Insertion of 275 kV Transmission Line for Improving the Voltage Profile and Efficiency of Electrical Power System

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Abstract. The location of electricity generation generally lies in the centers of renewable energy sources which are generally far from urban centers, such as in the province of South Sulawesi, Indonesia. This condition becomes a separate issue related to the quality of the voltage and the efficiency of the electrical system that uses 150 kV transmission lines to transmitted electrical energy from the power plants. Therefore, to avoid waste and lack of quality electricity, it is necessary to insert a new transmission line from these power plants to the city of Makassar. Where the transmission line built is 275 kV transmission line because it increases the voltage profile and is efficient compared to 150 kV transmission line even though the network is added to the bank's capacitor. Therefore, this paper shows the reasons why a 275 kV transmission line was chosen for the improvement of voltage and reduction of power losses in South Sulawesi system.

1. Introduction
At present the use of electricity has become a very important need for humans. The need for electricity is increasing for urban areas. This condition causes the distribution of electrical energy to these areas. An electric power system is said to have a high level of reliability if the system is able to provide a continuous supply of electrical energy needed by consumers [1]. There are several problems faced by an electric power system to be able to supply electrical energy continuously. One of them is related to the problem of quality of electricity voltage and small power losses [2]. Because the load center is generally located in a location far from the center of electricity generation, the distribution of electrical power is needed to reach consumers.

Constant voltage values will maximize the performance of electrical equipment used by consumers. Whereas with small power losses will maintain the electricity supply to consumers as desired and can reduce financial losses during the electricity transmission process.

The process of repairing the voltage on the network can be done using the voltage regulation method which is by using a bank capacitor and a transformer tap [3]. The installation of capacitors is expected to reduce power losses and improve the voltage profile of transmission line systems [4]. With minimization of losses on the network, the bus voltage profile can be maintained at allowable values so that the continuity and quality of the operation of the electric power system can always be maintained.

Transmission line losses are directly proportional to the resistance of the conductor and inversely proportional to the transmission line voltage square [5], so the reduction in power losses obtained due to the transmission line voltage increase is far more effective than the reduction in power losses by
reducing the conductor resistance value. Consideration of increasing transmission line voltage is what tends to be done to reduce power losses in the transmission line. Therefore, one of the efforts to reduce power losses and improve the quality of voltage in the South Sulawesi System is the insertion of 275 kV transmission line. In addition to these reasons, the development of 275 kV transmission line in the South Sulawesi system is to connect power plants in the area of renewable electricity to the load center in South Sulawesi, namely the City of Makassar. South Sulawesi has many primary energy sources, especially in the form of hydropower which can be developed into Hydro Power Plant. The potential of hydropower that can be developed into a Hydro Power Plant around 1,996 MW. In addition, there is also the potential for natural gas for Natural Gas Power Plant and Combined Cycle Gas Turbine Power Plant with measured reserves of 470 BSCF, and there is potential for coal for Coal-fired Steam Power Plant of 37.3 million tons\(^3\) [6].

To see how much influence 275 kV transmission line has on the South Sulawesi system, the research is carried out, the results of which are outlined in this paper.

2. Research Method

2.1. Test system description
The case analyzed in this study is the South Sulawesi electricity system. The data used in this study are secondary data obtained from the interconnection system of South Sulawesi. The data includes the layout of the South Sulawesi system illustrated in the one-line diagram, covering the capacity of the generators, transformers and transmission lines, and the working voltages. Equipped with data on system loading and the current operating system patterns.

The electricity load of the province of South Sulawesi is mostly in the southern part of the city of Makassar, while the renewable energy plant is located in the northern and central parts of South Sulawesi. South Sulawesi’s electricity system currently consists of 70 kV and 150 kV interconnection systems shown in Figure 1. The South Sulawesi system is supplied from hydro power plant, coal-fired steam power plant, gas turbine power plant, combined cycle gas turbine power plant, diesel engine power plant, and wind turbine power plant. The total installed capacity of the power plant in South Sulawesi is 1367 MW. The power of the generator is around 1102 MW, while the peak load is 950 MW. The number of existing substations in South Sulawesi is 33 with a total capacity of 1888 MVA. The ratio of the number of household customers with electricity is 84.46%.

2.2. Simulation procedure
The reason for adding a network with an 275 kV transmission line is based on the following power losses equation (1):

$$\Delta P_i = \frac{P^2 \cdot R}{V_i^2 \cos^2 \phi}$$

with, \(P\) is load power at the receiving end of transmission line (watt), \(V_i\) is voltage at the end of the transmission receiver (volt), \(R\) is Resistant to transmission wire (ohm), and \(\cos \phi\) is Load power factor.

