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# ANNUAL ENERGY BASED ON TIME SIMULATION OF MICROHYDRO POWER PLANT (PLTMH) JAMUS GIRIKERTO VILLAGE, SINE DISTRICT, NGAWI REGENCY.

*Muhammad Khoirur Rifqi[1], Faradlillah Saves[1,] and Andi Patriadi[1]

[1]Faculty of Engineering, University of 17 Agustus 1945 Surabaya, Indonesia
*rifqim.k885@gmail.com

## Abstract

PT. Candi Loka Jamus switched to using micro hydro power plants to meet its electrical energy needs because of the high operational costs and environmental impact of fuel oil power plants. However, during the dry season, the micro hydro power plant is unable to produce enough energy to meet the needs, which could lead to damage of its components and decreased performance. To address this issue, the energy potential of the micro hydro power plant was calculated using operational time simulation and season time simulation. The rain data was analysed using the double mass curve analysis method and arithmetic mean method to calculate the discharge throughout the year. The dependable discharge was calculated using the F.J. Mock method and the basic year method, and the physical potential formula was used to calculate the energy potential. Based on the calculations, the dependable discharge energy potentials of $Q_{80}$, $Q_{70}$, $Q_{50}$, and $Q_{30}$ were found to be 569,173.91 KWh, 614,737.01 KWh, 589,640.81 KWh, and 619,855.44 KWh, respectively. The efficient operating time of the micro hydro power plant was determined based on the $Q_{80}$ dependable discharge energy potential with a simulation of operational time. The plant should be active from January 1 to August 15, deactivated for maintenance purposes from August 16 to October 31, and reactivated from November 1 to December 31. With an active period of 287 days, the Jamus micro hydro power plant has an energy potential of 488,732.17 KWh in one year.

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## 1. Introduction

In the industrial field, the use of fuel oil (fossil) as a source of electrical energy is still widely used. Currently, the provision of fossil fuel oil for industrial fields on a large scale is relatively difficult and expensive, which has a direct impact on the increasing operational costs of production. Air pollution caused by the use of fossil fuel oil also has a negative impact on the environment. Therefore, to meet the electrical energy needs in the industrial field, it is necessary to create cheap and environmentally friendly tools, one of which is the Micro Hydro Power Plant.

The Micro Hydro Power Plant, often abbreviated as PLTMH, is a small-scale power plant with a power of less than 100 kW that utilizes hydropower as an energy producing source (Patty, 1995). PLTMH is a new renewable energy source and deserves to be called clean energy because it is environmentally friendly. In terms of technology, PLTMH was chosen because of its simple construction, easy operation, and maintenance, as well as ease of supply of spare parts. Economically, its operating and maintenance costs are relatively low, while the investment costs are quite competitive with other power plants.

The Jamus tea plantations and factories are located on the slopes of northern Mount Lawu, precisely in Girikerto Village, Sine District, Ngawi Regency. To meet the electrical energy needs of Jamus tea plantations and factories, which are currently managed by PT. Candi Loka, the company switched to using PLTMH from the previously used fossil fuel oil sources due to the high operational costs and environmental impacts. The selection of PLTMH as a source of electrical energy is supported by the existence of the Sawahan Source spring water channel located in a tea plantation area of 478.20 ha. Besides, the Jamus tea plantation and factory have a significant height difference that allows the construction of PLTMH (located at an altitude of 800 MDPL to 1200 MDPL). (Bambang Sutriyono, 2021).

Currently, the PLTMH has been operating, but during the dry season, the energy produced is not sufficient to meet the needs. If the micro hydro power plant continues to operate, its components will be damaged, and the performance of the power plant may decrease.

## 2. Materials and Methods

### 2.1 Theoretical Frame Work

This study analyses the energy potential of micro hydro power plants based on operational time simulations and seasonal time simulations. The purpose of this study is to determine the magnitude of the annual energy potential of micro hydro power plants based on the dependable discharge of $Q_{80}$, $Q_{70}$, $Q_{50}$, and $Q_{30}$, the study also aims to determine the difference in energy potential generated before and after operational time and seasonal time simulations, and to identify the optimal operating time for the Jamus micro hydro power plant.

### 2.2 Research Location

The location of this study is at PLTMH Jamus which is located in the Jamus Tea Plantation area, Girikerto Village, Sine District, Ngawi Regency, with location coordinates namely S 07º 33' 37.08" and E 111º 10' 37.2" can be shown in figure 1.

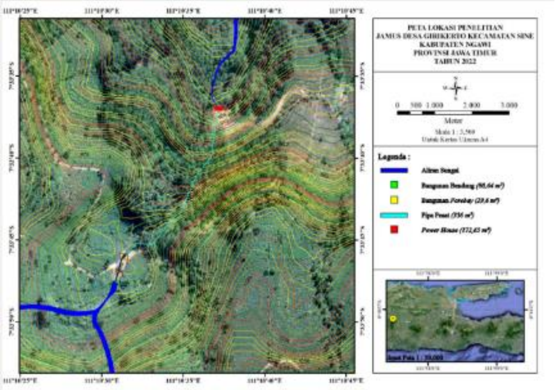

**Figure 1.** Research Location

### 2.3 Data

This study uses two types of data, namely primary and secondary data. Primary data is the data obtained directly from the field, including micro hydro power plant survey data, contour maps, and field documentation. Meanwhile, secondary data is the data obtained from other parties, including watershed maps, 10-year rain data (2012-2021), and climatological data.

