TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

Journal homepage: http://jurnal.untirta.ac.id/index.php/ju-tek/

Improvement of power factor on distribution feeder of Sutami 23 Lampung using capacitor bank and SVC

Alvin Harista Rahman [a]***, Ahmad Hidayahtullah*** [a]***, Afrida Nurul Ulfa*** [a]***, Rizal Zulfiqri Ahmad*** [a]***, Jimmy Trio Putra*** [a,1]

[a]*Department of Electrical Engineering and Informatics, Vocational College, Universitas Gadjah Mada, Jl. Yacaranda Sekip Unit III, Yogyakarta 55281, Indonesia.*
[1]*E-mail: jimmytrioputra@ugm.ac.id*

ARTICLE INFO

Article history:
Submitted 29 June 2021
Reviewed 23 August 2021
Received 3 September 2021
Accepted 25 October 2021
Available online on 1 November 2021

Keywords:
Power factor correction, capacitor bank, static VAr compensator, optimal capacitor placement.

Kata kunci:
Perbaikan faktor daya, kapasitor bank, static VAr compensator, optimal capacitor placement.

ABSTRACT

A good power distribution rate is the key to the success of electric power service providers in fulfilling consumer rights. A poor power distribution rate will cause a lot of losses, both for consumers and providers. The power distribution rate is closely related to the power factor value (PF). Low PF should be avoided to get a good power distribution rate. Sutami 23 Lampung feeder data shows 216 buses with a PF below the SPLN 70-1: 1985 standard, which is 0.85, so a PF correction is needed. In this research, PF corrections have been made with the ETAP simulation method for two kinds of components, namely capacitor bank, and SVC (static VAr compensator). The results showed that installing the capacitor bank is more recommended than SVC because the impact of installing the capacitor bank for PF correction is bigger than SVC. Capacitor bank can raise the PF from 0.82 to 0.98, while SVC can only raise the PF from 0.82 to 0.91. In addition, the investment cost for installing a capacitor bank is also much cheaper than SVC, with a cost difference of 1,932,000.250 IDR.

ABSTRAK

Salah satu cara yang dapat dilakukan untuk memperbaiki tingkat penyaluran daya adalah dengan melakukan upaya perbaikan faktor daya (PF). Standar SPLN 70-1: 1985 menyatakan nilai PF minimal adalah 0,85. Data Penyulang Sutami 23 Lampung menunjukkan terdapat 216 bus dengan nilai PF di bawah 0,85 sehingga diperlukan adanya upaya perbaikan. Pada penelitian ini telah dilakukan perbaikan nilai PF dengan menggunakan metode simulasi ETAP 12.6 melalui kapasitor bank dan static VAr compensator (SVC). Hasil menunjukkan bahwa komponen kapasitor bank lebih direkomendasikan untuk memperbaiki nilai PF Penyulang Sutami 23 Lampung karena dengan nilai kapasitas daya kVAr yang sama, tercatat nilai PF baru hasil perbaikan dari pemasangan kapasitor bank memiliki nilai yang lebih tinggi daripada nilai PF baru yang dihasilkan dari pemasangan SVC. Pemasangan kapasitor bank mampu memperbaiki nilai PF dari 0,82 menjadi 0,98. Sedangkan, untuk pemasangan SVC mampu memperbaiki nilai PF dari 0,82 menjadi 0,91. Selain itu, total biaya investasi yang dibutuhkan untuk pemasangan kapasitor bank juga lebih murah jika dibandingkan dengan SVC yaitu memiliki selisih biaya sebesar Rp1.932.000.250,-.

Available online at http://dx.doi.org/10.36055/tjst.v17i2.11729

1. Introduction

An electric power system consists of several systems, namely the generation system, transmission system, and distribution system. All these systems must ensure the quality and reliability of the electrical power supplied. The poor level of distribution of electric power will certainly fail in the fulfillment of consumer rights and also the losses that the electricity service provider must accept. A network with a poor level of power distribution will result in a lot of power losses, which will result in the electric power service provider having to generate much larger electrical power so that the active power needed by consumers can be distributed. The level of distribution of electric power is closely related to the value of the power factor. Power factor is the ratio of real power to a visible power, which can be used as an indicator of the effectiveness of a load in carrying out its functions about power dissipation [1]. Electric power service providers must be able to avoid low power factor values in order to avoid various kinds of losses. One way that can be done to improve the value of the low power factor is to make efforts to improve the power factor.

The selection of the Sutami 23 Lampung Feeder as the object of this research is due to many buses with a power factor value below the State Electricity Company Standard (SPLN) 70-1: 1985, which is less than 0.85. Therefore, it is necessary to improve the power factor of the Sutami 23 Lampung Feeder in the hope that losses due to the low power factor value can be minimized. The characteristics of the Lampung Sutami 23 Feeder can be seen by looking at the type of distribution channel system. The distribution channel system is a system that connects the substation with consumers. The distribution channel system consists of two types, namely the primary distribution channel system with medium voltage (TM) and the secondary distribution channel system with low voltage (TR) [2]. Based on the channel configuration, the medium voltage distribution system can be divided into several types: radial distribution channel system, loop distribution channel system, spindle distribution channel system, and net distribution channel system.

The distribution channel system at Feeder Sutami 23 Lampung is a type of radial distribution channel system. The radial distribution channel system is the simplest and easiest system to operate and maintain. The system is because the radial configuration has only one path of power flow to the load. This system is widely used to serve load areas with low to medium load densities [2]. This system is called radial because this channel is drawn radially from a point that is a power source or substation and is branched to the load points served. The specifications of this radial network are its simple shape and relatively low investment costs. However, the radial type distribution channel has poor power service quality because the losses in the channel are relatively large. In addition, the continuity of power service is also not guaranteed because between the source point and the load point. There is only one alternative channel so that if the channel is disturbed, then the entire series after the point of disturbance will experience a total "blackout".

Many methods can be used to improve the power factor value of the Sutami 23 Lampung Feeder. One of the most widely applied methods to improve the power factor value is to install a capacitor bank component. The capacitor bank is a circuit consisting of several units of capacitors. The capacity of the capacitor unit states the nominal reactive power generated at the nominal voltage and frequency, expressed in VAR base units [3]. The capacitor used to increase the power factor value is installed in parallel with the load circuit. When the circuit is given a voltage, then electrons will flow into the capacitor. When the capacitor is full of electrons, the voltage will change. Then the electrons will come out of the capacitor and flow into the circuit that needs it, so at that time, the capacitor generates reactive power. When the changed voltage returns to normal, the capacitor will store electrons again. When the capacitor discharges electrons, it can be said that the capacitor supplies reactive power to the load [3].

In addition to installing capacitor bank components, efforts to improve the power factor of the Sutami 23 Lampung Feeder can also be carried out by installing components with FACTS (flexible AC transmission system) technology. There are many FACTS components such as SVC, STATCOM, TCSC, and SSSC [4]. FACTS technology is generally used in improving the stability of electric power systems, such as research conducted by [5]. In this study, one of the FACTS components was taken as a sample to analyze power factor improvement on the Lampung Sutami 23 Feeder, namely SVC or Static VAR Compensator. SVC is one of the components of FACTS with a parallel connection, whose main function is to regulate the voltage on a particular bus by controlling the amount of equivalent reactance [6]. The working principle of SVC is by adjusting the angle of ignition of the thyristor to adjust the reactive power output of the SVC [7]. SVC consists of a fixed capacitor (FC) component, which is connected in parallel with a thyristor-controlled reactor (TCR) [8]. The component is connected in parallel with the TCR component or stands for the thyristor-controlled reactor. The ignition angle with the control system on the thyristor makes the SVC has the speed to respond. In addition, its response speed can also provide voltage regulation assistance and as a reactive power supplier.

