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Placement of photovoltaic and capacitors in the 20 kV Jeneponto Distribution Network

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Abstract. Indonesia is located on the equator which has a good intensity of solar radiation throughout the year. This radiation condition gives the potential for photovoltaic placement in Indonesia. Jeneponto Regency is one of the areas in South Sulawesi that has the high potential for the construction of photovoltaic (PV) with irradiation levels reaching 5.404 kWh/m²/day. This research aims to determine the location of photovoltaic and capacitor interconnection points in the 20 kV Jeneponto distribution system for optimizing voltage stability and minimizing power losses. The optimal simulation of the determination of interconnection points is carried out by simulating photovoltaic placement in different main buses, which are Jeneponto main distribution substation, Jeneponto switching substation, Tolo switching substation and Benteng switching substation. The results analysis showed that the photovoltaic interconnection point in Benteng switching substation produces the smallest power losses and all loads have a voltage profile that complies with both IEEE and PLN voltage standards.

1. Introduction

In general, solar energy does not only consist of direct sunlight to earth, but also includes indirect effects of the sun, which can be used as an energy source. How much energy is expended by the sun is difficult to imagine. According to an estimation, the solar core is a thermonuclear furnace with a temperature of 100 million °C, which can convert 5 tons of material into energy emitted into space as much as 6.41 x10² W/m² [1].

Indonesia that is located in the equatorial climate has the daily average of solar light of 4000-5000 Wh/m², while the average number of hours of sun exposure is between 4 to 8 hours per day [2]. Indonesia experiences a number of rainy days of around 170 days per year, the average air temperature between 26 to 32 °C with relative humidity averaging 80 to 90% and never drops below 60%. The condition of the sky in the tropics is cloudy, because the direct sunlight component is less than 40%. According to the National Energy Board, Indonesia has solar energy potential around 4.8 kWh per meter-square or 112,000 GWp [3]. These details are important for the study of solar energy, especially in the manufacture and selection of solar collectors for thermal solar systems. Fig. 1 shows the photovoltaic power potential in Indonesia and Fig. 2 describes the global horizontal irradiation map for South Sulawesi Province.



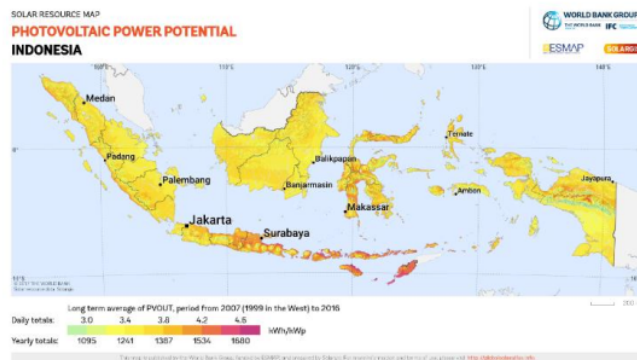


Figure 1. Photovoltaic power potential in Indonesia [4]

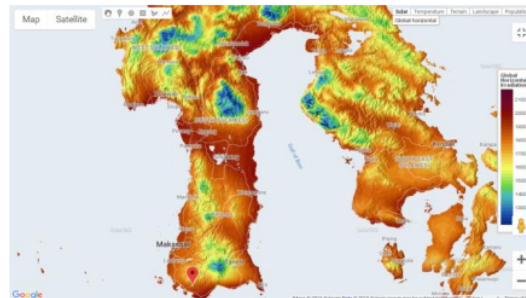


Figure 2. Global Irradiation Horizontal map for South Sulawesi Province [4]

Based on the forecast of the electricity needs by the Indonesian National Electricity Company (PLN) listed in the 2016 - 2025 Electricity Supply Business Plan, electricity demand in 2025 will be 457 TWh or grow by an average of 8.6% per year for 2016 period up to 2025 [5].