It can be seen that the transmission line power losses can be reduced in several ways, including by increasing the transmission line voltage, reducing the conductor resistance, and increasing the load power factor.

In the research that has been carried out, simulations are carried out with the use of bank capacitors as an attempt to raise the bus voltage level and optimize the distribution of power to the system. Usage shunt capacitors are useful as additional reactive resources to compensate for inductive power due to loading by performing reactive power compensation, which aims to keep the voltage profile always at allowable limits. The installation of a shunt capacitor is also expected to also reduce losses which means saving electricity energy which means a decrease in the electrical current flowing in the load.
Data processing is carried out using Load Flow simulation software [7]. There are several stages through which data is processed in five calculation scenarios. The scenario is:

1. Scenario 1 (basic scenario)
   This scenario is a basic or existing scenario, where the system is conditioned on conditions without any addition of transmission lines. This basic condition will be used as a basis to see the effect of 275 kV transmission line insertion, 150 kV transmission line, and the addition of bank capacitors.

2. Scenario 2, add a 275 kV transmission line in the South Sulawesi system.
   Scenario 2 is a system condition that has been added with 275 kV transmission line with ACSR type, 2 x 430 mm$^2$ type, along 195 km. The location of the 275 kV transmission line addition is shown in Figure 1, where the base of the transmission line is in the Palopo bus, and the base of the network receiver is in the Kima bus which is a bus representing the load center (Makassar city).

3. Scenario 3, add a 150 kV transmission line
   In this condition a 150 kV transmission network is inserted in the South Sulawesi system, where the sending bus is the Palopo bus and the receiving bus is the Kima bus. This 150 kV transmission line has the same network parameters as the 275 kV transmission line parameter in scenario 2, conductor type is ACSR 2 x 430 mm$^2$ for 195 km. As shown in Figure 2.

4. Scenario 4, 5, dan 6, add a 150 kV transmission line with conductor type of ACSR 2 x 430 mm$^2$ along 195 km, and add bank capacitors.
   • Scenario 4 is insertion scenario a 150 kV transmission line and installation of 20 MVar bank capacitors on sending bus side (Palopo bus), As show in Figure 3.
   • Scenario 5 is the condition of the system with the installation of 20 MVar bank capacitor on the Kima bus and the 150 kV transmission line insertion. As show in Figure 4.
Scenario 6 is the condition of installing a bank capacitor on the side of sending bus and the receiving bus which is 10 MVar each. And also inserting 150 kV transmission line to connect the two bus. As shown in Figure 5.

Based on the scenarios and data of the South Sulawesi system, power flow calculations are performed under normal conditions or conditions before insertion of new transmission lines and addition of bank capacitors (scenario 1). From the acquisition, it will be seen how the condition of the network on the system interconnection as well as how much power losses caused by the South Sulawesi network.

In multi-bus systems, it is necessary to complete the power flow to obtain voltage profiles and network power losses using Newton Raphson method. The method solves the problem of power flow by using a set of non-linear equations to calculate the voltage and voltage phase of each bus [7].

3. Result and Discussion

3.1. Power flow analysis results

Based on the calculation results of power flow analysis for South Sulawesi system, the results are obtained as in Table 1.

Table 1. The calculation results of power flow analysis for South Sulawesi system

| Scenario   | Scenario 1 | Scenario 2 | Scenario 3 | Scenario 4 | Scenario 5 | Scenario 6 |
|------------|------------|------------|------------|------------|------------|------------|
| Power Gen. | MW         | 1058.53    | 1045.08    | 1048.65    | 1048.47    | 1048.55    | 1048.5     |
|            | MVar       | 541.98     | 474.09     | 496.74     | 472.65     | 471.06     | 471.93     |
| Load       | MW         | 1024.66    | 1024.66    | 1024.66    | 1024.66    | 1024.66    | 1024.66    |
|            | MVar       | 284.47     | 284.47     | 284.47     | 284.47     | 284.47     | 284.47     |
| Losses     | MW         | 32.87      | 20.42      | 23.99      | 23.81      | 23.89      | 23.84      |
|            | MVar       | 353.28     | 288.52     | 310.09     | 306.45     | 305.53     | 305.94     |
| Bus Volt. Max. | %   | 100.13     | 100.22     | 100.07     | 100.57     | 100.30     | 100.39     |
| Bus Volt. Min. | %   | 94.59      | 96.11      | 95.65      | 95.89      | 96.05      | 95.97      |

The power flow at any time in the system is always changing, this is due to changes in load that occur at any time. In this study, the analysis of power flow was carried out in the condition of the last highest peak load that had occurred in the South Sulawesi electricity system until the time of this research. The highest peak load at that time was 1024.66 MW and the total generation was 1057.53 MW. Jeneponto Coal-fired steam power plant bus as a slack bus, namely a bus that must bear all the power shortages in the system after all other power plants operate, generate power of 37.8 MW. This power of power plant still meets the capacity of the Jeneponto bus at 114 MW.