From the two methods above, researchers will find the best method by comparing the results of component performance in improving the power factor value on the Sutami 23 Lampung Feeder bus. The performance of components in improving the power factor value can be known by performing simulations using ETAP (Electric Transient and Analysis Program) software. The expected result of this research is to recommend the best method that can be applied to the Sutami 23 Lampung Feeder based on the performance results and the investment costs required if using a capacitor bank or SVC.

2. Research Methology

2.1. ETAP 12.6

ETAP (Electrical Transient Analysis Program) is a comprehensive analysis software used to design and test electric power systems [9]. ETAP was first launched by Operation Technology, Inc. (OTI) in 1983. There have been several versions, one of which is version 12.6 [10]. In ETAP 12.6, several simulation-based calculation analysis features are available, including the following.

1. Load flow analysis.
2. Short circuit analysis.
3. Motor acceleration analysis.
4. Harmonic analysis.
5. Transient stability analysis.
6. Unbalanced load flow analysis.
7. Optimal power flow analysis.
8. Optimal capacitor placement.

From some of the ETAP calculation analysis features above, the researcher will use the load flow analysis and optimal capacitor placement features as research methods to find out the comparison of the capacitor bank and SVC installation in improving the low power factor in the Sutami 23 Feeder Lampung.

2.2. Power Flow Analysis Using ETAP 12.6

Power flow analysis is one of the analyzes that can display the performance of an electric power system, providing information related to transmission line loads, voltage rating values, currents, active power, reactive power, and also the power factor of the feeder bus [9]. Through ETAP 12.6, the power flow analysis process for the Sutami 23 Lampung Feeder can be carried out more easily because all calculations have been computerized automatically through the Load Flow Analysis feature [10]. Power flow analysis through ETAP 12.6 can be carried out with several calculation methods such as Newton-Raphson, Fast-Decoupled, and Accelerated Gauss-Seidel [11]. Of the three methods, the researcher chose to use the Newton-Raphson method because it is known to have a quadratic convergence rate, making this method faster to converge to the approximation root than the other two methods, which have a linear convergence rate [12].

The power flow analysis process will be carried out in several experiments in this study, including one to determine the initial conditions of the Sutami 23 Lampung feeder and several to determine the effect of changes that occur in the feeder after simulating the installation of capacitor banks and SVC. Some of the poor power factor values on the feeder bus may be recognized using ETAP 12.6's power flow analysis, allowing additional improvement attempts to be undertaken by adding capacitor banks and SVCs. The technique for finding the installation position and rating of the capacitor bank will be carried out using ETAP 12.6's Optimal Capacitor Placement (OCP) analysis tool.

2.3. Optimal Capacitor Placement Analysis using ETAP 12.6

Optimal Capacitor Placement (OCP) analysis determines the rating and optimal location of the capacitor bank installation in the electric power system [13]. The installation of capacitor banks is expected to improve the low power factor, reduce energy losses, and improve system voltage [14]. In this OCP analysis, several bus candidates with low power factors will be selected based on the previous power flow analysis results. The bus with a low power factor will be included in the calculation of the OCP analysis in order to know the optimal point of the capacitor bank installation and the capacitor bank rating that will be installed to improve the low power factor.

The results obtained through this OCP will be a reference for determining the rating value of the capacitor bank to be installed and the value of the SVC rating. In this study, the SVC rating value was deliberately equated with the capacitor bank rating value to be compared with each other. With the same rating value between SVC and capacitor bank, their performance in improving the low power factor can be compared based on the final result of the new power factor obtained.

2.4. Feeder Sutami 23 Lampung

The process of analyzing the power flow and OCP carried out in this study used single line diagram data from the distribution network of the Sutami 23 Lampung Feeder. With this single-line diagram data, all the information needed in the research can be known. Figure 1 below is the form of a single line diagram of the Sutami 23 Lampung Feeder, which is used in a comparative study of the installation of capacitor banks and SVCs.

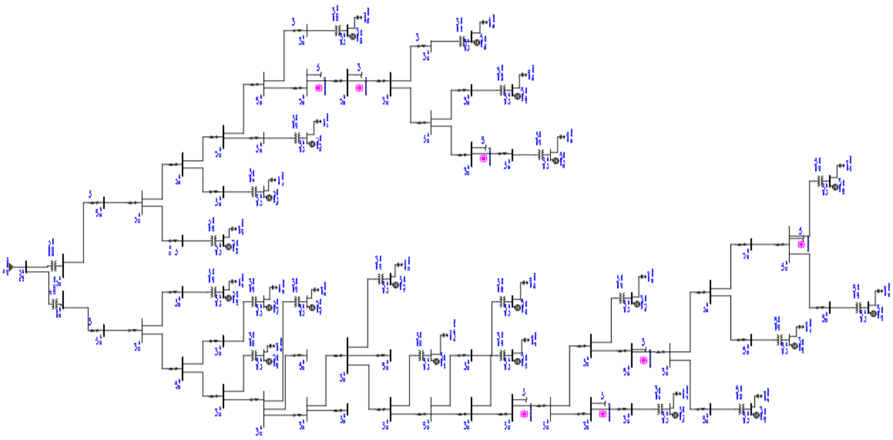


Figure 1. Single line diagram of feeder Sutami 23 Lampung.

Based on Figure 1 above, it can be seen that the shape of the Sutami 23 Lampung Feeder is quite complex. The single-line diagram shown in Figure 1 above does not include the inside of each Network in the feeder. The total number of networks from the single line diagram of the Sutami 23 Lampung Feeder is recorded as 20 networks with Lump loads and transformers. As additional information from Sutami Feeder 23 Lampung, the following researchers attach load data and transformer data from Feeder Sutami 23 Lampung, presented in Tables 1 and 2 below.

Table 1 above shows transformer data which contains information related to transformer rating, bus connection, primary voltage, secondary voltage, and percentage impedance. It is necessary to note that the transformer data presented in Table 1 above are 5 data samples from the entire data of the Sutami 23 Lampung Feeder transformer. The researcher did not attach all of the feeder transformer data due to a large amount of data and the limited research space. Table 2 above shows load data which contains information related to voltage rating, power, phase-type, bus location, and power factor. It is necessary to note that the load data presented in Table 2 above are five samples of data from the entire load data of Sutami 23 Lampung Feeder. The researcher did not attach the entire feeder load data due to a large amount of data and the limited research space.

2.5. Research Flow With ETAP Simulation Method 12.6

The research process begins with conducting a literature study and data collection. The literature study was carried out as a support for mastery of library collection in work and research. In the literature search, data collection related to the research object is also carried out, such as data that includes the minimum power factor that PLN has determined. Power factor is the ratio between active power and apparent power or the cosine value of the angle between active power and apparent power [15]. The power factor is formulated as follows:

$$PF = \frac{P}{S} \qquad (1)$$

Based on equation (1) above, it can be seen that the power factor is the ratio between active power (P) and visible power (S). In the power diagram, the value of the power factor is the cosine of the angle between the active power (P) and the visible power (S), as shown in Figure 2. Based on Figure 2, it can be seen that the angle is the angle formed between the active power (P) and visible power (S), while the reactive power (Q) is perpendicular to the active power (P). The minimum value of the power factor is zero, while the maximum value is 1. The higher the value of the power factor, the higher the visible power that can be utilized.

