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Determination of Capacitor Location to Improve Power Factors in Tambak Lorok 03 Feeder

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Abstract: The power factor is a value that shows how much of the effectiveness of the distribution of electric power. The power factor is formulated as the ratio between real power and apparent power. The maximum value for the power factor is 1 and the minimum is 0. Loads with an induction motor absorb high reactive power so that the power factor is low. The lower the power factor, to deliver the same real power, a greater apparent power is needed. In Tambaklorok 03 feeder PT. PLN Semarang Area has a fairly low power factor, which is 0.72. This results in not optimal use of transformer capacity, losses, and voltage drop.To improve the power factor of the Tambaklorok 03 feed, a capacitor can be used as a reactive I source which is installed parallel to the network. The capacitor will produce reactive power in the opposite direction to the reactive power of the induction motor. So that it will compensate for the reactive power absorbed by the induction motor. By using a capacitor, it is hoped that it will reduce the reactive power in the network so that the apparent power and losses also decrease. The power factor improvement is by installing capacitors in pole number TBL.03.047 with reactive power compensation of 1500 kVAR for fixed capacitors and if the switching capacitors are of 1000 kVAR, 2000 kVAR and 3000 kVAR, respectively. So the power factor increases to 0.873 for the fixed capacitor and 0.944 for the switching capacitor.

Keywords: power factor, capacitor, losses, switching

1. Introduction

In the distribution of electricity to consumers, there are three types of power, consisting of real power, reactive power, and apparent power. Real power is that which is actually used and converted into labor. Reactive power is the power generated by the load which is reactance, namely capacitive and inductive. This power cannot be utilized so that the amount of reactive power needs to be reduced as little as possible. Meanwhile, apparent power is the trigonometric sum of the two powers distributed to consumers by the power supply company. Besides, the power factor is the ratio between active and apparent power which shows the effectiveness of the capacity of the electric power system used. A system with a low power factor is caused by the reactive power that is too large so that the apparent power that is transmitted cannot be used optimally.

The load in general is inductive in the form of a motor coil. If a network does not have a reactive power source in the area around the load, the reactive load needs to be charged by the generator, so that reactive current flows in the network. If this requirement is large enough, the current flowing in the network will also increase which will result in a decreased power factor, large power losses, increased voltage drop at the end of the line, and a larger transformer capacity.

To supply reactive power to the distribution system, one way that can be done is to supply reactive power to the medium voltage network. The reactive power supply can be the addition of a capacitor bank to the voltage network. The addition of reactive power to the system allows an improvement in the system in the form of a decrease in the load on the transformer. So that the electricity provider can allocate the apparent load resulting from the decrease after the installation of bank capacitors to be resold to consumers to make it more useful.

Tambaklorok 03 (TBL 03) feeder is a feeder that supplies electricity to the Kaligawe area of East Semarang to the Terboyo Megah industrial area. Based on observations of PT. PLN Distribution Regulatory Area (PPE) Central Java and DIY, the power factor in these feeders is quite low. The average power factor for February 2019 was 0.722 lagging. Therefore, it is necessary to install a capacitor so that the power factor value is close to unity so that the apparent power supplied from the Tambaklorok GI transformer can be used optimally..

2. Research Methods

a. Existing Network of Case Study Sites

The Tambaklorok 03 feeder stretches from the Tambaklorok area, then crosses the Banger River to Kaligawe then stops at the Megah Terboyo industrial area. Tambaklorok 03 feeder is a feeder that serves two different types of rayon, namely PT. PLN Central Semarang District with a length of about 1.95 kms and PT. PLN East Semarang District with a length of about 3.30 kms. So that the total length of the Tambaklorok 03 feeder is 5.25 kms. The following is a single line diagram of a Tambaklorok 03 feeder.

