A cross-flow Type Design of 5 kW Micro Hydro Power Plant for Rural Area In West Java

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Abstract. A 5 kW of cross-flow type micro hydro power plant has been designed to fulfill the need of energy in rural area in West Java. The primary data is taken on site by considering the height of water level, water flow rate, and other parameters related to topography of the location. The system is designed by two main steps of theoretical calculation and calculation-based construction. After installation on site, a maximum water flow rate of 63.7 liters/s and generator output power of 4,025 watt are smoothly reached. The expected 5 kW of generator output power is not yet obtained, due to many losses that still occur. This situation should encourage further study for more promising development.

1. Introduction
The progress of a nation depends so much on Energy as a fundamental sector [1]. Energy is also extremely needed to support most aspects of life including infrastructure, health, and education in order to meet the required standard of living and economic development [2]. The demands for power generators have increased along with significant increase of development of industrialization, economic, and urbanization [3]. Renewable energy seems to be very reasonable and the best option we have to be seriously explored and managed in order to be able to support sustainable economic and human population growth [5].

According to blueprint data of national management of energy 2005-2025 published by department of energy and mineral resources in 2005, the stock of fossil fuel in Indonesia will be run out in 18 years by the ratio of stock/production in 2004. Meanwhile, natural gas and coal are predicted to be run out in 61 years and 147 years, respectively [6]. The availability of water resources has not been fully utilized. The amount of natural water in west java is as much as 4.3 billion m³/year, and only 28% is already used [7]. Power generator is one of many potential forms of water utilization. Micro hydro power is not new, the idea of such water utilization has existed since 1970. Unfortunately, we still rarely find such application in Indonesia. The use of renewable energy for power generator in 2012 was still rare, only 11.31% of total produced energy [8].

Hydro power energy is the best option to produce clean energy from renewable sources [3]. In rural areas of developed or less developed countries, small-scaled hydropower or micro-hydro is reasonable for becoming one of the most effective technologies in cost for producing electricity [10].

Based on those facts and advantages, this research was expected to have an output of design of a cross-flow type micro hydro power plant, as shown in figure 1, which would be installed in Petir village, Dramaga Sub-district, Bogor Regency, West Java Province.
2. Steps of design for micro hidro power plane

The procedure of designing such cross-flow type micro hydro power plant involves the steps of obtaining the site data and calculations of parameters used to obtain the expected power output.

2.1. Preparing the site data

The site data shown in Table 1 was taken directly on site by measuring all needed parameters using appropriate hand tools.

| Parameters                              | Value       | Unit    |
|-----------------------------------------|-------------|---------|
| Coordinate                              | Lon: 106.725315 E / Lat: -6.620515 S |
| Location height                         | ±300        | masl    |
| Size of area                            | ±440000     | m²      |
| Potential water flow rate on site       | ±70         | liters/s|
| Tilt of land surface                    | 15          | degree  |
| Designed head                           | 8           | meters  |
| Size of water storage                   | 4 x 4 x 1   | meters  |
| Designed length of penstock             | 31          | meters  |

2.2. Calculations of designed parameters

The calculation involves the following parameters [13]:

a. Effective head ($H_{eff}$)

Effective head is determined by using equation

$$ H_{eff} = H_{actual} - H_{losses} $$  \hspace{1cm} (1)

b. Water flow rate ($Q$)

This parameter is calculated by using equation

$$ Q = V \times A $$  \hspace{1cm} (2)

whereas $V$ is the flow velocity and $A$ is the flow area determined by using equation below.

$$ A = Width_{average} \times Depth_{average} $$  \hspace{1cm} (3)

Figure 1. Designed cross-flow type micro hydro power plant
The flow area, $A$, is obtained by measuring manually on site and dividing the area into three measurement points as shown in table 2.