Table 1. Sutami 23 Lampung feeder transformer data

Trafo Name	From Bus	To Bus	MVA	Prim. kV	Sek. kV	%R	%X	%Z
T2	TT _1_1	Bus 1	30	150	20	1.03	34.98	35
TRF2_1	2_1	TR2_1	0.8	20	0.38	142.24	479.34	500
TRF2_2	2_2	TR2_2	1.6	20	0.38	70.73	239.79	250
TRF2_3	2_3	TR2_3	2	20	0.38	52.45	193	200
TRF2_5	2_5	TR2_5	0.63	20	0.38	163.6	613.48	634.92

Table 2. Sutami 23 Lampung feeder load data

Load	Bus	Phase	kV	kVA	kW	%Pf	kVAr
Lump_1	TR2_11	3	0.38	106	89.77	85	55.634
Lump_2	TR2_1	3	0.38	279	237	85	147
Lump_3	TR2_46	3	0.38	120	102	85	63.288
Lump_4	TR2_10	3	0.38	74.9	63.646	85	39.444
Lump_5	TR2_45	3	0.38	25.1	21.374	85	13.246

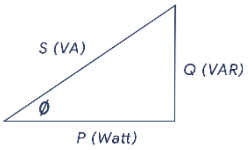


Figure 2. Power chart [17].

After the literature study and data collection have been completed, the next step is power flow modeling and analysis through the Load Flow Analysis ETAP 12.6 simulation process using single line diagram data from Sutami 23 Lampung Feeder. Based on the results of the Load Flow Analysis simulation, it can be seen that the bus data has a power factor value that is less than the standard required by PLN, which is 0.85. The next stage is the ETAP 12.6 Optimal Capacitor Placement (OCP) simulation. OCP analysis is carried out to determine the estimated reactive power capacity of capacitors and SVCs that need to be installed on each bus. After getting the kVAr value from the OCP analysis, then the parameter value is attached to the capacitor bank and SVC components which are then placed on the bus that has been determined. Furthermore, the component is re-stimulated using the ETAP 12.6 software to obtain a new power factor improvement value for the capacitor bank and SVC.

3. Results and Discussion

3.1. Initial Condition of Sutami 23 Distribution Channel

The beginning circumstances of the Sutami 23 Distribution Channel, particularly the value of the power factor on each Bus, may be determined by running a load flow analysis simulation using the ETAP 12.6 program. Before adding a capacitor bank or SVC, the initial load flow analysis simulation results will be utilized to reference the baseline power factor value. The starting power factor value generated from the Load Flow Analysis simulation is shown in the explanation of Table 3 below. Table 3 shows that as many as 216 buses on the Sutami 23 Distribution Channel have power factor values below the standard determined by PLN. Therefore, it is necessary to improve the power factor value by installing a capacitor bank or SVC so that the new power factor value is expected to be following the standards set by PLN, which is above 85.

3.2. Determination of kVAr Power Capacity Value

Improving the bus power factor value begins by determining the value of the kVAr power capacity of the capacitor that needs to be installed. The method of determining the kVAr capacity of the capacitor is carried out through the simulation of Optimal Capacitor Placement (OCP) ETAP 12.6. Through the OCP simulation, it can be seen that at least 79 capacitor installation points are needed to be able to repair all buses that have a low power factor (below the PLN standard). Figure 3 is one of the results of the OCP simulation that has been carried out. Table 4 shows the results of the OCP calculation for the value of the kVAr power capacity of each Bus.

Table 4 shows the results of the OCP (Optimal Capacitor Placement) calculation for the value of the kVAr power capacity that can be applied to the capacitor bank and SVC components. The values of the kVAr power capacity above are then applied to the capacitor and SVC components for further Load Flow Analysis simulations to determine the effect of changes from the addition of a capacitor or SVC component. Based on the results of the Load Flow Analysis simulation that has been carried out, the addition of a capacitor or SVC component at 79 Bus points has been proven to change all the power factor values in the Sutami Feeder 23. However, a new problem arises because the new power factor value obtained shows a negative value. According to several literature sources, negative power factors can potentially harm the source side, making efforts to avoid them. Therefore, as a solution to this problem, the value of the kVAr power capacity applied to both the capacitor and SVC needs to be reduced in nominal terms to make the new power factor value positive between 85 - 100. The method of reducing the kVAr power capacity value refers to the following formula.

$$\text{New kVar value} = \text{kVar calculation result OCP} - (\text{kVar calculation OCP x } 10\%) \quad (2)$$

Table 3. Information on the initial power factor value of the Sutami 23 distribution line bus.

No.	ID BUS	Power Factor Value (PF)
1.	Bus1	82.4
2.	1_1	82.7
3.	2_71, TR2_71	83.3
4.	5_16, 5_37	83.5
5.	2_12, 2_46	83.6
6.	2_13, 2_14, 5_23	83.7
7.	2_16, 2_57, 5_44, 5_45, 5_48, TR2_66	83.8
8.	2_8, 2_22, 2_27, 2_35, 2_64, 4_2, 5_1, 5_30, 5_50, 5_51, 5_55, 5_56, TR2_8, TR2_18, TR2_22, TR2_27, TR2_33, TR2_34, TR2_35, TR2_37	83.9
9.	2_15, 2_19, 2_25, 2_32, 2_33, 2_37, 2_63, 2_65, 2_68, 2_77, 4_4, 5_33, 5_34, 5_49, TR2_14, TR2_15, TR2_19, TR2_25, TR2_31, TR2_32, TR2_63, TR2_64, TR2_77	84
10.	2_10, 2_11, 2_23, 2_24, 2_26, 2_29, 2_31, 2_34, 2_36, 2_47, 2_58, 2_61, 2_66, 2_67, 2_75, 2_78, 2_79, 5_3, 5_19, 5_20, 5_27, 5_31, 5_38, 5_53, 5_54, 5_57, 5_58, 5_59, TR2_10, TR2_11, TR2_12, TR2_13, TR2_16, TR2_23, TR2_26, TR2_29, TR2_36, TR2_47, TR2_58, TR2_61, TR2_65, TR2_67, TR2_79, TT_1_1	84.1
11.	2_17, 2_18, 2_20. 2_21, 2_44, 2_55, 2_56, 2_59, 2_62, 2_69, 2_70, 2_72, 2_73, 2_74, 2_76, 5_6, 5_28, 5_29, 5_32, 5_46, 5_47, TR2_17, TR2_20, TR2_21, TR2_24, TR2_44, TR2_46, TR2_55, TR2_56, TR2_57, TR2_62, TR2_68, TR2_69, TR2_70, TR2_73, TR2_74, TR2_76, TR2_78	84.2
12.	2_5, 2_28, 2_30, 2_38, 2_40, 2_43, 2_51, 2_53, 2_54, 2_60, 2_80, 5_9, 5_14, 5_39, 5_60, TR2_5, TR2_28, TR2_30, TR2_38, TR2_40, TR2_42, TR2_43, TR2_51, TR2_53, TR2_54, TR2_60, TR2_75, TR2_80	84.3
13.	2_3, 2_9, 2_39, 2_42, 2_45, 2_48, 5_4, 5_7, 5_8, 5_10, 5_11, 5_12, 5_18, 5_21, 5_42, 5_43, TR2_3, TR2_9, TR2_39, TR2_45, TR2_48, TR2_59,	84.4
14.	2_1, 2_2, 2_6, 2_7, 2_49, 2_50, 5_5, 5_13, 5_17, 5_24, 5_26, 5_40, 5_41, TR2_1, TR2_2, TR2_6, TR2_7, TR2_41, TR2_49, TR2_50,	84.5
15.	2_41	84.5
16.	2_52, TR2_52	84.6
17.	TR2_72	84.7