Nowadays, photovoltaic is the most used energy conversion among renewable energy generation [6]. The development of photovoltaic will be very helpful in meeting the electricity needs and dealing with the environmental deterioration in Indonesia [7]. In addition, a 1 kWp PV installation can help to reduce CO₂ emission for 25-30 tons during its lifetime [8, 9]. However, the determination of PV interconnection points needs to be considered carefully because PV cannot be connected straightforward in a system with other existing plants. Hence it is necessary to do research, observation and proper calculations to determine the interconnection location [10]. The study of determining the location of PV interconnection points needs to be done to minimize network losses and optimize the voltage profile and voltage stability in the interconnected power system [11-13]. Other issues that need to be overcome with PV integration is its dispatchability [14], congestion management [15] and optimal operation of system [14, 16, 17].

Based on irradiation data obtained from Solargis shows that Jeneponto Regency has the highest irradiation level in the Southern Sulawesi power system area with global horizontal irradiation of 2020 kWh/m², horizontal diffuse irradiation of 776 kWh/m² and direct normal irradiation of 1724 kWh/m²/year [4]. By taking into account this irradiation data, the research on determining PV placement was carried out by focusing to the determination of PV in the 20 kV feeder distribution system of Jeneponto Regency. Fig. 3 provides information on global horizontal irradiation (GHI), horizontal diffuse irradiation (HDI) and direct normal irradiation (DNI) in Jeneponto Regency.

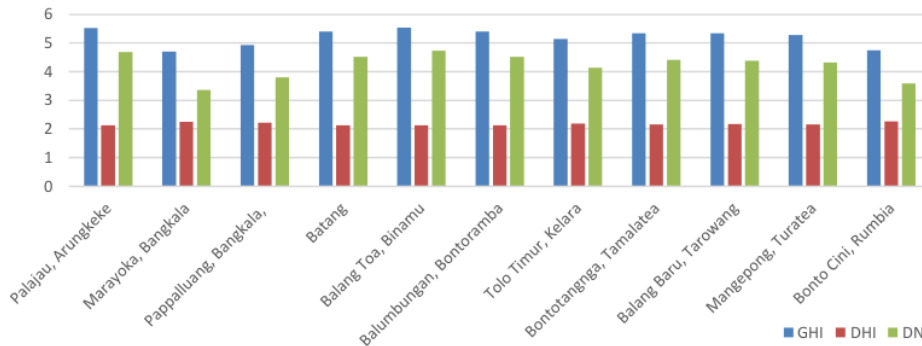


Figure 3. Global Horizontal Irradiation (GHI), Horizontal Diffuse Irradiation (HDI) and Direct Normal Irradiation (DNI) values in Jeneponto Regency

However, PV can only produce active power. On the other hand, an electric power system does not only require active power supply, but also requires reactive power. Therefore, in addition to plants that only produce active power such as PV, studies need to be carried out on reactive power compensation equipment as well, such as capacitors to inject reactive power into electric power systems [18, 19]. Therefore, this study examines PV interconnection and capacitors in minimizing network losses and optimizing voltage stability in the Jeneponto distribution system.

2. Methodology

To find PV and capacitor placement locations, this study uses the Newton-Raphson method power flow analysis with the objective function of minimizing network losses as well as optimizing voltage profiles and voltage stability. The Newton Raphson power flow analysis is more efficient and practical for use on radial systems because it has fewer number of iterations to reach the convergent values. The Newton Raphson power flow algorithm can be explained as follows [20]:

- Equation of active power on the bus i :

$$P_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \cos(\theta_{ij} + \delta_i - \delta_j) \quad (1)$$

- Equation of reactive power on the bus i :

$$Q_i = \sum_{j=1}^n |V_i| |V_j| |Y_{ij}| \sin(\theta_{ij} + \delta_i - \delta_j) \quad (2)$$

