Micro Hydro Electric Power Plant (MHEP) Prototype A Study Of The Effect Of Blade Numbers Toward Turbine Rotational Velocity

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Abstract. Micro hydro electric power plant (MEPP) prototype is a small scale power plant (less than 100 kW) that utilizes height difference and water discharge per second. Prototype consists of a water pump, where capacity of 41 liter per minute serving as turbine driving force channelled through a nozzle, with a 40 liter water reservoir, and the water flow rate controller is a gate valve. The results show that at blade counts of 4,8,12, and 16, and with water discharge at 40 l/s, 35 l/s, 30l /s, and 25 l/s, with nozzle shooting angle of 50 °, the turbine rotational velocities are 310 rpm, 639 rpm, 655.5 rpm, and 691.3 rpm respectively. Furthermore, at water discharge of 35 l/s, the velocities are 293.3 rpm, 375,3 rpm, 412.7 rpm, 446.2 rpm, and at water discharge of 30 l/s, they are 240.3 Rpm, 395.0 rpm, 430.5 rpm, 445.2 Rpm. Moreover, at water discharge 25 of l/s, the speeds are 285.5 rpm, 330.5 rpm, 426.0 rpm, 431.1 rpm. It is concluded that the higher the water discharge rate, the greater the number of rotation, and it is also concluded that shooting angle has a significant effects on pelton turbine rotation and power.

Keywords: power plant; turbine; water pump; flow rate; water discharge

1. Introduction

Indonesia is rich in natural resources, but it has not been optimally utilized. It has an enormous potential both in fossil energy, such as coal, petroleum, natural gas and others; and non-fossil energy, such as geothermal, wind power, solar power, hydropower and micro hydro. Indonesia is listed as a country rich in micro hydro energy resources. Micro hydro energy utilizes hydropower on a smaller scale potentially generates 75.67 GW of electricity throughout Indonesia. However, only 4.2 GWs are utilized and among which is 450 MW for mini/micro hydro potential and about 230 MW is installed until 2008. Generally, remote rural areas in the mountainous region has great potential for water energy, so micro-hydro is one of the energy sources that can be developed to improve the quality of life and the growth of rural economy. The availability of electric energy in rural areas, in addition to meeting household needs, can also encourage the improvement of health, education and environmental

security facilities and provide new occupation. The environmental impact of waterwheel operation on a secondary irrigation canal is measured in the water at the rear and in front of the wheel. The measurement is conducted at a distance of two meters from the rear and in front of the wheel testing physical factors, which include temperature, dissolved solids and suspended solids; and chemical factors, which include BOD, COD, dissolved oxygen, pH and fatty oil [1]

Micro hydro electric power plant (MEPP) is a power plant that utilizes a continuous flow of rivers. One of which in South Sumatera Province having the potential of micro-hydro power is Kemumu River in Bedegung Village Muara Enim Regency. Bedegung waterfall enables the development of Micro Hydro Power Plant; as a result it is expected to fulfil the need of electric power around the village. It is the basis for the researcher to discuss the study of development planning of Micro hydro electric power plant (MHEP) at Bedegung Waterfal, Bedegung Village, Muara Enim Regency.

1.1. Micro Hydro Electric Power Plant (MEPP)

Micro hydro electric power plant (MEPP) prototype is a small scale power plant (less than 100 kW) that utilizes height difference and water discharge per second. Water flow rotates turbine shaft that generates mechanical energy. This energy further drives generators to generate electricity. Technically, micro hydro has three main components: water as energy source, water turbine and generator. Flows of water with a certain capacity is channelled to a particular height through a penstock pipe to power house.

Table 1. Classification of Hydroelectric Plant

Type	Capacity (kW)
Micro Hydro	<100
Mini Hydro	101-2000
Small Hydro	2000-25000
Large Hydro	>25000

(source: Teacher Manual Diploma Hydro Power)

In the power house, water hits the water turbine that it produces mechanical energy which turns the water turbine shaft. In this study, pelton turbine with working principle as described in figure 1 below was used:
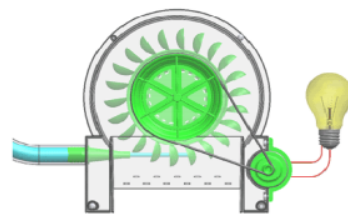

Figure 1. Pelton Turbine Working Principles

Water is directed to the turbine blades, causing a spin on the turbine which will then be converted to the motion energy of the generator. The converter converts the motion into electrical energy especially for lighting purposes.