### 2.4 Analysis Method

#### 2.4.1 Instantaneous Discharge

An instantaneous discharge that can be calculated is a discharge that passes through a weir. The discharge through the weir can be calculated by the following equation:

$$Q = \frac{2}{3} \mathrm{Cd} \times B\sqrt{2g(Yo - P)^3}$$

Q is discharge ($m^3/s$), B is width of weir (m), $C_d$ is discharge coefficient (0,9). ($Y_o$ – P) is the vertical distance between the water level from the weir and the lighthouse.

#### 2.4.2 Calculation of Height Difference

Head height or height difference is calculated by using the Tacheometric Method with theodolite tools for surveying. The calculations are performed using equations:

$$\begin{aligned} S &= D \times \cos m \\ &= (BA - BB) \times 100 \times \cos^2 m \end{aligned}$$

$$\Delta H = \frac{1}{2}(BA - BB) \times 100 \sin 2m + i - BT$$

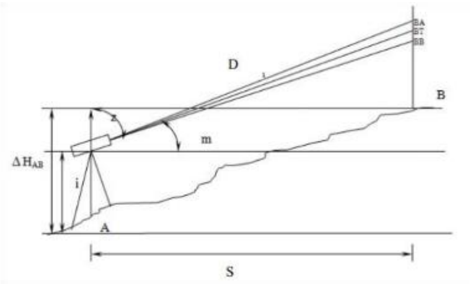

**Figure 2.** Tacheometric Method

S is horizontal distance, ΔH is height difference, i is height of tool, BA is upper thread readings, BB is lower thread readings, BT is middle thread readings, m is oblique angle, z is zenith angle (90˚ - m), and D is oblique distance.

### 2.4.3 Evapotranspiration

Evapotranspiration is the total amount of water that is returned to the atmosphere from the ground surface, water bodies, and vegetation due to the influence of climatic factors and vegetation physiology (Chay Asdak, 1995). In other words, the magnitude of evapotranspiration is the sum of evaporation (water evaporation from the soil surface), interception (re-evaporation of rainwater from the surface of vegetation leaves), and transpiration (evaporation of groundwater into the atmosphere through vegetation).

### 2.4.4 Missing Rain Data Filling

Since this study will calculate the discharge during both flooded and dry periods, it is necessary to fill in the missing rain data because complete data is required for the next rain-discharge transformation calculation using the F.J Mock method. The missing rain data will be filled in using the Reciprocal method, which is considered better than the Normal Ratio method (Bambang Triatmodjo, 2009) for calculating lost rain data because it takes into account the distance between stations (Li). This is done using the formula shown in the equation:

$$P_x = \frac{\sum_{i=1}^{n} \frac{Pi}{Li^2}}{\sum_{i=1}^{n} \frac{1}{Li^2}}$$

$P_x$ is missing rain data at station X, $P_i$ is rain data at surrounding stations in the same period (mm), $L_i$ is the distance between station X and the surrounding stations (km), and n is the number of rain stations in the vicinity.

### 2.4.5 Consistency Test of Rain Data

This study employed the double mass curve method to assess the consistency of rainfall data. Consistency can be deemed to be present if $R^2 \sim 1$. The equations used in our analysis were as follows:

$$R^2 = \frac{\sum xiyi - \sum xi \sum \frac{yi}{n^2}}{\sum xi^2 - \frac{(\sum xi)^2}{n} - \frac{(\sum yi)^2}{n}}$$

$R^2$ is coefficient of determination, n is the amount of data, $x_i$ is the rain data, $y_i$ is the average of the rain data.

### 2.4.6 Regional Rainfall

The rainfall of the region is calculated using the arithmetic mean method. This method involves measuring all precipitation at the specified station, summing it, and then dividing the result by the number of observation rain stations. The average rainfall in the Jamus PLTMH area is thus obtained.

$$CH_{average} = \frac{\sum Ri}{n}$$

$CH_{average}$ is average of rain data, $R_i$ is magnitude of CH at station I, and n is number of rain stations.

### 2.4.7 F.J. Mock Method

The Mock method is a water balance model that enables the calculation of monthly discharge from rainfall data, evapotranspiration, soil moisture, and groundwater reservoirs. Developed based on watershed research conducted throughout Indonesia, the Mock water balance model provides a relatively straightforward calculation method for various components (KP-01, 2010).

### 2.4.8 Dependable Discharge

The dependable discharge of a river is defined as the minimum discharge level that can be met with a certain percentage of probability, such as 90%, 80%, or other values, and can be utilized for specific purposes. The degree of reliability of such discharges can be determined based on the probability of their occurrence, calculated using the Weibull formula. The formula is as follow as:

$$P = \frac{i}{(n+1)} \times 100\%$$

i is the number of discharge sequence, n is the amount of data, and P is the probability of observing the expected set of values during the observation period.

### 2.4.9 Basic Year Method

Basic Year analysis is a method used for calculating rain discharge based on annual average data. The Basic Year method is often used to calculate the dependable discharge, which is the minimum discharge level that can be relied upon to meet certain needs, such as for irrigation or hydropower generation. The steps for calculating the dependable discharge using the Basic Year method are as follows:

1. Calculate the dependable discharge data using the Basic Year method formula.
2. Sort the discharge data from smallest to largest.
3. Determine the reference data for calculations using the Basic Year method formula."

$$R_i = \frac{\frac{n}{100\%}}{100\%-i} + 1$$

$R_i$ is the dependable discharge used, and n is the amount of data.

### 2.4.10 Micro Hydro Power Plants

PLTMH is defined as a power plant that uses hydropower as the main medium for driving turbines and generators. The power scale of micro hydro is generated from 5 kW to 50 kW. The process of changing kinetic energy in PLTMH is used to drive water turbines and electric generators to produce electrical energy (Notosudjono, D., 2002).

