International Journal of Electrical, Energy and Power System Engineering (IJEEPSE)
e-ISSN: 2654-4644
Vol. 4, No. 1, pp. 121-126, February 2021
Accredited by KEMENRISTEKBRIN, No. 200/M/KPT/2020
http://www.ijeepse.ejournal.unri.ac.id

Feasibility Study of Hydropower Plant at Lubuak Gadang Sangir South Solok

Hidayat*
Department of Electrical Engineering
Faculty of Industrial Engineering
Universitas Bung Hatta
Padang, Indonesia
hidayat@bunghatta.ac.id

Azriyenni Azhari Zakri
Department of Electrical Engineering,
Faculty of Engineering
Universitas Riau
Pekanbaru, Indonesia
azriyenni@eng.unri.ac.id

Iman Satria
Department of Mechanical Engineering
Faculty of Industrial Engineering
Universitas Bung Hatta
Padang, Indonesia
imansatria@bunghatta.ac.id

**Corresponding author: hidayat@bunghatta.ac.id*

Abstract*—The feasibility study is one of the principal documents in building a hydropower plant consisting of technical, economic, and financial aspects. Contained technical studies on civil, mechanical, and electrical. This requires data on hydrologic, geology, land contours, river discharge, water catchment areas, and so on. Economic and financial studies include cost and financial parameters such as; BEP, IRR, NVP, BCR, and others. The installed capacity of a hydropower plant is given in optimization based on the Flow Duration Curve (FDC) and the Capacity Factor (CF) used the Newton Interpolation Method. The results showed that the installed power capacity was 11.99 MW. The water discharge was 31.603 m^3/secs and the effective head was 37.5 meters. Annual income is around IDR 103.026 billion. Finally, HPP Lubuak Gadang is technically, economically, and financially feasible, so it is feasible to carry out the next process.

***Keywords*— Economic, Capacity Factor, Flow Duration Curve, Hydropower Plant**

I. INTRODUCTION

To increase the supply of cheaper and environmentally friendly electrical energy, the government and Independent Power Purchase (IPP) as providers of electrical energy are developing a Hydropower Plant (HPP) and Mini Hydropower Plant (MHP) [1]. The government has issued regulations that are very beneficial for IPP through the ESDM regulation No. 3 of 2015 for HPP power and ESDM regulation No.19 of 2015 for MHPP. The power capacity of MHPP below is 10 MW, while the HPP is above 10 MW [2][3]. One of the energy sources is the Batang Sangir river in Sangir sub-district, South Solok. One of the energy sources is the Batang Sangir River in Sangir sub-district, South Solok. The potential study that has been carried out at coordinates 00^o 12' 89" there is a potential power of around 12 MW, which is called MPP Lubuak Gadang [4].

A hydroelectric power plant functions to change the potential of hydropower which has a discharge and heat water to produce electrical energy [5]. The conversion process is held from water potential power to kinetic energy, then from kinetic energy to mechanical power using a turbine, and then mechanical power to electricity using a generator. Mini Hydropower Plant is intended to be established on an synthetic irrigation canal with a maximum flow rate of 40 m3/sec and a water head of 20 m [6], feasibility for hydro PV hybrid system functioning [7]. The main parameters to identify the capacity of an MPP are the discharge (Q) and ahead or height of the waterfall (H). The head is constant, while the water discharge changes according to natural conditions [8]. Therefore, the accuracy in determining the installed discharge capacity will produce an optimal generating capacity. For this reason, Newton's Interpolation method is applied to the FDC curve in determining the optimal water discharge to be used for HPP [9]. This research will discuss technical aspects, financial, regulation, socioeconomic and environmental aspects.

