Optimization of capacitor capacity to reduce electric power losses in distribution networks in Jampang Kulon Sukabumi

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Abstract. The electric power system consists of three main parts, one of which is the distribution system. The distribution system has the role of channeling electrical energy from the substation to the consumer. In the distribution of electric power, high reliability is needed so that the quality of electric power is maintained well. There are many factors that can reduce power quality, including power losses. One effort to maintain the quality of electrical power by reducing electrical power losses is to install capacitors on distribution channels. The capacitor is installed as a reactive power compensator so that the power factor approaches 1. In the Jampang Kulon feeder, there are considerable power losses, namely on bus 85-16-1 at 61.6 kW and bus 86-14-1 at 16.5 kW. By determining the capacitor capacity using ETAP, a 3 x 900 kVAR capacitor is mounted on bus 85-16-1 and a 3 x 300 kVAR capacitor on bus 86-14-1. The highest reduction in power losses occurred on buses 85-16-1 and buses 82-17-1. On bus 85-16-1 the power losses have decreased from 61.6 kW to 50 kW (reduced by 11.6 kW), while on bus 82-17-1, the power losses have decreased from 59.4 kW to 49.2 kW (reduced by 10.2 kW).

1. Introduction
There are three main parts to the electric power system, namely the generation system, transmission system, and distribution system. The distribution system is one part of the electric power system which is located closest to the consumer. The distribution system has a very important role because it is directly related to the distribution of electrical energy from the substation to the consumer [1].

To meet the electricity needs, the electric power system must have a high level of reliability so that electricity with good quality power is available. There are several important parameters that must be considered so that the quality of electric power is maintained, including harmonic problems, voltage fluctuations, frequencies, power factors, power losses and voltage drops. From these parameters, low power factor and power losses are common problems [1].

One way to improve the power factor is to reduce reactive power in the distribution channel. If the reactive current component can be reduced, the total reactive current will be reduced so that the power factor will be greater as a result of reduced reactive power. Installation of capacitors in the distribution channel will reduce reactive power because the capacitors supply reactive power to the load [2,3]. The value of capacitor capacity was found using ETAP [4,5].
2. Methods

This research is a quantitative research. Determination of the capacitor capacity on the distribution network was done by descriptive analysis methods, namely by collecting data, analysing data, and drawing conclusions. It was necessary to determine the capacitor capacity to be installed on the distribution network.

In Figure 1, a research flow diagram was presented. In this study, the data collected were power losses, power factors, and active power distributed in the Jampang Kulon feeder distribution channel. Therefore, calculate the value of the capacitor capacity to be used to correct power losses.

The determination of the capacitor capacity value is done using the following equation.

\[ Q_c = P \times \left[ \left( \frac{1}{\sqrt{pf_{a}}} - 1 \right) - \left( \frac{1}{\sqrt{pf_{b}}} - 1 \right) \right] \]  

(1)

where \( Q_c \) is the capacitor capacity (kVAR), \( P \) is Active power (kW), the initial \( Pf \) is the original power factor, and the new \( Pf \) is the desired power factor.

![Figure 1. Research flow diagram.](image-url)
After getting the results of the calculation of the capacitor capacity to be installed, an estimate of the reduction in power losses can be calculated. Calculation of reducing power losses that occur in the Jampang Kulon channel was done using the ETAP 12.6.0 simulator. When the capacitor value was known, the capacitor was placed in a position in the distribution channel using ETAP.

Preliminary data obtained from the source, namely data on power losses that occurred before the installation of capacitors were listed in Table 1, while the power factor data on feeder buses were in Table 2. It can be seen that the power losses in the Jampang Kulon feeder distribution channel were sufficient and the power factor was less than 1. To overcome this, a capacitor have been installed. Using this data, the capacitor capacity needed to approach the power factor of 1 have been determined or calculated.

