Microhydro with Tube: A Powerhouse Solution for Rural Electricity

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Abstract. The rivers in Indonesia have great potential for Microhydro Power Plants that have not been maximized as one of the alternatives of eco-friendly energy sources. These potentials are spread throughout Indonesia with an approximate of total capacity up to nearly 550 MW, yet, only 4.7% of the existing potential has been utilized. The 2005-2025 national energy management blueprint suggests the amount of mini / microhydro energy resources is equivalent to 0.46 GW while the installed capacity was 0.216 GW. This research seeks to utilize water resources with micro-hydro power plants by applying 80 mm diameter cross flow turbines and 130 mm runner tubes as power houses. A micro-hydro power plant with a tube as a powerhouse can be built individually with low investment and easy operation, so that it can be owned by rural communities both personally and in groups. The required flowrate to run this system is considered small (12 L/s), and with a head of 3.5m, the electricity energy that can be produced is around 420 Watts. A modeling assessment was carried out to analyze the effectiveness of a cross flow turbine with a diameter of 80 mm and a length of 130 mm using a Microhydro Power Plant with a tube as an impermanent powerhouse. The number of blades varied from 16, 20, to 24 blades with a blade angle of 15° and 20°. During the modeling process, the design was modified simultaneously by varying the shape of the nozzle, changing the angle of the guide vane, and varying the number of runners. A simulation was done individually to get the best efficiency.

Keywords: Water Potential, Turbine, Mover, and Runner.

1. Introduction
The presence of rivers in Indonesia, especially in the city of Magelang, has not yet been utilized to its full potential, where its use is limited to washing and irrigation of rural agriculture, while its utilization as an alternative energy source is still limited. At present, a popular small-scale power plant, called the Microhydroelectric Power Plant (PLTMH Tube) which is a tube as a powerhouse, has been built, but its application is very small compared with the potential of existing water [12]. All PLTMH currently in construction are made permanent and only function to move an electric generator [3]. Many aspects are being considered such as the sensitivity to environmental issues related to civil works for mini /
microhydro plants and the familiarization of incentives for the production of renewable energy [15]. The civil structures of most power generating systems are quite massive in both the volume of work and materials used during construction, and the space needed is quite extensive. This leads to expensive investment and maintenance. However, in the interest of maximizing the use of renewable energy sources on a regular and large-scale basis, the application of integrated energy is the most decisive prerequisite [14]. With these characteristics, it becomes an obstacle for the distribution and development of a microhydro power plant (MHP) in the community [10]. This is a big loss because the potential energy that is in front of their eyes cannot be utilized immediately. Noting the reality of the challenges and expectations above, a question arises on how to create a practical power generating system with low investment costs and easy operation so that it can be easily owned by individuals or village community groups [8]. An overview of turbine construction can be found in Khosrowpanah's work which details the influence of the number of blades, the outer diameter of the runners and the nozzle entry angle on turbine efficiency [17]. The author tries to come up with an idea to build an initial drive system Cross Flow Turbine as an important component of the Microhydro Power Plant system with a drum model as a powerhouse [9]. A cross flow turbine consists of two components which are stationary nozzles and spinning runners. Nozzles function to accelerate the inflow and direct water towards the runner at an angle $\beta_1$ for maximum efficiency, where the value of $\beta_1$ must match the angle of the outer blade of the runner taking into consideration the rotating coordinates [4]. The performance of a cross flow turbine is determined and influenced by its structure, water flow (head), turbine blades, the position and the shape of the nozzles and the number of blades [16]. The cross flow turbine allows water to flow through the blades twice i.e. water flows from outside to inside and vice versa compared with the vertical and horizontal types of turbines [13]. The advantage of this drum model power generating system is that the system, starting from the drum/sink until the drain, can be broken down into several components, thus the implementation of construction/assembly in the field is relatively faster and with cheaper investment than other systems so that it becomes a solution in accelerating the spread and development of microhydro power plants going forward, by using a 3.5 meter head and a discharge rate of 12 l/s. This plant is used to drive generators that can produce electricity of 420 watts, so that it can be used by the community to power lighting for household scale at night. It is expected that with this electricity the community will be more productive [23].