### 2.4.11 Building Components of Micro Hydro Power Plants

- Weir
  A weir is a water structure that serves to raise the height of the water level, allowing some of the water to flow over it.
- Forebay
  The function of forebay is to control difference in discharge in the pipe (penstock).
- Rapid Pipe (Penstock)
  A pipe or penstock is a tube that functions to carry water from the reservoir down to the turbine. When planning the installation of a penstock, factors to consider include its diameter, thickness, and material selection.
- Pipe Hydrolysis
  High-pressure losses consist of major and minor losses. Major losses are caused by friction in the pipes, while minor losses are caused by factors such as turns, reducers, valves, and other components (Sularso, 2006).
- Major Head Losses
  Major head losses is the pressure drop that occurs in a fluid flow system due to frictional losses in the piping system. The Darcy equation can be used to calculate friction loss between the pipe wall and fluid flow, assuming no change in cross-sectional area.

  $h_f = f \times L \times v^2 \times D^2 \times g$

  $h_f$ is major head losses, D is diameter of the pipe (m), L is length of the pipe (m), v is velocity of the fluid, f is friction factor, and g is acceleration due to gravity (9,81 m/s$^2$).
- Minor Head Losses
  Minor head losses refer to the pressure drop that occurs in a fluid flow system due to obstructions such as valves, fittings, bends, and changes in pipe diameter. Minor head losses are generally expressed by the equation:

  $h = \frac{K.v^2}{2g}$

  h is minor head losses, K is minor losses coefficient which is specific to the type of obstruction in the pipe based on Table 1, v is the average velocity of the fluid in the pipe and g is acceleration due to gravity (9,81 m/s$^2$).

**Table 1.** The Value of Minor losses Coefficient

| No. | K value | |
|---|---|---|
| 1 | Pipeline inlet | 0,5 |
| 2 | Sharp bend joints | 0,9 |
| 3 | The bend connection is not sharp | 0,75 |
| 4 | One-way valve | 2,5 |
| 5 | Accessories | 1,8 |

- Net Head of The Turbine
  The net head of the turbine refers to the difference in elevation between the water level in the reservoir or source and the water level at the turbine intake, taking into account any losses due to friction, bends, and other obstructions in the water flow. Effective height of turbine is calculated by this following formula:

  $H_{netto} = H_{static} - Hf_{total}$

  $H_{netto}$ is effective height of turbine, $H_{static}$ is height of static head which is the difference in elevation between the water level in the reservoir and the turbine inlet, Hf is the head loss due to friction in the penstock or pipeline carrying the water to the turbine.
- Rapid Pipe Diameter
  Rapid pipe diameter is defined as the internal diameter of the pipe, which is typically measured in millimeters or inches. According to the micro design standard hydro penstock diameter is calculated by this following equation:

  $D = 0,72 \times (Q_{dependable}) \times 0,5$

  $d = 2,69 \times \left(\frac{n^2 \times Q^2 \times L}{H}\right)^{0,1875}$

  D is penstock diameter (m) and Q is dependable diameter (m$^3$/s). d is penstock diameter, n is manning coefficient, Q is maximum discharge passes through penstock (m$^3$/s), L is length of penstock, and H is falling height (m).
- Power House
  The power house is a building or facility where the generators are located, which convert the mechanical energy produced by the turbine into electrical energy. In a hydropower system, water flows through the penstock and drives the turbine, which in turn drives the generator.

#### 2.4.12 Hydropower Capability Design

- Falling Height (Head)

  Falling height is used to determine the potential energy available in the water to generate electricity which is the vertical distance between the water level at the intake and the turbine measure in meters. The falling height is difference between the gross falling height and the falling height of the water losses pressure.

  $H_{eff} = H_{gross} - H_{losses}$

  $H_{eff}$ is the effective falling height, $H_{gross}$ is gross falling height, and falling height of the lost water pressure.
- Usable Power

  The power generated can be estimated preliminarily by calculating the effective fall height, discharge, water density, and turbine efficiency. The efficiency of the turbine depends on the type of turbine used, therefore, different types of turbines will result in different power outputs. (Dietzel Fritz, 1990). The usable power can be calculated with this equation:

  $P = \eta_t \times g \times Q_{dependable} \times H_{eff}$

  P is usable power, $\eta_t$ is turbine efficiency, g is acceleration due to gravity (9,81 $m/s^2$), Q is dependable discharge, and $H_{eff}$ is the effective falling height.

#### 2.4.13 Time Simulation

The time simulation used as the basis for calculations here involves two types:

- Time simulation based on the operational time of PLTMH, where it is determined whether or not PLTMH can meet the power needs of plantation operations and Jamus Tea Factory. When PLTMH is unable to meet power needs, it will be deactivated for maintenance purposes. After that, the difference in annual energy potential will be calculated if the PLTMH is activated at any time, compared to the current deactivated PLTMH as mentioned above.
- Time simulation based on the time of the season. The basis for determining the season here is based on rainfall at an interval of 3 months. The highest rainfall during the 3-month period will be determined as the rainy season, followed by the interval of the next season. Then, the energy potential will be calculated for each time interval of the season.

## 3. Result and Discussion

### 3.1 Rain Data Consistency Test

After filling in the missing rainfall data, a rainfall consistency test is then carried out to determine whether the rainfall data used for calculations is reliable or not. The consistency of the annual rainfall data is tested using the Double Mass Curve Analysis method, where the station's rainfall data is considered consistent when R2~1. If it does not meet this requirement, the rainfall data is considered inconsistent, and it is necessary to analyze the calculations with correction factors.

