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Mini Hydropower Plant for Supporting the Renewable Resources at Madong, Toraja Utara Regency Sulawesi Selatan Province-Indonesia

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Abstract*: *Sulawesi Selatan is one of the provinces with high amount of electricality consumption. By the high amount of electricity consumption, electrical energy is needed to be provided. To provide the electricity we need the energy source. The river in Madong village, Toraja Utara Regency has the characteristic that potentially can be an energy source. To get the benefit from the Madong river, we need the study of designing and economic analysis. From analyzed data of the selected flood discharge (Q_{100}) to be 488.55 $m^3.s^{-1}$ and the selected plant discharge (Q_{40}) to be 13.18 $m^3.s^{-1}$. This hydropower was designed with a concrete and circle-shaped weir. There are the other components such as intake, feeder canal, settling basin, volume, headrace, fore bay and penstock. The penstock is using the welded steel material, with 2 m of diameter and 12 mm of thickness. Then, there is a tailrace that will transmit the water back to the river. The selected turbines are 2 units of Francis type, with the 12.59 MW power produced and 68.92 GWh energy produced in a year. The result of economic analysis, the project is feasible with BCR 1.29, NPV 135 Billion rupiahs, IRR 12.68%, and Payback period within 15.43 years.

Keywords*: *hydropower, electrical, flow, penstock, economic analysis.

I. INTRODUCTION

The demand for energy has been continuously growing with the ever increasing global population and rapid industrialization. The use of fossil fuels is becoming less attractive due to their adverse environmental impacts and the role they play in global warming through greenhouse gas emissions [1][2][3]. Hydropower is a reliable and renewable source of energy to generate electricity. Due to its low environmental impacts, flexibility and low operation and maintenance costs, hydroelectric production is seemingly growing around the globe, especially in developing countries [4][5], like Indonesia.

However, hydroelectric power plants do not use up resources to create electricity nor do they pollute the air, land, or water, as the other power plants may. Both small and large hydroelectric power developments were instrumental in the early expansion of the electrical power industry. Hydroelectric power comes from the flowing water, winter and spring runoff from the mountain streams and clear lakes. Water, when it is falling by the force of gravity, can be used to turn the turbines and generators that produce electricity [6]

In last years, the electricity is one of the primary thing people needs. In order to support the activities, the essential power has to be fulfilled for the people in the country, Indonesia. But, until now electricity is not available for the people, because of the resource that potentially becomes an electrical energy was not exploited yet. Much of the renewable energy is potentially become as the electrical sources such as like thermal energy, wind, vapor, water etc. Indonesia as a country with many natural resources [7] like the water, of course it can be exploited. Water energy potentially produces the high energy, but in this country water is not maximally exploited yet [7]. Micro-hydro, mini-hydro, or the other systems of hydropower can be as the solutions to increase the electrical production in Indonesia.

In many watersheds around the world, where the importance of assessing a watershed as a whole is overlooked, the new water resources projects are designed solely based on the historical flow data. Such projects might fail to operate satisfactorily when it is designed without considering the uncertainties associated with the future hydrological changes [9][10]. Sulawesi Selatan as one of the provinces in Indonesia with its capital city, Makassar, is growing up as the industrial and trading center in the eastern region of Indonesia. By the development of the districts, the cities or regions in Sulawesi Selatan, so that it is needed to increase the electrical energy production to fulfill the power demands. Reviewing the discharge and head in the Madong river, Toraja Utara regency, Sulawesi Selatan province, basically can built a run-of-river hydropower. So that, it is needed to study, design and analyze to estimate the energy and Madong's hydropower design and its feasibility.

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II. MATERIALS AND METHODS

A. Hydropower

Hydropower that exploited the water, basically the system uses the water flow (discharge) and head. So, reviewing the water flow [5] and head is to consider the location that potentially becomes the hydropower.

A.1. Hydropower classification [11]

Based on its capacity of the power: micro-hydropower for the hydropower < 100 kW of the power production; mini-hydropower for the hydropower 100 kW – 10000 kW of the power production; hydropower for the hydropower >10000 kW of the power production

Based on the head: the high head is for the hydropower system upper than 100 m; the medium head is for the hydropower with 30 m < Head < 100 m; and the low Head is for the hydropower with the Head < 30 m

Based on the operation system: the run-of-River; reservoir; pumped storage; and n stream technology. Based on the purposes are the single purpose and the multi purposes. Based on the economic: the individual hydropower and the operation hydropower

A.2. Rain Data Check Analysis [12]

Hydrology analysis will analyze the flood discharge and probable discharge that will be as the design discharge of hydropower. We have to carry out the analysis.

A.2.1. Outlier test

The examination of outlier data is the data that deviates quite far from the group trend. Testing this method sets the lower threshold (XL) and upper threshold (XH) as follows:

$$X_H = \exp(\bar{x} + Kn\ S) \qquad (1)$$

$$X_L = \exp(\bar{x} - Kn\ S) \qquad (2)$$

Where X_H = upper threshold; X_L = lower threshold; $\bar{x}$ = average data; Kn = value of depending the number of data; S = deviation standard; N = number of data