- If $\Delta P_i^{(k)}$ dan $\Delta Q_i^{(k)}$ do not reached the convergence value in the initial iteration then it will be continued by assigning Jacobian matrix elements.
- Compute the new value for phase angle $\delta^{(k+1)}$ and voltage magnitude $V^{(k+1)}$

$$\Delta \delta_i^{(k+1)} = \delta_i^{(k)} + \Delta \delta_i^{(k)} \quad (3)$$

$$|\Delta V_i^{(k+1)}| = |V_i^{(k)}| + \Delta |V_i^{(k)}| \quad (4)$$

- If the new value of the phase angle and voltage magnitude are obtained, then continue to the next iteration process.
- Iteration process stops when all values converge (ϵ)

The power flowing from bus i to bus j is obtained by this equation:

$$S_{ij} = P_{ij} + jQ_{ij} = V_i \cdot I_{ij}^* \quad (5)$$

Whereas current flowing from bus i to bus j is computed by using:

$$I_{ji} = \left(V_j - V_i + V_j \frac{Y'_{ji}}{2} \right) \quad (6)$$

Hence, network power losses at line i - j becomes:

$$SL_{ij} = (S_{ij} + S_{ji}) \quad (7)$$

Where,

$|V_i^{(k+1)}|$ = New voltage magnitude value

$|V_i^{(k)}|$ = Old voltage magnitude value

$\Delta|V_i^{(k)}|$ = Voltage correction value

$\Delta\delta_i^{(k+1)}$ = New phase angle value

$\delta_i^{(k)}$ = Old phase angle value

$\Delta\delta_i^{(k)}$ = phase angle correction value

The procedure for completing the iteration process will stop if the convergent value has been fulfilled.

The decrease in voltage in the distribution network is the difference between the voltage at the sending end and the voltage at the receiving end. On the AC lines, the size of the voltage drop also depends on the value of impedance, line admittance, load and power factor.

3. Results and Analysis

3.1. Jeneponto Distribution Network Data

The network data used in this study is obtained from the PT. PLN (Persero) Transmission Service Unit and the Substation which is in charge of Jeneponto distribution network. In the Jeneponto distribution system, there are 1 distribution substation, 3 switching substations and 10 feeders. The substations in the Jeneponto distribution system are Jeneponto distribution substation, Tolo switching substation, Jeneponto switching substation dan Benteng switching substation.

3.2. Initial Power Flow Analysis

This simulation is for observing the initial values before PV and capacitor placement. For the initial conditions, the network active power losses are 931.95 kW. The total active power from the grid, total load and losses as well as their values in percentage can be seen in Fig. 4 and 5, respectively. There were around 136 loads that experienced under voltage conditions as seen in Table 1.

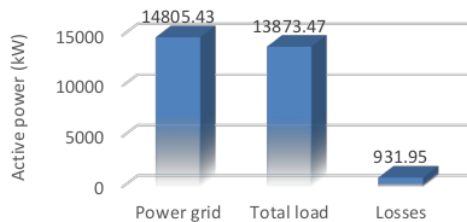


Figure 4. Comparison active power of the grid, total load and losses

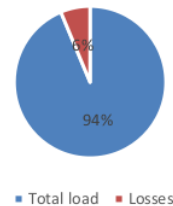


Figure 5. Total load and losses in percentage

Table 1. List of feeders with under voltage condition

Feeder	Under voltage	Amount of loads
Pasar Karisa	No	0
Bantaeng	No	0
Tolo	No	0
Malakaji	No	0
Taring	No	0
Kodim	No	0
Bontosunggu	No	0
Sapanang	No	0
Karamaka	Yes	15
Bontotangga	Yes	121

3.3. Power Flow Simulation with PV Integration

This study reviews changes in network losses if PV is integrated into the Jeneponto distribution system. This simulation aims to see the condition of power flow after the placement of PV in the Jeneponto distribution system. The simulated PV capacities are 1 MWp, 3 MWp and 5MWp. The simulations are done at 4 locations according to the substations in Jeneponto. Fig. 6 shows the magnitude of the total network losses and the lowest bus voltage for 1 MWp PV placement if it is placed in Jeneponto distribution substation, Tolo switching substation, Jeneponto switching substation and Benteng switching substation. It can be seen from the placement of 1 MWp PV, placing PV on Benteng switching substation will result in the lowest network losses, which are 610.23 kW and the system voltage profile is more stable, with th lowest voltage of 0.95 p.u. compared to PV placement at another substations.

