Evaluation of 20 kV Distribution Network Losses In Radial Distribution Systems Due to Distributed Generation Penetration

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Abstract. The installation of distributed generation with renewable energy becomes a solution when the demand for electricity is increasing and electricity generation with fossil energy is increasingly limited. There has been a change in power flow before and after the installation of distributed generation. However there can be a negative impact on the distribution network losses applicable to reactive power flows. There are cases where the distributed generation capacity is greater than the supplied load, resulting in distributed generation operating as a system voltage regulator and requiring reactive power, so that DG will absorb the reactive power from the system. The increasing demand for reactive power in DG also causes an increase in the current flowing in the network, and causes an increase in losses in the network, especially for the losses in reactive power.

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1. Introduction

The growth in demand for electrical energy is very large at this time is a sign that the economy of a society is getting better, of course, it really requires an additional supply of energy from new generators [1]. Limited natural resources such as petroleum, gas and coal which are non-renewable energy sources require the government to encourage the development of renewable energy sources, a policy has been issued by the Government by issuing a regulation on the purchase price of electricity by companies State electricity from photovoltaic generation, biomass, biogas, waste, geothermal and water [2,3].

The penetration of distributed generation in the distribution network will have an effect on the distribution system such as power flowing from the distribution to the transmission system, operation of the distribution network at its thermal limit, increased network losses due to the large amount of reactive power flowing in the distribution system, increased voltage on consumers who are near the substation and distributed generation working in conditions of under excited [4-7].

This research was conducted on the Tanah Jawa distribution system which has 2 distributed generations, namely the Tonduhan Mini Hydro Power Plant and Silau 2 Mini Hydro Power Plant. In distributed generation, where the location and capacity of the generator are certain, such as the spread of generators with water sources, of course contrary to this statement. Tonduhan Mini Hydro Power Plant with a capacity of 2 x 200 kW owned by PT. PLN, and the Silau 2 Mini Hydro Power Plant with a capacity of 2 x 3500 KW owned by PT. The Simalungun Energi brothers, who are connected to the 20 kV grid system via PM.06 feeders. The placement of a small-scale hydropower plant, both micro-hydro and mini-hydro, is determined based on the source location and water discharge. The negative effects of this distributed generation will in turn give benefits depending on the placement and power...
capacity of distributed generation in the distribution network [8]. Power plants with a water source are usually far from the load center and fast detection and power quality degradation [9] issues will be evaluate. In this research, it will evaluate whether there are negative effects on the distribution system.

2. Distributed Generation

2.1. General Definition of Distributed Generation

The International Council on Large Electric Systems (1999) defines DG as a plant that is not centered, usually connected to a network distribution system and capacity between 50 kW to 100 MW.

However there was a presentation on the capacity of DG differentiated as follows [10], Micro (1W to 5 kW), Small (5 kW up to 5 MW), Medium (5 MW up to 50 MW), and Large (50 MW up to 300 MW).

2.2. Impact of DG Placement

With placement and size of DG in power system has to improve the voltage profile and decrease system losses. A simple two buses is considered to analysis the impact of the DG in the voltage profile and power losses [11], shown in Fig. 1a and its phasor diagram in Fig. 1b.

From the phasor diagram, we can write:

\[ V_R = V_0 - jZ \]  

Where Z is the \( R + jX \) is the impedance of the line.

From the equation (1), if we reduce the voltage drops \( jZ \) the received voltage can be improved. Therefore, are three ways to reduce the voltage drops or \( jZ \) component.

1. Provide active power support to the system locally using distributed resources.
2. Provide reactive power support to the system locally using static condensers or FACTS.
3. Use of anti-Z element, which is possible through series capacitance.

![Figure 1. A two bus network](image-url)

The first two methods will result in reduction in I component, while the third method will decrease the Z. The method when we provide the active power support (-PG) to the system locally and the phasor diagram, which shows that the introduction of DG will reduced the active line components of the current from I to I’ to I” (I >I’ >I”) as the DG size will increase. This will result in lesser voltage drops (I “Z< I’Z< I Z), as shown in phasor diagram (Figure 1b).

DG is used primarily for providing active support of energy in the system. However, distributed generators also generate reactive power, and the results can be seen to partially support the reactive power injected at bus. Figure 1 shows the method when we provide the reactive power support (-QG) to the system locally. This will reduced the reactive line components of the current from I to I’ to I” (I >I’ >I”). This will result in lesser voltage drops.