1.2. Water discharge

The water discharge is the amount of water flowing through a particular river cross section per unit of time [2]. In order to obtain the capacity of MEPP, it is necessary to calculate how much water can be

used to generate MEPP. The ideal design discharge of a MEPP is 1.2 or 120% of the minimum discharge of a river.

1.3. Water's Height of Fall
The height of the fall depends on the geography of the location. Essentially, micro hydro plants are classified into two categories that determine the type of turbine to be used, low (up to 20 meters) and high (more than 20 meters) [3].

1.4. MEPP Power
The equations for finding out generated electric power due to height differences are as follows: [4]
Theoretical power:

$$P = 9.81. Q. Heff \qquad (1)$$

The above theoretical equations should also be added to the efficiencies of penstock pipe, turbine and generator, so that the generated power equations are as follows.
Power Generated:

$$P = 9,81. \eta p. \eta t. \eta g. Q. H \qquad (2)$$

In which :
η_p : 0.90 - 0.95 (depending on length of the pipe)
η_t : 0.7 - 0.85 (depending on turbine type)
η_g : 0.80 - 0.95 (depending on generator capacity)

1.5. Dams and Intakes
Dams are buildings that serve to turn the direction of the water flow. The dam construction aims to increase and control the water level in a river significantly so that the water level is sufficient to be diverted into the intake. The intake construction aims to drain the water from the dam to the carrier channel. Mostly, intake construction is equipped with sluice gate for sediment rinsing.

Figure 2. Dams
(Source: Megkidy, 2012)

1.6. Carrier Channel
The carrier channel is a building that streams water from the intake into a tranquilizer and serves to maintain the stability of the water discharge. The discharge through the carrier channel can be calculated by the following equation:

$$Q = V \, x \, A \qquad (3)$$

The flow velocity of the carrier channel can be obtained by the Manning-Strikler equation as follows: [5]

$$V = \frac{1}{n} x R^{\frac{2}{3}} x S^{\frac{1}{2}} \tag{4}$$

$$R = \frac{A}{P} \tag{5}$$

In which:

Q : Discharge (m3 / s)
V : Average velocity (m / s)
R : Hydraulic radius (m)
A : Wet section area
P : The circumference of wet cross section
S : slope of channel bed
n : coarseness coefficient

1.7. Tranquilizer Basin

The tranquilizer serves to control the discharge difference in penstock pipe and carrier channel as a result of load fluctuations. Apart from serving as water tranquilizer, it also acts as the final deposition and waste filter. Its capacity is calculated as follows:

$$V_f = A_f \, x \, h_f \tag{6}$$

$$V_f = B \, x \, L \, x \, d_f \tag{7}$$

In which:

V_t : Volume of tranquilizer (m3)
A : Area of tranquilizer (m2)
B : Width of tranquilizer (m)
L : Length of tranquilizer (m)
H_f : Water level in the tranquilizer (m)
D_f : Difference in normal water level at discharge design

1.8. Penstock Pipe

Penstock pipe is a pressure pipe that channels the flow to drive turbine.

a. The speed at the penstock pipe can be obtained by using the Darcy-Weisbach equation as follows: [5]

$$V = \frac{Q}{A} \tag{8}$$

In which:

V : Speed (m / s)
Q: The generation debit (m3 / s)
A: Area of rapid pipe cross section (m2)

b. The pipe's minimum diameter can be counted as follows: [5]

$$D = 2.69 \, x \left(\frac{n^2 x Q^2 x L}{H} \right)^{0.1875} \tag{9}$$

In which:

D : The diameter of penstock pipe (m)
Q : Generating discharge (m3 / dt)
H : Height of fall (m)
L : Length of penstock pipe
N : Manning coefficient

c. The planned penstock pipe thickness can calculated as follows: [4]

$$\delta = d^3 \sqrt{\frac{np_o}{2E}} \qquad (10)$$

In which:
  d: Pipe diameter (m)
  n: Security factor
  n: 2 for ground-covered pipes
  n: 4 for pipe outside
  p_0: Air pressure ..0.1 Mpa
  E : Modulus of elasticity of..200 Gpa

1.9. Water Turbine

In general, the results of field research show a potential development of MEPP with 6 - 60 m head height, which can be categorized in low and medium head. Graphic below can help in the selection of turbine.
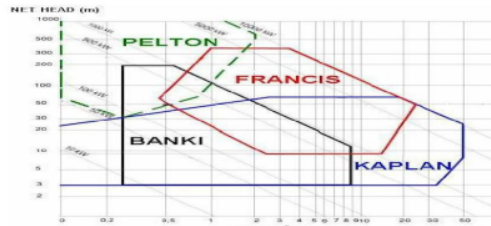