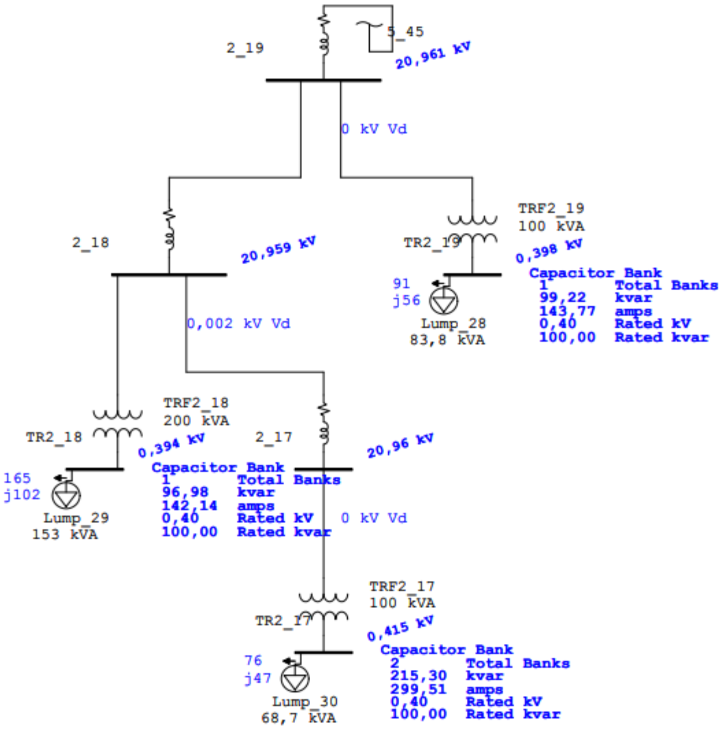


Figure 3. Screenshot of OCP simulation result sample.

Based on the above formula, it can be seen that the kVAr value from the OCP calculation is reduced by 10% to get a new power factor value that is suitable for 85-100. The capacity value is acquired by repeating the load flow analysis simulation experiments—new kVAr power, as illustrated in Figures 4 and 5 below.

Table 4. OCP calculation result for capacitor kVAr power capacity.

No.	ID BUS	Nilai kVAr Kapasitor & SVC (kVAr)
1.	TR2_1	352
2.	TR2_2	784
3.	TR2_3, TR2_9	2175
4.	TR2_5	792
5.	TR2_6	346
6.	TR2_7	6957
7.	TR2_8	96.6
8.	TR2_10, TR2_20, TR2_57, TR2_71, TR2_75	101
9.	TR2_11	99.69
10.	TR2_12, TR2_13, TR2_21, TR2_59, TR2_68, TR2_69, TR2_70, TR2_78	100
11.	TR2_14	97.33
12.	TR2_15, TR2_77	388
13.	TR2_16	99.03
14.	TR2_17	430
15.	TR2_18	96.98
16.	TR2_19	99.22
17.	TR2_22	97.31
18.	TR2_23	98.4
19.	TR2_24	394
20.	TR2_25	96.28
21.	TR2_26	99.36
22.	TR2_27	96.54
23.	TR2_28	98.27
24.	TR2_29	99.88
25.	TR2_30	108
26.	TR2_31	106
27.	TR2_32	97.93
28.	TR2_33	97
29.	TR2_34	96.45
30.	TR2_35	96.31
31.	TR2_36	98.33
32.	TR2_37	96.62
33.	TR2_38	88.17
34.	TR2_39	87.99
35.	TR2_40	88.45
36.	TR2_41	390
37.	TR2_42	90.05
38.	TR2_43	386
39.	TR2_44	88.89
40.	TR2_45	97.54
41.	TR2_46	99.14
42.	TR2_47, TR2_62, TR2_65, TR2_74, TR2_76, TR2_79	107
43.	TR2_48	2185
44.	TR2_49	350
45.	TR2_50	5536
46.	TR2_51	89.42
47.	TR2_52	348
48.	TR2_53	362
49.	TR2_54	3114
50.	TR2_55	98.52
51.	TR2_56	108
52.	TR2_58	98.37
53.	TR2_60	98.77
54.	TR2_61	99.88
55.	TR2_63	97.7
56.	TR2_64	97.74
57.	TR2_66	97.79
58.	TR2_67	99.81
59.	TR2_72	103
60.	TR2_73	99.97
61.	TR2_80	434

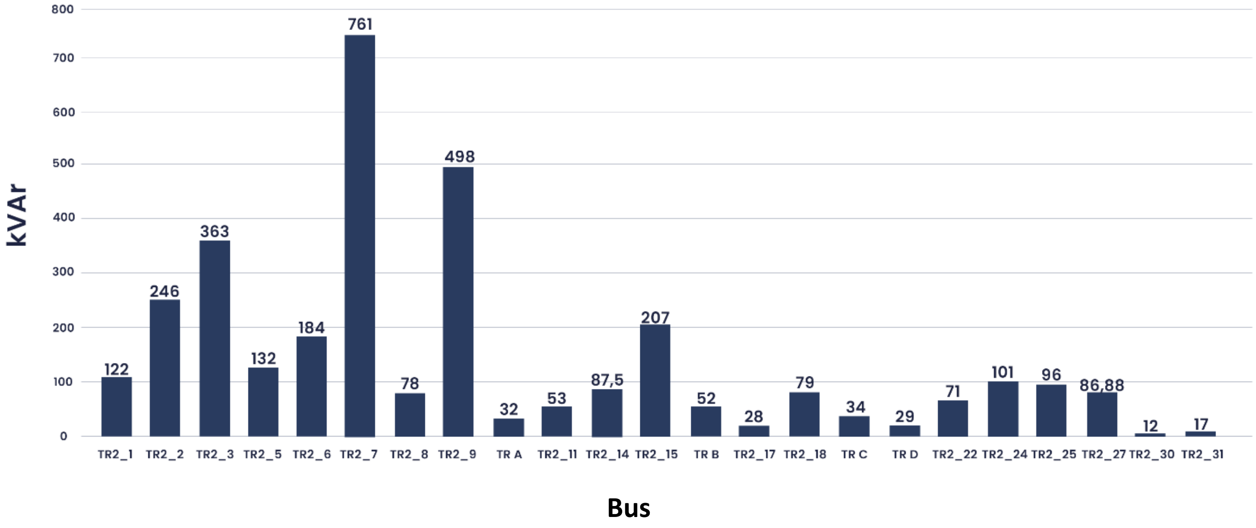
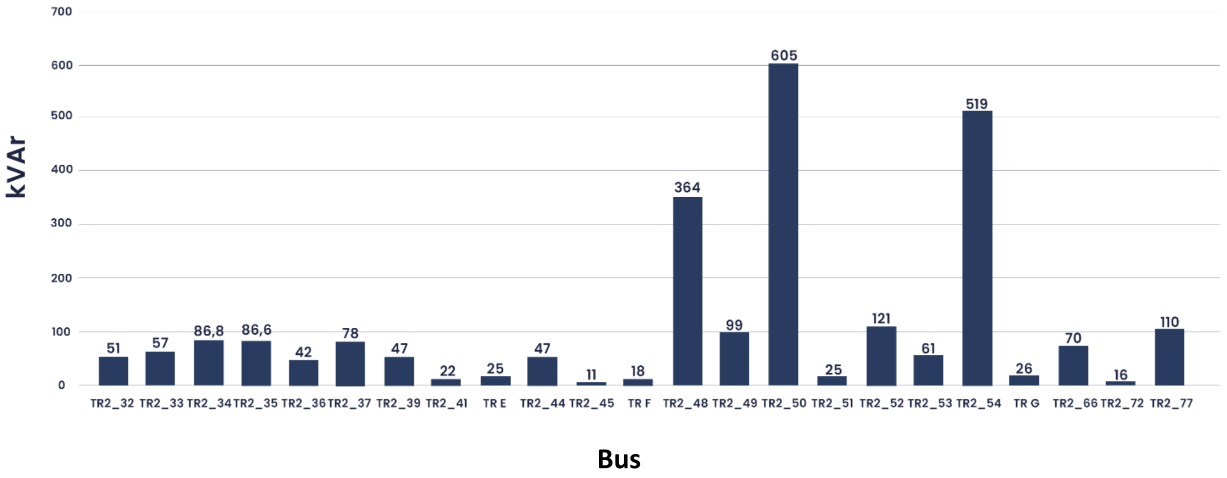


Figure 4. Value of kVar power capacity after adjustment.