II. HYDRO POWER PLANT SYSTEM

A. Component of MPP

HPP is a power plant that uses water as an energy source. Water discharge (Q) and head (H) are the main parameters that determine the HPP capacity. The scheme and main components of MHP are consists of intake weir, settling basin, head race, forebay, penstock, powerhouse, tailrace, and distribution circuit as shown in Fig. 1 [8]. In the hydropower, process is possible that the flow of river water at the intake is dammed to increase the water level. Then the water is channeled through the waterway to the for bey. Bey is a sedative pool that functions to calm the water so that it is free from air bubbles. The calm water is converted into high-pressure water at the stockpile with a uniform fall

Received: January 27, 2021 | Revised: February 16, 2021 | Accepted: February 20, 2021

at a slope of 45° to 60° to the powerhouse to turn the turbine as a generator drive. The water from the turbine is then discharged through the tailrace to the river, where the amount of discharge is not reduced before. The generator functions are converting the energy of motion into electrical energy, then supplied to consumers through a distribution line.

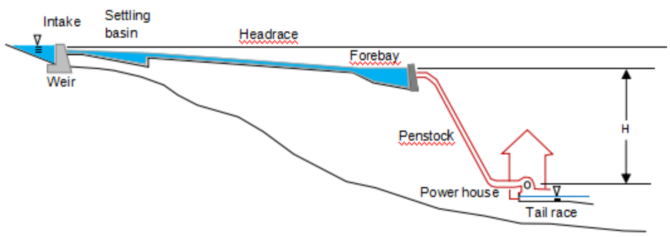

Fig.1. The scheme and main components of HPP

B. *Power and Energy of HPP*

HPP power capacity is determined by the head (H), the water flow (Q), and the velocity of gravity (g = 9.8 m^2/sec). The basic concept of the power plant conversion is shown by equation (1), P is a power (kW), H is a gross head (m), Q is water discharge (m^3/sec), E_o is a conversion efficiency (%).

$$P = 9.8 * H * Q * E_o \quad (1)$$

Electrical energy (electricity) is the multiplication of power (P) with Capacity Factor (CF), and time, as shown by equation (2),

$$E_{Electricity} = P * CF * t \quad \text{(kWh)} \quad (2)$$

If the HPP operates 350 days a year (15 days for maintenance) and 24 hours a day, then the electrical energy per year as seen in equation (3),

$$E_{Electricity} = P * 350 * 24 \text{ (kWh)}$$

C. *Hydro Graph, Flow Duration Curve (FDC) & Capacity Factor (CF)*

Usually, to represent the probability of the mean river discharge per year, it is expressed by Flow Duration Curve (FDC). It can be obtained from the hydrological data by grouping the same flow and determining the percentage of occurrence, as showed in Fig. 2. The capacity of HPP to be installed is based on the FDC. It can be observed that high flow discharge is only obtained at low probability. Applying high discharge will get a high installed power capacity, while the probability is low. Meanwhile, the application of minimal discharge will also get a low installed power capacity, while there is still potential that can be utilized. Therefore, it is needed to determine the CF, which is a comparison between the amount of the actual energy generated in a year with the energy-based on discharge design. Fig. 3 illustrates the determination of CF [9]. The maximum energy generated by HPP within a year, as described by the ABCD area. Whereas the actual energy generated by HPP can be calculated based on the sum of energy on the actual duration of power generated within one-year intervals, as described by the bcCD area. AbcCD area can be determined using the boundary integrals, where a curved line equation that describes the probability annual discharge is determined by Newton's interpolation method. CF can be determined by equation (3).

$$CF = AbcCD\ Area\ /\ ABCD\ Area \quad (3)$$

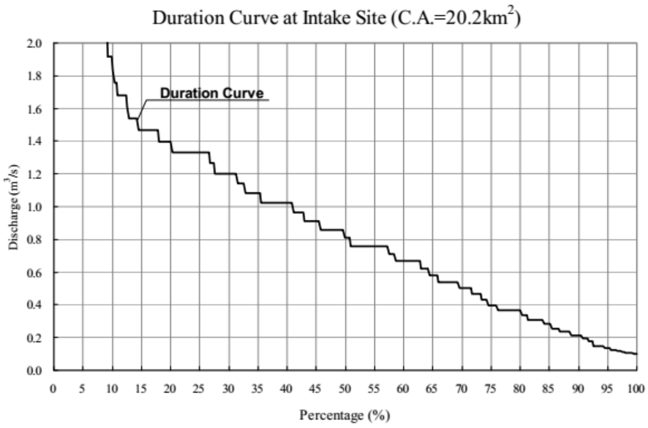

Fig.2. Flow Duration Curve (FDC) [8]