A.2.2. Rescaled Adjusted Partial Sums

The RAPS method will perform the test using rain data from a predefined station by performing a cumulative test of quadratic deviation to the mean value. The formula used in the RAPS test is as follows:

$$S_k^{*} = \sum_{i=1}^{k}(Y_i - \bar{Y}) \qquad (3)$$

$$S_k^{**} = \frac{Sk^{*}}{Dy} \qquad (4)$$

$$D_y^2 = \frac{\sum_{i=1}^{n}(Y_i-\bar{Y})^2}{n} \qquad (5)$$

$$Q = max|Sk^{**}|\ ;\ 0 \le k \le n \qquad (6)$$

$$R = max\ Sk^{**} - \min\ Sk^{**} \qquad (7)$$

where: Sk* = rainfall (X) – mean rainfall ($\bar{x}$); Sk** = square value of Sk* divide by Dy; Dy2 = square value Sk* divided by sum of the data; Q = attributes of statistic value equation (6); R = attributes of statistic value equation (7)

B. Firm Discharge

Firm discharge is flow that available during a year with probability of failure risk. Steps to determine the firm discharge as follow [12][13]: 1) to collect the flow data within determined interval or use the simulation flow by theoretical analysis (F.J Mock, NRECA, Tank Model); 2) to check the duration of recorded data; 3) to validate the flow data ; to calculate and arrange the data from the highest to the lowest[and 5) to calculate the probability by using the Weibull equation as follow:

$$P = \frac{m}{n+1} \times 100\% \qquad (8)$$

where: P = probability (%); m = number of data; n = total data Then, 6) to calculate the firm discharge based on the probability that corresponding to the design discharge; and to make graph the flow duration curve.

C. Flood Discharge

Calculated flood discharge will be a based value to design the hydropower components, in this case flood discharge as the design discharge of Madong's hydropower weir. To calculate the flood discharge of the river, this observation will use Nakayasu Synthetic Unit Hydrograph and Limantara Synthetic Unit Hydrograph as follows [12]:

a. Nakayasu Synthetic Unit Hydrograph [13]

$$Qp = \frac{1}{3{,}6} A.R_0 \frac{1}{(0{,}3Tp + T_{0,3})} \qquad (9)$$

Where: Qp = peak discharge ($m^3.s^{-1}$); A = catchment Area (km^2); R_0 = rain unit (mm); Tp = peak time (hour); $T_{0,3}$ = time to decreasing 30% of Discharge

b. Limantara Synthetic Unit Hydrograph [14][15]

$$Q_p = 0{,}042.A^{0{,}451}L^{0{,}497}Lc^{0{,}356}S^{-0{,}131}n^{0{,}168} \qquad (10)$$

Where: Qp = peak discharge ($m^3.s^{-1}$); A = catchment area (km^2); L = river length (km); Lc = river length to the nearest central point of catchment (km); S = slope; N = roughness

D. Weir and Stilling Basin

Weir is a structure that will raise the water surface in order to transmit the flow through the high designed water level. Equation of energy-discharge height for low height weir with squared-shape is *Basin* [16]

$$Q = Cd\ \frac{2}{3}\sqrt{\frac{2}{3}g}\ bH_1^{1,5} \qquad (11)$$

Where: Q = discharge ($m^3.s^{-1}$); Cd = discharge coefficient ; g = gravitation ($m.s^{-2}$); b = weir length (m); H_1= energy height at the top of weir (m)

However, stilling basin is as a part to reduce the flow energy after throughout weir. There are the requirements of stilling basin based on *Froude number*. (1) Froude ≤ 1.7; Without stilling basin (2) 1.7 ≤ *Froude* ≤ 2.5; Using sill, (3) 2.5 ≤ *Froude* ≤ 4.5; USBR Type IV (4) *Froude* ≥ 4.5; USBR Type III (5) Type IV is not recommended from KP-02, so that we can use MDO/MDS type.

E. Intake

Intake is an inlet of the design discharge. The intake capacity can be designed 120% of the plant discharge. This is an equation of flow that through the intake as follows *Basin* [16]:

$$Q = \mu\ b\ a\ \sqrt{2\ gz} \qquad (12)$$

Where: Q = discharge ($m^3.s^{-1}$); μ = discharge coefficient ($\mu = 0.80$); b = intake width (m) a = height of opened gate (m); g = gravitation (9.81 $m^2.s^{-1}$; z = head loss (m)

F. Settling basin

For designing a settling basin, we will use an equation from *Velikanov* as follow *Basin* [16]:

$$LB = \frac{Q}{W}.\frac{\lambda^2}{7{,}51}.\frac{v}{w}.\frac{(H^{0,5}-0{,}2)^2}{H} \qquad (13)$$

Where: L = length (m); B = width (m); L/B > 8; Q = discharge ($m^3.s^{-1}$; w = settling velocity ($m.s^{-1}$); H = = *Gauss* coefficient

G. Head race

For head race, there are 2 types open and close channel. By using an open channel, the flow through the channel is *Basin* [17]

$$Qd = \frac{A R^{\frac{2}{3}} S_L^{\frac{1}{2}}}{n} \quad (14)$$

Where: Qd = design discharge ($m^3.s^{-1}$); A = area (m^2); R = radius (m); area/perimeter; P = perimeter (m); S_L = slope; n = roughness coefficient

H. Head pond

Head pond capacity is defined as the depth of water from hc to h0 from the length of head pond. The design of can be designed as follow [17]

$$Vsc = As.dsc = B.L.d_{sc} \quad (15)$$

Where: As = area (m^2); B = width (m); L = length (m); D_{sc} = water depth (m)

When the electrical director has responded the change of power demand, the head pond capacity can be designed with 30 – 60 times of design discharge (Qd).

