Analysis of Generating Pico Hydro Power Plants (PLTPH)
Case Study: Reservoir E Institut Teknologi Sumatera

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Abstract: The mission of the Institut Teknologi Sumatera (ITERA) is to contribute to the empowerment of the potential that exists in the Sumatra region. In line with this mission, in an effort to support the acceleration of renewable energy growth in Sumatra, labor needs to be prepared that can be used directly by students to prove theory in class, one of which is a hydroelectric power plant, with a small capacity (pico hydro) with the use of ITERA reservoir water. This paper will discuss the design of a pico hydro power plant that matches the conditions of the ITERA reservoir by modeling using Matlab / Simulink. The simulation results with a 5.46 meter head and a 0.4 m³ / s discharge obtained a power of 12.61 kW.

1. Introduction
As a country with diverse geographical conditions and has an even distribution of population, Indonesia is still facing unequal access to electricity in several regions, this problem occurs due to the lack of investor interest in utilizing energy potential, lack of expert in the field of energy generation, as well as a decrease in power electricity at the time of distribution of electrical energy to remote areas. The effect of this situation is that some regions in remote areas do not get electricity supply, limited access to energy to run daily activities that require electrical energy, and the detriment of economic development and education [1].

Meanwhile, ITERA has source of electricity generation in the form of a variety of wide and deep water reservoirs, this water reservoir is intended for the construction of Pico Hydro Power Plant that can be utilized to create access to electrical energy evently and cleanly. With the variation in width and depth in the reservoir, this requires the author to conduct a survey to obtain a reservoir of water with supporting characteristics to be used as the location of electricity generation [2]–[4]. The characteristics of the desired water reservoir are as follows:

a. Continuous water rate
b. Water discharge is relatively stable or there is no significant change in a year
c. Under conditions of water overflow in the reservoir, no potential damage to Pico Hydro Power Plant
d. The location of the tail race and the spillway.

With the selection of suitable reservoir water, the power generated by the Pico Hydro Power Plant is estimated to reach 7.500 MW, but for the time being the load used is 600 MW [5]. In this case, the electric power generated depends on the height of the head and the flow of water flowing, the head is the difference in height between the surface of the upper water and the bottom of the water surface which is calculated in meters (m). The method use to calculated the head is as follows:

1) Transparent Water Hose Method, this method uses a transparent water hose filled with water and a measuring tape a tool in its implementaion. Measurement using this method is done by...
determining the measurement point that has a height difference, then the height value is obtained by measuring the difference in the level of water contained in a transparent hose.

2) Abney Level Method, this method uses clinometer in its implementation. Clinometer is used to measure the slope angle of the water reservoir. The height value is obtained by measuring the vertical angel between the surface of the upper water and the lower water surface with a clinometer and knowing the distance of the hypotenuse [5].

The construction of pico hydro power plant at ITERA is designed so that water can fall through the channel to the power plant in the form of a generator. In this case the difference in the height of the water surface above the generator will affect the potential energy of the water which will drive the turbine on the generator [6]. This can be made in a mathematical equation as in equation 1.

\[ E = mgh \]  

where, \( m \) = water mass (kg); \( h \) = Height (m); \( g \) = acceleration of gravity (9.8 m/s\(^2\))

Power is the energy per unit time \( (E/\delta t) \), so the equation can be expressed as:

\[ E/\delta t = m/\delta t \times gh \]  

By substituting \( P \) with \( (E/\delta t) \) and substituting \( \rho Q \) against \( (m/\delta t^2) \)

\[ P = \rho \times Q \times g \times h \]  

where, \( P \) = power (watt); \( Q \) = flow capacity \( (m/\delta t^2) \); \( \rho \) = water density (kg/m\(^3\))

Besides utilizing falling water, it can also be obtained from flat water flow. In this case the available energy is kinetic energy.

\[ E = \frac{1}{2} \rho v^2 \]  

where, \( v \) = velocity of water flow \( (m/\delta t) \)

Or by using an equation,

\[ E = \frac{1}{2} \rho A v^3 \]  

where, \( A \) = cross-sectional area of water flow (m\(^2\))

The output from this turbine will then drive the generator and produce an induction emf and electric power. The output of this generator will then be corrected with a step-up transformer so as to produce the appropriate voltage and frequency for the home electricity [7], [8].

By paying attention to the efficiency of the system, theoretically the power can be written:

a. Water power source

Water power in water power source can be calculated by equation:

\[ P_s = Q \times h_{eff} \times g \]  

where, \( P_s \) = Power on water source (watt); \( Q \) = Water discharge \( (m/\delta t^2) \); \( h_{eff} \) = Height (m)

b. Mechanical Power Source

The amount of mechanical power that drive the turbine is:

\[ P_m = P_s \times \eta_T \]  

where, \( \eta_T \) = turbine efficiency; \( P_m \) = electric power generated (watt)

c. Electrical Source

The amount of electric power that can be generated is:

\[ P = P_m \times \eta_G \]  

where, \( P \) = electricity generated (watt); \( \eta_G \) = Generator Efficiency

After falling water turns the turbine, then the water will be accommodated in the disposal reservoir. This shelter is due to the type of reservoir which is rain fed, so that the water cycle will be made in the
The design of a pico hydro power plant to restore falling water. The electricity generation scheme shown in Figure 1.