1.1 Problem Formulation

Microhydro power plant installation (PLTMH Tube) uses water as an energy source to drive turbine runners. Microhydro Electric Discharge (PLTMH Tube) as a potential alternative energy that can be utilized to be developed in all corners of the country given the topography of the region in Indonesia [20]. The Microhydro Power Plant Model (PLTMH Tube) has been tested in Magelang region by utilizing its potential of water that is not too large [1].

1.2 Theoretical Basis

The Microhydro Power Plant (PLTMH Tube) consists of 4 main components which are easy to obtain so it is suitable for rural conditions. These components include [5].

a. Inlet, this channel serves to direct water into the tube (Calming Bath), which is made with a rubber coated board so that the water does not leak or can be made with a pipe, so that water can enter the tube optimally.

b. The tube (the calming bath) functions to store water from nature before being discharged through an engine (turbine) to generate power.

c. The engine (turbine) as a generator is chosen as the flow type because it has suitable characteristics (discharge, head and powerhouse).

d. Exhaust channel, this channel serves to direct water that comes out of the turbine so as not to damage the power plant location.
The Microhydro Power Plant (PLTMH Tube) was built based on the fact that there is water flowing in an area with adequate capacity and height. The term capacity refers to the amount of water flow in volume per unit of time (flow capacity) while the difference in height between the flow area and the installation is known as the head [6]. Microhydro is also known as white resources, and with free translation it can be said to be "white energy", because power plant installations like these use resources that have been provided by nature and are environmentally friendly. A fact that nature provides waterfalls and other types of water flows. The energy of water flow along with the energy of the difference in height of a certain area (where the installation will be built) can be converted into electrical energy. Technically, Microhydro has three main components namely water (as an energy source), turbines and generators [7]. Microhydro generates energy from water flow which has a certain height difference. Basically, micro hydro uses the potential energy of a waterfall (head).

![Figure 1. Schematic of Installing a Microhydro Power System with Tube](image)

The higher the waterfall, the greater the potential energy of water that can be converted into electrical energy. In addition to geographical factors (river layout), the height of waterfall can also be obtained by blocking the flow of water so that the surface water becomes high. Water is flowed through a pipe rapidly into the power plant which is generally built on the riverbank to drive a turbine or microhydro water wheel [19]. Mechanical energy that comes from the turbine shaft rotation will be converted into electrical energy by a generator.

### 1.3 Advantages of Microhydro Power Plants (PLTMH Tube)

a. Compared to other types of power plants, this Microhydro Power Plant tube is quite cheap because it uses natural energy.

b. Has a simple construction and can be operated in remote areas by skilled local residents with little training.

c. Does not cause pollution.

d. Can be integrated with other programs such as irrigation and fisheries.

e. Encourage people to be able to preserve forest so that water availability is guaranteed.

### 1.4 Testing Procedure

The testing procedure of 16, 20, and 24-blade runners cross flow turbine with blade angles of 15° and 20° on Microhydro Power Plants (PLTMH Tube) system is as follows:

a. Prepare the Microhydro Power Plants (PLTMH Tube) components and supporting equipment needed such as the runner, tube, inlet, overflow channel, exhaust line, turbine, and generator.

b. Arrange the Microhydro Power Plants (PLTMH Tube) components to be well assembled.

c. Set the valve of the cross flow turbine to full closing.

d. Open inlet irrigation to tube.
2. Research Methods
The research carried out consist of the stages of literature study, field surveys, design, making working, drawings, manufacturing, and testing the Microhydro power plants (PLTMH Tube) that will be built by the author himself. The type of data used as a reference are primary data from field surveys.

The data were then processed through the engine element planning formulas with the Turbine Cross Flow application and the results of the planning were used as a guideline in the process of manufacturing to realize a complete initial system and assemble it into a Microhydro Electric Power System (PLTMH Tube). Testing is the final stage carried out in the field on the efficiency of the system (PLTMH Tube), the achievement of the ability of the turbine components and in particular the efficiency of the Cross-Flow Turbine.