3.2. Effect of bus voltage profile

The results of the calculation of the bus voltage profile for each scenario are shown in Figure 6, where when the initial conditions (scenario 1) based on the study of power flow obtained the voltage profile of each bus ranged from 94.59% to 100.13%. The minimum value of the working voltage of the South
Sulawesi system is below the minimum limit of the SNI standard voltage and IEEE Standard, which is the lower limit of -5% and the limit of +5% of the nominal voltage (100%). Bus number 31 namely Sinjai bus which has the lowest voltage compared to other buses, which is 94.59%.

In scenarios 2, 3, 4, 5, and 6, the voltage on all buses has improved. Scenario 2 which inserts 275 kV transmission line into the South Sulawesi system gets results that have an impact on bus voltage, which can increase the voltage profile on all buses in the system, which is changed to 96.11% until 100.22%. Likewise in scenario 3, the bus voltage profile becomes 95.65% - 100.07%. For scenario 4 the bus voltage profile is between 95.89% - 100.57%. Also for scenario 5, the results of the bus voltage profile between 96.05% - 100.30% are shown. And the scenario 6 also produces a voltage profile that is better than scenario 1, which is between 95.97% - 100.39%.

Figure 6. The bus voltage profile for each scenario

3.3. Effect of system power losses

From the Table 1 it can be seen that the initial conditions are conditions that exist in the system without transmission line insertion or addition of bank capacitors, active power and reactive power generated by all plants in the South Sulawesi system of 1057.53 MW and 1045.08 MVar with power losses in the system of 32.87 MW and 353.28 MVar. When the South Sulawesi system was inserted a 275 kV transmission line, the total power generation was 1045.08 MW and 474.09 MVar, while the power losses dropped to 20.42 MW and 288.52 MVar.

In the comparative scenario, scenarios 3, 4, 5, and 6 were obtained for scenario 4 that inserting a 150 kV transmission line on the system obtained total generation power of 1048.65 MW and 496.74 MVar, power losses of 23.99 MW and 310.09 MVar. Table 1, it show about the power generation and power losses in scenario 4, scenario 5, and scenario 6, differing slightly from scenario 3.

If Figure 6 is analyzed, the voltage profile value when inserted is 275 kV transmission line (scenario 2) and 150 kV transmission line (scenario 3, 4, 5, and 6) are almost the same. However, scenario 2 allows more optimal reduction in power losses compared to other scenarios. Scenario 2 active power losses is 288.52 MW or down 12.45 MW, while scenario 3 is 310.09 MW, as well as scenario 4, 5 and 6 which differ only slightly compared to scenario 3. So scenario 2 has a better impact on the South Sulawesi system.

Likewise in the reduction of the reactive power of the South Sulawesi system, seen in Table 1, the application of 275 kV transmission line inserts will reduce reactive power losses by 64.76 MVar which previously amounted to 353.28 MVar.
4. Conclusion

Insertion of 275 kV transmission line in the South Sulawesi system can increase the bus voltage profile and reduce power losses. The scenario shows that the busbar voltage on all busbars is included in the permissible voltage range. This means that the average voltage level of this scenario is greater than the voltage level of the basic scenario. Scenario 2 also shows that after insertion of 275 kV transmission line, system power losses is less than initial conditions (scenario 1). Scenario 2 also shows the insertion of 275 kV transmission line has more optimal impact in terms of voltage quality and power transmission efficiency compared to the 150 kV transmission line insertion scenario and the addition of bank capacitors (scenarios 3, 4, 5, and 6). This can be seen in the average voltage level of scenario 2 is greater than the voltage level of scenarios 3, 4, 5 and 6. Similarly, the reduction in power losses, where the application of 275 kV transmission line in the South Sulawesi system reduces losses more system power compared to 150 kV transmission line (scenarios 3, 4, 5, and 6).

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