**Table 2.** Recapitulation of Average Rain Data

| Year | Rain Station | | | Average | Cummulative Average |
|---|---|---|---|---|---|
| | Ngelak | Waduk Gebyar | Dawung | | |
| 2012 | 1631 | 1753 | 1403 | 1596 | 1596 |
| 2013 | 2854 | 2767 | 2011 | 2544 | 4140 |
| 2014 | 3136 | 1776 | 1035 | 1982 | 6122 |
| 2015 | 1910 | 1240 | 1265 | 1472 | 7594 |
| 2016 | 2490 | 2077 | 2184 | 2250 | 9844 |
| 2017 | 1851 | 1618 | 1648 | 1706 | 11550 |
| 2018 | 777 | 1560 | 1542 | 1293 | 12843 |
| 2019 | 1877 | 1678 | 951 | 1502 | 14345 |
| 2020 | 2358 | 1191 | 1192 | 1580 | 15925 |
| 2021 | 1647 | 1150 | 1417 | 1405 | 17329 |

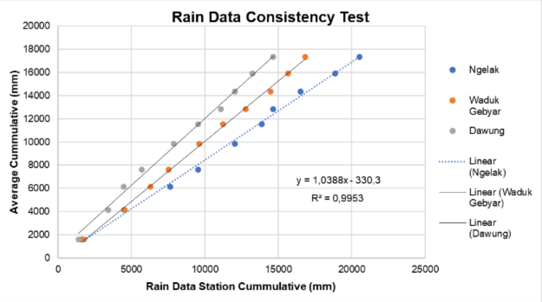

**Figure 3.** Rain Data Consistency Test Graph

### 3.2 Regional Rainfall Analysis

The calculation of the regional rainfall of the three stations is calculated using the arithmetic average method. The region's rain data is calculated in the 15-day period. The calculation steps are as follows:

- Used example is rain data in January first 15 days in 2012 which is :

  Ngelak = 203 mm
  Waduk Gebyar = 254 mm
  Dawung = 108 mm
- Regional rainfall is calculated with this formula:

  $P = \frac{203+254+108}{3} = 188{,}33$ mm

  The calculations is continued until 2021. The results of calculations are presented on this table below.

**Table 3.** Rain Data of 15 Days Period

| Year | 15 Daily | Month | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Okt | Nov | Des |
| 2012 | I | 188 | 157 | 92 | 121 | 46 | 100 | 0 | 0 | 0 | 3 | 18 | 138 |
| | II | 143 | 95 | 50 | 38 | 4 | 13 | 0 | 0 | 0 | 37 | 191 | 161 |
| 2013 | I | 277 | 179 | 161 | 250 | 0 | 92 | 8 | 0 | 0 | 0 | 84 | 241 |
| | II | 198 | 109 | 175 | 148 | 159 | 83 | 0 | 0 | 0 | 95 | 73 | 214 |
| 2014 | I | 205 | 124 | 107 | 111 | 52 | 13 | 46 | 0 | 0 | 0 | 47 | 111 |
| | II | 279 | 46 | 209 | 138 | 48 | 100 | 16 | 3 | 10 | 0 | 143 | 172 |
| 2015 | I | 81 | 165 | 143 | 122 | 0 | 0 | 0 | 20 | 0 | 0 | 45 | 82 |
| | II | 159 | 147 | 253 | 62 | 7 | 0 | 0 | 0 | 0 | 0 | 65 | 120 |
| 2016 | I | 36 | 210 | 66 | 51 | 20 | 62 | 24 | 44 | 33 | 110 | 179 | 86 |
| | II | 71 | 205 | 75 | 52 | 55 | 80 | 56 | 30 | 105 | 127 | 426 | 49 |
| 2017 | I | 50 | 183 | 139 | 136 | 34 | 2 | 0 | 0 | 0 | 86 | 93 | 78 |
| | II | 217 | 84 | 83 | 111 | 48 | 4 | 0 | 0 | 40 | 57 | 161 | 101 |
| 2018 | I | 147 | 119 | 159 | 48 | 4 | 0 | 5 | 0 | 0 | 5 | 55 | 56 |
| | II | 153 | 163 | 113 | 107 | 2 | 19 | 0 | 0 | 0 | 11 | 71 | 54 |
| 2019 | I | 114 | 162 | 159 | 71 | 49 | 0 | 1 | 0 | 0 | 0 | 16 | 121 |
| | II | 132 | 186 | 117 | 62 | 8 | 3 | 0 | 0 | 0 | 4 | 27 | 270 |
| 2020 | I | 143 | 167 | 104 | 100 | 50 | 25 | 12 | 36 | 10 | 39 | 41 | 145 |
| | II | 65 | 106 | 108 | 37 | 60 | 3 | 10 | 28 | 11 | 114 | 79 | 88 |
| 2021 | I | 49 | 138 | 78 | 62 | 40 | 48 | 17 | 4 | 8 | 12 | 99 | 78 |
| | II | 129 | 88 | 159 | 28 | 34 | 65 | 0 | 0 | 18 | 28 | 121 | 102 |

### 3.3 Rain and Discharge Transformation with Mock Method

Calculating the rain-discharge transformation with the mock method is based on the data from the calculation of 15 daily or monthly rainfall of the region, data from the evapotranspiration calculation, and regional parameter data. The calculation results is presented by this table below.

