Preliminary Design of Micro Hydro Power Plant in Kelekar River, Ogan Ilir District

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Preliminary Design of Micro Hydro Power Plant in Kelekar River, Ogan Ilir District

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Abstract— The use of micro hydro power plants (PLTMH) in utilizing existing water resources has been widely carried out, especially for people in rural areas who experience difficulties in accessing electricity networks and are spread throughout Indonesia. One of the rivers in the province of South Sumatra, Indonesia, which has a swift flow of water to be able to drive a turbine is the Kelekar River located in Ogan Ilir district. Besides having a quite heavy flow of water, Kelekar River is supported by the presence of the reservoir basins that is Embung of Sriwijaya University which has an overflow design be equipped 2 sluice gates with dimensions of 2 x 1.5 m and width threshold with top point elevation +6.00. This study aims to calculate the initial design of micro hydro power plants on the Kelekar River based on the river flow rates and the height of the water falling. Stages of analysis include rainfall analysis, test the suitability of data distribution, calculate concentration time, determine runoff coefficient values, calculate runoff discharge and calculate the height of the water falling, initial design analysis of micro hydro power plants (PLTMH). Based on the calculation analysis, it is obtained that the flowrate of the kelekar river is 211.109 m^3/sec (Q_{Rmax}) and 15.732 m^3/sec (Q_{Rmin}), design discharge (Qd) = 0.45m^3/sec, the high of effective energy (H) = 3.475792 m, power from water flow 15.344 kW, dan the power produced by the turbine is P_t = 11.508 kW with the turbine efficiency η_t = 0.75.

Keywords— Micro Hydro Power Plants (PLTMH), design discharge, the water falling

1. Introduction

Energy is needed by humans to support daily activities, in addition to the rapid development of technology and industry that will drive an increase in energy needs. Electrical energy is one of the energy that is very widely used, among others to meet the needs of companies, factories, offices and households [1]. At this time fossil energy is generally used to meet the needs of electrical energy so that continuous use can lead to reduced fossil energy and even run out, for this reason many researches have been conducted on the use of alternative energy as a substitute for fossil energy which can be used as a source of electrical energy, among others the utilization of water energy, solar energy, geothermal energy [2],[3],[13].

One alternative energy that is widely used in the country of Indonesia today is water energy because the Indonesian state is rich in water resources so it has a very high potential to be able to produce electricity using these water resources [4]. The use of micro hydro power plants (PLTMH) in utilizing existing water resources has been widely carried out, especially for people in rural areas who experience difficulties in accessing electricity networks that are spread throughout Indonesia [4][5][6]. Micro-hydro power plants (PLTMH) use water energy that can drive turbines to turn generators that will produce electrical energy [7][11][12], where the type of turbine used will depend on the flow of existing water flow and the height of water falling [1].

One of the rivers in Indonesia that has a quite heavy flow of water to be able to drive turbines is the Kelekar River located in Ogan Ilir Regency, South Sumatra Province [6]. Besides having a quite heavy flow of water, Kelekar River is supported by the presence of the reservoir basins that is Embung of Sriwijaya University which has an overflow design be equipped 2 sluice gates with dimensions of 2 x 1.5 m and width threshold with top point elevation +6.00 [8]. This study aims to calculate the initial design of micro hydro power plants (PLTMH) on the Kelekar River based on the river flow rates and the height of the water falling.

2. Metodology

2.1 Data collection

The choice of turbine type that will be used in micro hydro power plants (PLTMH) design depends on the flow of river water and water falling height, so the data needed includes primary data consisting of measurements and calculations of river water flow velocity, river discharge and the height of the water falling. While secondary data consists of rainfall data, river dimensions, reservoir dimensions (Embung of Sriwijaya University) and other data needed related to calculations and analysis.

2.2 Study area

This study was conducted in the Kelekar River and the reservoir (Embung of Sriwijaya University) located in Ogan Ilir District, South Sumatra Province, Indonesia. Geographically, Ogan Ilir District is located at position 3^0 02′- 3^0 48′ LS and between 104^0 20′ - 104^0 48′ BT, with an area of 2.666,07 km^2 [10]. The average rainfall is 2902 mm per year, where the highest average rainfall is 435 mm in November, while the lowest average rainfall is 83 mm in August. With this potential the Kelekar River can be developed as a Micro Hydro Power Plant (PLTMH) so that it can supply electrical energy in the area around the river. The study area can be seen in Figure 1.