Gambar 5. Nilai kapasitas daya kVar setelah dilakukan penyesuaian.

Description:

1. TR A consists of buses TR2_10, TR2_12, TR2_13, TR2_42, TR2_61, TR2_67, TR2_68, dan TR2_71.
2. TR B consists of buses TR2_16, TR2_23, TR2_28, TR2_46, TR2_55, TR2_58, TR2_60, TR2_63, dan TR2_64.
3. TR C consists of buses TR2_19, TR2_26, TR2_38, dan TR2_40.
4. TR D consists of buses TR2_20, TR2_21, TR2_29, TR2_69, TR2_70, TR2_73.
5. TR E consists of buses TR2_43 dan TR2_80.
6. TR F consists of buses TR2_47, TR2_56, TR2_62, TR2_65, TR2_74, TR2_76, dan TR2_79.
7. TR G consists of buses TR2_57, TR2_59, TR2_75, dan TR2_78.

Figures 4 and 5 depict the results of the new kVAr power capacity value calculation based on formula (2), which can be applied to the capacitor bank and SVC components.

3.3. *Testing the Placement of Bank Capacitors and SVCs on Each Bus*

The value of the kVAr power capacity as shown in the graphs of Figures 4 and 5 above has been proven to improve the power factor value of the Sutami 23 Feeder Bus. The following table is the result of the Load Flow Analysis simulation, which shows changes in the power factor value before and after installing a capacitor or SVC with a value of kVAr power capacity which refers to the graphs of Figure 4 and 5.

Table 5. Load flow analysis simulation results.

No.	ID BUS	Initial %PF	%PF K	%PF S
1.	1_1	82.7	98.7	91.2
2.	2_1	84.5	98.6	91
3.	2_2	84.5	98.7	91.5
4.	2_3	84.4	98.5	91.4
5.	2_5	84.3	99.1	92
6.	2_6	84.5	99.1	91.8
7.	2_7	84.5	99.1	92.2
8.	2_8	83.9	99.8	91.5
9.	2_9	84.4	100	93.5
10.	2_10	84.1	99	88.4
11.	2_11	84.1	99.8	88.6
12.	2_12	83.6	98.6	88.5
13.	2_13	83.7	98.6	88.7
14.	2_14	83.7	100	90.4
15.	2_15	84	99.7	89.5
16.	2_16	83.8	99.9	89.7
17.	2_17	84.2	98.5	89.6
18.	2_18	84.2	99.9	90.5
19.	2_19	84	98.4	89.1
20.	2_20	84.2	98.9	89.7
21.	2_21	842	98.9	89.8
22.	2_22	83.9	100	91.1
23.	2_23	84.1	99.8	90.3
24.	2_24	84.1	99.3	89.8
25.	2_25	84	100	91.3
26.	2_26	84.1	99	89.7
27.	2_27	83.9	100	91.7
28.	2_28	84.3	99.6	90.4
29.	2_29	84.1	98.5	90.4
30.	2_30	84.3	98.4	89.1
31.	2_31	84.1	98.9	91.4
32.	2_32	84	99.3	90.5
33.	2_33	84	98.9	90.7
34.	2_34	84.1	100	91.9
35.	2_35	83.9	100	91.8
36.	2_36	84.1	98.6	89.6
37.	2_37	84	99.8	91.2
38.	2_38	84.3	98,5	91
39.	2_39	84.4	99,8	93.5
40.	2_40	84.3	98,5	90.9
41.	2_41	84.5	99,9	92.6
42.	2_42	84.4	100	95.3
43.	2_43	84.3	98,7	93.1
44.	2_44	84.2	99,9	93.5
45.	2_45	84.4	98,6	90.9

No.	ID BUS	Initial %PF	%PF K	%PF S
46.	2_46	83.6	99,1	88.2
47.	2_47	84.1	99,8	91.9
48.	2_48	84.4	98,6	91.2
49.	2_49	84.5	98.7	91.7
50.	2_50	84.5	98.5	91.6
51.	2_51	84.3	98.4	90.9
52.	2_52	84.6	98.5	91.4
53.	2_53	84.3	100	93.8
54.	2_54	84.3	99	92
55.	2_55	84.2	99.5	89.5
56.	2_56	84.2	99.9	91.1
57.	2_57	83.8	98.5	89.9
58.	2_58	84.1	99.6	89.9
59.	2_59	84.2	98.2	89.3
60.	2_60	84.3	99.8	89.8
61.	2_61	84.1	99.3	90
62.	2_62	84.2	99.9	91.6
63.	2_63	84	99.1	89.9
64.	2_64	83.9	99.1	90
65.	2_65	84	99.4	91.4
66.	2_66	84.1	99.8	91.4
67.	2_67	84.1	99.2	90.3
68.	2_68	84	99.6	90.4
69.	2_69	84.2	98.8	90.3
70.	2_70	84.2	98.8	90.3
71.	2_71	83.3	99,3	91.6
72.	2_72	84.2	100	92.1
73.	2_73	84.2	98.8	90.3
74.	2_74	84.2	100	91.6
75.	2_75	84.1	99.1	92.1
76.	2_76	84.2	99.9	92
77.	2_77	84	98.4	90
78.	2_78	84.1	98.6	90.8
79.	2_79	84.1	99.7	91.9
80.	2_80	84.3	99.2	91.3
81.	4_2	83.9	99.2	89.9
82.	4_4	84	99.1	90
83.	5_1	83.9	99.2	89.8
84.	5_3	84.1	99.8	90.7
85.	5_4	84.4	98.3	90.4
86.	5_5	84.5	98.8	91.4
87.	5_6	84.2	98.8	91.4
88.	5_7	84.4	98.4	93.1
89.	5_8	84.4	98.7	90.9
90.	5_9	84.3	98.9	91.5
91.	5_10	84.4	98.7	91.4
92.	5_11	84.4	98.7	91.4
93.	5_12	84.4	98.9	91.5
94.	5_13	84.5	99	91.4
95.	5_14	84.3	98.8	91.6
96.	5_16	83.5	99.2	89.2
97.	5_17	84.5	98.4	90.9
98.	5_18	84.4	98.9	91.5
99.	5_19	84.1	99.7	87.8
100.	5_20	84.1	99.1	89
101.	5_21	84.4	98.8	91.6
102.	5_23	83.7	99.2	88.6
103	5_24	84.5	98.8	91.5
104.	5_26	84.5	98.3	91.8
105.	5_27	84.1	99.2	90
106.	5_28	84.2	98.7	90.3
107.	5_29	84.2	98.7	90.1
108.	5_30	83.9	99.6	90.3
109.	5_31	84.1	98.3	88.8
110.	5_32	84.2	99.2	89.7
111.	5_33	84	99.1	90
112.	5_34	84	99.8	90.8
113.	5_37	83.5	99.1	89
114.	5_38	84.1	98.8	91.3
115.	5_39	84.3	98.8	91.4
116.	5_40	84.5	98.9	91.7
117.	5_41	84.5	98.3	90.9
118.	5_42	84.4	98.9	91.6
119.	5_43	84.4	98.9	91.6
120.	5_44	83.8	99.2	89.6
121.	5_45	83.8	99.2	89.6
122.	5_46	84.2	99.2	88.9
123.	5_47	84.2	99.1	88.8
124.	5_48	83.8	99.3	89.8
125.	5_49	84	99.9	90.5
126.	5_50	83.9	99.2	90
127.	5_51	83.9	99.2	89.9
128.	5_53	84.1	98.9	89.9
129.	5_54	84.1	99	89.6
130.	5_55	83.9	99.6	90.4
131.	5_56	83.9	99.8	90.8
132.	5_57	84.1	98.9	90
133.	5_58	84.1	98.4	90.2
134.	5_59	84.1	98.7	90.1
135.	5_60	84.3	98.7	90
136.	Bus1	82.4	99	88.8
137.	TR2_1	84.5	98.5	90.6
138.	TR2_2	84.5	98.5	91.1
139.	TR2_3	84.4	98.3	90.8
140.	TR2_5	84.3	98.9	91.5
141.	TR2_6	84.5	99	91.4
142.	TR2_7	84.5	98.9	91.8
143.	TR2_8	83.9	99.7	90.6
144.	TR2_9	84.4	100	93
145.	TR2_10	84.1	98.6	87.5
146.	TR2_11	84.1	99.7	87.8
147.	TR2_12	84.1	98.2	87.6
148.	TR2_13	84.1	98.2	87.9
149.	TR2_14	84	100	89.5
150.	TR2_15	84	99.5	88.6
151.	TR2_16	84.1	99.8	89
152.	TR2_17	84.2	98.2	88.9
153.	TR2_18	83.9	99.7	89.6
154.	TR2_19	84	98	88.1
155.	TR2_20	84.2	98.6	89
156.	TR2_21	84.2	98.6	89.1
157.	TR2_22	83.9	99.9	90.2
158.	TR2_23	84.1	99.6	89.5
159.	TR2_24	84.2	99.1	89.1
160.	TR2_25	84	99.9	90.4
161.	TR2_26	84.1	98.7	88.9
162.	TR2_27	83.9	100	90.8
163.	TR2_28	84.3	99.5	89.8
164.	TR2_29	84.1	98.2	89.6
165.	TR2_30	84.3	98.1	88.5
166.	TR2_31	84	98.5	90.6
167.	TR2_32	84	99	89.6
168.	TR2_33	83.9	98.6	89.7
169.	TR2_34	83,9	100	91
170.	TR2_35	83,9	99,9	90.9
171.	TR2_36	84,1	98,3	88.8
172.	TR2_37	83,9	99,7	90.3
173.	TR2_38	84,3	98,2	90.4
174.	TR2_39	84,4	99,7	93
175.	TR2_40	84,3	98,3	90.3
176.	TR2_41	84,5	99,9	92.2
177.	TR2_42	84,3	99,9	94.8
178.	TR2_43	84,3	98,4	92.6
179.	TR2_44	84,2	99,8	92.9
180.	TR2_45	84,4	98,3	90.4