**Table 2.** Data of width and depth of the flow area

| Point | Width (m) | Depth (m) |
|-------|-----------|-----------|
|       |           | $H_1$     | $H_2$     | $H_3$     | Average (m) |
| 1     | 0.6       | 0.15      | 0.15      | 0.17      | 0.157       |
| 2     | 0.7       | 0.21      | 0.17      | 0.15      | 0.176       |
| 3     | 0.65      | 0.13      | 0.1       | 0.12      | 0.116       |
| Total | 1.95      | Total     | 1.35      |           | Average 0.149 |
| Average | 0.65    | Average   |           |           |             |

c. Input flow speed ($V_1$)

Based on the site data of water flow height, the input flow speed can then be determined by using equation

$$ V_1 = \eta h \sqrt{2gH} $$

(4)

d. Output flow speed ($V_2$)

Since the water flow in pipe 6” equals that in pipe 4” or $Q_1 = Q_2$, then the output flow speed ($V_2$) can be obtained by using equation

$$ V_2 = \frac{Q_1}{\frac{1}{2\pi x D_1^2}} $$

(5)

e. Mass flow rate ($\dot{m}$)

Based on the site data of water flow rate and 997 kg/m$^3$ of water density at 25°, then the mass flow rate can be determined by using equation

$$ \dot{m} = \rho x Q $$

(6)

f. Input power ($P_{in}$)

Input power can be calculated by using equation below and site data,

$$ P_{in} = \rho x g x Q x H $$

(7)

g. Output power ($P_{out}$)

Once the turbine efficiency is determined, then the output power can also be obtained by using equation

$$ P_{out} = \rho x g x Q x H x \eta_T $$

(8)

h. Specific turbine speed ($N_s$)

The specific turbine speed can now be determined by using equation

$$ N_s = \frac{\sqrt{P}}{H^{3/4}} $$

(9)

i. Generator output power (P)

Once we have the turbine efficiency and generator efficiency combined with the site data, then the generator output power can be obtained by using equation

$$ P = \rho \cdot g \cdot Q \cdot H \cdot \eta_T \cdot \eta_B $$

(10)
The summary result of these designed parameters is viewed in Table 3, and continued to application in 3D model design of 5 kW construction of cross-flow type micro hydro power plant (Figure 1) before finally implemented and installed on site.

| Table 3. Summary results of designed parameters |
|-----------------------------------------------|
| Parameters                  | Symbol | Value | Unit |
| Height of water flow        | H      | 8     | m    |
| Major losses                | H\text{major} | 0.73 | m    |
| Minor losses                | H\text{minor} | 1.47 | m    |
| Effective height of water flow | H\text{eff} | 5.8  | m    |
| Water flow rate             | Q      | 0.07  | m\(^3\)/s |
| Input velocity of flow      | V\text{1} | 3.76 | m/s  |
| Output velocity of flow     | V\text{2} | 38.8 | m/s  |
| Mass flow rate              | \dot{m} | 97.7  | kg/s |
| Turbine speed               | N      | 300   | rpm  |
| Specific turbine speed      | N\text{s} | 57.71 |      |
| Input power                 | P\text{in} | 7.6  | kW   |
| Output power                | P\text{out} | 6.7  | kW   |
| Output power of generator   | P      | 4.2   | kW   |
| Turbine efficiency          | \eta   | 65.7  | %    |

3. Result analysis

As there are two valves in two pipes work respectively from 0 to 100% of opening through eight steps, the water flow rate shown in Figure 2 seems to be increasing smoothly and significantly. At the last step of opening where it reaches 100% of opening, the trend does not rise significantly. The last 12.5% of valve opening was initiated when the flow rate almost reached its highest level of 63.7 liter/s.

Figure 3 shows that the trend does not start to rise at less than 11.6 liters/s of water flow rate which means that the turbine starts to spin when the water flow rate reaches over 11.6 liters/s. This situation refers to the load that the turbine needs to handle until it can produce power to run the generator.

The trend in Figure 4 depends so much on situation in Figure 3 whereas the generator seems to start producing power when the water flow rate reaches 11.6 liters/s and so does the turbine at the same rate. After passing over this rate of flow, the trend seems to rise insignificantly. This situation could just be caused by some losses during the travel of energy from turbine to generator.

![Figure 2. Water flow rate vs Valve opening](image-url)
4. Conclusion
Many losses still occur during the operation of this cross-flow type micro hydro power plant as the output power of generator obtained less that what is expected. The topography of the location contributes significant number of losses, besides the construction and selected materials. The construction design still needs to be improved as well as the selected materials in order to have better output power and efficiency.
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