I. Penstock

Diameter of penstock can be calculated by this equation [17]

Warnick (1984)

$$D = 0.72Q^{0.5} \quad (16)$$

USBR (1986)

$$D = 1.517Q^{0.5}/H^{0.25} \quad (17)$$

Fahlbusch (1987)

$$D = 1.12Q^{0.45}/H^{0.12} \quad (18)$$

Sarkaria (1987)

$$D = 3.55x(Q^2/2gH)^{1/4} \quad (19)$$

RETscreen Canada (2005)

$$D = (Q/np)^{0.43}/(H)^{0.14} \quad (20)$$

ESHA (2005)

$$D = 2.69\left(\frac{n^2 Q^2 L}{H}\right)^{0.1875} \quad (21)$$

Where: D = penstock diameter (m); Q = design discharge ($m^3.s^{-1}$); H = head; g = gravitation (9.81 $m.s^{-2}$); np = number of penstock; n = material roughness

The thickness of penstock can be calculated by this equation

$$e = \frac{P \times d}{2 \times \sigma_f \times K_f} + e_s \quad (22)$$

Where: e = thickness of penstock (mm); P = hydrostatic pressure ($kN.mm^{-2}$); d = inner diameter (mm); σ_f = maximum stress ($kN.mm^{-2}$); k_f = weld efficiency (0.90-1.00); e_s = extra thickness for safety reason (mm)

J. Head loss

Head loss to analyze in hydropower system are trash rack, intake, feeder canal, settling basin, headrace, head pond, penstock, also valve at the power house.

H. Hydro mechanical

H.1. To decide the turbine

To choose the turbine, based on ESHA (*European small hydropower agency*), there is a graph also specific velocity calculation to make a decision choosing the turbine.

H.2. Cavitation

Cavitation happens when hydrodynamic pressure of flow falls under the vapor pressure. So, there is a evaporation. To avoid the cavitation, we have to estimate the distance between the turbines to TWL (tail water level) by this equation [17]

$$Hs = \frac{P_{atm} - P_v}{\rho.g} + \frac{V^2}{2.g} - \sigma.H \quad (23)$$

Where: Hs = suction head (m); P atm = atmosphere pressure; Pv = vapor pressure; ρ = density ($kg.m^{-3}$); g = gravitation ($m.s^{-2}$); V = velocity ($m.s^{-1}$); σ = Thoma's value; H = head (m)

The equation of Thoma's value for Francis turbine is [17]

$$\sigma_t = 1.2715 \times n_s^{1.41} + \frac{V^2}{2.g.H} \quad (24)$$

Where:

$$n_s = \frac{1.924}{H^{0.512}} (Francis)$$

H.3. Generator

Generator is electrical component that will change movement energy to be electrical energy. To determine the synchronize velocity (turbine and generator), the equation is EUROPEAN SMALL HYDROPOWER ASSOCIATION, 2008)

$$Velocity\ (n) = \frac{120 \times f}{p} \quad (25)$$

Where: f = frequency (50 Hz or 60 Hz); p = number of pole

H.4. TURBNPRO

TURBNPRO is software for hydropower developer, consultant and student. By using TURBNPRO, determination of turbine and hydro mechanical components can be done easily.

I. Power and Energy [17]

The power of hydropower production can be calculated as follow:

$$P_{nett} = g.Q.H_{nett} \quad (26)$$

The energy produce by hydropower can be calculated as follow :

$$E = g.\eta_g.\eta_t.Q.H_{nett}.n \quad (27)$$

Where: P = power (Watt); G = gravitation ($m.s^{-2}$); Q = discharge ($m^3.s^{-1}$); H = head (m); η_g = generator efficiency; η_t = turbine efficiency ; n = time period (hour)

J. Economic Analysis [18]:

J.1. Cost

Cost is estimated payment to build the hydropower. Estimation of hydropower cost is stated by *RETscreen* Canada.

J.2. Benefit

Benefit value of the project especially of hydropower surely from the total electrical energy production. So, the total benefit in a year depends on the total energy and electrical cost per kWh. Based on PERMEN ESDM No.12 2014 for Sulawesi, average cost is 1,056 rupiahs per kWh.

J.2.1. Benefit cost ratio (BCR)

Equation for benefit cost ratio is

$$BCR = \frac{\sum Benefit}{\sum Cost} \quad (28)$$

Where: Benefit = total present value of benefit; Cost = total present value of cost

J.2.2. Net present value (NPV)

To get the NPV value the calculation is

$$NPV = PWB - PWC \quad (29)$$

Where: PWB = present worth benefit; PWC = present worth cost

J.2.3. Internal rate of return (IRR)

$$IRR = iNPV_+ + \frac{NPV_+}{|NPV_+ + NPV_-|}(iNPV_- + iNPV_+) \quad (30)$$

To get the IRR value, it is need some variable of MARR. In order to know the interest rate when NPV < 0 and NPV > 0

J.2.4. Payback period

Payback period analysis, basically to know the duration of the project until get the return of paid cost.

$$k_{PBP} = \frac{Investasi}{Annual\ benefit} \times periode\ waktu \quad (31)$$

Where: k_{PBP} = payback period; Investment = total of investment cost; *Annual benefit* = benefit in a year ; Time period = duration in a period (a year)

J.2.5. Sensitivity

Sensitivity need to be done, to know how much percentage of every variable can be change. The variable is usually like the decreasing of energy production, the increasing of cost, and both of them. Every variable is in measured percentage of change.