No.	ID BUS	Initial %PF	%PF K	%PF S
181.	TR2_46	84,2	98,8	87.4
182.	TR2_47	84,1	99,6	91.2
183.	TR2_48	84,4	98,3	90.7
184.	TR2_49	84,5	98,5	91.3
185.	TR2_50	84,5	98,3	91.2
186.	TR2_51	84.3	98.1	90.2
187.	TR2_52	84.6	98.4	91
188.	TR2_53	84.3	100	93.3
189.	TR2_54	84.3	98.8	91.4
190.	TR2_55	84.2	99.3	88.8
191.	TR2_56	84.2	99.8	90.4
192.	TR2_57	84.2	98.1	89.2
193.	TR2_58	84.1	99.3	89
194.	TR2_59	84.4	98	88.8
195.	TR2_60	84.3	99.7	89.2
196.	TR2_61	84.1	99	89.3
197.	TR2_62	84.2	99.8	90.9
198.	TR2_63	84	98.7	89
199.	TR2_64	84	98.8	89.2
200.	TR2_65	84.1	99.2	90.6
201.	TR2_66	83.8	98.8	90.4
202.	TR2_67	84.1	98.9	89.5
203.	TR2_68	84.2	99.4	89.7
204.	TR2_69	84.2	98.5	89.6
205.	TR2_70	84.2	98.5	89.6
206.	TR2_71	83.3	98.8	90.1
207.	TR2_72	84.7	100	91.8
208.	TR2_73	84.2	98.5	89.6
209.	TR2_74	84.2	99.9	91.5
210.	TR2_75	84.3	98.9	90.5
211.	TR2_76	84.2	99.8	91.4
212.	TR2_77	84	98	89.1
213.	TR2_78	84.2	98.3	90.1
214.	TR2_79	84.1	99.5	91.1
215.	TR2_80	84.3	98.9	90.7
216.	TT_1_1	84.1	99	91.2

Description:

1. % PF K is the new power factor value after the capacitor bank has been installed..
2. % PF S is the new power factor value after installing SVC.

According to the load flow analysis simulation findings presented in Table 5, all buses with low power factor values in Sutami 23 Feeder have rectified their power factor values using the combination of optimum capacitor placement and the kVAr power capacity reduction approach described above. With an increased power factor of more than 85 (PLN Standard). Additionally, as shown in Table 5, the change in power factor value caused by the installation of a capacitor bank has a larger yield than SVC for the same kVAr power capacity.

3.4. Comparison of Bank Capacitor Investment Costs and SVC

The ideal value calculated for either the capacitor bank or SVC value is usually not available in the market. Therefore, adjustments are needed to get the closest value between the ideal value and the value provided on the market. Based on the list of goods issued by CV Adityapratama through the https://cvadityapratama.com/2018/03/08/harga-panel-kapasitor-bank/ page, a list of capacitor panels provided by the industry along with prices with the Schneider trademark is obtained as shown in Table 6.

Table 6. Price list of Schneider brand capacitor panels.

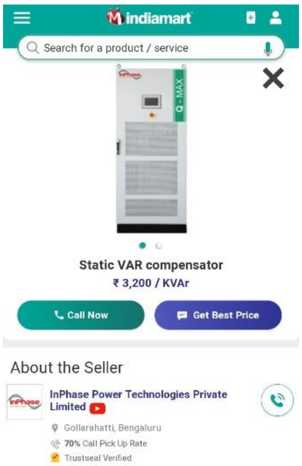
No.	Capacitor bank panels	Price (Rp)
1.	10 kVAr	16,000,000
2.	15 kVAr	16,800,000
3.	25 kVAr	19,400,000
4.	30 kVAr	21,700,000
5.	50 kVAr	22,200,000
6.	60 kVAr	24,000,000
7.	80 kVAr	27,900,000
8.	100 kVAr	30,200,000
9.	120 kVAr	32,300,000
10.	150 kVAr	48,800,000
11.	180 kVAr	52,500,000
12	200 kVAr	56,800,000
13.	250 kVAr	62,300,000
14.	300 kVAr	73,000,000
15.	400 kVAr	109,400,000
16.	500 kVAr	123,000,000
17.	600 kVAr	136,800,000
18.	720 kVAr	163,000,000
19.	800 kVAr	183,500,000
20.	1000 kVAr	245,500,000
21.	1200 kVAr	291,450,000
22.	1500 kVAr	339,850,000

Table 6 shows that the price of the Schneider brand capacitor bank panel is based on the required power capacity (kVAr). The greater the power capacity (kVAr), the higher the price of the capacitor bank panel. Since the ideal kVAr value obtained from the calculation results is not round with the capacitor bank panels available by the industry, then the capacitor bank panels used are determined to round the values obtained to the closest value. Table 7 shows that the overall investment cost for installing a capacitor bank to improve the power factor in the Sutami 23 Distribution Channel is Rp. 2,474.200.000,-. As for the investment cost of installing SVC, the SVC price list is available in several online buying and selling media such as indiamart.com. Figure 5 below is an example of an SVC product marketed on indiamart.com via the https://m.indiamart.com/inphasepower/ page by Inphase Power Technologies Private

Limited. The price offered for one SVC depends on the size of the required kVAr power capacity, which is 3,200 Rupees or equivalent to Rp. 625,550 (the condition of the Indonesian rupiah to Indian rupee exchange rate on June 9, 2021) for each kVAr value.