2.1. Research Stages
The initial stage of the research was to conduct a literature study of scientific journals, research reports and other reference books relating to the topic of Microhydro Power Plant (PLTMH Tube). Armed with the knowledge and information obtained, the author could emphasize the identification and formulation of the problem to be examined [7]. The next step was to carry out a plan that included determining the PLTMH Tube system and determining the material specifications and sizes of the components of the initial turbine, which involved a lot of engineering planning formulas [18]. The results of the next plan were standardized and converted to machine drawings. The next stage was the optimization of workshop / laboratory equipment production processes and procurement of tools and materials needed, then the process of making the initial driving components could begin [10]. After all the initial drive components had been produced properly, then a preliminary assembly was carried out to determine the suitability, compatibility and harmony of the functions and appearance of the PLTMH Tube system formed [15]. The refinement process was carried out right away until finally an optimal PLTMH Tube system and components were produced and ready for field testing. Indicators of measurable test performance as outputs of this study include power that could be generated (HP), runner rotation at maximum discharge position (rpm), turbine starting drive efficiency (%), and quality of valves in closing leaks (%), and avoidance of joint connections from the risk of leakage (%).

3. Result and Discussion
Analysis of application of the Bernoulli microhydro power plant (PLTMH Tube) system is explained in Figure 2.

Figure 2. Application of the Bernoulli microhydro power plant (PLTMH Tube) system
The Bernoulli’s energy equilibrium equation is [11]:

\[ \frac{P_1}{\gamma} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\gamma} + \frac{V_2^2}{2g} + Z_2 + H_1 \]  

(1)

Where:

- \( Z_1 \) = \( V_2^2 / 2g + Z_2 + H_1 \)
- \( V_2^2 / 2g = (Z_1 - Z_2) - H_1 \)
- \( V_2 = (2gH_1) \frac{1}{2} \)

then,

- \( V_2^2 / 2g = 3.5 \text{ m} - 0.2 \text{ m} \)
- \( V_2^2 / 2g = 3.3 \text{ m} \)
- \( V_2 = (2 \times 9.8 \text{ m/s} \times 3.3 \text{ m}) \frac{1}{2} \)
- \( V_2 = 12 \text{ m/s} \)

Notes,

- \( P_1 \) = Pressure of water in tube
- \( P_1 \) = 1 atm, ambient pressure
- \( V_1 \) = water velocity inside tube
- \( V_1 \) = 0, the position never changes/falls
- \( Z_1 \) = level of the water surface inside the tube container
- \( P_2 \) = pressure on the water surface in the exhaust channel
- \( P_2 \) = 1 atm, equal to the ambient air pressure
- \( V_2 \) = the speed of water in the exhaust channel
- \( Z_2 \) = the level of water surface in the exhaust channel
- \( Ha \) = actual head
- \( Ha \) = 3.5 meter
- \( H_1 \) = head loss
- \( H_1 \) = 20 cm, assumed for the water passes

### 3.1. Exhaust water disposal

The formula for maintaining the stability of flowrate in the tube (PLTMH Tube) system is:

Inlet water discharge = turbine discharge + exhaust channel discharge:

\[ Q_{in} = Q_{turbine} + Q_{w} \]  

(2)

Where:

- \( Q_{in} = 1.5 \times Q_{turbine} \)
- \( Q_{turbine} = 1.5 \times 12 \text{ l/s} = 18 \text{ l/s} \)

Exhaust water under normal condition:

- \( Q_1 = 18 \text{ l/s} - 6 \text{ l/s} = 12 \text{ l/s} \)

Calculation in planning the size of the run off channel was conditioned not to be in an ideal/critical condition. A sudden closing of the valve occurred would cause all water discharged from inlet to flow into the overflow until \( Q_1 = 12 \text{ l/s}, \) then the run off channel planned in pipes, the water flow speed in the run off channel was assumed to be \( V_1 = 2 \text{ m/s}, \) and the diameter of the PVC pipe used can be obtained as [5]:

\[ Q_1 = A_1 \cdot V_1 \]  