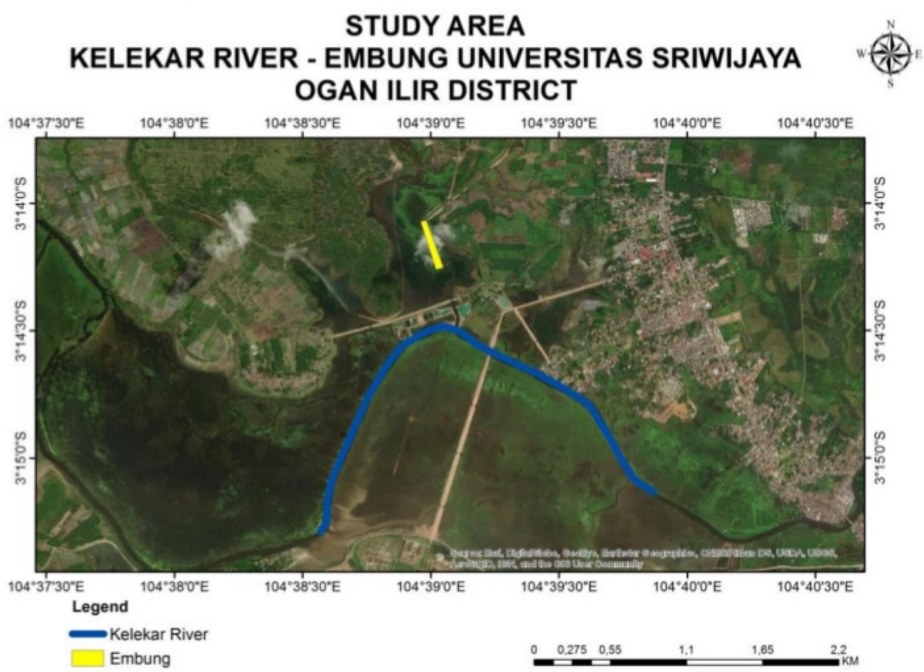

Figure 1. Study Area

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2.2 Analysis Method

The stages carried out in this study include: (i) rainfall analysis, (ii) test the suitability of data distribution, (iii) calculate concentration time, (iv) determine runoff coefficient values, (v) calculate runoff discharge and calculate the height of the water falling, (vi) initial design analysis of micro hydro power plants (PLTMH).

3. Result

3.1 Rainfall Analysis

In this study, the data used are the maximum daily rainfall data for the past 10 years. Starting from 2009 until 2018 obtained from the Meteorology Climatology and Geophysics Council of Palembang City, namely: in 2009 (Rmin = 41 mm; Rmax = 374 mm); in 2010 (Rmin = 71.8 mm; Rmax = 510 mm), in 2011 (Rmin = 14 mm; Rmax = 270 mm), in 2012 (Rmin = 15 mm; Rmax = 427.5 mm), in 2013 (Rmin = 75.6 mm; Rmax = 456.5 mm), in 2014 (Rmin = 8 mm; Rmax = 392.5 mm), in 2015 (Rmin = 6.5 mm; Rmax = 305.8 mm), in 2016 (Rmin = 72 mm; Rmax = 386 mm), in 2017 (Rmin = 26.5 mm; Rmax = 474 mm), in 2018 (Rmin = 3 mm; Rmax = 582.5 mm).

The pattern of rainfall distribution is determined from the analysis of maximum rainfall data obtained from frequency analysis. Frequency analysis uses 3 distribution methods namely, Normal distribution, Normal Log and Gumbel. The results obtained from the 100 year return period, i.e: Rmax = 635.26 mm and Rmin = 102.19 mm using the Normal method; Rmax = 699.03 mm and Rmin = 288.50 mm using the Normal Log method; and Rmax = 796.33 mm and Rmin = 153.21 mm using the Gumbel method.