III. RESULTS AND DISCUSSION

A. Firm Discharge

Based on result of evapotranspiration analysis until discharge simulation by F.J Mock method, the following figure show flow duration curve [19], completed by plant discharge, operation discharge and maintenance flow. In this case, the pobability smaller than plant discharge will known as spillout, as follow

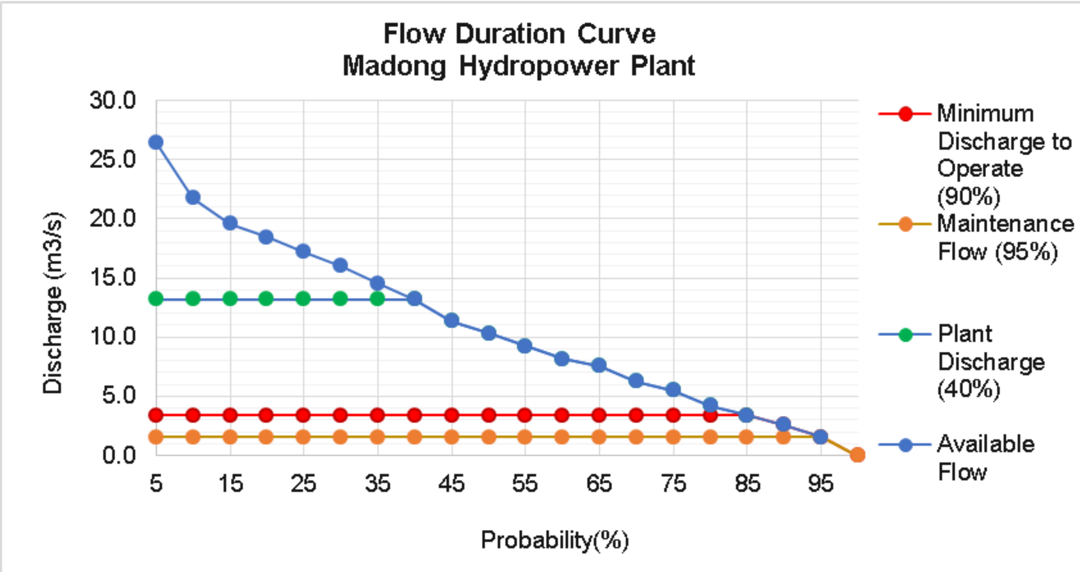

Fig. 1 Flow Duration Curve (Source: own study)

Plant discharge for the hydropower is 13.18 $m^3.s^{-1}$ that represents as the discharge with 40% probability.

B. Flood Discharge

To analyze the flood discharge is using the hydrograph synthetic unit of Nakayasu and Limantara. The following table, show the result of flood discharges in the 2, 5, 10, 25, 50 and 100 years.

Table- I Result of flood discharge calculation

Period (Years)	Nakayasu $m^3.s^{-1}$	Limantara $m^3.s^{-1}$
2	343.069	158.501
5	389.475	179.784
10	410.180	189.281
25	429.290	198.045
50	440.021	202.967
100	448.547	206.877

The calibration from AWLR (Automatic Water Level Recorder) data indicates that Nakayasu represents the value of flood discharge. Then, the 100 years flood discharge of Nakayasu is chosen as the design discharge.

C. **Civil equipment**

C.1. Weir

Weir is in circled-shape, with the dimension as follows: Flood discharge = 448. 47 $m^3s^{-1;}$ Width = 31.70 m; Height = 4.00 m; Radius of weir = 2.50 m; Water height on weir crest= 3.45 m; Base elevation = +952.00. Based on the design and analysis, the stilling basin is using the MDO/MDS type with 13 m length.

D. Intake

The intake is designed by 120% of the design discharge (13.18 $m^3.s^{-1}$). So, the intake has the following design: threshold height = 2.00 m; Threshold elevation = +954.00; Design discharge = 120% × 13.18 $m^3.s^{-1}$ = 15.82 $m^3.s^{-1}$. Intake width = $\frac{Q}{K.\mu a.\sqrt{2gh}} = \frac{15.82}{1 x 0.8 x 1\sqrt{2 x 9.81x.2}}$ = 3.20 m; Gate width per unit = 1.10 m (3 units); Discharge per gate =K. □. a. b $\sqrt{2gh}$ =1x0.80x1x1.10$\sqrt{2x9.81x2}$ = 5.5 $m^3.s^{-1}$

D.1. Feeder canal

To transmit the flow to settling basin, there is needed a feeder canal with the dimension below: Width = 5.30 m; Shape = square; Slope = 0.0015; Water depth = 1.25 m; Freeboard = 0.40 m

D.2. Settling basin

Result of settling basin analysis and design are: Design discharge = 15.82 $m^3.s^{-1;}$ Sediment diameter = 0.30 mm; Channel width = 7.00 m; Flushing period = 7 days; Temperature = 20˚C; Sediment content = 0.1 $^o/_{oo;}$ Settling volume= ($^o/_{oo}$) sediment × sum of day × Q_d× 24 × 3600 = 0.1 $^o/_{oo}$ × 7×15.82×24×3600 = 956. 55 m^3

Based on the analysis, the settling basin has the 60 meters length. By the condition of the length greater than 8 times of the settling basin width, so L (60.00 m) > 8.B (56.00 m) …OK! Based on the *champ* graph settling the efficiency is 95% and based on the *shield* graph 0.30 mm of the sediment diameter or smaller will be flushed.

