Ikhlas KITTA, Salama MANJANG, Wahyu SANTOSO

Electrical Engineering Department, Hasanuddin University, Indonesia

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The technical and economic approach to the connection of the MHPP in the distribution network

***Abstract**. The Government of Indonesia is accelerating the use of new and renewable energy for electricity supply. The use of renewable energy also intends to reduce greenhouse gas emissions. Electricity generated will be connected in a transmission and distribution network on the grid that is available to be distributed to consumers. Renewable energy sources, especially the Mini Hydro Power Plant (MHPP) with a capacity of 1 - 10 MW, are located in rural areas far from the load center. Long distances will result in reduced voltage and power losses in the power distribution system. Therefore the connection of renewable energy plants especially MHPP should not have a negative impact on the existing electricity system. In general, the connection is declared successful if the voltage drop is in the range between a maximum of +5% and a minimum of -10% of nominal voltage, small power losses, and short circuit current is not large. The MHPP connection must be carried out with a technical and economic approach when making decisions on determining the connection point. Because sometimes the decision to choose a connection location is technically fulfilling but economically it does not meet, on the contrary, there is also technically not good even though it is economically feasible, or both are not feasible. As shown in the decision making for the Bontosalama MHPP which is directly connected to the Sinjai substation although investment is expensive it is not constrained from the technical limitations of the Sinjai system.*

Streszczenie.** Wytworzona energia elektryczna jest podłączona do sieci przesyłowej, która jest dostępna do dystrybucji wśród odbiorców. Odnawialne źródła energii, zwłaszcza mini elektrownia wodna (MHPP) o mocy 1–10 MW, znajdują się na obszarach wiejskich z dala od centrum obciążenia. Duże odległości powodują zwiększenie strat napięcia i mocy w systemie dystrybucji energii. Podłączenie elektrowni odnawialnych, zwłaszcza MHPP, nie powinno mieć negatywnego wpływu na istniejący system elektroenergetyczny. Zasadniczo połączenie uznaje się za udane, jeśli spadek napięcia mieści się w przedziale od maksimum + 5% do minimum -10% napięcia nominalnego. Połączenie MHPP musi być wykonane z technicznym i ekonomicznym podejściem przy podejmowaniu decyzji o ustaleniu punktu przyłączenia. Ponieważ czasami decyzja o wyborze lokalizacji połączenia jest technicznie satysfakcjonująca, ale ekonomicznie nie spełnia, wręcz przeciwnie, nie jest również technicznie niedobra, nawet jeśli jest to ekonomicznie wykonalne lub oba są niewykonalne. Jak pokazano w procesie decyzyjnym dla Bontosalama w Indonezji MHPP, który jest bezpośrednio podłączony do podstacji Sinjai, chociaż inwestycja jest droga, nie jest ograniczona technicznymi ograniczeniami systemu Sinjai.* ***(Techniczne i ekonomiczne podejście do podłączenia MHPP w sieci dystrybucyjnej.)

Keywords: technical and economic; connection; mini hydro power plant; distribution network
Słowa kluczowe: techniczne i ekonomiczne; połączenie; mini elektrownia wodna; sieć dystrybucyjna

Introduction

Electrical energy is a necessity in the current modern era. The demand for electricity in Indonesia increases with the development of technology, population growth, business, and industry. New power plants are needed to serve the high electricity demand. Power plants must be adapted to the conditions of their respective regions. Currently, the most widely used power plant in Indonesia are hydro power plant, steam power plant, and diesel power plant. To address the growing need for electricity, the Indonesian government provides opportunities for those who wish to invest in the development of the electricity sector.

Indonesian government makes rules in the use of renewable energy sources for electricity generation, where the Indonesian government accelerates the use of new and renewable energy for the supply of electricity by encouraging the utilization of water, biomass, solar and wind energy into electricity. The policy for the development of renewable energy power plants also intends to reduce greenhouse gas emissions [1]. Electricity generated will be integrated into a transmission and distribution network to be distributed to consumers.