(3)

\( Q_1 = 0.785 \times D_{1/2} \times V_1 \)

\( D_1 = \left( \frac{Q_1}{(0.785 \times V_1)} \right)^{1/2} \)

\( D_1 = \left( 0.03 \text{ m}^3 / \text{sec} / (0.785 \times 2 \text{ m/s}) \right)^{1/2} \)

\( D_1 = 5 \text{ inches} \)
3.2 Leakage Observation

One of the most crucial things in a water turbine generator system is the problem of leakage. This was prone to happen since the water in the tube and in the starting drive has a considerable pressure. Even with the 3.5m head, the water pressure at the base of the tube could reach 125,000 N/m$^2$ or 1.25 atm. The welded joints between tube, seams and seals used were not good, and it was very likely that leaks would occur. There were two circles of welding joints on the tube that were quite long, three extension joints and four seal connections, namely two on the runner shaft and two on the valve shaft. From observations of 5 hours of turbines operation, there was no leakage reported. The condition of the tube and the drive remained dry and clean. Thus, the performance of microhydro can be said to be 100% free from the risk of leakage, as explained in Table 1:

Table 1. The achievement of mini/micro hydro generator free from leakage risk

| No. | Position                                    | Achievement of leakage free (%) |
|-----|--------------------------------------------|---------------------------------|
| 1.  | The joint of welding tube                   | 100                             |
| 2.  | The joint of tube connecting with elbow     | 100                             |
| 3.  | The joint of elbow with nozzle              | 100                             |
| 4.  | The joint of per pack and turbine house     | 100                             |
| 5.  | The joint of runner shaft seal and connecting bearing | 100                     |
| 6.  | The joint of valve shaft seal and connecting ring | 100                   |

3.3 Efficiency of Test Regulator and Valves

The regulator serves to ease and facilitate change in the position of the valve from the closing position and vice versa. The regulator works in the rotation wheel are in charge of converting translational motion into rotational motion. From the test results, the total rotations needed to change the valve position from pulley closing to pulley open were 38 rounds. Since the real flowrate was relatively small, the measurement of discharge that flowed through the exhaust was done directly, accommodated into a vessel/container for 6 seconds.

\[ V_t = p_b \cdot l_b \cdot t_a \]  \hspace{1cm} (4)

Where:
- \( p_b \) = vessel cross section length
- \( l_b \) = vessel cross section width

The real discharge of turbine intake water was obtained by the following formula:

\[ Q_{rt} = \frac{V_t}{t} \]  \hspace{1cm} (5)

3.4 Efficiency Test Transmission System

System transmission fan belt-pulley in the existence of round losses due to slip, and the percentage of slips can be calculated through following formula [5].

\[ S = \frac{(n_{g1} - n_{g2})}{n_{g1}} \cdot 100\% \]  \hspace{1cm} (6)

Where:
- \( N_{g1} \) = pulley generator without slip
- \( N_{g1} \) = \( n_t \cdot d_p / d_g \)
- \( N_{g2} \) = generator rotation

Then,
- \( N_{g1} = 1605 \text{ rpm} \)
- \( S = 0.4 \)

belt-pulley transmission efficiency as 99%.
3.5 Test of Generating System Efficiency
In this efficiency testing, cross flow turbine starter was used to drive the induction motor with maximum discharge of intake water turbine at 12 l/s, using power meter measurement, the electrical characteristics produced by generator obtained are as shown in Table 2:

Table 2. The characteristics of electricity generated

| No | The characteristics of electricity | Value       |
|----|------------------------------------|-------------|
| 1. | Power                              | 3000 Watt   |
| 2. | Voltage                            | 220 Volt    |
| 3. | Current                            | 0.4 A       |
| 4. | Cos φ                              | 1           |
| 5. | Frequency                          | 50 Hz       |
| 6. | Generator rotation                 | 1740 rpm    |
| 7. | Turbine Rotation                   | 1049 rpm    |
| 8. | Max discharge of turbine inlet water | 12 l/s     |