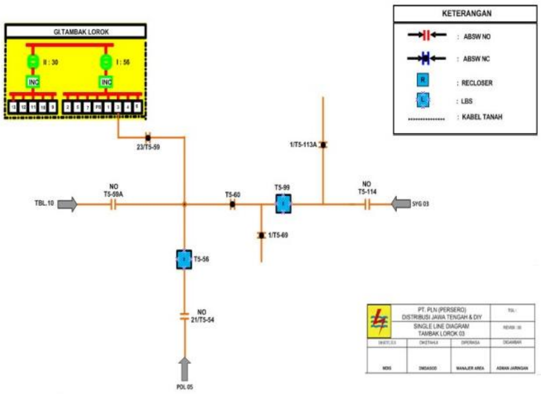


Figure 1. Singe line feeder TBL 03 [10]

b. Tambak Lorok data feeder 03

To determine the conditions at the observation location, it is necessary to measure the power factor continuously in order to determine the ideal compensatory power. Measurements are carried out automatically through the SCADA (Supervisory Control and Data Acquisition) system. So that measurement data including current, voltage, and power factor can be downloaded. The following are the measurement results of the TBL 03 feeder.

Table 1 Measurement of Outgoing TBL 03 on February 2, 2019 [11]

METERING_TIME	PHASE_A_CURRENT	PHASE_B_CURRENT	PHASE_C_CURRENT	VOLTAGE	POWERFACTOR
6:00:00	101.2	52.6	81	20631	0.6056
6:15:00	106.9	59.8	87	20565	0.8619
6:30:00	107.9	62.7	88.4	20589	0.8705
6:45:00	119.5	79.7	102.7	20769	0.8879
7:00:00	120	80.4	103.7	20492	0.6095
7:15:00	142.5	102.7	119.8	20598	0.6175
7:30:00	163.2	123.3	143.8	20433	0.6542
7:45:00	176	136	154	20389	0.6556
8:00:00	186.5	147.9	166.7	2038	0.6625
8:15:00	205.2	166.7	182	2056	0.8979
8:30:00	209.4	172.4	189.4	2056	0.6682
8:45:00	215.5	181.5	195.5	20574	0.6451
9:00:00	216.8	181.5	194.3	20466	0.6495
9:15:00	228.2	191.5	205.5	20454	0.6433
9:30:00	228.1	189.7	204	20455	0.7071
9:45:00	230.7	193.8	207.3	20389	0.861
10:00:00	229.2	189.9	203.4	20612	0.8568
10:15:00	234.7	193.5	210.2	20631	0.858
10:30:00	242.2	201.1	215.3	20586	0.8736

c. Network Modeling with ETAP

The making of a single line is adjusted to the actual situation in the TBL03 feeder based on the survey and data obtained. Figure 3.3 is a single line TBL 03 feed built on ETAP.

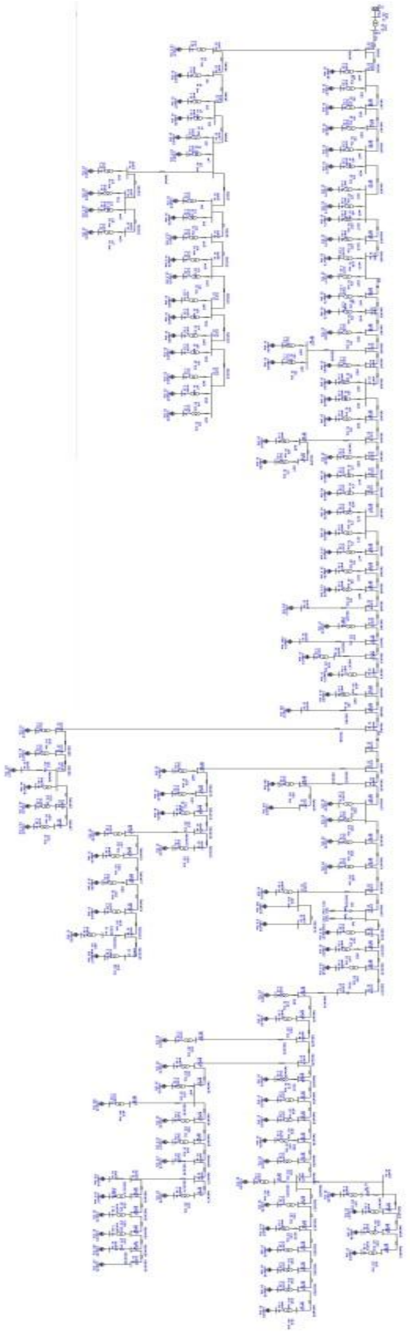


Figure 2. Single Line ETAP TBL03 Feeder

3. Result and Analysis

a. Monitoring the Load Characteristics of Tambaklorok Feeder 03

Monitoring load characteristics is needed to determine the amount of reactive compensation power that will be installed so that it is in accordance with the existing load characteristics. To make it easier to monitor the load of the TBL 03 feeder, the authors used a Microsoft Excel simulation. The database used for load monitoring is the measurement database of PT. PLN APD Central Java and DIY in February 2019. Figure 3 is a simulation display of the monitoring of load characteristics of TBL 03 feeders.

