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Determination of optimal power capacity for run of river hydro power plant based on flow duration curve using newton's interpolation method

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Hidayat ; Amita ; Cahayahati ; Mirza Zoni ; Saiful Jamaan All Authors

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This paper determines the optimal power capacity installed for Run of River Hydro Power Plant (RORHPP). This is necessary in order to obtain an effective and efficient RORHPP, because the installed capacity will determine the investment and the energy produced. If the installed power capacity is too high, the investment cost will also be high, but if the installed power capacity is too low then the potential of water energy will be wasted. The main factors affecting the installed capacity of RORHPP are river flow and height of water fall. The river flow may change, while the water level falls steadily. Therefore, river flow is a variable parameter and the water falling level is a fixed parameter. Accurate determination of river flow discharge design is necessary to optimize RORHPP installed capacity. River flow discharge is obtained from hydrological data and catchment area which is then processed into flow duration curve (FDC). Based on the RORHPP design can be obtained the maximum power and energy generated by RORHPP, but this is not fixed at any time. The capacity factor (CF) is the ratio of real potential energy to the maximum energy generated in a year. Therefore, CF must be considered in determining installed power capacity. Furthermore, financial aspects such as NPV, IRR, BCR and BEP are also the ...

Determination of Optimal Power Capacity for Run of River Hydro Power Plant Based on Flow Duration Curve Using Newton's Interpolation Method

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***Abstract*—This paper determines the optimal power capacity installed for Run of River Hidro Power Plant (RORHPP). This is necessary in order to obtain an effective and efficient RORHPP, because the installed capacity will determine the investment and the energy produced. If the installed power capacity is too high, the investment cost will also be high, but if the installed power capacity is too low then the potential of water energy will be wasted. The main factors affecting the installed capacity of RORHPP are river flow and height of water fall. The river flow may change, while the water level falls steadily. Therefore, river flow is a variable parameter and the water falling level is a fixed parameter. Accurate determination of river flow discharge design is necessary to optimize RORHPP installed capacity. River flow discharge is obtained from hydrological data and catchment area which is then processed into flow duration curve (FDC). Based on the RORHPP design can be obtained the maximum power and energy generated by RORHPP, but this is not fixed at any time. The capacity factor (CF) is the ratio of real potential energy to the maximum energy generated in a year. Therefore, CF must be considered in determining installed power capacity. Furthermore, financial aspects such as NPV, IRR, BCR and BEP are also the considered parameters. Newton's interpolation method was used to determine CF, which is applied in RORHPP design of Lubuk Gadang. Simulation results show that installed capacity has low investment cost and high energy production as expected**

Keywords—RRHPP; optimal; Installed power capacity; Newton's interpolation

I. INTRODUCTION

The demand of electrical energy increases steadily every year, so its provision should also be continuously improved. The National Power Company (PLN) and independent power purchase (IPP) which received the mandate from the government as a national electrical energy provider continues to develop a number of eco-friendly generators. To encourage this acceleration, the government issued a favorable regulation for IPP through Department of Energy and Human Resources No. 3 of 2015 for hydroelectric power capacity of 10 MW, and Regulation No. 19 of 2015 for capacities above 10 MW [1], [2].

One of the water potential development as a power plant is by utilizing river water discharge, by a direct run of river method or by reservoir system. Run of river method is done by diverting the river flow through the water way,sand trap, penstock and then move the turbine. While the reservoir method is done by damming water and stored in the pond, then released it to drive a turbine through the penstock. This method requires a large area as a water storage [3]. The most widely developed method is run of river, because it doesn't require a large area. The disadvantage is that river water discharge fluctuations have a direct effect on the electricity generated. Therefore, RORHPP planning is always based on hydrological and catchment area data to produce flow duration curve (FDC). FDC represents the relationship between the annual probability to the river flow (Q). The planning of electric energy RORHPP generated refers to FDC.

Conventionally, Q_d is generally selected with a probability of 40 to 65% [3]. The accuracy in choosing Q_d has an impact on technical and financial aspects. A large capacity equipment and big investment is required if the Q_d selected is too large. If Q_d is too small then the equipment capacity required is small and investment cost is also low, but potential utilization of available river flow is not maximal. Therefore a method is needed to determine the optimal installed power capacity. Generally in feasibilty study, the energy that can be generated by RORHPP per year is obtained from the installed power capacity multiplied by capacity factor (CF) and operating hours a year. CF obtained from FDC is calculated from the ratio of real energy (Er) to the maximum energy (Em) generated in a year. Newton's interpolation method was used to determine CF optimum.