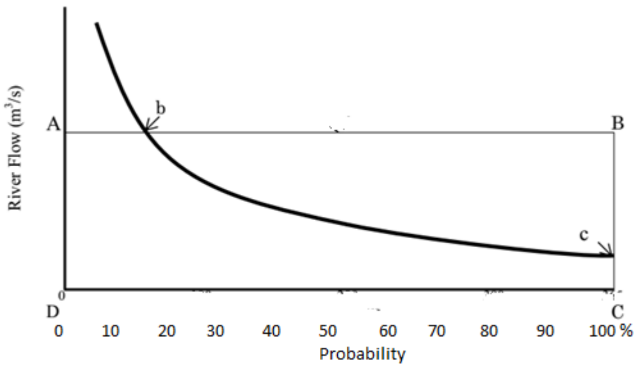

Fig. 3. Illustration in determining CF base on FDC [8]

D. *Penstock*

A penstock is a component that functions to channel high-pressure water from the forebay to the turbine. The following are some of the factors in civilian studies in the design of penstock. The diameter of penstock can be determined by equation (4).

$$D = \left(\frac{10.3 * n^2 Q^2 L}{h_g}\right)^{0.1875} \quad (4)$$

The thickness of penstock can be determined by equation (5), n is a roughness of forged steel 0.015, L is the length of penstock (m), h_g is a gross head (m), t_{min} is addition of pipe thickness for corrosion factor, D is inner of diameter of the pipe, n is safety factor, n is two for underground of pipe, n is four for pipe above ground level, P_o is air pressure, 0,01 Mpa, E is elastic modulus, 200 Gpa.

$$t_{min} = \frac{(D+20)}{1000} \text{ or } t_{min} = \sqrt{\frac{nP_o}{2E}} \quad (5)$$

Received: January 27, 2021 | Revised: February 16, 2021 | Accepted: February 20, 2021

E. Turbine

Water turbine is a mechanical construction equipment that functions to convert the potential energy of water into mechanical energy. The turbine will spin when hit by high-speed water. The turbine is coupled with a generator so that when the turbine rotates, the generator will rotate and produce electrical energy. Based on the working principle, water turbines are divided into two groups [10][11][12].

1) Impulse Turbine

The water turbine works by converting all of the water energy (consisting of potential energy + pressure + speed) available into kinetic energy to rotate the turbine, thus producing torsional energy. The pressure on each side of the blade of the runner and the rotating part of the turbine is the same. For example, the cross-flow turbines, Pelton and Turgo.

2) Reaction Turbine

The reaction turbine works by converting all the available water energy into kinetic torsional energy to turn the turbine, thus producing torsional energy. Reaction turbines are divided into two types namely Francis and Propellers. An example of a reaction turbine is the Francis & Kaplan Propeller turbine). The determination of the turbine in an MPP is based on the advantages and disadvantages of each. However, there are special parameters that greatly affect the turbine operating system, namely head height (H) and speed (N). The effective head net and discharge factors that will be utilized for turbine operation, are as shown in Table 1. The speed of the turbine rotation to be transmitted to the generator. The selection based on speed (N) is shown in Table 2. Based on the continuity equation, the flow of water flowing in a pressurized pipe can be determined by using equation (6), which is Q is debit (m^3/dt), V is speed of water flow (m/dt), A is pipe cross-sectional area (m^2).

$$Q = V.A \quad (6)$$

The specific speed of each turbine (Ns) has a certain range that is distinguished by the type of runner and is an important parameter in designing a water turbine, according in equation (7), H_e is effective head (m), N is speed design of turbine (rpm).