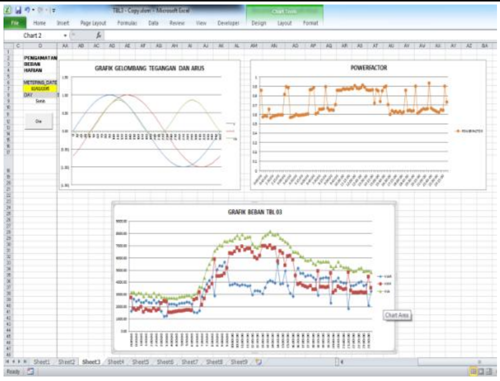


Figure 3.Observation of TBL 03 Daily Expenses Chart

By observing the measurement data, the results show that the power factor of the TBL 03 feeder is fluctuating and has a fairly low average value so that a capacitor needs to be installed to improve the power factor value of the feeder.

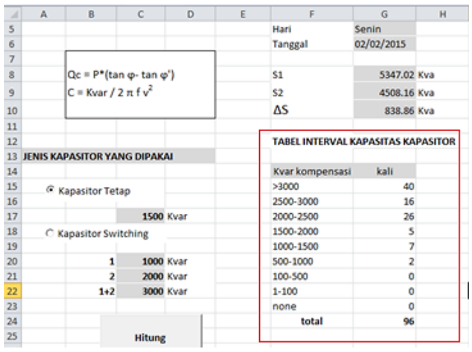
b. Capacitor Compensated Reactive Power Calculation

The calculation of the capacitor compensation reactive power can be calculated in the observation simulation based on the measurement data. The capacitor compensation power is installed according to the network requirements, so as to improve the power factor to close to unity.

Assuming the value of the power factor after the capacitor is installed is one, the amount of reactive power compensation for the capacitor (Qc) can be calculated based on the formula:

$$Q_C = P\,[\,\tan \varphi_1 - \tan \phi_2\,]$$

By performing the same calculation at each load measurement time, it is possible to obtain a breakdown of the amount of reactive compensation power required for one day. Compensation reactive power grouping is needed to make it easier to determine the capacitance of the capacitor to be installed. Figure 4.2 is the grouping of compensated reactive power in the Tambaklorok 03 feeder on Monday, February 2, 2019 using a Microsoft Excel simulation that has been made.



Gambar 4 Interval Kapasitas Kapasitorpada 2 Februari 2019

To determine the amount of reactive power of the capacitor to be installed, the approach from the interval table is used. So that the reactive power of compensation will appear in the Microsoft Excel simulation in column C on the left side table of the Microsoft Excel simulation. The choice of capacitor used can be adjusted to the budget and existing field conditions. This simulation will calculate the amount of reactive power compensation for both fixed and switching capacitors.

The calculation of the capacitor compensation reactive power is carried out for one week, this is because the load characteristics are different every day, it will result in different compensation reactive power requirements. So it is necessary to calculate the sample for one week so that the reactive power compensation of the capacitor to be selected can improve the power factor every time. Table 2 shows the reactive power compensation class interval for one week by taking samples on 2-8 February 2019.

Table 2. Interval of Capacitor Capacity for 1 Week

Kvar kompensasi	Frekuensi
>3000	259
2500-3000	147
2000-2500	99
1500-2000	56
1000-1500	87
500-1000	13
100-500	6
1-100	0
none	5
total	672

So that by using the approach of the number of members of each existing class, the results obtained for the load characteristics sample on February 2-8 2019, the amount of reactive power compensation for fixed capacitors is 1500 kVAR, while for consecutive switching capacitors is 1000 kVAR, 2000 kVAR, and 3000 kVAR.