II. TYPICAL AND FORMULATION OF RORMPP

A. RORMPP System

Basically, hydro power plants function to convert the water potential energy of water flow with certain discharge (Q) and high fall (H) into kinetic and mechanical energy thus generating electrical energy. The general schema and RORMPP components [4] are shown in Figure 1. The RORMPP component consists of weir, waterway, headpond, penstock, power house and distribution circuit.

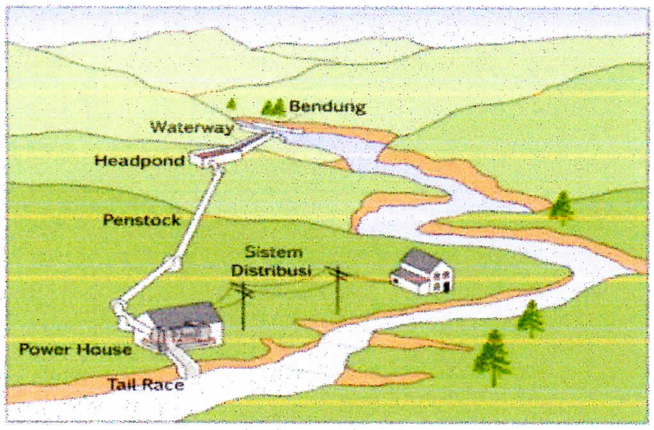

Figure.1. General Schema and RORMPP Components [4]

B. Power and RORMPP Generator Energy

Basically, energy can not be created nor destroyed, but can only be changed from one form to another, called the law of conservation energy. In terms of power, the general equation of power conversion is;

$$\text{Power In} = \text{Power Out} + \text{Loss} \quad (1)$$

$$\text{Power Out} = \text{Power In} \times \text{Conversion efficiency} \quad (2)$$

Equations (1) and (2) are usually used to describe small differences. The incoming power or total power absorbed by the hydro scheme is the gross power (P_{gross}). Power whose benefits are delivered is net power (P_{net}). All efficiency of hydropower components in the scheme of Figure 1 is called E_o.

$$P_{net} = P_{gross} \times E_o \quad (3)$$

The gross power is head gross (H_{gross}) multiplied by the water flow (Q) and then multiplied by the velocity of gravity (g = 9.8 m2/sec)), so the basic concept of the power plant conversion equation is:

$$P_{net} = g \times H_{gross} \times Q \times E_o \quad (4)$$

Where:

Where:	P_{net}	: Net Power (BkW)
	H_{gross}	: *gross head* (m)
	Q	: Water discharge (m^3/dt)
	E_o	: conversion efficiency (%)

$$E_o = E_{ff\ civil\ construction} \times E_{ff\ penstock} \times E_{ff\ turbin} \times E_{ff\ generator} \times E_{ff\ control\ system} \times E_{ff\ network} \times E_{ff\ trafo} \quad (5)$$

$E_{ff\ civil\ construction}$: 1,0– (length of channel × 0,002 ~ 0,005)/ H_{gross}

$E_{ff\ penstock}$: 0,90 ~ 0,95 (Depend on its length)

$E_{ff\ turbin}$: 0,70 ~ 0,85 (Depend on the turbine type)

$E_{ff\ generator}$: 0,80~0,95(Depend on generator capacity)

$E_{ff\ sistem\ control}$: 0,97

$E_{ff\ jaringan}$: 0,90 ~ 0,98 (Depend on the length of network)

$E_{ff\ trafo}$: 0,98

Electrical energy is the multiplication of net power (P_{net}) with CF, and time, as indicate by equation (6).

$$E_{Electricity} = P_{net} \times CF \times t \quad (Wh) \quad (6)$$

If the Hydro Power Plants operates 350 days a year (15 days for maintanance) and 24 hours a day, then the electrical energy required per year as seen in equation (7)

$$E_{Electricity} = P_{net} \times 350\ hari \times 24\ jam \quad (Wh) \quad (7)$$

