs (SMP). Based on data processing looking for the most influential variables using the Yates algorithm, if you change the Angle of Entry of PATs (SMP) from 45° to 90 °, there will be an increase in the rotational speed of the Pump As Turbines (PATs) by 30.1 rpm while changing the Angle of the Impeller Tip (SUI) from 40° to 30° can only increase the rotational speed of Pump As Turbines (PATs) by 18.6 rpm. The optimum conditions of the 2^2 factorial design experimental design are found in a combination of 90° PATs (SMP) Entry Angle and 30° Impeller Tip Angle (SUI) with an average rotational speed of 998.1 rpm.

The alternator capacity that can be produced by Pump As Turbines (PATs) is 100W, based on electric power testing by conducting 3 measurement experiments using a load in the form of an incandescent light bulb. The electric power that can be generated by Pump As Turbines (PATs) uses the test sample at optimum conditions, namely the entry angle of 90° and the impeller tip angle of 30° at the water pressure of the pump input of 0.375 bar (g). The results of the loading of electrical energy that are given using an incandescent light bulb with a power of 5 W, 10 W, 25 W, 40 W and 100 W, there is the lowest voltage, namely 194 V on a light bulb with 100 Watt power with an alternator rotating speed of 855.7 rpm in the 3rd experiment.

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