Economic and environmental problems will cause power plants to be generally located in rural areas far from the load center. Long distances will result in a reduction in power reaching the load because in the transmission of power from the generator to the consumer there is a decrease in voltage and power losses. Therefore the connection and operation of renewable energy plants should not have a negative impact on the existing electricity system [2].

Mini-scale hydroelectric power or in terms of electricity generation in Indonesia is Mini Hydro Power Plant (MHPP), included in the level of distributed generation, if connected to a 20 kV distribution network will have a significant effect on improving the quality of the efficiency of the power distribution system which includes: power flow, repairs voltage profile, increased reliability, and decreased power losses [3]. Most power distribution networks are designed in the type of radial network so that the flow of power flows in one direction. The application of MHPP in Indonesia has provided additional energy sources in several power distribution systems. MHPP is a small-scale power plant that uses hydro energy as its driving force [4], for example, irrigation channels, rivers or waterfalls by utilizing the height of the head and the amount of water discharge. Sinjai Regency (one of the regencies in Indonesia) has a hydro power potential of around 50 MW [5], so it is planned to utilize the hydro source. The location of the MHPP development plan is located in the Bontosalama village, which is then used as the name for the Bontosalama MHPP with a capacity of 6.3 MW or 6300 kW. This MHPP will support development activities, especially the availability of electricity in Sinjai Regency.

Bontosalama MHPP will be connected to grid 20 kV distribution system. In making the connection there are several interconnection point choices made in the form of a connection scenario. Each option needs to be examined to know which scenarios are the most feasible and the impacts caused before and after interconnection. The connection is declared successful if the voltage drop value is +5% and -10%, small power losses, and short circuit current does not exceed the value of the short circuit current resistance of the distribution system equipment. This interconnection study was carried out using a technical and economic approach at the time of analysis to make decisions on determining the connection point. So that the chosen connecting point is a decision that deserves to be implemented.

Analysis Object

The case reviewed here is the connection of MHPP in Sinjai Regency, South Sulawesi, Indonesia. Capacity development and expansion of the 20 kV medium voltage distribution network that will consistently meet the electricity needs of industry and other customers in Sinjai District, requires proper handling in terms of supply selection so that load centers in the area can be served, so that a service system is obtained optimal. Before the Bontosalama MHPP was connected to the Sinjai distribution system, the Sinjai area had been served by Sinjai substation with a transformer capacity of 30 MVA. Substation (SS) serves Sinjai's load of 11661 kW.

Sinjai SS has 3 main feeders, namely Lamattirilau, Lita and Lappa. Lita's feeder has a Bikeru subfeeder as shown in Figure 1.

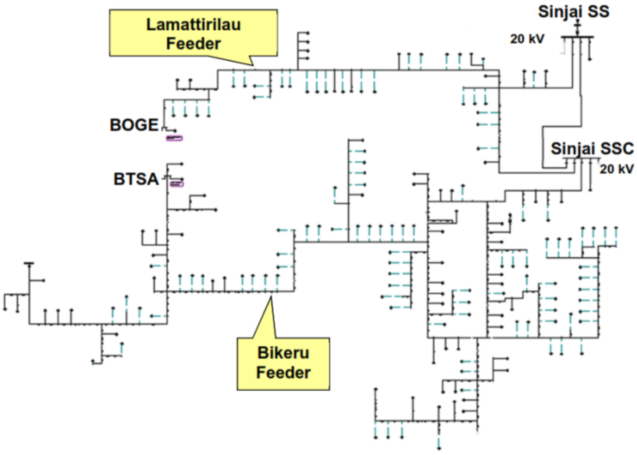

Fig. 1. Single line diagram of the Sinjai system

Based on the measurement results of the power generation experts, that the Bontosalama MHPP is capable of producing 6300 kW of electricity which is designed to be 2 x 3150 kW. The Bontosalama MHPP is connected to the South Sulawesi System grid [16] via the Sinjai SS so that the Sinjai SS load is reduced by 6300 kW. Two (2) synchronous generator units are planned to be installed in the Bontosalama MHPP. Each 3-phase synchronous generator with a capacity of 3150 kW and with a voltage of 6.3 kV is directly connected to a horizontal shaft Francis type turbine.