C. Flow Duration Curve (FDC) and Capacity Factor (CF)

Flow Duration Curve (FDC) is a curve that represents the annual river flow discharge probability. FDC is obtained from the hydrological data by grouping the same flow and determining the percentage of occurrence, as shown in Figure 2. The FDC curve is indispensable in determining the RORMPP installed power capacity. Figure 3 show that high flow discharge percentage in a year is very small. The selection of high flow discharge will result in large install capacity (4), as well as high investment cost, while the energy produced annually is not necessarily higher than the lower installed capacity

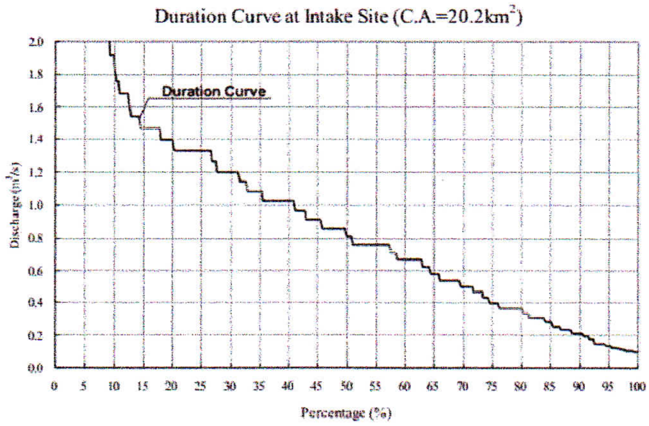

Figure.2. Flow Duration Curve (FDC) [5]

Therefore it is necessary to determine the capacity factor (CF), which is a comparison between the amount of the actual energy generated in a year with the energy based on discharge design. Figure 4 illustrates the determination of CF

The maximum energy generated by RORMPP within a year (ABCD Area);

$$E_{max} = P_{max} x\ 360\ hari\ x\ 24\ jam \quad (Wh) \quad (9)$$

Whereas the actual energy generated by RORMPP is calculated based on the sum of energy on the actual duration of power generated within one year intervals (Area AbcCD).

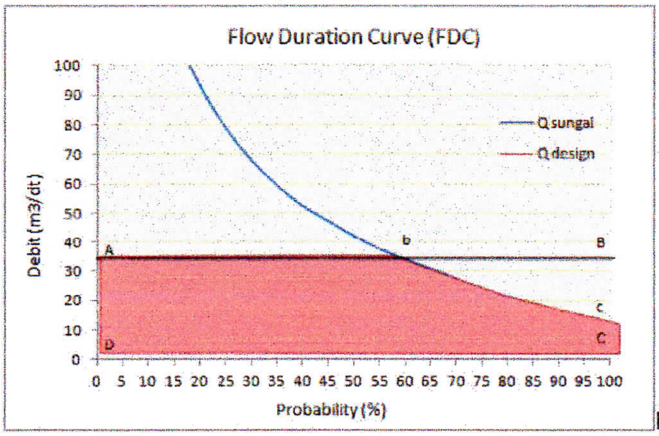

Figure .3. Illustration in determining CF

The calculation of AbcD area can use the boundary integrals, where a curved line equations that describe probabilility annual discharge is determined by the Newton interpolation method.

$$CF = \frac{Area\ of\ AbcD}{Area\ of\ ABCD} \qquad (8)$$

D. Newton's interpolation

Newton's interpolation can be used to construct functions of a given set of points [5], [6].

The bc line in Figure 4 is a set of points whose function will be determined. The purpose is to determine the AbcCD area using the integral boundary. The basis of Newton's interpolation is the Lagrange interpolation. For example, two points are given (x0, f (x0)) and (x1, f (x1)) with x0 ≠ x1. Then by using the equation of line (P_1 (x)) based on Lagrange Interpolation with 2 dots, obtained;

$$P_1(x) = \left[\left[\frac{x-x_1}{x_0-x_1}\right]\right]_{y_0} + \left[\left[\frac{x-x_0}{x_1-x_0}\right]\right]_{y_1} \qquad (9)$$

$$P_1(x) = a_0 + a_1(x - x_0)$$

Where:

$$a_1 = \frac{y_1-y_0}{x_1-x_0} \text{ or } a_1 = \frac{f(x_1)-f(x_0)}{z_1-x_0}$$

This is a form of divided differences, it can also be written as a_1 = f [x1, x0]. Newton's interpolation for 3 points can be written as;