Table 7. List of capacitor bank values along with the total investment cost.

No.	BUS ID	Ideal value of capacitor bank (kVAr)	Values available for schneider brand (kVAr)	Unit price (Rp)
1.	TR2_1	122	120	32,300,000
2.	TR2_2	246	250	62,300,000
3.	TR2_3	363	300	73,000,000
4.	TR2_5	132	120	32,300,000
5.	TR2_6	184	180	52,500,000
6.	TR2_7	761	720	163,000,000
7.	TR2_8	78	80	27,900,000
8.	TR2_9	498	500	123,000,000
9.	TR2_10	32	30	21,700,000
10.	TR2_11	53	50	22,200,000
11.	TR2_12	32	30	21,700,000
12	TR2_13	32	30	21,700,000
13.	TR2_14	87.597	80	27,900,000
14.	TR2_15	207	200	56,800,000
15.	TR2_16	52	50	22,200,000
16.	TR2_17	28	30	21,700,000
17.	TR2_18	79	80	27,900,000
18.	TR2_19	34	30	21,700,000
19.	TR2_20	29	30	21,700,000
20.	TR2_21	29	30	21,700,000
21.	TR2_22	71	80	27,900,000
22.	TR2_23	52	50	22,200,000
23.	TR2_24	101	100	30,200,000
24.	TR2_25	96.28	100	30,200,000
25.	TR2_26	34	30	21,700,000
26.	TR2_27	86.886	80	27,900,000
27.	TR2_28	52	50	22,200,000
28.	TR2_29	29	30	21,700,000
29.	TR2_30	12	10	16,000,000
30.	TR2_31	17	15	16,800,000
31.	TR2_32	51	50	22,200,000
32.	TR2_33	57	60	24,000,000
33.	TR2_34	86.805	80	27,900,000
34.	TR2_35	86.679	80	27,900,000
35.	TR2_36	42	50	22,200,000
36.	TR2_37	78	80	27,900,000
37.	TR2_38	34	30	21,700,000
38.	TR2_39	47	50	22,200,000
39.	TR2_40	34	30	21,700,000
40.	TR2_41	22	25	19,400,000
41.	TR2_42	32	30	21,700,000
42.	TR2_43	25	25	19,400,000
43.	TR2_44	47	50	22,200,000
44.	TR2_45	11	10	16,000,000
45.	TR2_46	52	50	22,200,000
46.	TR2_47	18	15	16,800,000
47.	TR2_48	364	400	109,400,000
48.	TR2_49	99	100	30,200,000
49.	TR2_50	605	600	136,800,000
50.	TR2_51	24	25	19,400,000
51.	TR2_52	121	120	32,300,000
52.	TR2_53	61	60	24,000,000
53.	TR2_54	519	500	123,000,000
54.	TR2_55	52	50	22,200,000
55.	TR2_56	18	15	16,800,000
56.	TR2_57	26	25	19,400,000
57.	TR2_58	52	50	22,200,000
58.	TR2_59	26	25	19,400,000
59.	TR2_60	52	50	22,200,000
60.	TR2_61	32	30	21,700,000
61.	TR2_62	18	15	16,800,000
62.	TR2_63	52	50	22,200,000
63.	TR2_64	52	50	22,200,000
64.	TR2_65	18	15	16,800,000
65.	TR2_66	70	60	24,000,000
66.	TR2_67	32	30	21,700,000
67.	TR2_68	32	30	21,700,000
68.	TR2_69	29	30	21,700,000
69.	TR2_70	29	30	21,700,000
70.	TR2_71	32	30	21,700,000
71.	TR2_72	16	15	16,800,000
72.	TR2_73	29	30	21,700,000
73.	TR2_74	18	15	16,800,000
74.	TR2_75	26	25	19,400,000
75.	TR2_76	18	15	16,800,000
76.	TR2_77	110	100	30,200,000
77.	TR2_78	26	25	19,400,000
78.	TR2_79	18	15	16,800,000
79.	TR2_80	25	25	19,400,000
Total investment cost of capacitor bank				2,474,200,000



Static VAR compensator
₹ 3,200 / KVAr

About the Seller
InPhase Power Technologies Private Limited
Gollarahatti, Bengaluru
70% Call Pick Up Rate
Trustseal Verified

Figure 6. SVC value.

As shown in Figure 6, the SVC price is then used as a reference for determining the total investment cost required if the power factor improvement at the Lampung 23 Sutami Distribution Feeder uses SVC. The information in Table 8 is the total investment cost required for the installation of the SVC based on the unit price offered by Inphase Power Technologies Private Limited. Table 8 shows that the overall investment cost for the installation of SVC as an effort to improve the power factor in the Sutami 23 Distribution Channel is Rp. 4,406,200,250,-.

Table 8. List of SVC values along with total investment costs.

No.	BUS ID	SVC rating (kVAr)	Unit price (Rp)
1.	TR2_1	122	76,195,100
2.	TR2_2	246	153,639,300
3.	TR2_3	363	226,711,650
4.	TR2_5	132	82,440,600
5.	TR2_6	184	114,917,200
6.	TR2_7	761	475,282,550
7.	TR2_8	78	48,714,900
8.	TR2_9	498	311,025,900
9.	TR2_10	32	19,985,600
10.	TR2_11	53	33,101,150
11.	TR2_12	32	19,985,600
12	TR2_13	32	19,985,600
13.	TR2_14	88	54,960,400
14.	TR2_15	207	129,281,850
15.	TR2_16	52	32,476,600
16.	TR2_17	28	17,487,400
17.	TR2_18	79	49,339,450
18.	TR2_19	34	21,234,700
19.	TR2_20	29	18,111,950
20.	TR2_21	29	18,111,950
21.	TR2_22	71	44,343,050
22.	TR2_23	52	32,476,600
23.	TR2_24	101	63,079,550
24.	TR2_25	96	59,956,800
25.	TR2_26	34	21,234,700
26.	TR2_27	87	54,335,850
27.	TR2_28	52	32,476,600
28.	TR2_29	29	18,111,950
29.	TR2_30	12	7,494,600
30.	TR2_31	17	10,617,350
31.	TR2_32	51	31,852,050
32.	TR2_33	57	35,599,350
33.	TR2_34	87	54,335,850
34.	TR2_35	87	54,335,850
35.	TR2_36	42	26,231,100
36.	TR2_37	78	48,714,900
37.	TR2_38	34	21,234,700
38.	TR2_39	47	29,353,850
39.	TR2_40	34	21,234,700
40.	TR2_41	22	13,740,100
41.	TR2_42	32	19,985,600
42.	TR2_43	25	15,613,750
43.	TR2_44	47	29,353,850
44.	TR2_45	11	6,870,050
45.	TR2_46	52	32,476,600
46.	TR2_47	18	11,241,900
47.	TR2_48	364	227,336,200
48.	TR2_49	99	61,830,450
49.	TR2_50	605	377,852,750
50.	TR2_51	24	14,989,200
51.	TR2_52	121	75,570,550
52.	TR2_53	61	38,097,550
53.	TR2_54	519	324,141,450
54.	TR2_55	52	32,476,600
55.	TR2_56	18	11,241,900
56.	TR2_57	26	16,238,300
57.	TR2_58	52	32,476,600
58.	TR2_59	26	16,238,300
59.	TR2_60	52	32,476,600
60.	TR2_61	32	19,985,600
61.	TR2_62	18	11,241,900
62.	TR2_63	52	32,476,600
63.	TR2_64	52	32,476,600
64.	TR2_65	18	11,241,900
65.	TR2_66	70	43,718,500
66.	TR2_67	32	19,985,600
67.	TR2_68	32	19,985,600
68.	TR2_69	29	18,111,950
69.	TR2_70	29	18,111,950
70.	TR2_71	32	19,985,600
71.	TR2_72	16	9,992,800
72.	TR2_73	29	18,111,950
73.	TR2_74	18	11,241,900
74.	TR2_75	26	16,238,300
75.	TR2_76	18	11,241,900
76.	TR2_77	110	68,700,500
77.	TR2_78	26	16,238,300
78.	TR2_79	18	11,241,900
79.	TR2_80	25	15,613,750
Total investment cost of SVC			4,406,200,250