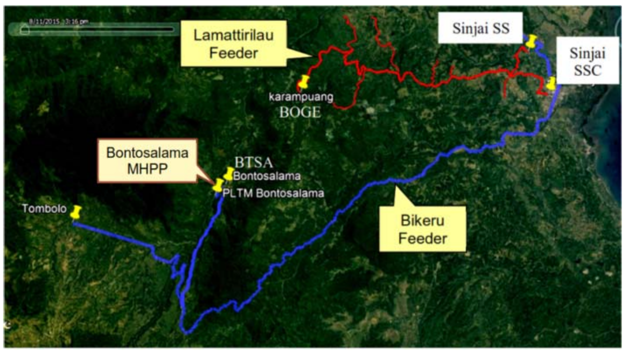

Fig. 2. Position map of Bontosalama MHPP

In the distribution of electricity systems, near the Bontosalama MHPP location there is a 20 kV overhead distribution network, namely the Bikeru subfeeder with a distance of 1.5 km, and the Lamattirilau feeder with a distance of 17.5 km. The distance between Sinjai SS and MHPP Bontosalama if the network follows the Bikeru feeder path as far as 61.5 km, while if through the Lamattirilau feeder path is 45.5 km. This can be seen in Figure 2.

Connection Scenario

The Bontosalama MHPP distribution plan to the Grid will use the Bikeru sub feeder to Sinjai SS (one of the analysis scenarios), where Sinjai switching station (SSC) is located in the city of Sinjai which is the capital of Sinjai Regency. Currently, the burden contained in Sinjai SSC is supplied from Sinjai SS.

Besides being able to pass the Bikeru sub feeder and Lamattirilau feeder, electrical energy from the Bontosalama MHPP can also be directly connected to the Sinjai SS which is an express feeder type that will follow the Lamattirilau feeder path. So that the plan to connect the Bontosalama MHPP to the Sinjai system will be analyzed in 3 option/scenario models as follows:

- Scenario 1: Bontosalama MHPP is connected to the Bikeru sub feeder for 1.5 kmc.

This scenario is scenario where the Bontosalama MHPP is connected to the grid through the Bikeru sub feeder through an additional 1.5 kmc of AAAC 240 mm^2 auxiliary network where the connecting point at the BTSA is the end of the Bikeru sub feeder located in Bontosalama Village as shown in Figure 3.

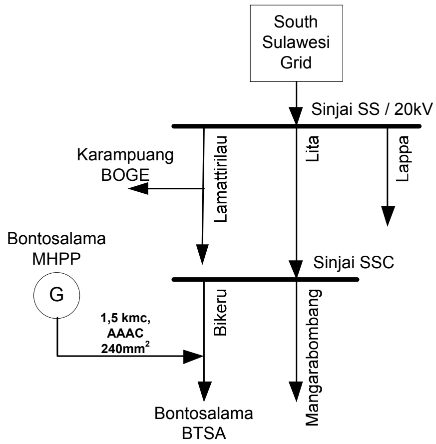

Fig. 3. Scenario 1

Scenario 2: MHPP Bontosalama is connected to the Lamattirilau feeder via an additional network along 17.5 kmc.

This scenario 2 positions the Bontosalama MHPP connected to the Lamattirilau feeder in BOGE, Karangpuang village, Sinjai district. The required length of a new overhead distribution network type of AAAC 240 mm^2 is 17.5 kmc to the end of the Lamattirilau feeder, where the length of the feeder reaching Sinjai SS is 28 kmc as shown in Figure 4.

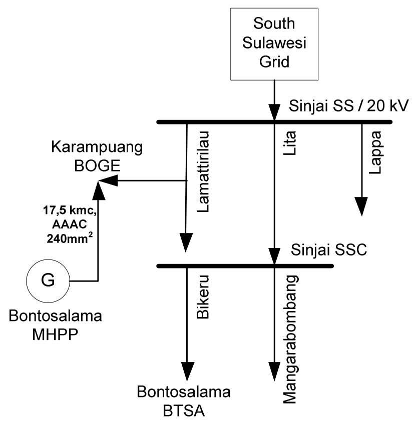

Fig. 4. Scenario 2

- Scenario 3: Bontosalama MHPP is connected to GI Sinjai via an ± 45.5 kmc express feeder.