(X0, f (x1)) and (x1, f (x1)) with x0 ≠ x1 ≠ x2 or using polynomial 2 degree, and the next polynomial can be obtained;

$$P_2(x) = a_0 + a_1(x - x_0) + a_2(x - x_0)(x - x_1)$$

$$P_3(x) = a_0 + a_1(x - x_0) + a_2(x - x_0)(x - x_1) + a_3(x - x_0)(x - x_1)(x - x_2)$$

$$\ldots \qquad (10)$$

$$\ldots$$

$$P_n(x) = a_0 + a_1(x - x_0) \ldots + a_n(x - x_0)(x - x_1) \ldots (x - x_{n-1})(x - x_n)$$

By the difference of each:

$$a_0 = f[x_0] = f(x_0) = y_0)$$

$$a_1 = f[x_0, x_1] = \frac{f[x_1] - f[x_0]}{x_1 - x_o} = \frac{y_1 - y_0}{x_1 - x_0}$$

$$a_2 = f[x_0, x_1, x_2] = \frac{f[x_1, x_2] - f[x_0, x_1]}{x_2 - x_o}$$

$$a_3 = f[x_0, x_1, x_2, x_3] = \frac{f[x_1, x_2, x_3] - f[x_0, x_1, x_2]}{x_2 - x_o}$$

....

$$a_n = f[x_0, \ldots x_n] = \frac{f[x_1 \ldots, x_n] - f[x_0 \ldots, x_{n-1}]}{x_n - x_o} \qquad (11)$$

With the value obtained from $a_0, a_1, a_2 \ldots \ldots a_n$ the FDC line equation can be determine.

E. RORMPP Cost

RORMPP cost consists of fix cost and variable cost. The fix costs include investment costs, while variable costs covers operational and maintenance costs. Investment costs include civil, mechanical and electrical building costs that are comparable to the installed power capacity and land contours of the RORMPP development site. Accuracy in determining the civil buildings dimensions will affect the investment cost. Therefore, investment cost is also an important factor in optimizing the installed power capacity of RORMPP.

The NPV method is used to determine the feasibility of investing with equations;

$$NPV = \frac{F}{(1+i)^n} \qquad (12)$$

Where;

NPV = Net *Present Value*
F = The value in the n^{th} year
I = Interest rate (%)
N = Year 1,2,3, ... etc

III. RESEARCH METHODS

Planning is required prior to RORMPP construction. Proper planning will result in optimal production and minimal cost of the electrical energy. The application of Newton's interpolation method in determining the optimal installed power capacity of RORMPP Lubuak Gadang utilizing the flow of Batang Sangir river in South Solok. The initial step of RORMPP planning is to find potential and determine the appropriate location for RORMPP construction. This early stage required data of positions, altitude, water discharge, and so forth. The required equipment include; maps and GPS, which serves as a guide to the research location. Google Earth is used to determine the point of research location.

Research data is divided into two, namely primary data and secondary data. Primary data obtained directly in the field, while secondary data obtained from existing references, such as company records or documentation, government reports, magazines, and so forth.

Hydrological data, cahcment area is a secondary data obtained from meteorology and geophysics agency (BMKG) and AWLR poos. The height and points of RORMPP component placement are the primary data obtained from the measurement results. Flow Chart as the stages of research shown in Figure 4.

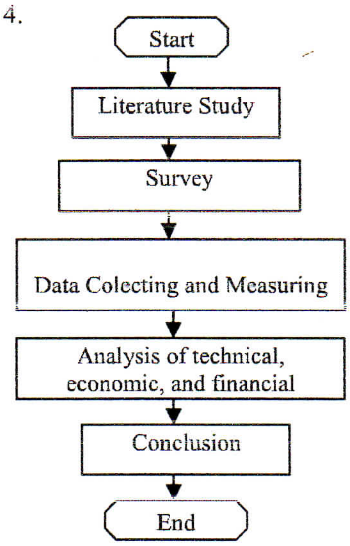

Figure. 4. The Research Flow Chart

IV. CALCULATION AND ANALYSIS

Data hydrograph show the variation of river flow and time throughout the year. By categorizing the same debit and determining the occurrence percentage, then the statistics of discharge average from Batang Sangir river on the watershed of 1,421.00 km2 obtained as in Table 1 [7] [8] Table 1. The Average Flow Rate of Batang Sangir River