**Table 4.** The Results of Dependable Discharge in 2012

| Month | 15 Daily | Dependable Discharge |
|---|---|---|
| Jan | I | 11,7070 |
|  | II | 7,6799 |
| Feb | I | 9,7033 |
|  | II | 5,6672 |
| Mar | I | 4,9370 |
|  | II | 1,4432 |
| Apr | I | 5,7821 |
|  | II | 1,1665 |
| Mei | I | 1,0059 |
|  | II | 0,6493 |
| Jun | I | 3,3566 |
|  | II | 0,5882 |
| Jul | I | 0,4216 |
|  | II | 0,3372 |
| Aug | I | 0,2698 |
|  | II | 0,2158 |
| Sep | I | 0,1727 |
|  | II | 0,1381 |
| Okt | I | 0,1238 |
|  | II | 0,2695 |
| Nov | I | 0,1557 |
|  | II | 8,3495 |
| Des | I | 5,8459 |
|  | II | 9,2282 |

**Table 5.** Recapitulation of Every Year Discharge with Mock Method

| Month | 15 Daily | Year |  |  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|---|
|  |  | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 | 2021 |
| Jan | I | 11,707 | 17,58 | 11,239 | 2,949 | 0,478 | 1,568 | 7,413 | 4,561 | 5,746 | 0,586 |
|  | II | 7,68 | 11,51 | 15,962 | 9,395 | 0,588 | 9,946 | 7,69 | 6,182 | 0,9 | 5,049 |
| Feb | I | 9,703 | 10,81 | 4,86 | 9,466 | 8,9 | 9,323 | 2,943 | 8,839 | 7,931 | 5,871 |
|  | II | 5,667 | 6,089 | 1,444 | 9,471 | 9,06 | 1,737 | 10,002 | 10,07 | 4,305 | 3,118 |
| Mar | I | 4,938 | 10,041 | 4,545 | 7,914 | 1,122 | 8,611 | 9,136 | 7,65 | 4,1 | 2,055 |
|  | II | 1,443 | 9,028 | 11,548 | 14,576 | 1,005 | 2,442 | 3,367 | 5,274 | 4,795 | 6,38 |
| Apr | I | 5,782 | 16,881 | 4,898 | 4,959 | 0,76 | 6,689 | 1,267 | 1,416 | 3,44 | 1,18 |
|  | II | 1,166 | 8,55 | 7,656 | 2,437 | 0,663 | 5,02 | 4,257 | 2,08 | 0,961 | 0,716 |
| Mei | I | 1,006 | 1.850 | 1,447 | 1,204 | 0,424 | 1,182 | 0,834 | 1,435 | 0,865 | 0,658 |
|  | II | 0,649 | 9,852 | 1,189 | 0,997 | 0,531 | 1,045 | 0,661 | 0,658 | 0,79 | 0,535 |
| Jun | I | 3,357 | 5,172 | 0,829 | 0,771 | 0,511 | 0,659 | 0,52 | 0,495 | 0,521 | 1,063 |
|  | II | 0,588 | 4,175 | 4,811 | 0,617 | 1,809 | 0,538 | 0,508 | 0,412 | 0,336 | 1,986 |
| Jul | I | 0,422 | 1,28 | 0,738 | 0,493 | 0,335 | 0,416 | 0,357 | 0,322 | 0,316 | 0,373 |
|  | II | 0,337 | 0,994 | 0,619 | 0,448 | 0,566 | 0,333 | 0,266 | 0,254 | 0,251 | 0,234 |
| Aug | I | 0,27 | 0,795 | 0,433 | 0,414 | 0,369 | 0,266 | 0,213 | 0,203 | 0,336 | 0,209 |
|  | II | 0,216 | 0,636 | 0,361 | 0,253 | 0,268 | 0,213 | 0,17 | 0,162 | 0,265 | 1,15 |
| Sep | I | 0,173 | 0,509 | 0,277 | 0,202 | 0,258 | 0,17 | 0,136 | 0,13 | 0,153 | 0,156 |
|  | II | 0,138 | 0,407 | 0,27 | 0,162 | 4,268 | 0,328 | 0,109 | 0,104 | 0,135 | 0,184 |
| Okt | I | 0,124 | 0,326 | 0,177 | 0,129 | 3,935 | 2,755 | 0,111 | 0,083 | 0,257 | 0,133 |
|  | II | 0,269 | 1,487 | 0,142 | 0,103 | 4,814 | 0,478 | 0,124 | 0,084 | 4,005 | 0,195 |
| Nov | I | 0,156 | 1,365 | 0,343 | 0,301 | 10,349 | 3,295 | 0,324 | 0,132 | 0,413 | 2,916 |
|  | II | 8,35 | 2,555 | 5,884 | 0,293 | 27,697 | 8,505 | 0,315 | 0,043 | 1,318 | 6,144 |
| Des | I | 5,846 | 12,724 | 4,619 | 1,441 | 4,79 | 1,836 | 0,319 | 2,436 | 5,76 | 2,641 |
|  | II | 9,228 | 12,008 | 9,887 | 5,014 | 1,837 | 1,576 | 0,301 | 16,311 | 3,081 | 3,401 |

**Table 6.** The Result of Mock Method Control

| Year | WS-RO Corelation | Note |
|---|---|---|
| 2012 | 0,9860 | OK |
| 2013 | 0,9887 | OK |
| 2014 | 0,9906 | OK |
| 2015 | 0,9888 | OK |
| 2016 | 0,9938 | OK |
| 2017 | 0,9814 | OK |
| 2018 | 0,9897 | OK |
| 2019 | 0,9932 | OK |
| 2020 | 0,9834 | OK |
| 2021 | 0,9907 | OK |

### 3.4 Dependable Discharge Analysis with The Basic Year Method

Dependable discharge refers to the amount of water available to meet needs while taking into account the risk of failure. It is calculated to ensure that the amount of water is likely to be available throughout the year, even during the dry and rainy seasons. The most commonly used measures of dependable discharge are $Q_{80}$, $Q_{70}$, $Q_{50}$, and $Q_{30}$, which correspond to the probability of discharge being available at 80%, 70%, 50%, and 30%, respectively.