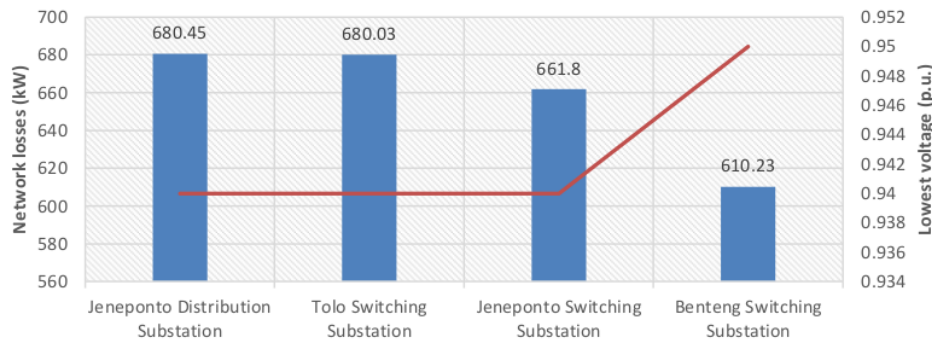


Figure 6. Total network losses and the lowest bus voltage for 1 MWp PV placement at different substations

Fig. 7 shows the results of the total network losses calculation of PV of 1 MWp, 3 MWp and 5 MWp are placed on substations in the Jeneponto distribution system. It can be seen that the most suitable PV capacity placed is 3 MWp in Benteng switching substation with the minimum total network losses of 561.29 kW. This is the smallest network losses compare to other PV size and locations. In addition, with this capacity, the voltage profile at Jeneponto distribution system are within the IEEE and the PLN standard.



Figure 7. Total network losses for 1 MWp, 3 MWp and 5 MWp PV placement at different substations

3.4. Power Flow Simulation with PV 1 MWp and Capacitors

This simulation is to assess whether the system needs reactive power injection. Fig. 8 compares total network losses and the lowest bus voltage for 1 MWp PV and 1 MWp PV plus capacitor of 2.8 MVAR at Benteng switching substation placement. Based on Fig. 8, there is an increase of losses in the system of 610.23 kW to 687.2 kW if capacitor is added to the system. Nevertheless, with capacitor, the system's voltage becomes more stable, where the lowest voltage value increase from 0.95 p.u. to 0.97 p.u.

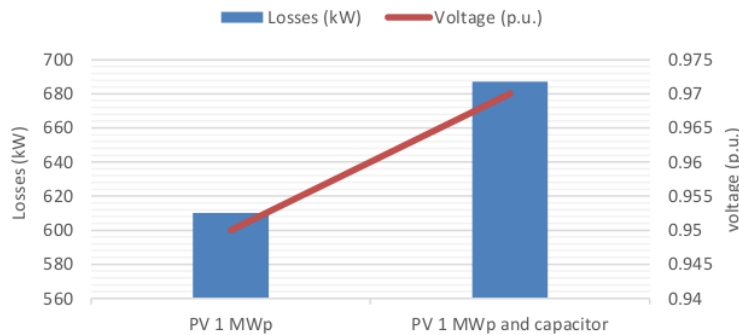


Figure 8. Total network losses and the lowest bus voltage for 1 MWp PV and 1 MWp PV plus capacitor at Benteng switching substation placement

4. Conclusions

The voltage stability in the Jeneponto distribution system before the integration of PV shows that the Jeneponto distribution system still has some loads that are in under voltage conditions. The selection of the best location for interconnection point in the Jeneponto Distribution System is Benteng switching substation where the simulation results show the smallest losses and voltage profiles that are still within the IEEE and PLN standard with a voltage tolerance of 0.9 p.u. to 1.05 p.u. The most optimal PV capacity is 3 MWp which is placed on the Benteng switching substation. The addition of capacitors in the Jeneponto distribution system makes network losses increase but can improve the system's voltage profile.

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