In this scenario 3 the Bontosalama MHPP is connected to the Sinjai GI via a 45.5 kmc express feeder with 240 mm² AAAC type of conductor as shown in Figure 5.

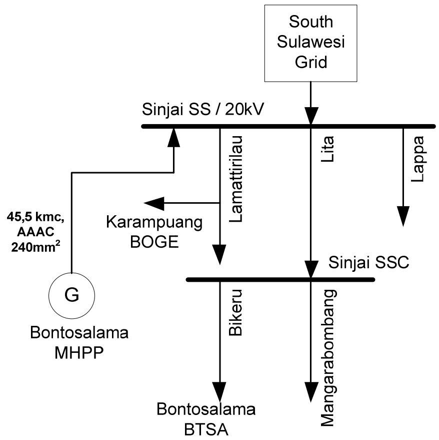

Fig. 5. Scenario 3

Calculation

To obtain objective simulation results carried out with the initial conditions at 1) Bontosalama MHPP operated maximum with the Power Flow Control operating mode, and 2) Tap / OLTC position of the power transformer at the Sinjai substation at a nominal voltage of 20 kV.

The things that will be considered in the analysis for these three scenarios are as follows:

(1) $P_{Sinjai-SS} = P_{Load} + P_{Losses} - P_{PLTM}$

- The limit of current carrying capacity of the conductor in the network that will be passed by an electric current.

In conducting a connection simulation, it is necessary to choose the type of conductor that has a current carrying capacity that is able to flow the current from the Bontosalama MHPP. In general, the 20 kV network in Indonesia uses AAAC conductor types. Bontosalama MHPP uses AAAC 240 mm². Continued analysis of the current carrying capacity of the conductor to connecting the Bontosalama MHPP. Calculation of current carrying capacity (CCC) will follow the form of equation (2).

(2) $I_{CCC-Grid} \geq I_{Nominal-MHPP} \times 1.25$

where equation (2) states the current carrying capacity of the connecting point grid ($I_{CCC-Grid}$) must be 1.25 times greater than the nominal current of Bontosalama MHPP ($I_{Nominal-MHPP}$).

- Changes in voltage at the connection point by looking at the voltage drop.

There is a voltage drop in some networks caused by the presence of different parts of the voltage in the distribution system and is also supported by resistance, reactance on the network. The voltage drop on the line represents the difference between the sending voltage and the reception voltage for electricity.

The voltage drop consists of two components, namely: $I.R_s$ (voltage losses from line coverage), and $I.X_l$ (voltage losses due to network inductive reactance). The amount of voltage drop can be determined as follows:

(3) $\Delta V = I \times Z$

where ΔV is the voltage drop (Volt), I is the current flowing (Ampere), and $Z = R + jX$ = network impedance.

The voltage in the Sinjai distribution system must follow the standard voltage limits. The voltage is:

(4) $|V_{min}| < |V_i| < |V_{max}|$

where $|V_i|$ is the magnitude of the voltage at any bus i, $|V_{min}|$ and $|V_{max}|$ are the magnitude of the minimum and maximum voltage limits taken as 0.9 per unit and 1.05 per unit, respectively [1].

- Value of power distribution system losses,

In determining the economic distribution of loads among power plants there is a need to consider power losses in distribution networks. The main power losses in the networks are the amount of power lost in the network, the amount of which is equal to the power supplied from the power source minus the amount of power received in the main connection equipment. Power loss is influenced by the resistance and the amount of current flowing in the network, so that power loss in the form of heat is lost in the network.

The amount of 3 phase power loss is expressed as equation (5):

(5) $P_{Losses} = 3 \times I^2 \times R$

where P_{Losses} is the power losses in the network (Watt), I is the load current in the netwrok (Amperes), R is the resistance of network (Ohm).

In a multi-bus system such as the Sinjai distribution system, a more accurate completion of the power flow is needed to obtain the voltage profile and the value of the network power losses. One method of power flow that is often used is the Newton Rhapson Method [7]. So that in this analysis will use Newton Raphson's method.