3.2 Match Test

Match test is carried out to test the suitability of sample frequency distribution data against the opportunity distribution frequency was estimated. Match test uses the Smirnov-Kolmogorov test. Match test results show the difference in the value of Δmax 0.566 % > 0.409 % (Δ criticism) (not accepted) and Δmin = 0.270 % < 0.409 % (Δ criticism) (accepted) on the Normal method; difference in the value of Δmax 0.680 % > 0.409 % (Δ criticism) (not accepted) and Δmin = 0.633 % > 0.409 % (Δ criticism) (not accepted) on the Normal Log method; and the difference in the value of Δmax 0.086 % < 0.409 % (Δ criticism) (accepted) and Δmin = 0.172 % < 0.409 % (Δ criticism) (accepted) on the Gumbel method.

The results of the Smirnov-Kolmogorov match test calculation, for Δmax only the gumbel distribution can be accepted because it has a value of Δmax < Δcritic. For Δmin, there are two acceptable probability distributions, the normal distribution and the gumbel distribution, because the gumbel distribution has the smallest value Δmax < Δcritic compared to the normal distribution, which is 0.172 % < 0.409 %, so the gumbel distribution is chosen. Based on the results of the calculation of the compatibility test using the Smirnov-Kolmogorov test it was concluded that the calculation results using the Gumbel distribution method are best used for further calculations.

3.3 Concentration Time (Tc)

In this study the location of the river taken was in sub-watershed 3 while the calculation of the area and slope of the river flow was obtained with the help of Google Mapper from previous research [6], the river slope (S) obtained was 0.144, the length of the river (L) is 5 km. From the results of data processing using the ArcMap 10.3 program, the concentration time (Tc) of 0.4826 hours was obtained.

3.4 Runoff Coefficient

The breakdown of types, area and percentage of land use in watersheds 3 is as follows: (i) settlements of 0.1434 km^2 (4.44%); (ii) plantations/ farming at 2,3172 km^2 (71.69%), and shrubs at 0.7716 km^2 (23.87%). From the area in this catchment area, the runoff coefficient can be calculated, as in Table 1.

Table 1. Calculation of runoff coefficient in watersheds sub 3

Description	Area (km^2)	Total Area (A)	C	C x A	∑C x A	C Land
Settlements	0.1434		0.750	2.42415		
Plantations/ farming	2.3172	3.2322	0.200	0.64644	3.29684	1.02
Shrubs	0.7716		0.070	0.22625		

From Table 1 it can be seen that the runoff coefficient is 1.02.

3.5 Runoff Discharge

Runoff discharge is calculated using the rational method, with equations:

$$Q_{Rmax} = 0.278\ C\ I\ A$$

Where: Q is runoff discharge; C is runoff coefficient of 1.02; A is catchment area of sub-watershed area 3 ie: 3.2322 km2 [6]; I is rainfall intensity (Rmax of 230.337 mm/hour and Rmin of 17.165 mm/hour).

$$Q_{Rmax} = 0.278\ C\ I\ A = 0.278 \times 1.02 \times 230.337 \text{ mm/jam} \times 3.2322 \text{ km}^2 = 211.109 \text{ m}^3\text{/sec}$$
$$Q_{Rmin} = 0.278\ C\ I\ A = 0.278 \times 1.02 \times 17.165 \text{ mm/jam} \times 3.2322 \text{ km}^2 = 15.732 \text{ m}^3\text{/sec}$$

3.6 Falling Water Height

Embung of Sriwijaya University discharges the discharge for micro hydro at Q = 0.45 m^3/sec, with the following details: water level elevation at Embung UNSRI +6 m, as-turbine elevation + 1 m and the number of Turbines as a generator drive is 1 unit. So the total energy and discharge height that can be used to drive 1 turbine is H = 4 m, Q1 turbine = 450 liters/second.