Figure 3. Selection of Water Turbine

1.10. Dimmensions of Water Turbine

The cross-flow turbine consists of two main parts, the nozzle and the turbine wheel. The turbine wheel is made of two circular disks put together on the rim by the blades. The nozzle with a rectangular cross-section emits water filling out the entire turbine width with an absolute angle of 160. Water hits (figure 2.4), flows through, and leaves the blade through an empty space between the inner rim and thenre-enter the rim on the other side before then finally exits.
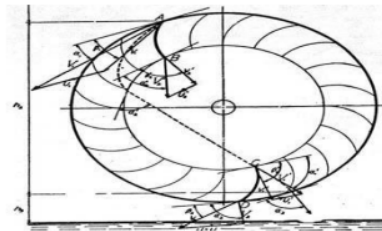

Figure 4. Water flows in turbine

1.   Diameter and Width of the runner are counted with the following equation: [6]

$$L = 210.6 \ Q \ / \ D1 \ H^{1/2} \qquad (11)$$

2.   Water Turbine Rotation: [6]

$$N_t \ = \frac{862 \ xH^{\frac{1}{2}}}{D_1} \qquad (12)$$

3. Blades Distance
   To determine the distance between blades, the following equation is used.

$$t = \frac{k x D_1}{sin \beta_1} \qquad (13)$$

   In which:
   t: Distance between blades
   β_1 : Angle of blade = 290 50 'or approximately 300
   S_1 : Receiver of water flow
   k: Speed coefficient

4. Number of Blades
   The appropriate blades are thin and smooth. The equation for obtaining the number of blades is as follows: [6]

$$N = \frac{\pi x D_1}{t} \qquad (14)$$

   In which:
   N: Number of blades

5. Width of Radial circumference
   To determine the radial circumference width, the following equation can be used: [6]

$$\alpha = 0.17 \, D_1 \qquad (15)$$

   In Which:
   N: Number of blades

6. Curvature of Blades
   The following formula is to calculate the curvature of blades: [6]

$$\rho = 0.326 \, r1 \qquad (16)$$

   In which :
   ρ: Curvature of runner blade
   r_1: The runner's spokes

7. Distance of water flow from center of shaft. The distance is counted as follows: [6]

$$y_1 = (0.1986 - 0.945 \, k) \, D_1 \qquad (17)$$

   In which:
   y_1: The distance of water flow from the center of the shaft
   k : Speed coefficient = 0.087
   D_1: Outside diameter of runner

8. Distance of water flow from inside rim of runner
   The distance is calculated as follows: [6]

$$y_2 = (0.1314 - 0.945 \, k) \, D_1 \qquad (18)$$

1.11. Water Turbin Characteristics

1. Speed Factor. It is counted as follows: [4]

$$\varphi = \frac{D x D_t}{84,6\sqrt{H_n}} \qquad (19)$$

   In which:
   Nt : Number of rotation per minute (rot/minute)
   D : Diameter (m)

2. Unit Speed
   The unit speed is the speed of a turbine (the rotating part) that is geometrically similar to H_{net}= 1 meter and D = 1 meter. The unit speed is counted as follows: [12]

$$N_{11} = \frac{ND}{\sqrt{H_n}} \qquad (20)$$

   In which :
   N_{11}: The unit speed (rad / s)
   N   : Number of rotation per minute (rot/minute)
   D   : Diameter (m)
   H_n: The difference in water level reduced by loss of height (m)

3. Unit Discharge
   Unit discharge is a geometrical turbine discharge similar to H_{net} = 1 meter and D = 1 meter. The unit speed is counted as follows:[4]

$$Q_{11} = \frac{Q}{D^2 \sqrt{H_n}} \tag{21}$$

   N_{11} : The unit speed (rad / s)
   N   : Number of rotation per minute (rot/minute)
   D   : Diameter (m)
   H_n: The difference in water level reduced by loss of height (m)
4. Specific Rotation
   The specific rotation is the magnitude of the turbine rotation geometrically similar so that H_{net} = 1 meter produces power of 1 kW. The specific rotation is counted as follows: [4]

$$N_s = \frac{N P^{0,5}}{H_n^{\frac{5}{2}}} \tag{22}$$

   In which:
   N_S : Specific rotation (rot/minute)
   N   : Number of rotation per minute (put/mnt)
   P   : Power (kW)
   H_n : The difference in water level reduced by loss of height (m)