$$N_s = N \frac{\sqrt{Q}}{(H_e)^{3/4}} \quad (7)$$

TABLE 1 DETERMINATION OF TURBINE TYPE BASE ON HEAD

Type of Turbine	Head Variation
Kaplan	2 < H < 20
Propeller	2 < H < 20
Francis	10 < H < 350
Crossflow	6 < H < 100
Pelton	50 < H < 1000
Turgo	50 < H < 250

TABLE. 2 DETERMINATION OF TURBINE TYPE BASE ON SPEED

Type of Turbine		Speed (Ns)
Impulse Turbine	a. One jet (Pelton Turbine)	4-30
	b. Many jets (Double Turbine)	30-70
Reaction Turbine	a. Francis	
	Ns low	50-125
	Ns normal	125-200
	Ns high	200-350
	Ns express	350-500
	b. Propeller	
	Fixed blade (Nagler Turbine)	400-800
	Control blade (Kaplan Turbine)	500-1000

III. RESEARCH METHOD

The initial design of the MHP required location data, the elevation of the potential energy. Therefore, equipment such as maps and GPS are needed to guide the research location. Google Earth can be used as a guidance in finding the location points to be studied. Books and pens are for recording research results. Research materials are sourced from primary data and secondary data. Primary data is data obtained directly in the field, while secondary data is data obtained from existing references such as company records or documentation in the form of government reports, magazines, and so on.

IV. DATA AND MEASUREMENT

A. Location

The condition in which the area has sufficient water potential is a great opportunity for the development of HPP. One of them is in Lubuak Gadang Sangir which has the Lubuak Gadang river. The research location is in Sangir sub-district, South Solok district as shown in Fig. 4. South Solok district, Sangir sub-district, is located in an area adjacent to preserved protected forest and mountains. It is a tectonic area that has a large enough potential for water energy [4].

Fig. 4. The Picture of HPP Lubuak Gadang Area [4]

B. Topography

Topographic analysis is needed to determine the height of the water fall on an HPP. Data for topographical analysis were obtained from the AWLR of Sangir, South Solok office, which was presented in the form of topographical images [4]. Based on the topographical data can be determined the head loss using the meaning formula; (47/4.04) * (2.46/2*9.8) = 11.63 * 0.12 = 1.45m. Head net is the difference between head gross and head loss. Head gross can be calculated by the difference between the for-bay elevation and the tail race elevation. The tail race elevation and for bay elevation such as 431.05m and 470m. The head net for HPP Lubuak Gadang is $Head_{net} = head_{gross} - head_{loss}$ = 38.95m - 1.45m = 37.5m.

C. Hydrology

Hydro logical analysis is needed to obtain reliable discharge that will be applied to a power plant and also to determine the design flood discharge. For this reason, it is necessary to collect hydro-meteorological data in the MHP location such as rainfall data, climate data, evaporation, river discharge data and so on for a long period of time. The scope of hydro logical work includes; Measurement of instantaneous discharge with current meter equipment at the planned weir and tail race locations. Making a flow duration curve (FDC) as the basis for determining the discharge design for the HPP. Low flow analysis to obtain long-term discharge characteristics and determine water availability for HPP. Planning flood discharge analysis with a return period of 2 years, 5 years, 50 years, 100 years, and 1000 years.

1) Debit Data

Batang Sangir river is a recording of the river flow discharge which is located downstream of the HPP Batang Sangir weir with coordinates 01^0 30' 40" North Latitude 101^0 17' 5.1" East Longitude. Discharge data was recorded for 10 years from 2002 to 2012. In addition to the AWLR recording data, it was also obtained by measuring the instantaneous discharge into the field using the TH-0 Tatonas Current Meter. Instantaneous discharge measurements were carried out in the Batang Sangir River at coordinates 01^o 37' 28.99" North Latitude 101^o 20' 17.34" East Longitude which is located ± 10 metre at the upstream weir of HPP Sangir.