For a simple two bus network, the losses that occurs in the line is given by,

\[ P_e + jQ_e = I^2(R + jX) \]  

Where \( P_e \) is the active power loss; \( Q_e \) the reactive power loss; and \( I \) is the line current, given by:

\[ I = \frac{V_0\angle\delta - V_l\angle\delta}{R + jX} \]
Where
\[ V_s \angle \delta_s = V_s (\cos \delta_s + j \sin \delta_s) \]
\[ V_r \angle \delta_r = V_r (\cos \delta_r + j \sin \delta_r) \]
Combining equation (2) and (3) results in,
\[ \Delta V_s \angle \delta_s = (P_r + j Q_r) (R + j X) \quad (4) \]
From (2) and (3), we can conclude that:
1. The line resistance and reactance have a very crucial role for voltage stability.
2. The line power losses can be reduced for stable and improved voltage profiles and by providing active and reactive power support to system. Economically it is not possible to provide support on each bus. Therefore, the maximum benefits could be achieved if the most suitable site and size of DG will be selected.

3. Methodology

3.1. Power Flow Calculation
Power flow calculations are paramount in planning, operating and developing systems, to obtain the operating characteristics of the generation or transmission system in steady state. In the power flow calculation, the operating system is assumed to be in the 3 phase equilibrium conditions, so that the calculation can be represented by a series of one phase that exists [12]. In the power flow study, many methods can be used, but the common and widely used method is Newton Raphson.

3.2. Research Steps
The stages in this research were carried out as follows:
1. Take existing data on the system.
2. Carry out power flow calculations prior to installation of distributed generation.
3. Observing the results of the power flow calculation on system behavior prior to installation of distributed generation.
4. Carry out power flow calculations after installation of distributed generation.
5. Observing the results of the power flow calculation on the system behavior after the installation of distributed generation.
6. Carry out comparisons of power flow results before and after the installation of distributed generation.
7. Make conclusions from the system behavior that occurs.

4. Results And Discussion
After distributed generation operation, it is known that there is an increase in reactive power flow in the PM.06 feeder from 2.79 MVAr to 4.36 MVAr (Table 1). One of the reasons is the large reactive power requirement of the Silau 2 Mini Hydro Power Plant on bus 38, namely 0.6 MVAr.

The operation of distributed generation shows a significant increase in distribution losses, namely on line 8, line 10, line 37, line 41, line 45, line 59, line 65, line 67, line 111, line 118 and line 26. Line 118 and line 26 are networks interconnected to distributed generation.

Prior to distributed generation operation, the active power sent from the Siantar Substation to PM.06 feeders (Bus 2 to Bus 19) was 4.592 MW and reactive power was 2.796 MVAr. The distribution network losses in this condition (existing condition) amount to 0.438 MW. After distributed generation operates, there is a change, namely at the relay station substations, receiving active power from distributed generation is 1.617 MW and transmitting reactive power is 4,363 MVAr. Network losses in this condition increase to 1.128 MW.

This applies inversely to the reactive power flow as shown in Figure 2, the reactive power flow increases by 56.04% (1.57 MVAr). This increase was due to the reactive power requirements of the Silau 2 Mini Hydro Power Plant after being interconnected.
Table 1. Distribution losses in the Tanah Jawa distribution system