| No. | Device ID   | Losses (kW) |
|-----|-------------|-------------|
| 1   | bus 538-2-1 | 13,8        |
| 2   | bus 51-17-1 | 27,6        |
| 3   | bus 39-15-1 | 27,6        |
| 4   | bus 62-17-4 | 10,7        |
| 5   | bus 62-17-1 | 10,4        |
| 6   | bus 207     | 19,2        |
| 7   | bus 62-17-3 | 10,5        |
| 8   | bus 65-16-1 | 26,7        |
| 9   | bus 66-15-1 | 19          |
| 10  | bus 85-16-1 | 61,6        |
| 11  | bus 82-17-1 | 59,4        |
| 12  | bus 86-14-1 | 16,5        |
| 13  | bus 83-16-1 | 33,1        |
| 14  | bus 84-18-1 | 23,6        |
| 15  | bus 84-18-3 | 30,6        |

**Table 1.** Power losses in Jampang Kulon feeder.

| No | Device ID | %PF | Cos $\phi$ |
|----|-----------|-----|------------|
| 1  | bus 538-2-1 | 81,5 | 0,815      |
| 2  | bus 51-17-1 | 81,7 | 0,817      |
| 3  | bus 39-15-1 | 81,6 | 0,816      |
| 4  | bus 62-17-4 | 81,5 | 0,815      |
| 5  | bus 62-17-1 | 85   | 0,85       |
| 6  | bus 207     | 81,6 | 0,816      |
| 7  | bus 62-17-3 | 81,6 | 0,816      |
| 8  | bus 65-16-1 | 81,7 | 0,817      |
| 9  | bus 66-15-1 | 85   | 0,85       |
| 10 | bus 85-16-1 | 81,6 | 0,816      |
| 11 | bus 82-17-1 | 85   | 0,85       |
| 12 | bus 86-14-1 | 82,5 | 0,825      |

**Table 2.** Power factor data on Jampang Kulon feeder buses.
Table 2. Cont.

| No | Device ID     | %PF | Cos $\varphi$ |
|----|---------------|-----|---------------|
| 13 | bus 83-16-1   | 82,5| 0,825         |
| 14 | bus 84-18-1   | 82,1| 0,821         |
| 15 | bus 84-18-3   | 81,9| 0,819         |

3. Results and discussion

3.1. Bus data on distribution channels

Data on measurements of power losses, power factor, and active power have been taken from PT. PLN (Persero) Rayon Pelabuhan Ratu, Sukabumi Regency. Distribution Channels used as the object of research were the channels on Jampang Kulon feeders. There are 314 buses. However, in this study, only 15 buses were used as the study sample, namely buses with high power losses.

Table 3. Bus data on Jampang Kulon Feeder in PT. PLN (Persero) Rayon Pelabuhan Ratu.

| Device ID | Power Losses (kW) | %PF | P (MW) |
|-----------|-------------------|-----|--------|
| bus 538-2-1 | 13.8              | 81.5| 5147   |
| bus 51-17-1  | 27.6              | 81.7| 5078   |
| bus 39-15-1  | 27.6              | 81.6| 5098   |
| bus 62-17-4  | 10.7              | 81.5| 4576   |
| bus 62-17-1  | 10.4              | 85.0| 4465   |
| bus 207      | 19.2              | 81.6| 4397   |
| bus 62-17-3  | 10.5              | 81.6| 4515   |
| bus 65-16-1  | 26.7              | 81.7| 4246   |
| bus 66-15-1  | 19.0              | 85.0| 4360   |
| bus 85-16-1  | 61.6              | 81.6| 3979   |
| bus 82-17-1  | 59.4              | 85.0| 3788   |
| bus 86-14-1  | 16.5              | 82.5| 1518   |
| bus 83-16-1  | 33.1              | 82.5| 3827   |
| bus 84-18-1  | 23.6              | 82.1| 3912   |
| bus 84-18-3  | 30.6              | 81.9| 3862   |

3.2. Calculation of capacitor capacity

At this stage, a capacitor has been installed in a 20 kV distribution system on the Jampang Kulon feeder. Installation of capacitors aims to minimize electrical power losses. The bus that should be installed on the Jampang Kulon feeder capacitors can be seen in Table 4.

Table 4. Bus data that should be installed by capacitor.

| No. | Device ID | Pf   | P (MW) |
|-----|-----------|------|--------|
| 1   | bus 85-16-1 | 0,816| 3979   |
| 2   | bus 86-14-1 | 0,825| 1518   |
Using Equation (1), the capacitor capacity values to be installed in the Jampang Kulon feeder are presented in Table 5. After getting the capacitor capacity needed, the capacitors were installed on the buses that have been determined using the ETAP simulation application 12.6.0.