To determine the availability of water in the watershed at the location of the Lubuak Gadang HPP plan, especially the low flow rate, it is necessary to carry out a low flow simulation analysis. The design discharge analysis in the Lubuak Gadang HPP feasibility study was carried out by comparing the Sangir stem watershed (410.94 km^2) with the Sangir AWLR Watershed (845.2 km^2).

Flow duration curve (FDC) shows the percentage of time of the same or more discharges during a certain period, which also shows the characteristics of the flow. It can be formed from daily discharge data, averaging 10 days, averaging 15 days and a monthly average. It can be obtained based on the data of Sangir AWLR [4], [10]. The result of the FDC curve is shown in Fig. 5

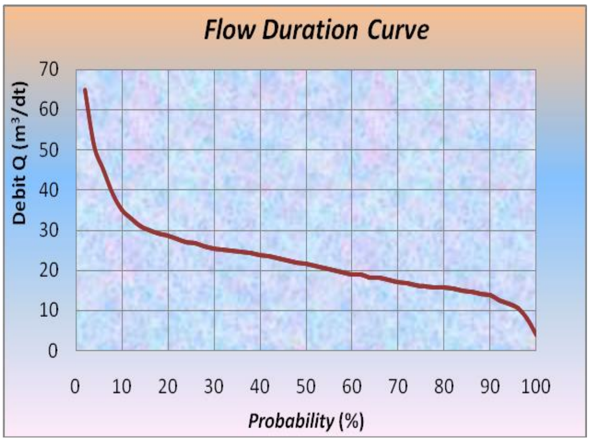

Fig. 5. Flow Duration Curve of Catchment Area of Batang Sangir River

The capacity factor (CF) of a HPP can be determined based on FDC using equation (3). A large Q determination will result in a large MHP installed capacity, but the discharge probability is low, so that the energy produced will also be low. If the determination of the discharge is too low, it causes the installed power to be low, so that a lot of energy cannot utilized. Therefore, it is necessary to optimize the debit calculation. Further, calculated the electrical power that can be generated and the annual energy production.

V. Technical and Hydro Calculation

A. Debit Design

Watershed discharge at the location of the Batang Sangir HPP for various probabilities is shown in the FDC and the net head is 37.5 m. To determine the probability of discharge, the continuity of rainfall must be considered. For a 20% probability of rainfall, a discharge of 31,603 m^3/s was obtained with stable rainfall for 73 days per year for 10-15 years. CF of MHP for a probability of 20% can be calculated using the Newton's Interpolation Method [9] CF 20% = 0.6. Further, the power and energy are calculated for a 20% probability using the equation (1) and (3), the result are 11,99 MW and 60,601 GWh a year. The power and energy that can be generated per year, for other discharge probabilities are shown in Table 3. Using Newton's Interpolation optimization method [10], it is found that the discharge to be used in the planning of PLTA Lubuk Gadang Sangir South Solok is 31.603 m^3/s with the installed power capacity for PLTA Lubuak Gadang of 11.99 MW.

TABLE 3. DETERMINE INSTALL CAPACITY

Probability (%)	Capacity Factor (CF)	Install Capacity (MW)	Energy/year 24 Hours, 350 days (MWh)
5%	0.1	14.88	12.499
10%	0.55	12.91	59.653
20%	0.6	11.99	60.601
30%	0.65	7.52	41.059
40%	0.7	6.56	38.573
50%	0.75	5.71	35.986
60%	0.83	4.81	33.521
70%	0.85	4.05	28.903
80%	0.9	3.28	24.797
90%	0.95	2.72	21.706
100%	1	0.23	1.949

B. Turbine Design

Determination of a suitable turbine type depends on the head and design discharge. After the head and discharge are obtained, they are substituted in the specification diagram for several types of turbines. Base on measurements obtained H_{eff} = 37.5 m with Q = 31.603 m^3/s used an axial-radial flow reaction turbine, namely the Francis turbine. In the reaction turbine, all potential energy from water is converted into kinetic energy when the water passes through the curvature of the guide blades, thus the runner rotation is caused by changes in the momentum of water, then the shape of the axial-radial flow reaction turbine of the French turbine [11][7][13].