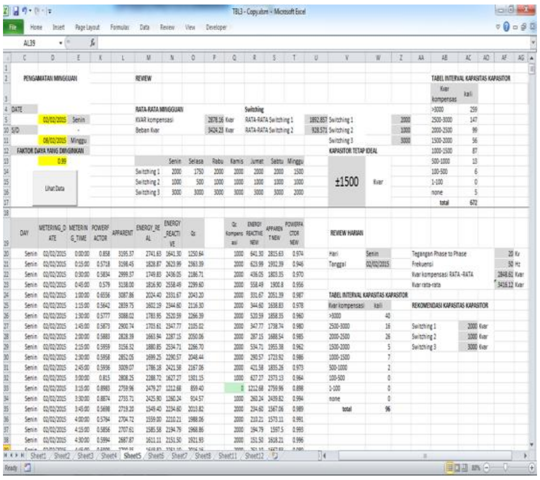


Figure 5. Calculation Results of Fixed and Switching Capacitor Compensation Reactive Power

c. Power Triangle and Sine Wave After Capacitor Installation

The following is a comparison table before and after capacitor installation based on simulations with Microsoft Excel, assuming the real power before and after the capacitor installation is fixed.

Table 3. Comparison of Before and After Fixed Capacitor Installation

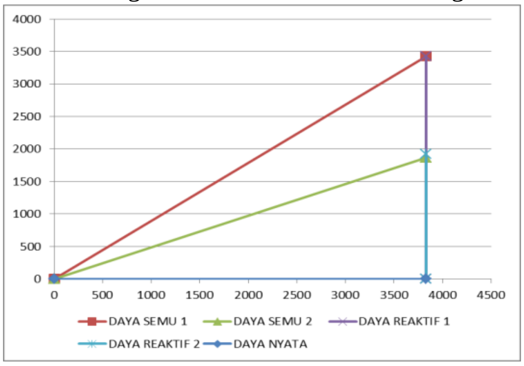
SEBELUM				SESUDAH			
POWER FACTOR RATA-RATA	0.727	43.34229	°	POWER FACTOR RATA-RATA	0.873	29.15954	°
DAYA REAKTIF RATA-RATA		3424.232	Kvar	DAYA REAKTIF RATA-RATA		1924.23	Kvar
DAYA SEMU RATA-RATA		5243.279	KVA	DAYA SEMU RATA-RATA		4414.05	KVA
DAYA NYATA RATA-RATA		3830.249	KW				

Table 4 Comparison of Before and After Switching Capacitor Installation

SEBELUM				SESUDAH			
POWER FACTOR RATA-RATA	0.727	43.34229	°	POWER FACTOR RATA-RATA	0.944	19.23382	°
DAYA REAKTIF RATA-RATA		3424.232	Kvar	DAYA REAKTIF RATA-RATA		1260.20	Kvar
DAYA SEMU RATA-RATA		5243.279	KVA	DAYA SEMU RATA-RATA		4069.73	KVA
DAYA NYATA RATA-RATA		3830.249	KW				

So that the power triangle of these results before and after installing the capacitor as shown in Figure 6.

Figure 5. Power Triangles Before and After Installing Fixed Capacitors



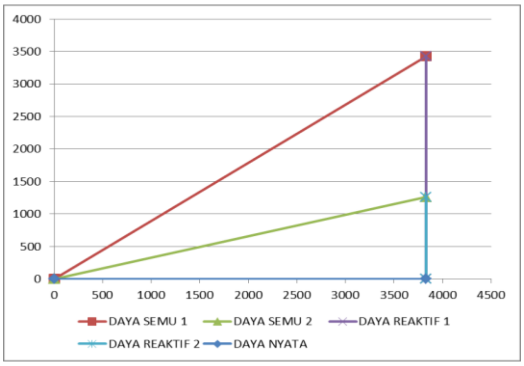


Figure 7. Power Triangle Before and After Installing the Switching Capacitor

d. Decreasing Load of Tambaklorok Substation Transformer

With the improvement in the power factor, the amount of apparent power charged to the transformer will be almost proportional to the real power, resulting in a decrease in apparent power load on the side of the GI transformer. To calculate the apparent power reduction can be calculated by the formula

$$\Delta S = S_1 - S_2$$
$$\Delta S = \sqrt{P^2 + (Q_1)^2} - \sqrt{P^2 + (Q_2)^2}$$