Cross Flow Turbine (ηsp) initial drive generator’s efficiency calculation:

\[ \eta_{sp} = \left( \frac{N_g}{N_p} \right) \times 100\% \]  

Where:

- \( N_g \) = generated power = 3000 Watt
- \( N_p \) = the potential power generated within maximum discharge condition of 12 l/s
- \( N_p = \gamma_{air} \times g \times Q_t \times H_t \)
- \( \gamma_{air} = \) specific gravity of water = 1,000 kg/m³
- \( Q_t = \) turbine real discharge = 12 l/s
- \( H_t = \) turbine head = 3.5 m

Thus,

\[ N_p = 1,000 \text{ kg/m}^3 \times 0.12 \text{ m}^3/\text{s} \times 3.5 \text{ m} = 420 \text{ Watt} \]

Table 3. The runner efficiency test data with 20 blades that were connected to the generating system at the plant are as follows:

| Loading (Watt) | V (Volt) | Light Bulbs | IC (A) | cos φ | Frequency (Hz) | Rotation (Rpm) | ηsp (%) |
|---------------|---------|-------------|--------|-------|----------------|----------------|---------|
| 0             | 230     | 0           | 0      | 0.67  | 1.00           | 51             | 1627    | 0      |
| 10            | 218     | 0.08        | 18.53  | 0.6   | 1.00           | 51             | 993     | 1617   | 7.26   |
| 20            | 202     | 0.19        | 38.38  | 0.6   | 1.00           | 50             | 975     | 1613   | 15.05  |
| 30            | 199     | 0.2         | 39.8   | 0.58  | 1.00           | 50             | 976     | 1609   | 15.61  |
| 40            | 187     | 0.23        | 43.01  | 0.54  | 1.00           | 50             | 978     | 1608   | 16.87  |
| 50            | 166     | 0.25        | 41.5   | 0.51  | 1.00           | 50             | 986     | 1612   | 16.27  |
| 60            | 151     | 0.31        | 46.81  | 0.42  | 1.00           | 51             | 1000    | 1625   | 18.36  |
| 70            | 136     | 0.35        | 47.6   | 0.41  | 1.00           | 51             | 1020    | 1639   | 18.67  |
| 80            | 122     | 0.4         | 48.8   | 0.38  | 1.00           | 51             | 1045    | 1696   | 19.14  |
| 90            | 109     | 0.47        | 51.23  | 0.34  | 1.00           | 52             | 1086    | 1762   | 20.09  |
Furthermore, the trend of the effect of changes in valve position on the efficiency of the starting drive runner of the crossflow turbine is explained by the following curve drawing (Figure 3). The picture shows the relationship between runner efficiency and enlargement of valve openings and torque which results in the addition of turbine inlet water flow expressed in percentage of valve openings. From the test results, it turned out that the 100% valve opening position showed the highest turbine efficiency at around 80%, and changes in valve openings from 50% onwards had little influence on the value of efficiency.

4. Conclusions and Recommendations
The results of the initial drive efficiency test of Cross Flow Turbine with 20 blades, a runner length of 130 mm, and a runner diameter of 80 mm showed the highest efficiency at 80% and would be suitable
for production for household-scale microhydro plants. Different characteristics were found between the results of planning and the results of real testing in the field i.e.

a. The maximum water intake for a turbine was 12 l/s or 48% smaller than the planned discharge flow that was 25 l/s.

b. The real turbine rotation was 1049 rpm or 23.4% greater than the planned rotation of 850 rpm.

**Suggestions and Recommendations**

a. Further research needs to be done to produce maximum efficiency on machine work so that it can be enjoyed by people who have not yet been reached by PLN electricity grid.

b. Cooperation between the community, technology innovators, policy makers and educational institutions is needed to development environmentally friendly technology.

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