$$P_t = 1000 * 9,81 * Q * H_{net} * \eta_{Tb} \text{ (kW)} \qquad (8)$$

The power capacity produced by the HPP turbine (P_t) in South Solok district at the design discharge (Q) can be

Received: January 27, 2021 | Revised: February 16, 2021 | Accepted: February 20, 2021

determined equation (8). H_{net} is effective head (m), η_{Tb} is turbine efficiency, the tourbine output power is P_t = 1000 kg/m^3 * 9.81 m/s * 31.603 m^3/s * 37.5m * 0.84, P_t = 12.63 MW.

TABLE 4. SPECIFICATION OF TURBINE FOR HPP AT LUABUAK GADANG

No	Component	Specification
1	Type	Francis
2	Head Effective	37.5 m
3	Debit of Design (Q_d)	31,603 m^3/s
4	Power	12.63 MW
5	Efficiency	0.84

C. Generator

Several brands of generators are available in the market or can be imported from abroad, such as Denyo, Kada, Shimizu, Nymar, Fujita, Mitsubishi, Kawasaki, STC generator and there are also many other brands. The price ranges from IDR 44 billion. From the calculation results, the generator to be used in HPP Lubuak Gadang is a generator with the KADA brand 3-phase synchronous [4]. The output power produced by HPP Lubuk Gadang is;

P_{tot} = 1000 kg/m^3 * 9,8 m/s^2 * 37.5 m * 31,603 m^3/s * 0.84 * 0.95 * 0.93 = 11.15 MW (Power Output of HPP).

Generated capacity is;
S = P_{tot} (MW)/Pf = 11,15 MW (0,8) = 13,93 MVA

Generator selection so that the maximum power generated by the generator is,

P_{gmax} = 9,8 MW+(100%*(12,63MW-11,15MW)) = 14,11 MW

VI. ECONOMIC AND FINANCIAL CALCULATION

A. Economic

The selling price of energy generated by MHP can be calculated based on the annual energy multiplied by the rate kWh. It is assumed that the MPP operates 24 days, the energy formula can be used;

Energy = 11.15 MW * 24 hours/days = 267.6 MWh

To get the selling price kWh, it is multiplied by IDR 1100 per kWh, which has been determined by PLN in Permen ESDM No. 1/2014. The maintenance is required 15 days a year, so HPP operates 350 days a year. Then the income obtained is IDR 103,026,000,000 a year. Based on the cost of all components required by MHP Lubuak Gadang is IDR 230,045,384,557.83 [4].

B. Financial

Financial analysis is needed to ensure that the HPP Lubuak Gadang project financially gives benefits to the developer. Financial analysis includes;

1) Operation and maintenance costs

Operation and maintenance costs are assumed to be about 20% of the annual investment value, which consists of personnel costs, maintenance and maintenance costs for facilities, routine office costs, tax costs and contribution costs for maintaining the Sangir watershed.

2) Life time project

In the financial analysis, the life time calculated for the Sangir HPP is 15-20 years, although the life time of civilian buildings and hydro power plants is designed for 25 years.

3) Cash flow analysis

Cash flow analysis is based on several sources of project funding. This analysis aims to evaluate the condition of the annual cash flow and to detect the time period needed to achieve the payback period for the total investment cost. Therefore, investment cost is also an important factor in optimizing the installed power capacity of HPP. The NPV method is used to determine the feasibility of investing with equations (9), NPV is Net Present Value, F is the value in the n year, I is interest rate (%), N is year 1,2,3, etc.

$$NPV = \frac{F}{(1+i)^n} \quad (9)$$

VII. RESULT AND ANALYSIS

The calculation of water potential that can be used as HPP based on the FDC curve using the Newton's Interpolation Method. In this method, the percentage of water discharge that appears in one year is grouped. The discharge sought is a percentage that is always stable to be used as a mainstay debit to calculate the installed power to be planned. By applying a discharge of 31,603 m^3/s, it can be obtained that the turbine and generator power capacities are 12.63 MW and 11.15 MW, respectively. The generator capacity is divided into 2 unit with power capacity 6 MW respectively. After the results are generated, energy costs and energy costs per day and month can be calculated from the HPP planning, energy calculations by multiplying the power with the operating time.