- Investment costs of additional networks.

To analyze the cost components needed in order to optimize the connection of MHPP on the existing grid, the assumption of investment costs for the conduction of 20 kV is first presented. Investment costs follow equation (6).

(6) $Inv_{Line-MHPP} = \sum_{i=0}^{n} Inv_i$

were the investment value of the additional MHPP connection ($Inv_{Line-MHPP}$) is the sum of all equipment costs in the additional network (Inv_i).

The cost components that comprise the total additional investment for the network are 20 kV overhead distribution networks installation, kWh meter, and MCB installation, test commissioning, cable network installation, surge protection system installation, and ground system installation.

Results and discussion

Power Supply Result

Table 1 shows the results of the calculation of the generation of each source in the existing conditions, scenario 1, scenario 2, and scenario 3. The influence of the Bontosalama MHPP interconnection to the Sinjai distribution system is very influential because it reduces the power supply from the Sinjai SS where the Sinjai SS is supplied by South Sulawesi system.

Table 1. Power supply of Sinjai system

Source	Without Bontosalama MHPP (kW)	Connection Scenerio of Bontosalama MHPP (kW)		
		1	2	3
GI Sinjai	11661	6776	7724	11661
Bontosalama MHPP	-	6300	6300	6300

Current Carrying Capacity of the Conductor

When the Bontosalama MHPP is connected to the Sinjai system, the current flowing to the Bikeru sub feeder and Lamattirilau feeder with AAAC 70 mm^2 conductor type must go through the current carrying capacity (CCC) of the conductor existing. The table 2 shows the condition of the capability of conductors in the Sinjai system, where scenarios 1 and 2 do not allow to connect electric current from the Bontosalama MHPP.

Table 2. Current carrying capacity of the conductor

Scenario / Connection Point	Conductor (mm^2) / CCC (A)	$I_{nominal}$ (A) / safety limits (A)	(%)
1 / Bikeru sub feeder	70 / 255	227 / 284	111
2 / Lamattirilau feeder	70 / 255	227 / 284	111
3 / Sinjai SS	240 / 585	227 / 284	48.5

Sinjai Distribution System Power Losses

To analyze of the effects of the Bontosalama MHPP connection to the Sinjai system on changes in the number of power losses in the system, the following is explained in the form of table 3 which shows the power losses that occur in the Sinjai electricity system.

Tabel 3. Power losses of Sinjai system

Power losses without Bontosalama MHPP (kW)	Power losses when Bontosalama MHPP is connected (kW)		
	Scenario 1	Scenario 2	Scenario 3
402	1809	2859	1132

For scenario 3, we obtain the total losses of the Sinjai distribution system after the interconnection of the Bontosalama MHPP in Sinjai SS is 1132 kW. And the losses in the conduit network Bontosalama to Sinjai SS as a contribution to the power losses of Bontosalama MHPP amounted to 730 kW.

Bus Voltage

Table 4 shows the results of the calculation of the voltage value in scenario 1, scenario 2 and scenario 3.

Table 4. Voltage for all scenarios

Source	Without Bontosalama MHPP (kV)	Connection scenerion of Bontosalama MHPP (kV)		
		1	2	3
Sinjai SSC	19.60	19.66	19.60	19.60
BTSA	17.72	20.58	17.72	17.72
BOGE	19.54	19.54	21.17	19.54

Network Investation

The investment costs for additional networks for connecting MHPPs that use 3 scenarios are shown in the table 5.

Table 5. Forecasting investment need

Scenario	Investment (biliion Rupiah)
1	1.94
2	17.94
3	46.16

Discussion

The results of the calculation of the Bontosalama MHPP connection scenarios in the Sinjai system show that the connection of the Bontosalama MHPP in scenario 1 will result in an optimum improvement of the voltage profile improvement on the Bikeru sub feeder, but will affect the power losses in the Sinjai distribution system which were previously 402 kW to 1809 kW, this is because there are 60 kms of Bikeru feeder channel with type AAAC 70 mm^2 which will be passed through large currents which result in additional power losses along the network. The addition of losses to the system is the responsibility of the Bontosalama MHPP so that the unsold Rupiah is very large, plus the investment costs to realize a connection network of 1.94 billion Rupiah. However, this explanation will be ignored because in terms of the Strong Conductivity as shown in table 2 that the electric current flowing from the Bontosalama MHPP of 227 amperes is very prone to passing the Bikeru subfeeder with 70 mm^2 section. Ideally, the cross-section of the conduit network is at least 284 amperes or 95 mm^2 in cross-section.