3.7 Design of Micro Hydro Power Plant (PLTMH)

a. *Dimensions of rapid pipe/ stocking*

From the topographic measurements that have been made obtained the following data:

Turbine design discharge (m^3/sec) : $Q_d = 0.45$ m^3/sec

High of total energy : $H_t = 4.0$ m

Rapid pipe length : L = 40 m

Estimate high of effective energy H_{emax}:

$$H_{emax} = Ht \times \frac{2}{3} = 4{,}0 \times \frac{2}{3} = 2.667 \text{ m}$$

The optimum flow velocity in a rapid pipe is calculated using the equation:

$$v = 0.125\sqrt{2\ gH_{emax}} = 0.904 \text{ m/sec}$$

The diameter of the rapid pipe is calculated by the equation:

$$D = \sqrt{\frac{4\,Q}{(\pi V)}} = \sqrt{\frac{4\,x0.450}{(\pi\ x0.904)}} = 0.796 \text{ m}$$

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So taken D = 0.80 m with a cross-sectional area of 0.503 m^2 and the optimum speed in the rapid pipe is 0.904 m/sec.

b. The calculation of minimum thickness of steel pipe/ stockpile

used equation $= to = \dfrac{Pxd}{2.\theta a\,\eta} + \delta t$ (cm)

Where: is the minimum thickness of a steel pipe (cm); P is 1.1 x hydrostatic pressure (1.7403 Kgf/cm2); D s the inner diameter of the steel (cm); θa is the permit voltage (Kgf/cm2) = SS 400 steel = 1300 Kgf/cm^2; η is the welding efficiency (0,85 ~ 0,9); δt is a general margin of 0.15 cm.

$$to = \frac{P.d}{2.\theta a.\eta} + \delta t = \frac{(1.1\ x\ 1.7403).0.80}{2\ x1300x0.85} + 0.15 = 0.151 \text{ cm.}$$

The minimum thickness of the pipe is used, i.e: 0.40 cm or 4 mm.

c. Maximum specific runner speed

Specific speed is a numerical quantity which shows the classification of runner or type of turbine which is a function of effective energy height, turbine power and Runner rotation speed. The specific speed of the maximum Runner is calculated to choose the type of turbine that is suitable for a certain high energy. The specific Runner maximum speed for various types of turbines can be calculated by the following equation: [7].

Pelton Turbine	: Ns max $\leq 85.49\ H^{-0.243} = 85.49x2.667^{-0.243}$
	Ns max ≤ 67.36
Cross-Flow Turbine	: Ns max $\leq 650\ H^{-0.5} = 650x2.667^{-0.5}$
	Ns max ≤ 398.02
Francis Turbine	: Ns max $\leq 30 + [20000/(H+20)]$
	Ns max $\leq 30 + [20000/(2.667+20)]$
	Ns max ≤ 912.34
Propeller Turbine	: Ns max $\leq 50 + [20000/(H+20)]$
	Ns max $\leq 50 + [20000/(2.667+20)]$
	Ns max ≤ 932.34

d. Permission speed limit of runner specific

The Runner specific speed limits for various types of turbines are as follows [7]:

Pelton Turbine	:	$12 \leq Ns \leq 25$
Francis Turbine	:	$60 \leq Ns \leq 300$
Cross-Flow Turbine	:	$40 \leq Ns \leq 200$
Propeller Turbine	:	$250 \leq Ns \leq 1000$

Based on the analysis results and the Maximum Runner specific speed limitation of each type of turbine, the suitable turbine type is used for the hydraulic conditions of the spillway of the reservoir basins (Embung of Sriwijaya University) is Propeller Turbine.

e. High of hydraulic energy effective as turbine driving

The effective hydraulic energy height of this turbine drive is analyzed using the following data:

Design discharge for 1 rapid pipe : 0.45 m^3/sec
Optimum speed (v) : 0.904 m/sec

High of total energy : 2.667 m
Rapid pipe diameter (f_{in}) : 0.80 m
Rapid pipe length : 40 m
Energy loss at the rapid pipe inlet, h_{in} : $h_{in} = f_{in} \frac{V^2}{2g} = 0.8 \text{ x } \frac{0.904^2}{2 \, x \, 9.8} = 0.033$ m

Energy loss at 2 turns 45° along the rapid pipe, h_b :
Turn , $f_b = 0.08$
$h_b = n \, . \, f_b . \frac{V^2}{2g} = 2 \text{ x } 0.08 \text{ x } \frac{0.904^2}{2x \; 9.8} = 0.007$ m