1.12. Mechanical Transmission
Power transmission acts to deliver power from the turbine shaft to the generator shaft.
a. Direct Transmission System
In this transmission system, the power from the turbine shaft (rotor) is directly transmitted to the generator shaft with a clutch. The construction is more compact, is easy to maintain, and has high efficiency.
b. Indirect Transmission System
In this system, the belt is used to move from 2 parallel shafts. The belt is an important to absorb the shock load and dampen vibration. Flat belt and V-belt is generally used. Flat belt is used on larger power transmission system, while the V-belt on power below 20 kW. The transmission requires supporting components which are pulley and bearings. In the transmission system of pulleys and belts, the following equation applies: [7]

$$\frac{n_1}{n_2} = \frac{r_2}{r_1} \tag{23}$$

In which:
   n_1 : Speed of pulley 1 n_2 : Speed of pulley 2
   r_1 : Radius of pulley 1 r_2 : Radius of pulley 2

1.13. Generator
Generator is the machine that converts mechanical energy from a turbine into electrical energy. The main components of the generator are the rotor and stator. Rotor is the rotating part, which is coupled with the turbine shaft for rotating power. Stator is the non-moving generator part. The stator produces the voltage when the rotor is amplified or magnetized.

1.14. Load Control System
In micro hydro electric power plant (MEPP), the load changes will give effect in the generator. If the turbine torque is not changed during load changes, there will be a change in the frequency and voltage generated which will result in damage to the generator or the load.
One of the ways to protect MEPP is by using Electronic Load Controller (ELC).

2. Research Methodology
Place and Date of Testing
- Place of testing: Lab. Engineering State Polytechnic of Sriwijaya.
- Testing Date: March 19-20, 2018
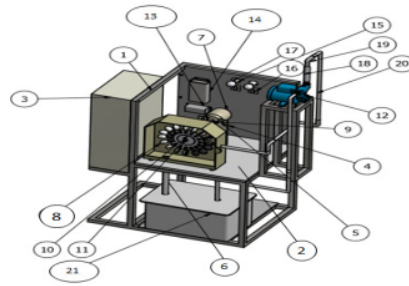
Instruments used:

Figure 5. MEPP Devices

Legends:

1. Tool Framework	8. Blade	15. Lights
2. Pedestal	9. Shaft	16. Switch
3. Control Panel	10. Impeller	17. Lights
4. Suction Pipe	11. Axle Bolt	18. Out Pipe
5. Clutch	12. Pumps	19. Elbow
6. Waste pipe	13. Inverter	20. Penstock Pipe
7. Rubber Clutch	14. Power supply	21. Container Basin

MEPP prototype device consists of several main components. First is a water pump with a capacity of 29 litter/min and a height lift of 33 mka, serving as a potential power for turbine drive through a nozzle. Second is reservoir with 40 litter capacity for water source. Third is a flowmeter to control rate. Then, it is one pelton turbine as a source of mechanical energy driving the generator. The next is DC generator to generate electrical energy, equipped with an inverter to change the DC voltage of 12 volts into AC voltage of 220 volt with capacity of 300 watts.

In The control panel process parameters, which are turbine rotation (RPM), voltage (volt), load current (ampere) and water discharge (lt / min), is read.

2.1. Data Collection Process
The data collection process is done with the following criteria: (1) nozzle angle of 50 ° and (2) variation of blade number and discharge amount. The results are presented as follows.

Table 2. Discharge of 40 Lt/det

Number of blade	shooting Angle	Motor Rotation (rpm)	Voltage (volt)	Current (amp)	Powet (wait)
4		310	200	0,07	14
8	50°	639,5	208	0,07	14,56
12		655,5	224	0,07	15,68
16		691,3	227	0,07	15,84

Table 3. Discharge of 35 Lt/det

Number of blade	shooting Angle	Motor Rotation (rpm)	Voltage (volt)	Current (amp)	Powet (watt)
4		293,3	192	0,06	11,52
8	50°	375,3	196	0,06	11,76
12		412,7	200	0,07	14,0
16		446,2	220	0,07	15,4

Table 4. Discharge of 30 Lt/det

Number of blade	shooting Angle	Motor Rotation (rpm)	Voltage (volt)	Current (amp)	Powet (watt)
4		290,3	188	0,07	13,16
8	50°	395,0	190	0,07	13,3
12		430,5	206,5	0,07	14,45
16		445,2	210	0,07	15,0

Table 5. Discharge of 25 Lt/det

Number of blade	shooting Angle	Motor Rotation (rpm)	Voltage (volt)	Current (amp)	Powet (watt)
4		285,5	182	0,07	12,74
8	50°	330,5	188,5	0,07	13,19
12		426,0	192,5	0,07	13,47
16		431,1	196	0,07	14,0

3. Discussion

The results are simplified In accordance with topic as follows:

a. The effects discharge toward power
b. The effect of number of nozzles the results of which are presented in figure 6 and 7.