After obtaining the total investment costs for the installation of capacitor banks or SVCs as an effort to improve the value of the power factor at the Sutami 23 Lampung Feeder, it can be seen that the investment costs for installing capacitor banks are much cheaper than the investment costs for installing SVC, which has a cost difference of Rp 1,932,000,250,-. In addition, capacitor banks can be better than SVC in increasing the power factor value. Based on the simulation results that have been obtained in Table 5 previously, it can be seen that with the same kVAr power capacity value, the new power factor value resulting from the capacitor bank installation has a higher value than the new power factor value generated from the SVC installation. Thus, it can be concluded that installing a capacitor bank as a solution to improve the power factor value at the Sutami 23 Lampung Feeder is more recommended than using SVC.

4. Conclusion

Based on the load flow simulation that has been done with the ETAP 12.6 software, 216 buses with a power factor below the standard SPLN 70-1:1985 were obtained, which is less than 85 percent on the Sutami 23 Lampung distribution feeder. Therefore, to optimize the installation of the capacitor bank and SVC panels for power factor improvement, we obtained 79 mounting points on the bus based on the results of the OCP simulation. The improvement in the average power factor value obtained after simulating the installation of the capacitor bank and OCP panels is 99.08240741 and 90.51018519, respectively. In addition, the investment costs for bank capacitor panels and SVC are Rp 2,474,200,000 and Rp 4,406,200,250, respectively. The result is that the installation of capacitor bank panels is more optimal compared to SVC. In addition to a more affordable investment cost, improving the power factor value is also greater.

REFERENCE

[1] Dani, A., & Hasanuddin, M. (2018). Perbaikan faktor daya menggunakan kapasitor sebagaii kompensator daya reaktif (studi kasus STT Sinar Husni). *Seminar Nasional Royal (SENAR) 2018, STMIK Royal – AMIK Royal*, pp. 673-678.

[2] Tanjung, A. (2014). Rekonfigurasi sistem distribusi 20 KV Gardu Induk Teluk Lembu dan PLTMG Langgam Power untuk mengurangi rugi daya dan drop tegangan. *Jurnal Sains, Teknologi, dan Industri*, vol. 11, no. 2, pp. 160-166.

[3] Alland, K., & Z. Arfah, E. (2013). Perancangan kebutuhan kapasitor bank untuk perbaikan faktor daya pada line mess I di PT. Bumi Lamongan Sejati (WBL). *Jurnal Teknik Elektro*, vol. 2, no. 1, pp. 29-35.

[4] Masood, A., Hassan, Q., & Mahmood, A. (2015). Flexible AC transmission system controllers: A review. *Int. Multi-Topic ICT Conf.*, pp. 393-403.

[5] Wibowo, S. S., Suyono, H., & Hasanah, R., N. (2013). Analisis implementasi fixed capacitor, SVC, dan STATCOM untuk perbaikan performansi stabilitas tegangan pada sistem petrochina. *Jurnal EECCIS*, vol. 7, no. 2, pp. 147-152.

[6] Masarrang, M. (2015). Aplikasi SVC dalam perbaikan jatuh tegangan pada sistem kelistrikan Kota Palu. *Jurnal Ilmiah Foristek*, vol. 5, no. 1, pp. 414-420.

[7] Hidayat, T., & Hayusman, L., M. (2016). Analisis dan pemodelan static var compensator (SVC) untuk menaikan profil tegangan pada outgoing Gardu Induk Probolinggo. *Seminar Nasional Inovasi Dan Aplikasi Teknologi Di Industri (SENIATI) 2016, B*, pp. 371-376.

[8] Putra, R., D. (2017). *Pemasangan SVC untuk perbaikan stabilitas tegangan sistem transmisi JAMALI 500 kV setelah penambahan pembangkit 1575 MW pada tahun 2017.* [Disertasi]. Surabaya: Institut Teknologi Sepuluh November..

[9] Otniel, F., Busaeri, B., & Sutisna. (2019). Analisa aliran daya sistem tenaga listrik pada bagian Penyulang 05EE0101A di area utilities II PT. Pertamina (Persero) Refinery Unit IV Cilacap menggunakan metode Newton-Raphson. *Journal of Energy and Electrical Engineering (JEEE)*, vol. 1, no. 1, pp. 1-6.

[10] Nigara, A., G., & Primadiyono, Y. (2015). *Analisis aliran daya sistem tenaga listrik pada bagian texturizing di PT. Asia Pasific Fibers Tbk Kendal menggunakan software ETAP Power Station* 4.0. [Dissertation]. Semarang: Universitas Negeri Semarang.

[11] Kumolo, C. (2016). Analisis aliran beban pada sistem tenaga listrik di KSO Pertamina EP-GEO Cepu Indonesia Distrik 1 Kawengan menggunakan software ETAP 12.6. *Jurnal Teknik Elektro*, vol. 16, no. 1, pp. 1-15.

[12] Bahar, A., K., A., & Febriyanto, G. (2019). Analisis aliran daya pada gedung bertingkat dengan sumber tegangan 20 kV menggunakan ETAP 12.6. *Jurnal Ilmiah Elektrokrisna*, vol. 7, no. 2, pp. 68-77.

[13] Dermawan, E., Samsinar, R., & Nurudin. (2019). Studi optimasi penempatan dan ukuran kapasitor dengan metode genetik algoritma pada distribusi Hotel Starlet. *Seminar Nasional Sains dan Teknologi 2019, FT UMJ*, pp. 1-8.

[14] Sari, N., K., Winarno, I., Rahmatullah, D., & Diah, I. (2020). Perbaikan kualitas daya menggunakan optimal capacitor placement (OCP) pada sistem kelistrikan PT. FMC Agricultural Manufacturing. *Media Elektrika*, vol. 13, no. 2, pp. 80-88.

[15] Hajar, I., & Rahayuni, S. M. (2020). Analisis perbaikan faktor daya menggunakan kapasitor bank di Plant 6 PT. Indocement Tunggal Prakasa Tbk. Unit Citeureup. *Jurnal Ilmiah Setrum*, vol. 9, no. 1, pp. 8-16.

[16] Marsus, S., & Noer, M. (2012). Analisa penghematan energi listrik menggunakan kapasitor bank berbasis electrical transient analyzer program (ETAP) (studi kasus Laboratorium Teknik Listrik Polsri). *Jurnal Teliska*, vol. 4, no. 3, pp. 11-21.

[17] Amir, M., & Somantri, A. M. (2017). Analisis perbaikan faktor daya untuk memenuhi penambahan beban 300 kVA tanpa penambahan daya PLN. *Sinusoida*, vol. 19, no. 2, pp. 33-44.