Energy loss due to friction along the rapid pipe, h_{gs} :
Steel Plate Pipe: $k_s = 0.045$ mm; $\frac{K_X}{D} = 0.0000563$
$R_e = \frac{D.V}{V} = \frac{0{,}8 \, .0{,}904}{(1{,}003 \, .10^{-6})} = 721036.889$

From the Moody Chart was obtained, $f_{gs} = 0.01$
$h_{gs} = f_{gs} \, . \, L. \frac{V^2}{2gD} = 0.01 \text{x } 10 \text{ x } \frac{0.904^2}{2 \, x \, 9.8 \, x \, 0.80} = 0.005212$ m

Energy losses in the Nozzles of rapid pipe, h_n :
$h_n = \{(\frac{1}{C_V{}^2} - 1\} \text{ x } \frac{V_n{}^2}{2g}$; $C_v = 0.95$
then: $h_n = 0.005506281 \, v_n^2$

$v_n^2 = 2g \text{ x } (H_t – h_{in} – h_b – h_{gs} – h_n)$
$h_{in} + h_b + h_{gs} = 0.045212$ m
$H_t – h_{in} – h_b – h_{gs} = 4.00 – 0.045212 = 3.954788$ m
$v_n^2 = 19.62 \text{ x } (3.954788 - 0.005506281 \, v_n^2)$
$v_n^2 = 77.59294 – 0.108033 \, v_n^2$;
$v_n = 9.3269$ m/sec; $h_n = 0.478996$ m

Energy loss along the rapid pipe: $h_{sp\text{-}p} = h_{in} + h_b + h_{gs} + h_n = 0.524208$ m

High of Effective Energy is $H = 4.0 – 0.524208 = 3.475792$ m

f. Dimensions of release channel/ tailrace of turbine

Release channel width required is:

$$Bo = \frac{Qd}{0.8.D.\sqrt{He}} = \frac{0.45}{0.8x0.5.x\sqrt{3.475792}} = 0.603428 \text{ m}$$

Release channel width was taken: Bo = 650 mm.

Release channel height : $Q = \frac{1}{n} \text{ x A x } (R)^{2/3} \text{ x } (I)^{1/2}$

$$= \frac{1}{0.0165} \text{ x } 0.650h \text{ x } \left(\frac{0.650h}{0.650 + 2h}\right)^{2/3} \text{ x } (0.01)^{1/2}$$

Try and error = 1.0 m

$$= 60.606 \text{ x } 0.65 \text{ x } \left(\frac{0.650x1}{0.650 + 2x1}\right)^{2/3} \text{ x } (0.01)^{1/2} = 1.5436 \text{ m}^3/\text{sec.}$$

Try and error = 1.5 m

$$= 60.606 \text{ x } 0.65 \text{ x } 1.5 \text{ x } \left(\frac{0.650x1.5}{0.650+2x1.5}\right)^{2/3} \text{ x } (0.01)^{1/2} = 2.4509 \text{ m}^3/\text{sec.}$$

Try and error = 2.0 m

$$= 60.606 \text{ x } 0.65 \text{ x } 2 \text{ x } \left(\frac{0.650x2}{0.650+2x2}\right)^{2/3} \text{ x } (0.01)^{1/2} = 3.3686 \text{ m}^3/\text{sec.}$$

Selectable dimensions of release channel/ tailrace of turbine by size = b x h = 0.65 m x 1.50 m.

g. *Power from water flow*

If the design discharge Q_d = 0.45 m^3/sec and high effective energy H = 3.475792 m, then the amount of power from the flow of water can be calculated as follows:

$P = \rho$ g Q H = 1000 x 9.81 x 0.45 x 3.475792

= 15343.88378 Watt

= 15.344 kW

With turbine efficiency η_t = 0.75, then the power produced by the turbine is:

$P_t = \eta_t$ P = 0.75 x 15.344 kW

= 11.508 kW

4. Conclusion

Based on the calculation analysis, it is obtained that the flowrate of the kelekar river is 211.109 m^3/sec (Q_{Rmax}) and 15.732 m^3/sec (Q_{Rmin}), design discharge (Qd) = 0.45m^3/sec, the high of effective energy (H) = 3.475792 m, power from water flow 15.344 kW, dan the power produced by the turbine is P_t = 11.508 kW with the turbine efficiency η_t = 0.75

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