D.3. Headrace

The headrace is designed with the maximum flow velocity 3 $m.s^{-1}$ with technical specification as follows: Design discharge = 14.50 $m^3.s^{-1;}$ Width = 3.00 m; Slope = 0.001; Channel slope = 0.5; Water depth = 1.73 m; Freeboard = 0.57 m; Velocity = 2.17 $m.s^{-1;}$ Material = concrete

D.4. Head pond

Plant discharge = 13.18 $m^3.s^{-1;}$ Design discharge = 14.50 $m^3.s^{-1}$ Based on the JICA, the capacity of head pond for the controlled power demand and discharge can be designed 30 times until 60 times of head pond design discharge. So that, the volume of head pond is Volume = 14.50 × 30 = 434.94 $m^3.s^{-1;}$ Width = 9 m; h_c = $\left(\frac{1{,}1x14.50}{9.81x\ 9}\right)^{1/3}$= 0.272 m; h0 = 1.73 m (from headrace); d_{sc} = 1.73 – 0.27 = 1.46 m; Length of head pond = B.L.$d_{sc;}$ Length = $\frac{434.94\ m^3}{9x1.46}$ = 33.30 .

D.5. Penstock

Based on the calculation, the diameter of penstock is presented in the Table- II.

Table- II. Diameter of penstock

No	Analysis	Diameter (m)
1	Warnick (1984)	2.61
2	USBR (1986)	1.70
3	Fahlbusch (1987)	2.03
4	Sarkaria (1987)	1.89
5	ESHA (2004)	1.53
6	RETScreen (2005)	1.57
Maximum		2.61
Minimum		1.53
Average		1.89
Chosen		2.00

Based on the analysis, the designed penstock is using 2.00 m of diameter. The distance between the block supports for penstock is 9.00 m. The thickness of penstock is 12 mm and the water hammer with the total head pressure is 155.50 m when the valve is closed for 5 seconds.

E. Head losses

Based on the evaluation and calculation of the head losses in the civil equipment, the calculated head losses are presented in the Table- III.

Table- III. Head losses

No	Location	HL (m)
1	Intake	0.0078
2	Trash rack of intake	0.0169
3	Turn of feeder canal	0.2038
4	Enlargement of width to settling basin	0.0605
5	Contraction of width to headrace	0.1004
6	Enlargement to head pond	0.0576
7	Trash rack of head pond	0.0115
8	Inlet of penstock	0.4482
9	Turn of penstock (1)	0.3585
10	Turn of penstock (2)	0.3585
11	Friction on penstock	1.270
12	*inlet valve*	0.1792
Total		3.0729

So that, the effective head will be

Hn eff = $H_{gross} - \sum HL$

= 111.00 m – 3.073 m

= 107.93 m

G. Hydro mechanic

G.1. Turbine

Based on the discharge and the head available, the turbine would be chosen by the graph as follow

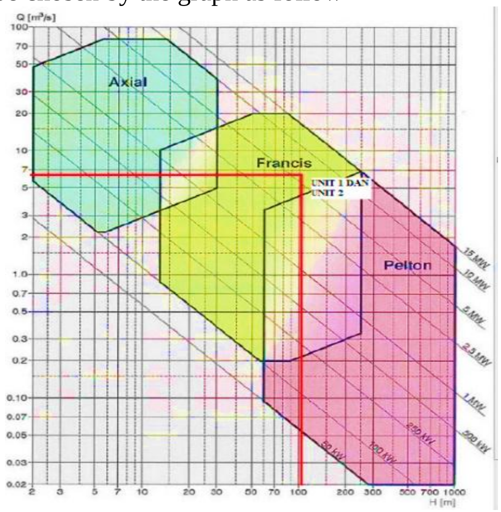

Fig. 2 Turbine estimation [17]

From the graph on the Figure 2, the turbines are Francis. Reviewing the specific velocity for the Francis type so that $Kec.\ spesifik = \frac{23{,}000}{(H+30)} + 40 = \left(\frac{23{,}000}{111+30}\right) + 40$ = 203.120 m-Kw (match for the Francis type)

G.2. Cavitation

Based on the Hs value, the turbine runner has to be located on the 2.66 m under the tail water level elevation. So that, the turbine runner is located on the 2.70 m under the designed tail water level elevation: +844.00 – 2.70 = +841.30

G.2.1. Hydro mechanical by ESHA calculation and TURBNPRO

The calculated hydromechanics calculation between the ESHA calculation and the TURBNPRO as follows:

Table- IV. Hydro mechanic calculation result

No	Parameter	Calculation (ESHA)	TURBNPRO V3
1	Power	6,289 kW	6,450 kW
2	Thoma's Value	0.111	0.109
3	Runner diameter	0.862 mm	0.908 mm
4	Maximum speed	945.757 rpm	1,309 rpm
5	Generator maximum speed	750 rpm	750 rpm
6	Generator frequency	50 Hz	50 Hz
6	Specific speed	203.121 m-kW	173.1 m-kW

G.2.2. Power and Energy

The estimation of power which is produced from the Madong hydropower is

$P = Q \times (\eta_{turbine} \times \eta_{generator}) \times g \times H_{nett}$ = 13.18 × 0.93 × 9.81 × 107.93 = 12,590.34 kW

The energy that is produced in a year by the Madong hydropower is 68,025,717.3 kWh or 68.02 GWh (in a year). With the minimum discharge for operating a unit turbine is 2.63 $m^3.s^{-1}$ on the discharge probability of 90%. However, the assessment of hydropower production at monthly time scale is not uncommon in the literature [20]. See for instance Afzali *et al*. [21]; Barros *et al*. [22]; and Cheng *et al*., [23].

H. Economic Analysis

H.1. Cost

The estimated cost of the Madong hydropower by *RETscreen* theory shows in the Table- V.

