The modeling of 80 mm diameter cross flow turbine runner for mini/microhydro environmentally friendly power plant

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Abstract. Indonesian river’s potentials on Mini or Microhydro fuelled power plants has not been maximally explored despite its big potentials of utilization. The 500 MW energy potentials of Mini or Microhydro throughout Indonesia have only reached the point of 4.5% while National Energy Management Blueprint in 2050 targeted 31% of renewable energy (RE) is coming from Micro hydro energy. The applications of 80 mm diameter cross flow turbine in a household scale have drawn an increase in its experience with 450 Watts of power produced through small discharge of 20 liters/second and 3-meter head. Cross flow turbines testing in 130 mm length and 80 mm diameter conducted using Mini/ micro hydropower Plant in environmentally friendly power House drum. Lower investment and operational design cost also to be made on its aim to reach community group or individual segments.

1. Background
Indonesian river’s potential has not been maximized; it is presented by its limited utilization as agricultural irrigation and domestic and industrial use only. River utilization as an alternative energy source to produce electricity has not been widely used on a larger scale. As there are still 4000 thousand villages that have not been reached by PLN electricity, the potentials of a river located in Rt 01/ Rw 12 Sub district Wates, District North Magelang of Magelang City were used as an energy alternatives though the current small-scale built power plants amount, known as Mini/ Micro Hydro Power Plant (MMHPP) is too little compared to the available water potential. All the MMHPP operated were built on permanent civil construction and the only function to drive the electricity generator [1].

The power plant building is also rather dominant in work volume and material use during the construction, the needs of the proper land site is also quite extensive. Thus, the investment and maintenance costs are relatively higher [2]. With such characteristics, the available energy potential cannot be taken to advantage immediately. Addressing to the big loss from untackled challenges and expectations above, more important questions arise; how can we create a practical generating system with cheap investment costs, easily operated system that can be easily acknowledged by individuals or village community groups [2].

The advantages of drum model generator system initially come from drums or settling tanks that had been broken down into several components. Thus the implementation of its construction in the field relatively faster and cheaper, adding acceleration to the solution of micro hydropower plant’s development and distribution in the future. Using 3-meter head and 20 liters/sec discharge system, the plant can
produce 450 watts of electricity that lift the community’s household lightning scale at night. Through this, it is expected that the community productivity will be arisen [3].

2. Research method

2.1. Place and time research

The research conducted in experimental scale research with material covered by stages of literature study, field survey, designing, work drawings, manufacturing processes and testing initial drive system of Cross Flow Turbine as an important component of micro hydro power plant built by the researchers in RT 01 / Rw 12 Sub district Wates, District North Magelang of Magelang City. The data shown presented from direct field data survey processed through machine element planning formulas using Cross Flow Turbine application [4]. The result then made into guidelines for the manufacturing process to reach complete initial drive system before it assembled into final PTMMMD system and carried out in the field to determine the efficiency of the system on the final stage. Calculating each turbine component capability achievement particular efficiency of the Cross-Flow Turbine initial drive are obtained [5].

a. Place of study:
   Sub district Wates Rt 01/ Rw 12 District North Magelang of Magelang City.

b. Research time.
   This study lasted for four months, from January 2018 to July 2018.

2.2. Research materials and tools place and time research

Tools used in the process of completing this experimental research are,

a. Workshop equipments for manufacturing process such as welding machines for connecting steel metal materials, drilling machines for holes, grinding machines for surfaces cleaning, cutting machines for cutting/splitting, lathes for turning the shaft, and bench work equipments such as snail-tap, stingy tools, hand saws, hammers and steel bases [6].

b. Measurement tools such as tachometer to measure the turbine and generator shaft rotation, power meter to frequently determine the amount of power generated.