TABLE I. PORBALITY AND DISCHARGE AVERAGE

No.	Probability of occurrence	Discharge station Discharge Average Watershed Coverage Area (km2) 1421.00
1	10%	122.32
2	20%	75.91
3	30%	55.34
4	40%	42.73
5	50%	34.23
6	60%	27.89
7	70%	22.33
8	80%	17.28
9	90%	13.36
10	100%	9.44

Flow Duration Curve (FDC) is obtained from the annual discharge probability graph as shown in Figure 5. The FDC curve is indispensable in determining the install capacity of generator and annual energy output. The optimal software of installed power capacity RORMPP is shown in Figure 6.

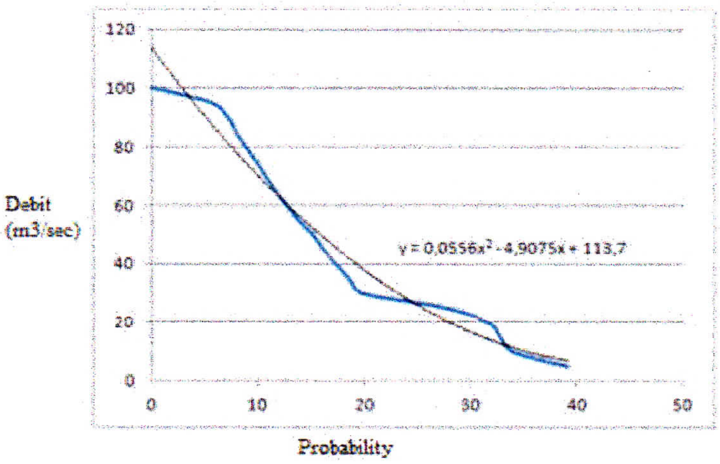

Figure . 5. Flow Duration Curve (FDC) of Batang Sangir Watersheds

Newton's interpolation method derives a function that represents the probability of annual discharge called FDC, as equation (9).

$$y = 0,0556x^2 - 4,9075x + 113,7 \quad (9)$$

The capasity factor (CF) of RORMPP can be calculated using equation (8). Energy is calculated using the boundary integrals. With a net head of 39.56 meters, a 350-day RORMPP operation in a year, a total efficiency of 0.85 is obtained by CF, power generation (4), annual energy (5) as shown in Table 2. BEP, NPV, IRR, BCR and Price/KWh is also obtained and be a consideration in optimizing installed power capacity ..

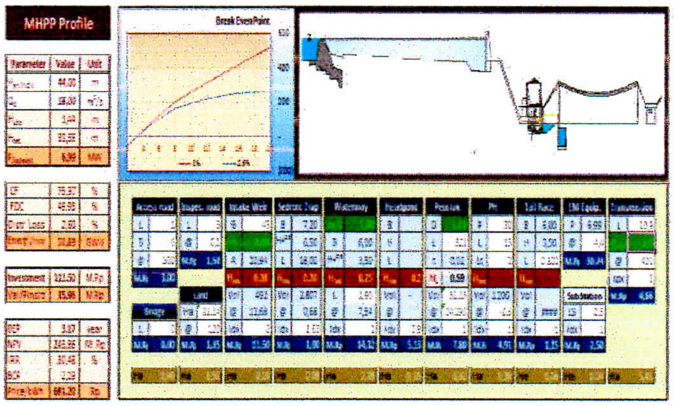

Figure .6. Optimum Installed Power Capacity Software

The optimum installed power capacity RORMPP Lubuak Gadang of 6.99 MW was obtained from the calculation. Capacity Factor of 75.95% and FDC of 49.95%. The Energy generated in a year as 45,754 GWh. The investment cost is 111.56 Billion Rupiah. Financial analysis show BEP 3.17 year, NPV 243,65 Billion Rupiah, IRR 30,48%, BCR 2,19 and price /KWH are 681,20 Rupiah. The obtained parameters show that RORMPP development is feasible to continue and have a high economic value, because the electricity production cost is still far below The National Power Company selling price to the consumer.

V. CONCLUSION

Determination of intalled power capacity with newton's interpolation method that has been designed using software, facilitates RORMPP planning. This software has considered the technical, economical and financial aspects. By using the flow duration curve (FDC) of watershed and head areas, technical and financial data of RORMPP can be obtained.

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