The result of energy calculation per year is 93,660 MWh. After all the calculation results are obtained, a comparison is made to find out how much profit the HPP Lubuk Gadang Sangir, South Solok will get in a period of time per year, with produces an investment cost of IDR 230,045,384,557.83. Operating costs are added to the maintenance costs to be IDR 20,773,200,000, then with a HPP income of IDR 103,026,000,000 a year. The return on capital or investment is achieved within a period of 2 years 7 months for operating time 15 to 20 years. The feasibility of HPP can be searched by using the NPV (Net Present Value) method where in the planning of HPP Lubuk Gadang it is said to be feasible with NPV> 0 and the investment made provides benefits to the company so the project can be run.

Received: January 27, 2021 | Revised: February 16, 2021 | Accepted: February 20, 2021

VIII. CONCLUSION

Based on technical, economic and financial analysis, the construction process of the Lubuk Gadang HPP with a capacity of 2*6MW is feasible to proceed to the Design Engineering Detail (DED) process. The IRR setting of 20%, within 5 years the investment costs have been covered and a NPV of IDR 15,510,189,516.

REFERENCES

[1] K. Kim, T. Park, S. Bang, and H. Kim, "Real options-based framework for hydropower plant adaptation to climate change," J. Manag. Eng., vol. 33, no. 3, p. 4016049, 2017.

[2] P. 19 ESDM, "Electric Price HPP per KWH," 2015.

[3] P. 3 ESDM, "Electric Price HPP per KWH," 2015.

[4] Dempo, "Feasibility Study of TA Lubuak Gadang," Padang, 2015.

[5] M. C. Tuna, "Feasibility Assessment of Hydroelectric Power Plant in Ungauged River Basin : A Case Study," Arab J Sci Eng, vol. 38, no. June, pp. 1359–1367, 2015.

[6] Z. Bitar, I. Khamis, Z. Alsaka, and S. Al Jabi, "Pre-feasibility Study for Construction of Mini Hydro Power Plant," Energy Procedia, vol. 74, pp. 404–413, 2015.

[7] T. Luis E, "Feasibility Study of Hydro PV Hybrid System Operating at a Dam for Water Supply in Soutern Brazil," J. Power Energy Eng., vol. 3, no. 9, 2015.

[8] Hidayat, Theory an Design Micro Hydro Power Plant. Padang: Bung Hatta Press, 2017.

[9] M. Z. Hidayat, Cahayati, Arnita, "Determination of Optimal Power Capacity for Run of River Hydro Power Plant based on Flow Duration Curve using Newton's Interpolation Method," in International Conference on High Voltage Engineering an Power System (ICHVEPS), pp. 1–6, 2017.

[10] S. J. Hidayat, Cahayati, Arnita, "Grid Study of Mini Hydro Power Plant (MHPP) of Palangai Hulu South Pesisir," in MATEC Web of Conferences, pp. 248–253, 2018.

[11] I. I. Hidayat, Arnita, "Evaluation of Micro Hydro Power Plant (MHPP) using Overall Equipment Effectiveness (OEE) Method," J. Eng. Appl. Sci., vol. 12, no. 18, pp. 5271–5275, 2017.

[12] J. Hell, "Application of Power Electronics on Hydropower Generation," J. Phys., 2017.

[13] C. P. J. P. A .Michaela, "Design of 15 kW Micro Hydro Power Plant for Rural Electrification at Valara," Energy Procedia, vol. 117, pp. 163–171, 2017.

Received: January 27, 2021 | Revised: February 16, 2021 | Accepted: February 20, 2021