![Figure 1. Cross flow turbine and generator](image1)

![Figure 2. The drum as power house](image2)
2.3. Research stages

Start

Literature Study
Scientific journal/research discussion MicroHydro Power Plant system drum modelling

Identification of Problem
opportunity and supporting factors determination on Cross flow Turbine initial drive

Formulation of Problem:
making Cross Flow Turbine initial drive for PTMMD applicable in the targeted scale

The planning and making initial drive shop drawing (assembly and projection images)

The procurement of tools and materials:
welding machine, drilling machine, grinding, steel profile, steel shaft, steel plate, bearing, seal, bolt – nut, per pack
3. Result and discussion background

3.1. Micro-hydro technology drum modeling

With the advancement of fluid mechanics technology and hydraulics science as well as stressing the possibility on accessing water energy resources availability in the countryside, in acknowledgment to the water discharge amount available, arising the potential of turbine plant in various head’s height [7]. The turbine potential objected by this research aiming to find the right system, shape, and size to get its maximum turbine efficiency [8].

3.1.1. Classification of Water Turbine Based on Specific Speed (n_s) [9].

The specific speed of the turbine is from the runner’s rotation speed which can produce an effective power of 1 BHP for each 1-meter head, or it can be written with the following formula [10].

\[ N_s = n \cdot N_t^{1/2} / H_t^{5/4} \]

Known,

- \( n_s \) = specific speed of the turbine
- \( n \) = Turbine rotation speed \( \ldots \ldots \) Rpm
- \( H_t \) = height of turbine effective fall \( \ldots \ldots \) m
- \( N_t \) = turbine effective power \( \ldots \ldots \) kW

Figure 3. Research flow chart
Each water turbine has its specific speed value, explaining the specific speed limit for some conventional turbines [10].

### Table 1. Conventional turbine specific speed

| No | Turbine type                  | Specific speed |
|----|-------------------------------|----------------|
| 1  | Pelton and waterwheel         | 10 - 35        |
| 2  | Francis                       | 60 - 300       |
| 3  | Cross-Flow                    | 70 - 180       |
| 4  | Kaplan dan propeller          | 300 - 1000     |

#### 3.1.2. The Advantages of Cross-Flow Turbine

Cross Flow Turbine is one of the types of action turbine (impulse turbine) water turbine. The working principle of this turbine was first discovered by A.G.M. Michell, an Australian engineer in 1903. The further development of the turbine then patented in Germany by Prof. Donat Banki made it called as Banki Turbine, it is sometimes also combined and known for Michell-Ossberger Turbine [11].

The use of Cross Flow Turbine type is more profitable than conventional waterwheel or other types of pico hydro turbines. The use of this turbine on the same power can save the cost on initial drive making up to 50% compared to another waterwheel in the same materials. This can be achieved by reduction on the size of the Cross Flow Turbine [1].

The diameter of the road wheel is commonly 2 meters up, and the diameter of the Cross-Flow Turbine can be made in only 20 cm in size. Likewise through the test on the turbine and the waterwheel usability carrying Ossberger German turbine, resulted in the usability of the water heater from its most superior type and Cross Flow Turbine's efficiency reached 70% and 82% respectively [11]. The higher efficiency achieved from Cross Flow Turbine was due to the double stages used in the water-energy process in the turbine. First, at water collision energy on the blades when the water starts coming in, and the second is the thrust of the water on the blades when the water was about to leave the runner [12].

![Figure 4. The Efficiency Curves of Some Turbines with Discharge Reduction as the variable](image)

The figure shows the relationship between efficiency and discharge reduction due to the setting of the valve opening which stated in the ratio of the discharge to the maximum discharge. For Cross Flow Turbine with Q/Qmax = 1 the efficiency is shown to be relatively higher for around 80%, in addition to changes in the discharge up to Q/Q max = 0.2 it indicates the relatively fixed price of efficiency [14].

From its simplicity when compared to other types of turbines, the Cross Flow Turbine is the simplest. Turbine Pelton blades, for example, are very complicated, the making must be technically poured. Likewise, the Francis Runner Turbine, Kaplan and Propeller runners are also made through casting or pouring process. And for Cross Flow runner Turbine it can be made from mild steel materials such as ST.37, by making it cold enough to be assembled with welding construction. Other components of this
turbine can all be made in general workshops with only basic equipment of electric welding machines, drilling machines, table grinding machines, lathes and bench work equipment required. It is the simplicity that makes Cross Flow Turbine can be classified as an appropriate technology that prospecting its development in rural communities due to its superiority in relevance to community expectations and capabilities [15].