To determine the dependable discharge, an analysis is conducted based on flow discharge data from 2012 to 2021. The main method used for calculating dependable discharge is the basic year planning method (Basic Year). The following steps and examples illustrate how to use this method:

1. Calculate the annual average discharge using the flow discharge data obtained from the Mock Method calculation. Recapitulate the results in the following table:

**Table 7.** Annual Dependable Discharge Recapitulation with Mock Method ($m^3/s$)

| Year | Dependable Discharge |
|---|---|
| 2012 | 3,301 |
| 2013 | 5,076 |
| 2014 | 3,924 |
| 2015 | 3,084 |
| 2016 | 3,555 |
| 2017 | 2,872 |
| 2018 | 2,139 |
| 2019 | 2,886 |
| 2020 | 2,124 |
| 2021 | 1,914 |

2. Sort annual dependable discharge from small to large. The result is presented in Table 8.

**Table 8.** Sorted Annual Dependable Discharge

| Year | Dependable Discharge |
|---|---|
| 2021 | 1,914 |
| 2020 | 2,124 |
| 2018 | 2,139 |
| 2017 | 2,872 |
| 2019 | 2,886 |
| 2015 | 3,084 |
| 2012 | 3,301 |
| 2016 | 3,555 |
| 2014 | 3,924 |
| 2013 | 5,076 |

3. Determine the year of dependable discharge to use as the basis for design, using the probability formula from Weibull.
   - Dependable Discharge $Q_{80}$

     For $Q_{80} = \dfrac{10}{\frac{100\,\%}{(100\%-80\%)}} + 1$

     = 3 (2018)

     The year 2018 is selected as $Q_{80}$ with average dependable discharge of 2,139 $m^3/s$.
   - Dependable Discharge $Q_{70}$

     For $Q_{70} = \dfrac{10}{\frac{100\,\%}{(100\%-70\%)}} + 1$

     = 4 (2017)

     The year 2017 is selected as $Q_{70}$ with average dependable discharge of 2,872 $m^3/s$.
   - Dependable Discharge $Q_{50}$

     For $Q_{50} = \dfrac{10}{\frac{100\,\%}{(100\%-50\%)}} + 1$

     = 6 (2015)

     The year 2015 is selected as $Q_{50}$ with average dependable discharge of 3,084 $m^3/s$.
   - Dependable Discharge $Q_{30}$

     For $Q_{30} = \dfrac{10}{\frac{100\,\%}{(100\%-30\%)}} + 1$

     = 8 (2016)

     The year 2016 is selected as $Q_{30}$ with average dependable discharge of 3,555 $m^3/s$.
4. Furthermore, a calculation of the power and energy potential of PLTMH Jamus will be carried out by using the probability discharge data from each year.
5. The dependable discharge is presented in the graph which is showed in these following figures below.

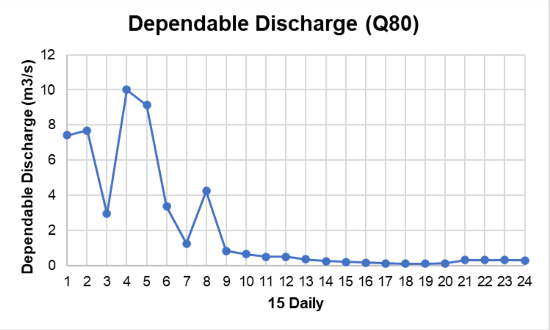

**Figure 4.** Dependable Discharge (Q80) - 2018

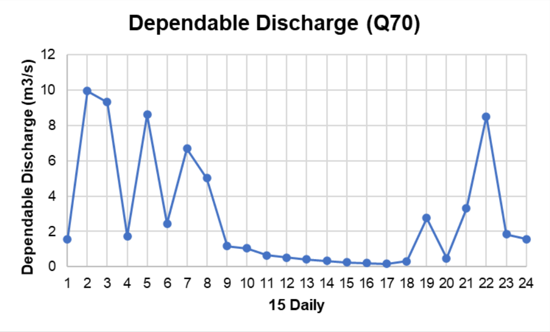

**Figure 5.** Dependable Discharge (Q70) - 2017

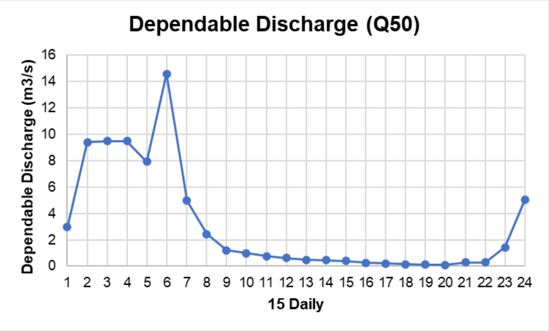

**Figure 6.** Dependable Discharge (Q50) - 2015

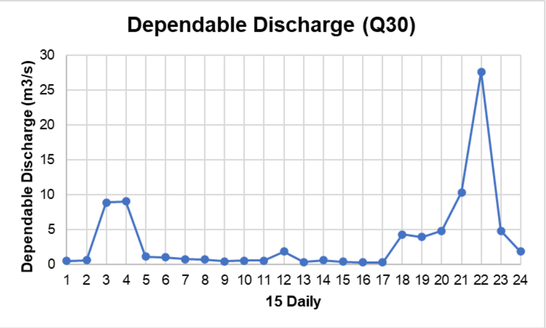

**Figure 7.** Dependable Discharge (Q30) – 2016

### 3.5 Potential Energy

1. Power Calculation

   The resulting electrical power can be calculated, with values ranging from 0.8 to 0.95. Since the existing turbine is old and has been used, its efficiency value is determined to be 0.8. An example of calculating electrical power using the maximum discharge through a pipe is shown below:

$$P = \eta_t \times g \times Q_{andalan} \times H_{eff}$$
$$= 0{,}8 \times 9{,}81 \times 0{,}179 \times 50{,}45$$
$$= 70{,}954 \text{ kW}$$