| Number | Line | Without DG | With DG |
|--------|------|------------|---------|
|        |      | kW         | KVAR    | kW      | KVAR    |
| 1.     | TD 1 | 38.7       | 1318.7  | 27.6    | 942.0   |
| 2.     | Line 17 | 0.7    | -1.9    | 0.7     | -2.0    |
| 3.     | Line 8 | 159.1     | 214.1   | 119.8   | 158.2   |
| 4.     | T1    | 0.0       | 0.0     | 5.6     | 17.3    |
| 5.     | T2    | 0.0       | 0.0     | 25.3    | 391.5   |
| 6.     | Line 118 | 0.0   | -5.4    | 0.7     | -5.7    |
| 7.     | Line 26 | 0.0    | -14.6   | 4.9     | -7.4    |
| 8.     | Line 10 | 38.2    | 50.5    | 39.0    | 51.6    |
| 9.     | Line 37 | 37.0    | 47.9    | 52.4    | 69.5    |
| 10.    | Line 39 | 4.6     | -6.9    | 4.9     | -7.4    |
| 11.    | Line 41 | 40.8    | 53.1    | 57.9    | 76.8    |
| 12.    | Line 43 | 0.0     | -0.7    | 0.0     | -0.8    |
| 13.    | Line 45 | 27.8    | 35.4    | 50.8    | 67.8    |
| 14.    | Line 47 | 0.5     | -3.2    | 0.6     | -3.6    |
| 15.    | Line 51 | 5.7     | 5.4     | 6.4     | 5.9     |
| 16.    | Line 59 | 4.1     | 1.4     | 89.7    | 122.2   |
| 17.    | Line 49 | 0.2     | -5.4    | 0.2     | -6.0    |
| 18.    | Line 55 | 0.1     | -14.5   | 0.1     | 16.5    |
| 19.    | Line 91 | 16.4    | 14.7    | 18.2    | 16.2    |
| 20.    | Line 61 | 0.3     | -10.3   | 0.3     | -12.1   |
| 21.    | Line 65 | 2.9     | -0.2    | 94.3    | 128.8   |
| 22.    | Line 63 | 0.6     | -18.5   | 0.7     | -22.3   |
| 23.    | Line 67 | 1.3     | -1.3    | 75.1    | 102.7   |
| 24.    | Line 69 | 1.5     | -3.3    | 1.7     | -4.2    |
| 25.    | Line 111 | 0.1   | -5.3    | 0.2     | -6.3    |
| 26.    | Line 71 | 1.5     | -21.7   | 1.8     | -26.8   |
| 27.    | Line 73 | 0.1     | -8.5    | 0.1     | -10.5   |
| 28.    | Line 75 | 3.6     | -11.2   | 4.2     | -14.1   |
| 29.    | Line 77 | 3.0     | -8.8    | 3.5     | -11.1   |
| 30.    | Line 79 | 0.5     | -1.9    | 0.6     | -2.4    |
| 31.    | Line 81 | 0.9     | -7.6    | 1.0     | -9.4    |
| 32.    | Line 85 | 0.9     | -21.8   | 1.0     | -26.8   |
| 33.    | Line 87 | 3.3     | -7.1    | 3.7     | -8.1    |
| 34.    | Line 93 | 9.4     | 6.0     | 10.4    | 6.5     |
| 35.    | Line 95 | 0.5     | -4.0    | 0.6     | -4.6    |
| 36.    | Line 97 | 1.1     | -0.6    | 1.3     | -0.8    |
| 37.    | Line 101 | 7.1    | -13.7   | 8.0     | -15.7   |
| 38.    | Line 99 | 0.0     | -7.5    | 0.0     | -8.5    |
| 39.    | Line 105 | 4.6    | -3.1    | 5.2     | -3.7    |
| 40.    | Line 103 | 0.8    | -11.7   | 0.9     | -13.4   |
| 41.    | Line 108 | 17.5   | -8.4    | 19.4    | -9.8    |
| 42.    | Line 113 | 2.9    | -1.8    | 3.3     | -2.2    |
|        |        | Total    | 438.3   | 1516.3  | 1128.0  |

The operating pattern and interconnection facilities (Bus 71 to Bus 42) along the 13.8 km long feeder requires a reactive power of 0.536 MVAr which is the cause of the increase in reactive power flow. The capacity of the Mini Hydro Glare 2 Power Plant is 7 MW which is much larger than the supplied load of 4.59 MW and makes it a voltage regulator for the distribution system. This plant operates underexited and requires reactive power of 0.604 MVAr. Whereas the Tonduhan Mini Hydro Power Plant with a capacity of 400 kW which is smaller than the power to be supplied, namely 4.59 MW, the plant operates with constant power factor control control. In this condition, the generator transmits a reactive power of 0.248 MVAr, so the need for an interconnection facility with a length of 5.1 kms of 0.017 MVAR can be met by the generating unit.

Figure 2. Power flow before and after distributed generation operation

5. Conclusion
The main objective of this paper is to describe the negative impact on the installation and operation of the Mini Hydro Power Plant distributed in the Pematang Siantar Indonesia distribution system.
1. There is a change in power flow after the installation of the distributed generation, namely a change in the flow of active power because the amount of power from distributed generation is 7.4 MW, which is greater than the required feed load of 4.59 MW, so that the excess power is transferred to the Pematang Substation, Siantar.

2. The operating pattern and interconnection facilities are the causes of increased reactive power flow, where the Mini Hydro Glare 2 Power Plant operates as a distribution and underexcited voltage regulator which requires reactive power. Whereas the Tonduhan Mini Hydro Power Plant operates with constant power factor control control, the reactive power requirements for the interconnection facility can be met by the generator.

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