With several advantages available, revealed by Haimerl, Ossberger Turbine manufacture has reached more than 5,000 units in its supply to particularly Germany and several countries. The article is as follows: “Today, numerous turbines throughout the world are operating on the Cross-flow principle, and most of these (more than 5,000 so far) have been built by Ossberger”. Furthermore, Haimerl stated that each unit of this turbine could be made to a power of approximately 750 kW, can be installed at head between 01 to 200 meters with up to 3 kg/second water discharge and makes it suitable for MMHPP, pump installation drive, agricultural machinery, workshops, and so on.

Cross Flow Turbine can generally be divided into two types, namely:

a. T1 Type, which is a low-speed Cross Flow Turbine (<500 rpm).

b. T3 Type, which is a high-speed Cross Flow Turbine (≥ 500 rpm).

![Figure 5. Types of cross-flow turbine](image)

3.2. The basics testing

The Cross flow turbines efficiency was tested through a various number of blades; 16, 20 and 24 in PTMMD systems of 15° and 20° angles respectively together with size specification, the right type of material for each component sin the initial drive turbine. The basis planning of this research, from the initial references, are turbine discharge, turbine head and turbine efficiency with the following potentials [8].

\[
\begin{align*}
Q_t &= \text{Turbine discharge} = 20 \text{ lt/ s} = 0.02 \text{ m}^3/ \text{s} \text{ (planning assumption)} \\
H_t &= \text{Turbine head} = 3 \text{ m} \\
\eta_t &= \text{Turbine efficiency} = 75\% \text{ (planning assumption)}
\end{align*}
\]

3.3. Power generated from the turbine (Nt)

The power generated from the turbine can be determined by the following formula:

\[
N_t = \rho_{air}. Q_t. H_t. \eta_t
\]

\[
\begin{align*}
N_t &= 1000 \text{ kg/ m}^3. 0.02 \text{ m}^3/ \text{s}. 3 \text{ m}. 0.75 \\
N_t &= 450 \text{ N. m/ sec} \\
N_t &= 450 \text{ joule / sec} \\
N_t &= 450 \text{ Watt} \\
N_t &= 0.450 \text{ kW}
\end{align*}
\]

3.4. Testing Procedure

The testing procedure of 16 blades, 20 blades, 24 blades runners with 15° and 20° blade angles on PTMMD system is as follows: [16]
a. Prepare the PTMMD components and other supporting equipments needed to the test location such as runner, drum container, inlet, overflow channel, exhaust line, initial drive turbine, generator, measuring instruments, hoes, crowbars, machetes, nails, keys, ropes, wire, ladder, Casso-wood for props/ frames and so on.

b. Assemble the components into a complete system to be tested, making sure that the PTMMD has been properly assembled, complete and strong.

c. Set the valve to its fully closed position by turning the regulator counter-clockwise.

d. Open up the rinsing hole in the irrigation channel to allow the water flows down and fall into the drum through the inlet.

e. Make sure that the drum has been filled with water marked by water coming out through the overflow channel.

f. Have a check and make some note if there is leak happening especially from the drum andperpack connection, and every seals initial drive system, record position of the leak if any.

g. Gradually open the valve, starting off with 25%, 50%, 75% into full openings (100%). Make each valve openings are loaded through every connection in the generator and record the maximum power generated.

h. Record the rotation speed of the turbine, the generator and the water discharge in all exhaust line at a full opening position.

3.5. Testing result
The application of the Bernoulli equation on the Mini/ Micro hydro power plant system with drums as the power house can be explained by the following picture [17].