After the prototype test, several results were recorded. First, at blade counts of 4,8,12, and 16, with water discharge of 40l/s, 35l/s, 30l/s, 25l/s, with nozzle shooting angle of50 °, it is obtained the following results: (1) for 40l/s water discharge, the rotation are 310 rpm, 639.5 rpm, 655.5 rpm, 691.3 rpm; the voltage are 200 volts, 208 volts, 224 volts, 227 volts; and the power are 14 watts 14.56 watts , 13.68 watts, 15.89 watts; (2) for 35l/s water with identical number of nozzles and shooting angle, the rotation are 293.3 rpm, 375.3 rpm, 412.7 rpm, 446.2 rpm; the voltage are 192 volt, 196 volt, 200 volt, 220 volt; and the power are 11.52 watts of power, 11.76 watts, 14.0 watts, and 15.4 watts; (3)) for 30l/s water with identical number of nozzles and shooting angle, the rotation are 290.3 rpm, 395.0 rpm, 430.5 rpm, 445.2 rpm; the voltage are 188 volts, 190 volts, 206 , 5 volts, 210 volts; and the power are 13.16 watts, 13.3 watts, 14.45 watts, 15.0 watts; (4)) for 35l/s water with identical number of nozzles and shooting angle, the rotation are 285.5 rpm, 330.5 rpm, 426.0 rpm, 431.1 rpm; the voltage are 182 volt, 188.5 volt, 192.5 volts, 196 volts; and the power are 12.74 watts of power, 13.19 watts,13.47 watts, 14.0 watts. Comparisons of the results are described in the following graphs.
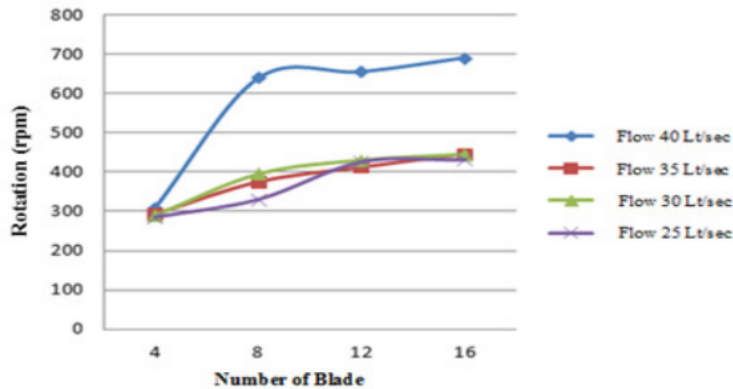
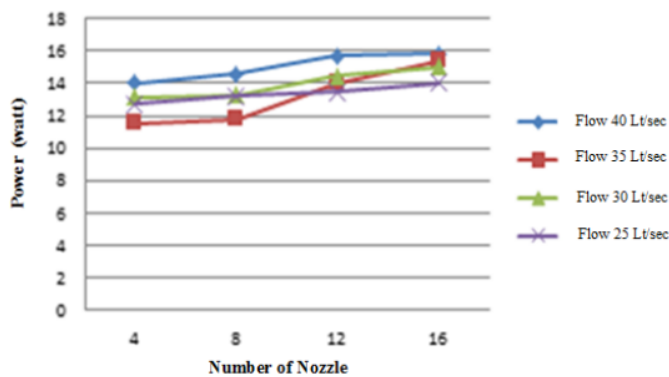**Figure 6.** Effects of blade number toward rotation (rpm)

Figure 7. Effects of blade number toward power (watt)

4. Conclusion

The results show that at blade counts of 4,8,12, and 16, and with water discharge at 40 l/s, 35 l/s, 30l /s, and 25 l/s, with nozzle shooting angle of 50 ° , the turbine rotational velocities are 310 rpm , 639 rpm, 655.5 rpm, and 691.3 rpm respectively. Furthermore, at water discharge of 35 l/s, the velocities are 293.3 rpm, 375,3 rpm, 412.7 rpm, 446.2 rpm, and at water discharge of 30 l/s, they are 240.3 Rpm, 395.0 rpm, 430.5 rpm, 445.2 Rpm. Moreover, at water discharge 25 of l/s, the speeds are 285.5 rpm, 330.5 rpm, 426.0 rpm, 431.1 rpm. From the results, it is concluded that the higher the water discharge rate, the greater the number of rotation, and it is also concluded that shooting angle has a significant effects on pelton turbine rotation and power.

Acknowledgement

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