2. Electrical Potential Energy

   Electrical energy is obtained by calculating the electrical power generated during the operating time of the PLTMH in a 15-day period. As an example, the calculation uses a 15-day (360-hour) operating duration, as shown below:

   $$E = P \times T$$
   $$= 70{,}95415 \times 360$$
   $$= 25543{,}49 \text{ kWh}$$

3. Electrical Energy Load

   The electrical energy load is calculated by adding up the electrical power load of production activities and employee housing in the PT Candi Loka Jamus Tea Factory area, which amounts to 67,7 kW. This value is then multiplied by the operational time of the PLTMH.

   $$E = P \times T$$
   $$= 67{,}7 \times 360$$
   $$= 24372 \text{ kWh}$$

   The result of all calculations is presented in Table 9 and Figure 8.

**Table 9.** Recapitulation of Potential Energy and Energy Load

| Month | 15 Daily | Potential Energy (kWh) | Energy Load (kWh) |
|---|---|---|---|
| Jan | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Feb | I | 25543,490 | 24372,000 |
| | II | 20434,790 | 19497,600 |
| Mar | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Apr | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| May | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Jun | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| Jul | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Aug | I | 25543,490 | 24372,000 |
| | II | 21798,210 | 25996,800 |
| Sep | I | 16348,660 | 24372,000 |
| | II | 13078,930 | 24372,000 |
| Okt | I | 13332,170 | 24372,000 |
| | II | 15883,770 | 25996,800 |
| Nov | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| Des | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |

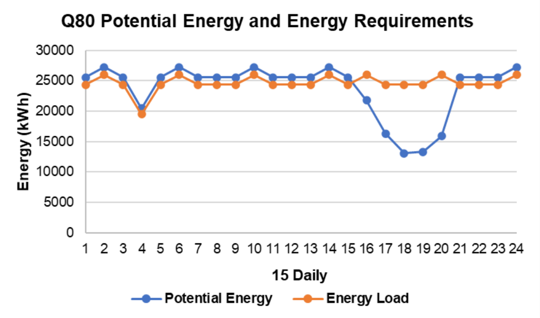

**Figure 8.** Q80 Potential Energy and Energy Requirements Graph

### 3.6 Time Simulation

The time simulation used as the basis for calculations here is of two types:

1. Time simulation based on the operational time of the Micro Hydro Power Plant, which is determined by whether or not the plant can meet the power needs of production activities and employee housing at PT Candi Loka Jamus. When the plant is unable to meet power needs, it will be deactivated for maintenance purposes. Afterwards, the difference in annual energy potential will be calculated if the plant is activated at any time, under the aforementioned conditions.

**Table 10.** Recapitulation of Potential Energy with Operational Time Simulation

| Month | 15 Daily | Potential Energy (kWh) | Energy Load (kWh) |
|---|---|---|---|
| Jan | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Feb | I | 25543,490 | 24372,000 |
| | II | 20434,790 | 19497,600 |
| Mar | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Apr | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| May | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Jun | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| Jul | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Aug | I | 25543,490 | 24372,000 |
| | II | 0 | 25996,800 |
| Sep | I | 0 | 24372,000 |
| | II | 0 | 24372,000 |
| Okt | I | 0 | 24372,000 |
| | II | 0 | 25996,800 |
| Nov | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| Des | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |

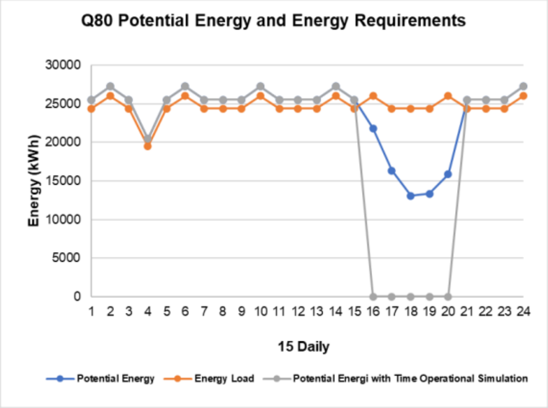

**Figure 9.** Q80 Potential Energy and Energy Requirement Graph with Operational Time Simulation

**Table 11.** Comparison of Potential Energy Before and After Operational Time Simulation

| Dependable Discharge | Before Simulation (kWh) | After Simulation (kWh) | Difference (kWh) |
|---|---|---|---|
| Q80 | 569173,910 | 488732,740 | 80441,170 |
| Q70 | 614737,010 | 534311,950 | 80425,060 |
| Q50 | 589641,810 | 541522,060 | 48119,750 |
| Q30 | 619855,440 | 619855,440 | - |

2. Time simulation based on the season. The basis for determining the season is the rainfall at intervals of three months. The period with the highest rainfall will be determined as the rainy season, followed by the next season interval. Then, the energy potential will be calculated for each interval of the season. During the dry season, the Micro Hydro Power Plant will be decommissioned.