![Energy equilibrium in mini/ microhydro system](image)

Noted,

- \( P_1 \) = pressure on the surface of the water in a drum container
- \( P_1 = 1 \) atm, equal to the outside air pressure
- \( V_1 \) = water velocity on the water surface inside drum container
- \( V_1 = 0 \), the position of the water surface never changes/ falls
- \( Z_1 \) = the level of the water surface inside the drum container
- \( P_2 \) = pressure on the water surface in the exhaust channel
- \( P_2 = 1 \) atm, equal to the outside air pressure
- \( V_2 \) = the speed of water in the exhaust channel
- \( Z_2 \) = the level of the water surface in the exhaust channel
- \( H_a \) = Actual head, i.e the difference of the water surface height on the container drum with the water surface in the exhaust channel
- \( H_a = 3 \) m
- \( H_l \) = head loses of the water flow from the container drum to the exhaust channel
- \( H_l = 20 \) cm, assumed to be relatively small considering the drum diameter is quite large, and there is only one elbow through for the water passes
Bernoulli’s energy equilibrium equation is:
\[ P_1 + \frac{V_1^2}{2.g} + Z_1 = P_2 + \frac{V_2^2}{2.g} + Z_2 + H_1 \]
\[ Z_1 = V_2^2/2.g + Z_2 + H_1 \]
\[ V_2^2/2.g = (Z_1 - Z_2) - H_1 \]
\[ V_2^2/2.g = H_2 - H_1 \]
\[ V_2 = (2. g . H_2)^{1/2} \]
Then,
\[ V_2^2/2.g = 3 \text{ m} - 0.2 \text{ m} \]
\[ V_2^2/2.g = 2.8 \text{ m} \]
\[ V_2 = (2 . 9.8 \text{ m/den . 2.8 m})^{1/2} \]
\[ V_2 = 7.4 \text{ m/diet} \]

3.6. Exhaust channel specification
The discharge balance in the mini/ micro hydro system is:
Inlet water discharge = turbine discharge + exhaust channel discharge:
\[ Q_m = Q_t + Q_l \]
Planned,
\[ Q_m = 1.5 . Q_t \]
\[ Q_m = 1.5 . 20 \text{ lt/sec} = 30 \text{lt/sec} \]
Exhaust discharge under the normal condition:
\[ Q_l = 30 \text{lt/sec} - 20 \text{lt/sec} = 10 \text{ lt/sec} \]
Calculation made to avoid a sudden valve closure, as for the exhaust channel are not made in ideal system (critical condition) with all water discharge from inlet flows into the exhaust channel (made of PVC pipes) in \( Q_l = 30 \text{lt/sec} \), the speed of water flowing into the exhaust assumed to be \( V_1 = 2 \text{ m/sec} \), we got the diameter of the PVC pipe used as:
\[ Q_l = A_1 . V_1 \]
\[ D_1 = (0.03 \text{ m}^3/\text{sec}/(0,785.2 \text{ m/sec}))^{1/2} \]
\[ D_1 = (0.03 \text{ m}/1.57)^{1/2} \]
\[ D_1 = 13.7 \text{ cm} \]
\[ D_1 = 5 \text{ inc} \]

3.7. Observation of leakage
Other crucial and significant problems in water turbine generating system are leakage problems. This could be easily happened in consider to the water inside the drum’s condition when the initial propulsion has quite large pressure. Even in the use of 3 m head, the water pressure at the bottom of the drum can reach up to 125,000 N/ m2 an equal with 1.25 atmospheres. Thus, securing the weld joint between the drums using a good per pack and seals are required. As the two circles of welded joints on the drum are quite long (consist of three per pack joints and four seal joints, namely two on the runner shaft and two on the valve shaft) [18].
Through 5 hours observation conducted, with environmental condition and initial drive remain dry and clean micro hydro generator appraisal performance on leakage risk reached 100% no leak available. Detailed data are shown in the following table:

| No. | Position | Achievement of leakage (%) |
|-----|----------|-----------------------------|
| 1.  | The joint of welding among drums | 100 |
| 2.  | The joint of drum per pack and elbow | 100 |
| 3.  | The joint of elbow per pack and nozel | 100 |
| 4.  | The joint of lid per pack and turbine house | 100 |
5. The joint of runner shaft seal and bearing 100
6. The joint of valve shaft seal and ring 100

3.8. Regulator and valve efficiency test

The regulator functions as easy to facilitate the change position of a valve from the closed open position and vice versa. The regulator works by changing the rotating wheel’s translational into rotational motion. The test carried out on four valve positions, with discharge consequences and valve efficiency from fully close to fully open position resulted in 36 rotations. Since the actual size of designed discharge is relatively small, the real discharge measurement must be measured directly. The water coming out of the exhaust channel is immediately accommodated into a vessel or container for 5 seconds. The collected water then to be measured at its volume, namely: [12]

\[ V_t = p_b \cdot l_b \cdot t_a \]