When Bontosalama MHPP is connected (scenario 2), the voltage on Sinjai SSC does not change. This is also supported by changes in power losses in the Sinjai system from 402 kW to 2859 kW. And it can be concluded that if scenario 2 is realized according to the current network conditions, the Bontosalama MHPP with a capacity of 6300 kW will reduce the performance of the Sinjai system. And it was also found that the impossibility of a Lamattirilau feeder because there was a 35 mm^2 conductor along 8 kmc would be used to deliver the Bontosalama MHPP because the known current carrying capacity (CCC) of the AAAC 35 mm^2 conductor was 170 Amperes. The investment cost in this scenario is 17.94 billion Rupiah.

Scenario 3 shows that there is no change in the voltage in the Sinjai system because the power supply from the Bontosalama MHPP is directly connected to the Sinjai SS. Power loss along the Bontosalama MHPP express feeder along 45.5 kmc is 730 kW. The small power losses are not proportional to the investment costs that must be spent in adding networks from Bontosalama MHPP to Sinjai SS, amounting to 46.16 billion Rupiah.

Of the 3 (three) scenarios, technically (voltage drop, power losses, and the CCC connecting point) the current scenario for connecting the Bontosalama MHPP is currently scenario 3, wherein the scenario is done by connecting the Bontosalama MHPP to the Sinjai SS through the feeder express. However, scenario 3 does not have a direct effect on the Sinjai system.

If the connection is viewed in terms of investment, scenario 1 is the cheapest scenario which has a connection network investment of 1.94 billion Rupiah. Gross profit every year from the sale of Bontosalama MHPP energy production is 41.79 billion Rupiah with the price of electrical energy 1500 Rupiah/kWh. Whereas in scenario 3, the connection investment cost is 46.16 billion Rupiah. Gross profit per year of 47.67 billion Rupiah. Then in Table 6 shows the cumulative profit for 10 years between scenario 1 and scenario 3. Seen for 7 years scenario 1 is profitable, but in the 8th year and so on scenario 3 has begun to profit.

Table 6. Cumulative advantages of Bontosalama MHPP operation.

Year	Cumulative Advantages (billion Rupiah)	
	Scenario 1	Scenario 3
1	39.85	1.41
2	81.64	48.98
3	123.43	96.56
4	165.22	144.13
5	207.01	191.70
6	248.80	239.28
7	290.59	286.85
8	332.38	334.42
9	374.18	382.00
10	415.97	429.57

So although scenario 3 is economically profitable for long-term investment, it is technically very feasible to use it as a connection scenario.

1. Conclusion

Based on the results obtained from Bontosalama MHPP interconnection, several conclusions can be drawn as follows:

1. The Bontosalama MHPP utilizes a source of hydro energy in the Sinjai area, so it is expected that it will help Sinjai in the availability of electrical energy.
2. The method of determining the location of a Bontosalama MHPP connection point must be seen from a technical and economic approach. This has been proven in 3 simple scenarios models for connecting Bontosalama MHPP, wherein the scenario, the position of Bontosalama MHPP is very close to the Bikeru sub feeder only 1.5 kmc away. But the connection cannot be carried out directly because ideally, the Bikeru network viewer is unable to pass through the power from the Bontosalama MHPP. Although it is economically very feasible.
3. Technically, scenario 3 is no problem but the investment is expensive. But it remains the first priority because it is not limited by the technical limits of the Sinjai system.

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***Authors**: Ikhlas Kitta, Salama Manjang, Wahyu Santoso, Electrical Engineering Department, Hasanuddin University, Makassar, South Sulawesi, Indonesia,*
E-mail: ikhlaskitta@gmail.com; salamamanjang@gmail.com

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