For fixed capacitors, the apparent power drop after installing the capacitor in the grid is

$$\Delta S = \sqrt{P^2 + (Q_1)^2} - \sqrt{P^2 + (Q_2)^2}$$
$$\Delta S = \sqrt{3830{,}25^2 + (3424{,}23)^2} - \sqrt{3830{,}25^2 + (1924{,}23)^2}$$
$$\Delta S = \sqrt{14.670.815{,}1 + 11.725.351{,}1} - \sqrt{14.670.815{,}1 + 3.702.661{,}1}$$
$$\Delta S = \sqrt{26.396.166{,}2} - \sqrt{18.373.476{,}2}$$
$$\Delta S = 5.137{,}719 - 4.286{,}429$$
$$\Delta S = 851{,}289\ kVAR$$

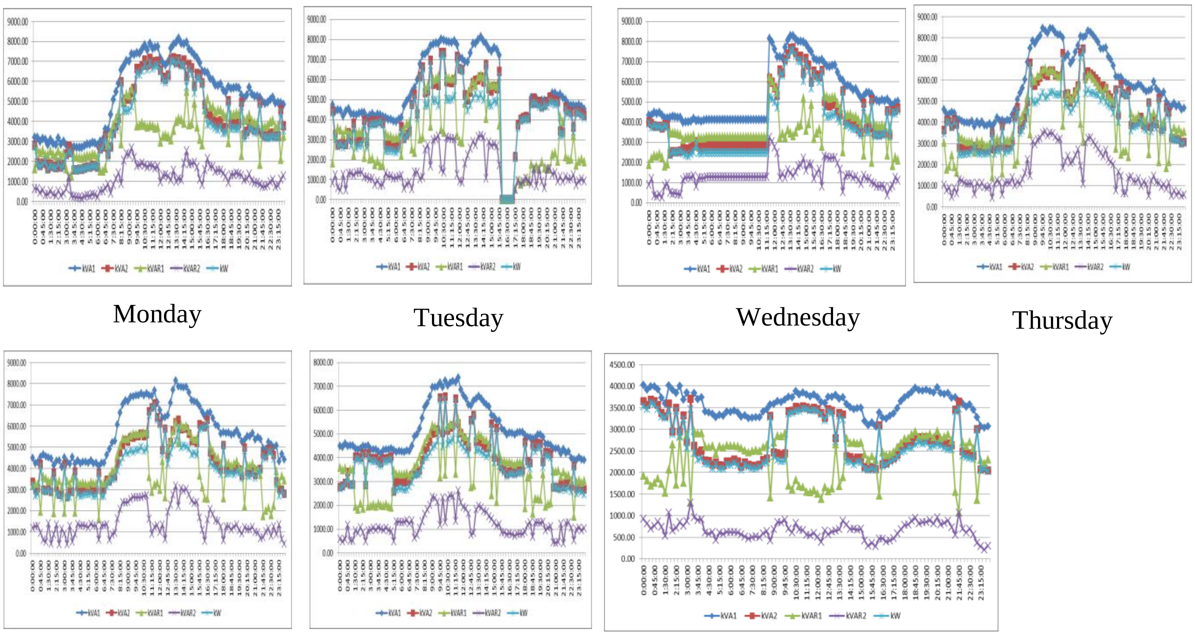
For a switching capacitor, the apparent power drop after installing the capacitor in the network is

$$\Delta S = \sqrt{P^2 + (Q_1)^2} - \sqrt{P^2 + (Q_2)^2}$$
$$\Delta S = \sqrt{3.830{,}25^2 + (3.424{,}23)^2} - \sqrt{3.830{,}25^2 + (1.260{,}20)^2}$$
$$\Delta S = \sqrt{14.670.815{,}1 + 11.725.351{,}1} - \sqrt{14.670.815{,}1 + 1.588.104{,}04}$$
$$\Delta S = \sqrt{26.396.166{,}2} - \sqrt{16.258.919{,}14}$$
$$\Delta S = 5.137{,}719 - 4.032{,}235$$
$$\Delta S = 1.105{,}48\ kVAR$$

From the above calculations it is concluded that through calculations with the assumption that real power is fixed, the use of capacitors can still reduce the apparent power consumption by 851,289 kVAR, while using switching capacitors can reduce the apparent power to a greater extent, namely 1105.48 kVAR.

e. Graph of Load Characteristics After Capacitor Installation

The presentation of this graph is based on measurement data on February 2-8, 2019, then a capacitor is installed with the assumption that the real power is fixed, so that there is a change in the value of reactive power and apparent power consumed by the load. The image below shows a graph of the load characteristics before and after the capacitor is installed for one week.