Note,
- \( p_b \) = the length of the vessel cross section
- \( l_b \) = the width of the vessel cross section

The actual water discharge came into the turbine can be searched using the formula:

\[ Q_{t} = V_{t} / t \]

3.9. Transmission system efficiency test

The belt-pulley transmission system in the existence of round losses due to slipping problem can be calculated through the following formula: [19]

\[ S = \frac{\left( n_{g1} - n_{g2} \right)}{n_{g1}} \cdot 100\% \]

Known,
- \( n_{g1} \) = ideal pulley generator rotation without slip
- \( n_{g1} = n_t \cdot \frac{d_{pt}}{d_{pg}} \)
- \( n_{g2} \) = measured generator rotation = 1533 rpm
- \( n_t \) = measured generator rotation = 961 rpm
- \( d_{pt} \) = turbine pulley diameter = 127 mm
- \( d_{pg} \) = generator pulley diameter = 76 mm

Then,
- \( n_{g1} = 961 \text{ rpm} \cdot \frac{127 \text{ mm}}{76 \text{ mm}} = 1605 \text{ rpm} \)
- \( S = \frac{(1605 \text{ rpm} - 961 \text{ rpm})}{1605 \text{ rpm}} \cdot 100\% \)
- \( S = 0.40 \% \)

We get the belt-pulley transmission efficiency as 99.6%.

3.10. Runner efficiency test with 16, 20, and 24 blades in 15° and 20°angles at a 3meters height turbine on the mini/micro hydro generator.

In this efficiency test, maximum inlet capacity of the water turbine at 20 liters/sec is used. The measurement using electrical characteristics power meter generated shown as follows [8]

| No | The characteristics of electricity | Value         |
|----|-----------------------------------|---------------|
| 1. | Power                             | 450 Watt      |
| 2. | Voltage                           | 198 Volt      |
| 3. | Current                           | 0.4 A         |
| 4. | \( \cos \varphi \)               | 1             |
| 5. | Frequency                         | 50 Hz         |
| 6. | Generator rotation                | 1740 rpm      |
| 7. | Turbine Rotation                  | 1049 rpm      |
| 8. | Maximum discharge of turbine inlet water | 20 lt/det |
Cross Flow Turbine (ηsp) initial drive generator’s efficiency calculation:

\[ \eta_{sp} = \frac{N_g}{N_p} \times 100\% \]

Known,

- \( N_g \) = generator-generated power = 450 Watt
- \( N_p \) = the potential power of water that can be generated within maximum discharge condition 20 lt/sec
- \( N_p = \gamma_{\text{air}} \cdot g \cdot Q_t \cdot H_t \)
- \( \gamma_{\text{air}} = \) specific gravity of water = 1.000 kg/m\(^3\)
- \( Q_t = \) turbinereal discharge = 20lt/sec
- \( H_t = \) turbine head = 3 m

Thus,

\[ N_p = 1.000 \text{ kg/m}^3 \times 0.02 \text{ m}^3/\text{det} \times 3 \text{ m} \]

\[ N_p = 45 \text{ kg m/sec} \]

\[ N_p = 450 \text{ N m/sec} \]

\[ N_p = 450 \text{ Watt} \]

Therefore, the value of the initial drive generator:

\[ \eta_{sp} = \left( \frac{450 \text{ Watt}}{450 \text{ Watt}} \right) \times 100\% \]

\[ \eta_{sp} = 45\% \]

The efficiency test determines torque generated by the turbine runner through the braking mechanism. Belt or brake strap as an important component in the braking process is installed around a semicircle pulley in \( \theta = 180^\circ \) contact angle. Both ends of the belts are connected to the spring scales, with one of the spring scales' hooks fixed and other subjected to tensile treatment (see Figure 7). In the process, \( F_{ta} \) tensile force and \( F_{te} \) compression force is shown to arise, the difference between \( F_{ta} \) and \( F_{te} \) are braking forces or friction force (\( F_g \)). The \( F_{ta} \) and \( F_{te} \) values used as a reference in this measurement are made while the turbine runner stops rotating. Occurrence of the torque obtained:

\[ T = F_g \cdot r \]