Table- V. Cost of hydropower components

Components	Cost
Technical	Rp 2,375,760,807.19
Electromechanical	Rp 31,737,265,597.80
Electromechanical Installation	Rp 4,760,589,839.67
Access Road	Rp 104,993,439,037.34
Transmission Cable	Rp 287,325,406.50
Transformer and Suibstances	Rp 587,107,571.64
Transformer & Substances installation	Rp 88,066,135.75
Civil works	Rp 65,215,797,814.91
Penstock	Rp 6,448,698,696.73
Installation of Penstock	Rp 1,612,174,674.18
Headrace	Rp 1,207,035.01
Other cost	Rp 16,941,482,558.27
Total	Rp 235,048,915,174.98

H.2. Benefit

The calculation of benefit with cost of Rp. 1056 per-kWh is Benefit = 68,025,717.26 kWh × Rp. 1,056 = Rp. 71,835,157,430.22 (in a year)

H.2.1. Benefit cost ratio

After the calculation of BCR with 2% of O&M and the interest rate of 10.50% so, the result is

$$BCR = \frac{PV\ Manfaat}{PV\ Biaya} = \frac{591{,}799{,}577{,}457.40}{456{,}541{,}847{,}684.46} = \mathbf{1.29}$$

H.2.2. Net present value

$$NPV = 591{,}799{,}577{,}457.40 - 456{,}541{,}847{,}684.46 = \mathbf{Rp135{,}257{,}729{,}772.9}$$

H.2.3. Internal rate of return

$$IRR = \frac{NPV - NPV_{13\%}}{NPV_{12\%} - NPV_{13\%}} \times (12\% - 13\%) + 12\% = \frac{0 - (-24{,}555{,}734{,}579.41)}{53{,}658{,}643{,}400.93 - (-24{,}555{,}734{,}579.41)} \times (12\% - 13\%) + 12\% =$$

12.68%

H.2.4. Payback period

Analysis of the payback period gives the payback duration within 15.43 years

H.2.5. Sensitivity

Based on the sensitivity analysis, the variable that affects the NPV and BCR is presented in the Table- VI.

Table- VI. Sensitivity analysis

Production Decreasing		
Percentage	NPV (billion)	BCR
10%	Rp. 76	1.16
20%	Rp. 16	1.03
23,1%	Rp. 0	1.00
Cost Increasing		
Percentage	NPV (Billion)	BCR
10%	Rp. 90	1.18
20%	Rp. 45	1.08
29,9%	Rp. 0	1.00
Decreasing of production & increasing of cost		
Percentage	NPV (Billion)	BCR
10%	Rp. 31	1.06
20%	Rp. -72	0.86

In the hydropower design of Madong regarding to the methodology and study design, it is needed to analyze the firm discharge for designing the hydropower turbine and structures. Data that are used in the firm discharge analysis are the monthly rainfall, the amount of rainfall day, and the climate data from 2006 until 2010. Analysis of evapotranspiration in this case is using the Penman method which uses some parameters that are become as the determinant of evapotranspiration value which is happened in surrounding of the Madang hydropower plan location. The parameters consist of the temperature, the long irradiation, and the wind velocity. Based on the analysis, it can be seen that the evapotranspiration in the study location is in the range of 2 until 4 mm/day. Then, this result will be used for analyzing the discharge by using the F.J. Mock method. The discharge analysis by using the F.J. Mock method is as the rainfall and evapotranspiration data generation from the previous analysis.

Based on the analysis by using F.J. Mock method, it is obtained the discharge value which is used for designing the Madang hydropower. The flow duration curve shows the discharge cumulative in the event probability with the range from 0 until 100%. The flow duration curve can be done due to the discharge analysis along 2005 until 2014 (based on the F.J. Mock method). Then the flow duration curve is used for estimating the most accurate discharge as the base of the design or it is usually mentioned as the firm discharge. In general, the firm discharge is selected depended on the maximum energy that is produced and it also consider the generator capacity and the economic factor of the structure design. The average discharge of the analysis result is 11.65 m^3/s.

Flood discharge is also as one of the aspects that is used in the Madang hydropower design, The flood discharge analysis is carried out through some stages which is started from the rainfall data evaluation, the design rainfall analysis, until the flood discharge analysis. The determination of the method which is used is depended on the parameter evaluation result and the characteristic of the study location. Result of the flood discharge analysis by using the Nakayasu and Limantara methods produce the flood discharge recapitulation and the estimation of water level due to the weir location. By analyzing the available flood discharge, the Nakayasu synthetic unit hydrograph more represents the discharge in the Madang River. Therefore, for the purpose of the flood discharge it is selected the result of the Nakayasu synthetic unit hydrograph. Then, the determination of flood discharge for the weir is analyzed based on the Indonesian Design Criteria Standard-2 (2013) which is published by the Indonesian Directorate General Work of Water Resources. The maximum flood discharge for the weir structure is taken as the flood discharge with the return period of 100 years. Therefore, for the purpose of weir design, it is used the flood discharge with the return period of 100 years such as 448.547 m^3/s as presented in the Table 1 above.

To obtain the most suitable discharge for designing and generating the Madang hydropower, it is needed the study as the determinants of the firm discharge and the flood discharge so the selected discharge is not out of the conditional standard and to be able to support the maximal operation of the hydropower. However, the firm discharge is fully used as the base for designing the component structure of the Madang hydropower such as the intake, the sedimentary tub, the feeder channel, the tranquilizers, the penstock until the selection of turbine. However, the flood discharge is used as the base for designing the weir. Based on the analysis result that has been carried out, the maximum energy production and the installed capacity of the generation discharge is 40% of it has the maximum value based on the Indonesia Ministry Rule of Energy and Human Resources (ESDM) No 10 (2017) about the usage of renewable energy source for supplying the electric (by the value minimum is 65%). Therefore, it is selected the firm discharge that meets the minimum capacity factor of 65% and has the maximum power and energy, so based on the energy production which is produced and the capacity factor, it is selected the generation discharge of 40% such as 13.182 m^3/s.