Monday Tuesday Wednesday Thursday

Friday Saturday Sunday

Figure 8 Graph of Load Characteristics After Capacitor Installation

f. Determining the Optimal Positioning of the Capacitor Using ETAP

Optimal Capacitor Placement (OCP) is a feature of ETAP software which functions to find the ideal capacitor installation location. By installing the capacitor in the optimal location it is expected to reduce losses better, improve the quality of the voltage, and improve the power factor. The OCP will use information from the previous single line simulation, as well as the value of the capacitor that will be used based on previous calculations. To run the OCP simulation, first input the capacitor data to be installed as well as the bus candidate that can be used for capacitor installation in the Optimal Capacitor Placement Study Case.

After the data input is complete, by running the OCP simulation, ETAP will automatically determine the optimal capacitor installation location. In this process, ETAP will perform repeated calculations on each bus candidate and compare them to find the optimal capacitor location. Figure 9 shows the results of the OCP simulation which has succeeded in determining the optimal capacitor placement.

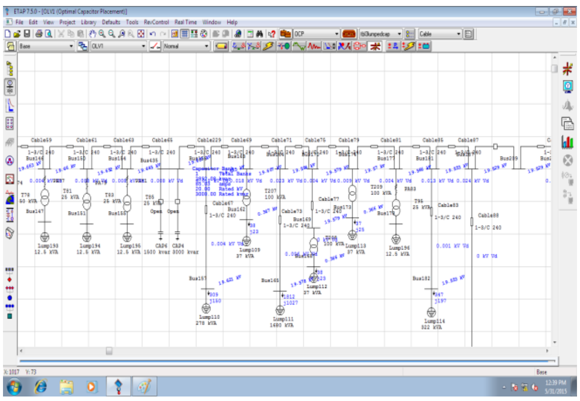


Figure 9. Display Simulation of Optimal Capacitor Placement ETAP 7.5

Based on the OCP simulation, the most ideal capacitor installation location on the TBL 03 feeder is on bus number 435, which is ± 4,050 kms from the GI, namely on pole number TBL.03.075.

To assess the feasibility of installing the capacitor, a load flow simulation is performed again on the ETAP using Load flow Analysis. to see the changes in power flow that occur. So that it can be compared with the power flow before and after the installation of the capacitor on the single line Tambaklorok 03 feeder.
From the results of the report manager with the installation of a switching capacitor, it can be compared with the previous load flow simulation without a capacitor that there is an increase in the power factor approaching one, namely 98.62 Lagging. Meanwhile, when using a fixed capacitor the power factor increases to 93.48 Lagging.

Table 5. Comparison of Loads Before and After Capacitor Installation in ETAP

Parameter	Sebelum	Sesudah Pemasangan Kapasitor	
		1500 kVAR	3000 kVAR
Daya Semu (kVA)	8161.783	7545	7182
Daya Nyata (kW)	7029.744	7053	7082
Daya Reaktif (kVAR)	4146.975	2680	1191
Faktor Daya	0.861	0.934	0.986

4. Conclusion

1. Power factor improvement is carried out by installing capacitors in parallel on the medium voltage network. Because the capacitive reactive power of the capacitor will reduce the inductive reactive power flowing in the network.
2. With the installation of capacitors in the network, there is an increase in the power factor approaching one from the previous 86.12 Lagging on February 2, 2019 data. For switching capacitors the power factor increases to 98.62 Lagging. Meanwhile, when using a fixed capacitor the power factor increases to 93.48 Lagging.
3. To calculate the required capacitor compensation power, it is necessary to observe the power factor fluctuation and load characteristics that exist for one week so that the calculation of the capacitor compensation power represents working days and holidays.
2. The amount of fixed capacitor compensation reactive power to improve the power factor of the TBL 03 feeder is 1500 kVAR. Whereas for the switching capacitor the amount of reactive power for the step level is 1000 kVAR, 2000 kVAR, and 3000 kVAR, respectively.
3. The optimal location of the capacitor installation in the Tambaklorok 03 feeder is at a distance of ± 4,050 kms from the substation. Namely on the pole number TBL.03.075.
4. The decrease in apparent power after the use of the switching capacitor is 979.83 kVA, while the use of the fixed capacitor is 616.783 kVA.

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