Known,

- \( r = \) turbine pulley spoke
- \( r = 127 \text{ mm/2} = 0.0635 \text{ m} \)

![Figure 7](image)

**Table 4. Torque braking characteristic test**

| Runner (Blade) | Valve (%) | Pulley Rotation (RPM) | Q Real Turbine (Lt/sec) | Tensile Force Fta (N) | Compression Force Fte (N) | Friction Force Fg (N) | Torque T (N.m) |
|----------------|-----------|-----------------------|------------------------|----------------------|------------------------|----------------------|--------------|
| 16             | 0         | 0                     | 0                      | 0                    | 0                      | 8                    | 0.51         |
|                | 25        | 728                   | 3.7                    | 26                   | 18                     | 8                    | 14           |
|                | 50        | 793                   | 7.4                    | 36                   | 12                     | 14                   | 0.89         |
|                | 75        | 887                   | 11.5                   | 45                   | 25                     | 20                   | 1.27         |
|                | 100       | 967                   | 15                     | 65                   | 37                     | 28                   | 1.78         |
| 20             | 0         | 0                     | 0                      | 0                    | 0                      | 0                    | 0            |

4. **Braking test characteristics (torque) result**
The following description determines amount of actual power generated by the Cross Flow Turbine initial drive generator at four valve positions, namely:

a. Valve position 25% opened

\[
T_1 = F_{g1} \cdot r \\
T_1 = 6 \, N \cdot 0,0635 \, m \\
T_1 = 0,38 \, N \cdot m \\
N_1 = 2 \cdot \pi \cdot n_1 \cdot T_1 \\
N_1 = 2 \cdot 3,14 \cdot 925 \, rpm \cdot 0,38 \, N.m \\
N_1 = 2 \cdot 3,14 \cdot 925 \, rot. \, 0,38 \, N.m / 60 \, sec \\
N_1 = 38 \, N.m/sec \\
N_1 = 38 \, Joule/sec \\
N_1 = 38 \, Watt
\]

b. Valve position 50% opened

\[
T_2 = F_{g2} \cdot r \\
T_2 = 15 \, N \cdot 0,0635 \, m \\
T_2 = 0,95 \, N \cdot m \\
N_2 = 2 \cdot \pi \cdot n_2 \cdot T_2 \\
N_2 = 2 \cdot 3,14 \cdot 970 \, rpm \cdot 0,95 \, N.m \\
N_2 = 2 \cdot 3,14 \cdot 970 \, rot. \, 0,95 \, N.m / 60 \, det \\
N_2 = 101 \, N.m/sec \\
N_2 = 101 \, Joule/sec \\
N_2 = 101 \, Watt
\]

| Valve Position (%) | Blade Number | Torque (Nm) |
|--------------------|--------------|-------------|
| 25                 | 25 Blade     | 0.38        |
| 50                 | 20 Blade     | 0.95        |
| 75                 | 24 Blade     | 1.52        |
| 100                | 24 Blade     | 2.03        |

Figure 8. Based graph characteristics of valve opening and torque from four different blade numbers variation
c. Valve position 75% opened
\[ T_3 = F_{g3} \cdot r \]
\[ T_3 = 24 N \cdot 0,0635 m \]
\[ N_3 = 2 \cdot \pi \cdot n_1 \cdot T_3 \]
\[ N_3 = 2 \cdot 3,14 \cdot 1005 \text{ rpm} \cdot 1,52 N.m \]
\[ N_3 = 2 \cdot 3,14 \cdot 1005 \text{ rot.} \cdot 1,52 N.m/60 \text{ sec} \]
\[ N_3 = 162 \text{ N.m/sec} \]
\[ N_3 = 162 \text{ Joule/sec} \]
\[ N_3 = 162 \text{ Watt} \]
d. Valve position 100% opened
\[ T_4 = F_{g4} \cdot r \]
\[ T_4 = 32 N \cdot 0,0635 m \]
\[ N_4 = 2 \cdot \pi \cdot n_2 \cdot T_4 \]
\[ N_4 = 2 \cdot 3,14 \cdot 1049 \text{ rpm} \cdot 2,03N.m \]
\[ N_4 = 2 \cdot 3,14 \cdot 1049 \text{ rot.} \cdot 2,03N.m/60 \text{ sec} \]
\[ N_4 = 224 \text{ N.m/sec} \]
\[ N_4 = 224 \text{ Joule/sec} \]
\[ N_4 = 224 \text{ Watt} \]