**Table 12.** Recapitulation of Potential Energy with Seasonal Time Simulation

| Month | 15 Daily | Potential Energy (kWh) | Energy Load (kWh) |
|---|---|---|---|
| Jan | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Feb | I | 25543,490 | 24372,000 |
| | II | 20434,790 | 19497,600 |
| Mar | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Apr | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| May | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |
| Jun | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| Jul | I | 0 | 24372,000 |
| | II | 0 | 25996,800 |
| Aug | I | 0 | 24372,000 |
| | II | 0 | 25996,800 |
| Sep | I | 0 | 24372,000 |
| | II | 0 | 24372,000 |
| Okt | I | 13332,170 | 24372,000 |
| | II | 15883,770 | 25996,800 |
| Nov | I | 25543,490 | 24372,000 |
| | II | 25543,490 | 24372,000 |
| Des | I | 25543,490 | 24372,000 |
| | II | 27246,390 | 25996,800 |

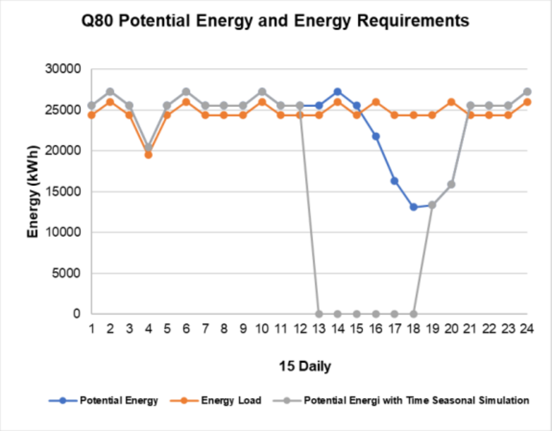

**Figure 9.** Q80 Potential Energy and Energy Requirement Graph with Seasonal Time Simulation

**Table 13.** Comparison of Potential Energy Before and After Seasonal Time Simulation

| Dependable Discharge | Before Simulation (kWh) | After Simulation (kWh) | Difference (kWh) |
|---|---|---|---|
| Q80 | 569173,910 | 439614,740 | 129559,170 |
| Q70 | 614737,010 | 463188,680 | 151548,330 |
| Q50 | 589641,810 | 439135,660 | 150506,150 |
| Q30 | 619855,440 | 463155,680 | 156699,760 |

### 3.7 Determination of Efficient PLTMH Operational Time

Based on a graph comparison of energy potential and needs, it can be concluded that the uptime of PLTMH based on operational time simulation (PLTMH is disabled when unable to meet electricity needs) is more efficient. Without sidelining maintenance time, the uptime of PLTMH based on the simulation of operational time is longer than the active time of PLTMH based on a simulation of season time (PLTMH is disabled throughout the dry season). This active time is directly proportional to the electrical energy produced. It is established that the operational time based on the calculation of the potential with the dependable discharge of the probability of 80% (Q80), namely:

- The first active period of PLTMH Jamus starts from January 1 (15th daily 1st) to August 15th (15th daily).
- PLTMH Jamus is deactivated from August 16 (15 to the 16th daily) to October 31 (15th daily 20th) because the river discharge was unable to produce enough energy to meet the electricity needs of production activities and houses of PT factory employees. Loka

Jamus Temple, so it will be deactivated for PLTMH maintenance needs.

- PLTMH is reactivated on November 1 (21st daily 15) to December 31 (24th daily 15), then continued into the following year.
- PLTMH has a total active period of 287 days with an energy potential of 488,732.17 kWh in one year.

## 4. Conclusion

Based on the results of the research that has been carried out, the following conclusions are obtained:

1. The amount of the river's flagship discharge based on the probability of dependable discharge is as follows:
   - Dependable discharge 80% probability (Q80) = 2.139 m3/dt
   - Dependable discharge 70% probability (Q70) = 2.872 m3/dt
   - Dependable discharge 50% probability (Q50) = 3.084 m3/dt
   - Dependable discharge 30% probability (Q30) = 3.555 m3/dt
2. The amount of energy potential that can be produced by PLTMH Jamus based on the dependable discharge probability is as follows:
   - Dependable discharge energy potential 80% probability (Q80) = 569,173.91 KWh
   - Dependable discharge energy potential 70% probability (Q70) = 614,737.01 KWh
   - Dependable discharge energy potential 50% probability (Q50) = 589,640.81 KWh
   - Dependable discharge energy potential 30% probability (Q30) = 619,855.44 KWh
3. The amount of energy potential produced by PLTMH Jamus based on time simulation is as follows:

**Table 14.** Comparison of Potential Energy Before and After Operational Time Simulation

| Dependable Discharge | Before Simulation (kWh) | After Simulation (kWh) | Difference (kWh) |
|---|---|---|---|
| Q80 | 569173,910 | 488732,740 | 80441,170 |
| Q70 | 614737,010 | 534311,950 | 80425,060 |
| Q50 | 589641,810 | 541522,060 | 48119,750 |
| Q30 | 619855,440 | 619855,440 | - |

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## 6. Author's Note

Everything written in this article is original because it sums up my studies with Mrs. Faradlillah Saves, S.T., M.T, and Mr. Dr. Andi Patriadi, S.T., M.T. The content of this article have been reviewed in a thesis defense at the Civil Engineering Study Program Faculty of Engineering, University of 17 Agustus 1945 Surabayam, on 16 December 2022 by Mrs. Faradlillah Saves, S.T., M.T, Mr. Dr. Andi Patriadi, S.T., M.T, and Mrs. Retno Trimurtiningsih, S.T., M.T.

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