![Electricity generation scheme](image)

**Figure 1. Electricity generation scheme**

2. Method
The stages of the research began by designing the desired picohydro generating system. After that, conducting a survey on five (5) reservoirs to determine the potential of the embankment owned. The next stage is modeling MATLAB. Through this modeling the output power and tangible indicators will be seen to choose the type of turbine to be used. Finally, the output of this research is in the form of a report, its shown in Figure 2.

![Block diagram system](image)

**Figure 2. Block diagram system**
3. Results and Discussion
The survey was conducted on five ITERA reservoirs, namely reservoir A, reservoir B, reservoir C, reservoir D, and reservoir E. This survey is a measurement with a range finder tool to determine the distance of points around the reservoir to the observer to be processed into discharge and to know the height of the head. Through the field data obtained, it will then be processed to determine the potential of each reservoir.

The determination parameter is by determining the total efficiency in equation 3.1 consisting of civil construction, penstock, turbine, generator, control system, network, and transformer. The efficiency increment range is shown in the following Table 1.

Table 1. Efficiency range

| Parameter         | Range       |
|-------------------|-------------|
| $E_{\text{construction}}$ | 1.0         |
| $E_{\text{penstock}}$ | 0.90 – 0.95 |
| $E_{\text{turbine}}$ | 0.70 – 0.85 |
| $E_{\text{generator}}$ | 0.80 – 0.95 |
| $E_{\text{control system}}$ | 0.97       |
| $E_{\text{network}}$ | 0.90 – 0.98 |
| $E_{\text{transformer}}$ | 0.98       |

Equation 9 shows the potential of the reservoir, where the potential of the reservoir is calculated using the gravitational constant, flow rate, total efficiency, and net head height, that is the head height after being reduced by the powerhouse height. The comparison of the head, discharge, and potential of each reservoir is shown in Table 2. From this table it can be concluded that the greatest potential is in reservoir E, which is 13.13 kW with a head height of 5.46 m and a discharge of 0.4 m$^3$/s.

Table 2. Data comparison for each reservoir

| No | Location   | Head (m) | Water discharge (m$^3$/s) | Potential (kW) |
|----|------------|----------|---------------------------|----------------|
| 1  | Reservoir A| 1.4      | 0.04                      | 0.33           |
| 2  | Reservoir B| 1.52     | 0.02                      | 0.18           |
| 3  | Reservoir C| 4.38     | 0.2                       | 5.26           |
| 4  | Reservoir D| 2.09     | 0.02                      | 0.25           |
| 5  | Reservoir E| 5.46     | 0.4                       | 13.13          |

After obtaining a reservoir that has the potential for a pico hydro power plant, the next step is to choose the type of turbine to be used. The selection of turbines is based on the turbine type diagram with head and discharge parameters. Based on the diagram, 5.46 m head and 0.4 discharge are in Kaplan and cross-flow turbine types. In this study, cross-flow turbine was chosen because it is a turbine with a lower discharge than Kaplan so it is very suitable for pico hydro power plants. Turbine specifications used are shown in Table 3.
Table 3. Specification of cross-flow turbine

| Parameter                              | Value         |
|----------------------------------------|---------------|
| Inner diameter of the runner           | 0.122 m       |
| Outer diameter of the runner           | 0.187 m       |
| Length of the runner                   | 2.906 m       |
| Numbere of angles                     | 19 buah       |
| Distance between angles               | 0.033 m       |
| Corner curvature radius                | 0.031 m       |
| Circumference speed of the runner      | 4.066 m/s     |
| Runner rounds                          | 414.921 rpm   |

\[
P_t = Q P_{ef} \eta_t \quad P_t = 0.4 \times 3.96 \times 9.8 \times 0.8 \quad P_t = 13.97 \, kW \tag{11}
\]

\[
P_g = Q H_{ef} \eta_g \eta_g \quad P_g = 0.4 \times 3.96 \times 9.8 \times 0.9 \times 0.903 \quad P_g = 12.61 \, kW \tag{12}
\]

\[
n = \left(60 \times 0.8 \sqrt{\left(2 g H_{ef}\right)} \right)/0.122\pi
\]

The head and discharge simulations given are 3.96 m and 0.4 m³/s. This input is processed in turbines with turbine efficiency 0.90, turbine power obtained is 13.97 kW shown in Equation 11 with turbine rotation 679.6 rpm (Equation 13). The output from the turbine then drives the generator by giving an induction emf parameter. The result is a generator output power of 12.61 kW (Equation 12). The output obtained from the generator is then stabilized with an inverter and gives Vrms 4.939 V. The simulation shows in Figure 3.

4. Conclusions
This pico hydro generator model that is designed is feasible to be built in the E ITERA reservoir as an educational medium for students, so that they have a complete understanding of hydroelectric power generation and are ready to develop water potential for generation in the Sumatra region. Matlab / Simulink simulation results obtained 12.61 kW generator output power, and Vrms 4.939 V.

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