While the theoretical water power potentials of the Cross Flow Turbines initial drive generator are:

a. Valve position 25% opened
\[ N_{p1} = \rho_{\text{water}} \cdot Q_1 \cdot H_1 \]
\[ N_{p1} = 1.000 \text{ kg/m}^3 \cdot 0,0022 \text{ m}^3/\text{sec} \cdot 3 \text{ m} \]
\[ N_{p1} = 54 \text{ kg m/sec} \]
\[ N_{p1} = 54 \text{ Watt} \]
b. Valve position 50% opened
\[ N_{p2} = \rho_{\text{water}} \cdot Q_2 \cdot H_1 \]
\[ N_{p2} = 1.000 \text{ kg/m}^3 \cdot 0,0049 \text{ m}^3/\text{sec} \cdot 3 \text{ m} \]
\[ N_{p2} = 120 \text{ kg m/sec} \]
\[ N_{p2} = 120 \text{ Watt} \]
c. Valve position 75% opened
\[ N_{p3} = \rho_{\text{water}} \cdot Q_3 \cdot H_1 \]
\[ N_{p3} = 1.000 \text{ kg/m}^3 \cdot 0,0077 \text{ m}^3/\text{sec} \cdot 3 \text{ m} \]
\[ N_{p3} = 189 \text{ kg m/sec} \]
\[ N_{p3} = 189 \text{ Watt} \]
d. Valve position 100% opened
\[ N_{p4} = \rho_{\text{water}} \cdot Q_4 \cdot H_1 \]
\[ N_{p4} = 1.000 \text{ kg/m}^3 \cdot 0,0104 \text{ m}^3/\text{sec} \cdot 3 \text{ m} \]
\[ N_{p4} = 225 \text{ kg m/sec} \]
\[ N_{p4} = 225 \text{ Watt} \]

Table 5. The efficiency of cross flow turbine initial drive at four valve opening position with 16, 20, 24 blades on 3 m height turbine as mini or micro hydro plants:

| Runner (blade) | Valve (%) | Water Power (Watt) | Real Power (Watt) | η Turbine (%) |
|---------------|-----------|--------------------|------------------|--------------|
| 16            | 25        | 91                 | 39               | 43           |
|               | 50        | 182                | 74               | 41           |
|               | 75        | 282                | 118              | 42           |
|               | 100       | 368                | 180              | 49           |
Trends on the influence of valve position changes to the efficiency of the Cross-Flow Turbine initial drive explained through following curve picture. The relationship between efficiency and valve opening enlargement which resulted in the addition of water discharge inlet turbine expressed by the percentage of valve opening (25%, 50%, 75%, 100%). The highest turbine efficiency of around 87.8% resulted from its fully opened position as shown in turbine efficiency characteristics graph:

![Graph of turbine efficiency characteristics](image)

**Figure 9.** Graph of turbine efficiency characteristics on the opening valve of 16, 20 and 24 blades with 15° and 20° blades with 3 m turbine head.

5. **Conclusion**
   The turbine cross flow runner modeling with an angle and number variations on each blade 15°, 20° and 16, 20, 24 respectively in the turbine cross flow with 130 mm length and 80 mm runner diameter applied to micro-hydro plants in drum-based powerhouse resulted as the following:
   1. The actual power produced by the cross-flow turbine approached its highest potential power at 87.8% in 1049 rpm turbine rotation.
   2. Cross flow turbine efficiency is not directly proportioned by the number or the angle of the blade, as more angles added, the runner gap also tightened thus given influence on the water discharge.
   3. The highest cross flow turbine efficiency in runners reached by 20 blades in 15° angle.

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