To analyze the cost, it is carried out by estimating the certain parameters for determining the cost approach which is produced with the variables of discharge and power that is generated. The formula which is used is based on the RETscreen Canada due to the estimation result of annual $_{production}$ energy and the cost until the BCR, the discharge as the generator is 40% of generated discharge such as 13.18 m^3/s. This discharge type produces the maximum energy and BCR although the cost is as the most expensive, however it can produce the maximum result.

Regarding to the location alternative which is selected, the weir is located in the coordinate: x = 81,232.818 and y = 9,673,208.426 with the weir elevation is +956. To know the flood water level, the width, the flow velocity, and the other parameters for designing the weir, it is analyzed the river cross section due to the parameters. Based on the analysis of water level head over the spillway, it is obtained the Hd (flood water level for Q_{100}= 448.654 m^3/s) is 3.45 m with the flood water level is 959.45 m. However, the water flow will be flowing through the mercu until to the stilling basin. The profile of water level is necessary to be known in order to be obtained the estimation of velocity and Froude number. In addition, the profile of water level becomes as the base of design of whirling pool by using the Froude number in the upstream of spillway To design the whirling pool, in this design it is selected based on the Froude number (for the whirling pool with the type of USBR). In addition, the other parameter as the mercu type and the weir height are also considered in this design.

In the intake structure, the generating discharge becomes as the main parameter. By designing the intake, it can be obtained the dimension of structure, the location until the operation. After the water through the intake, it is needed the feeder channel. The sedimentary tub has the function to prevent the sediment enters into the component of hydropower mainly the turbine. As is the sedimentary tub, it is hoped that it can reduce maximally the sedimentation by the water flow which has been through the sedimentary tub. Headway and waterway will flow the water regarding to the generating discharge until the dropping point before the penstock to the generator house. The reduction pond will reduce the turbine current before the inflow enters to the turbine, to control the discharge difference, and to minimize the sediment that may be still transported into the waterway.

In the case of the hydropower, the net power that is produced will be obtained after there is obtained the value of net head. However, the net head is the head after being decreased by the factor which decreasing the gross head. The factor is as the head loss which is happened on the hydropower line that starting from the water enters from the intake until the tailrace water level.

In the selection of turbine, it is carried out due to the discharge parameter and the effective head by using the graphic and based on the specific velocity (as presented in the Figure 2). After it is obtained the dimension of the spiral case, then it is carried out to analyze the draft tube. The draft tube is functioned as the outflow place that has circulated the turbine. In this design, there is used the vertical conical draft tube. It is due to the simple shape, it is easy to determine the dimension, and the parameter that is used is $D_{3.}$ To determine the Madang hydropower generator, there is considered the specific and the amount of the generator pole. Based on the study that has been carried out, it is obtained the range of the amount is 6 until 8. Therefore, the generator which is used is in amount of 8 poles with the rotate velocity is 750 rpm (50 Hz) or 900 rpm (60 Hz). However, it is selected the specification of generator with the frequency of 50 Hz. The analysis of power and energy produce the maximum power which is produced by the Madang hydropower. However, the analysis of energy produces the estimation of net energy which is produced during one year operation of the Madang hydropower.

Based on the economic analysis, the internal rate of return will be decreasing along by the increasing of the infestation cost or the decreasing of the electrical energy production. Based on the economic appropriateness for the internal rate of return (IRR) method, the IRR (Internal Rate of Return) > MARR (Minimum Attractive Rate of Return). By the interest rate or MARR which is used is the 10.50%, the Madang hydropower project will be sensitive if it experiences the increasing of cost and energy production until +-10%, and then it will be sensitive if there is happened the decreasing of energy production until +-15%. In addition, it will be sensitive if there is happened the increasing of cost until +133%.

IV. CONCLUSION

Based on the hydrology analysis plant, the discharge is 13.18 $m^3.s^{-1}$ with the discharge probability of 40%. The flood discharge analysis is using the Nakayasu synthetic unit hydrograph in the 100 years period of 488.55 m^3. The civil equipment design produces the result as follow: a) The weir with 31.70 m width and 4 m of height; b) The intake with 3 unit gates and has 1.10 m width for each gate with 14.50 $m^3.s^{-1}$ of capacity; c) The settling basin with 60 m length, 7 m width and 956.55 m^3 settling volume; d) The headrace with 3.00 m width, with 0.001 slope and 725 m length; e) The head pond with 9.00 m width and 33.30 m length. The capacity of head pond is 434.94 m^3; f) The penstock has 2.00 m diameter, and 12 mm thickness. The distance between the block supports is 9.00 m. The penstock uses the welded steel material; g) The mechanical components are 2 unit Francis turbines and 2 unit generators with 50 Hz frequency, 750 rpm of rotation speed.; h) The power that is produced by the Madong hydropower as high as 12.59 MW with the total energy which is produced in a year ia 68.02 GWh; i) From the economic analysis the BCR = 1.29; NPV = 135.25 billion rupiahs, IRR = 12.68% and the payback period is within 15.43 years. The project will be sensitive when there are 14% of cost increasing and the energy production decreasing/ respectively. The decreasing of energy production as big as 23.10% and 29.90% increasing of the cost