**Table 5.** Capacitor capacity that should be in Jampang Kulon Feeder.

| No. | Location     | Capacitor Capacity (kVAR) |
|-----|--------------|----------------------------|
| 1   | bus 85-16-1  | 3 x 900                    |
| 2   | bus 86-14-1  | 3 x 300                    |

From the results of calculations and simulations with ETAP, we got the results of changes in new power losses as presented in Table 6. Comparison of power losses that occur in the Jampang Kulon feeder distribution channel by placing capacitors can be seen in Table 7.

**Table 6.** Power loses after installed a new capacitor.

| No. | Device ID     | Power Losses (kW) |
|-----|---------------|-------------------|
| 1   | bus 538-2-1   | 10.3              |
| 2   | bus 51-17-1   | 20.6              |
| 3   | bus 39-15-1   | 20.6              |
| 4   | bus 62-17-4   | 8.2               |
| 5   | bus 62-17-1   | 8.0               |
| 6   | bus 207       | 14.9              |
| 7   | bus 62-17-3   | 8.1               |
| 8   | bus 65-16-1   | 21                |
| 9   | bus 66-15-1   | 14.8              |
| 10  | bus 85-16-1   | 50.0              |
| 11  | bus 82-17-1   | 49.2              |
| 12  | bus 86-14-1   | 13.6              |
| 13  | bus 83-16-1   | 27.4              |
| 14  | bus 84-18-1   | 19.6              |
| 15  | bus 84-18-3   | 25.4              |

**Table 7.** Comparison of power losses before and after installed a new capacitor.

| No | Device ID | Power Losses (kW) | Power Losses Decreasing (kW) | Power Losses Decreasing (%) |
|----|-----------|-------------------|------------------------------|----------------------------|
| 1  | bus 538-2-1 | 13.8 10.3 | 3.5 | 33.98 |
| 2  | bus 51-17-1 | 27.6 20.6 | 7.0 | 33.98 |
| 3  | bus 39-15-1 | 27.6 20.6 | 7.0 | 33.98 |
| 4  | bus 62-17-4 | 10.7 8.2 | 2.5 | 30.49 |
| 5  | bus 62-17-1 | 10.4 8.0 | 2.4 | 30.00 |
| 6  | bus 207     | 19.2 14.9 | 4.3 | 28.86 |
| 7  | bus 62-17-3 | 10.5 8.1 | 2.4 | 29.63 |
| 8  | bus 65-16-1 | 26.7 21.0 | 5.7 | 27.14 |
Table 7. Cont.

| No | Device ID     | Power Losses (kW) | Power Losses Decreasing (kW) | Power Losses Decreasing (%) |
|----|---------------|-------------------|-----------------------------|----------------------------|
|    |               | Before | after |                         |                            |
| 9  | bus 66-15-1   | 19.0   | 14.8  | 4.2                      | 28.38                      |
| 10 | bus 85-16-1   | 61.6   | 50.0  | 11.6                     | 23.20                      |
| 11 | bus 82-17-1   | 59.4   | 49.2  | 10.2                     | 20.73                      |
| 12 | bus 86-14-1   | 16.5   | 13.6  | 2.9                      | 21.32                      |
| 13 | bus 83-16-1   | 33.1   | 27.4  | 5.7                      | 20.80                      |
| 14 | bus 84-18-1   | 23.6   | 19.6  | 4.0                      | 20.41                      |
| 15 | bus 84-18-3   | 30.6   | 25.4  | 5.2                      | 20.47                      |

Figure 2. Chart of comparison of power losses before and after installed a new capacitor.

4. Conclusion
Power losses in the distribution channel have been decreased by installing a new capacitor. Installing capacitors on buses 85-16-1 and buses 86-14-1 reduced the value of power losses of 2.4 kW to 11.6 kW. The highest reduction in power losses occurred on buses 85-16-1 and buses 82-17-1. Power losses have been reduced by increasing the value of the power factor on the distribution channels.

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