REFERENCES

1. A. Sharifil, L. Kalin, and M. Tairishy, "A system dynamics approach for hydropower generation assessment in developing watersheds: a case study of Karkheh River Basin, Iran", *Journal of Hydrology Engineering*. September 3, 2012. doi:10.1061/(ASCE)HE.1943-5584.0000711
2. H.L. Raadal, L.I.S. Modahl, and O.J. Hansen, "Life cycle greenhouse gas (GHG) emissions from the generation of wind and hydro power", *Renewable and Sustainable Energy Reviews*, Vol. 15, 2011, page 3417-3422. *Key World Energy Statistics 2013 [online]*. [online] (2013). http://www.iea.org/publications/freepublications/

3. M. Shourian, S. Mousavi, and A. Tahershamsi, “Basin-wide water resources planning by integrating PSO algorithm and MODSIM”, *Water Resource Manage*, Vol. 22(10), 2008, page 1347-1366.
4. K. Kaygusuz, “Hydropower and the world's energy future”, *Energy Source*, Vol. 26(3), 2004, page 215-224.
5. J.P. Pantouw, M. Bisri, L.M. Limantara, and Rispiningtati. “Ratio between maximum and minimum discharge (Qmax/Qmin) as the anticipated indicator of river disaster in 30 watersheds of Indonesia”, *World Applied Sciences Journal*, ISSN 1818-4952, Vol 25(8), 2013, page 1031-1035
6. G. Ardizzon, G. Cavazzini, and G. Pavesi, “A new generation of small hydro and pumped-hydro power plants: Advances and future challenges”, *Renewable and Sustainable Energy* Reviews, Vol. 31, 2014, page 746-761
7. A. = Rudyanto, L.M. Limantara, U. Andawayanti, and E. Suhartanto. “Model of Water Balance Based on the System Dynamics”, *International Journal of Civil Engineering and Technology*, ISSN: 0976-6308, Vol. 9 Issue 12, 2018, p. 267-276
8. W.W.S. Anggara and L.M. Limantara, “Optimization of electrical energy at Batutegi Dam, Lampung Province of Indonesia”, *Academic Research International*, ISSN 2223-9553, Vol 1(2), 2011, page 61-69
9. Badan Standarisasi Nasional (National Standarization Department). ”Standar Nasional Indonesia (Indonesian National Standard) (SNI) SNI 6738:2015 Perhitungan Debit Andalan Sungai (Analysis of river dependable discharge)”, Jakarta : Dewan Standarisasi Indonesia, 2015.
10. L.M. Limantara, D. Priyantoro, L. Prasetyorini, and R. Darmawan. “Design of Stilling Basin for Decreasing Back Water in the Dam Foot”, *Internatiuonal Journal of Geomate*. ISSN 2186-2982, Vol. 15 Issue 51, 2018, p. 98-105.
11. Departemen ESDM (Department of ESDM). ”Buku Pedoman Studi Kelayakan PLTMH (Guide book for feasibility study of hydropower)*”.* Jakarta : IMIDAP, 2009.
12. Badan Standarisasi Nasional (National Standarization Department). ”Standar Nasional Indonesia (Indonesian National Standard) (SNI) SNI 2415:2016 Metode hitung debit banjir rencana (Method of flood discharge analysis)”, Jakarta : Dewan Standarisasi Indonesia, 2016.
13. L.M. Limantara, “Hidrologi praktis [Practical Hydrology]”, Bandung. CV Lubuk Agung, ISBN 978-979-505-205-2, pp 324, 2010.
14. L.M. LIMANTARA, “The limiting physical parameters of synthetic unit hydrograph”, *World Applied Sciences Journal*, ISSN 1818-4952, Vol 7(6), 2009, page 802-804
15. L.M. Limantara. “Evaluation of roughness constant of river in synthetic unit hydrograph”, *World Applied Sciences Journal*, ISSN 1818-4952, Vol 7(9), 2009, page 1209-1211
16. Department of Energy, ”Manuals and Guidelines for Micro-hydropower Development in Rural Electrification”, United Kingdom : JICA, 2009.
17. European Small Hydropower Association, ”Guide on How to Develop a Small Hydropower”, Belgium: ESHA, 2004.
18. R..J. Kodoatie, “Analisis ekonomi teknik (Analysis of engineering economy)”, Yogyakarta: Andi, ISBN 979-533607-X, pp 192, 1993.
19. J.P. Pantouw, L.M. Limantara, M. Bisri, and Rispiningtati, “Application of plural flow duration curve for producing optimum energy on mini hydro power plant”, *Journal of Basic and Applied Scientific Research*, Vol. 3(12), 2013, page 310-322
20. M. Karamouz, M. Akhbari, and A. Moridi, “Resolving disputes over reservoir-river operation”, *Journal of Irrigation and Drainage Engineering*, Vol. 137(5), 2011, page 327-339.
21. R. Afzali, S.J. Mousavi, and A. Chaheri, “Reliability-based simulation-optimization model for multi reservoir hydropower systems operations: Khersan experience”, *Journal of Water Resources Planning and Management*. Vol. 134(1), 2008, page 24-33.
22. M.T.L. Barros, F.T.C. Tsal, S. Yang, and J.E.G. Lopes, “Optimization of large-scale hydropower system operations”, *Journal of Water Resources Planning and Management*, Vol. 129, 2003, page 178-192.
23. C.T. Cheng, W.C. Wang, D.M. Xu, and K. Chau, “Optimizing hydropower reservoir operation using hybrid genetic algorithm and chaos”, *Water Resource Manage*, Vol. 22(7), 2008, page 895-909

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