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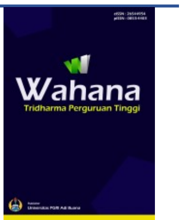

Analysis of Capasitor Bank Installation for Power Quality Improvement at PT. Sunrise Steel

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Abstrak

Banyaknya beban induktif yang digunakan yaitu motor induksi 3 fasa dan mesin las menyebabkan rendahnya faktor daya pada sistem kelistrikan di PT. Sunrise Steel. Pada industri ini terdapat 2 tempat produksi baja lapis yang diberi nama Continous Galvalume Line 1 dan Continous Galvalume Line 2. Terdapat 6 buah transformator yang menyuplai daya pada kedua tempat tersebut, namun terdapat 2 buah transformator yang mempunyai faktor daya yang sangat rendah, dimana Transformator 1 (Continous Galvalume Line 2) sudah dipasang kapasitor bank namun faktor dayanya masih rendah yaitu 0,67 dan Transformator 3 (Continous Galvalume Line 1) sebesar 0,66. Penambahan bank kapasitor tentunya sangat diperlukan untuk meningkatkan nilai faktor daya pada kedua sistem kelistrikan tersebut. Penelitian ini menargetkan peningkatan faktor daya menjadi 0,98, dimana Transformator 1 (Continuous Galvalume Line 2) memerlukan penambahan kapasitor sebesar 17,831 uF dan Transformator 3 (Continous Galvalume Line 1) memerlukan penambahan kapasitor sebesar 2948,81 uF dengan teknik kompensasi otomatis. Metode kompensasi yang digunakan pada keduanya adalah metode kompensasi global, yang dipasang pada LVMDP. Perangkat lunak ETAP *Power Station* digunakan untuk mensimulasikan hasil pemasangan kapasitor bank.

Abstract

The large number of inductive loads used, namely 3-phase induction motors and welding machines, has caused a low power factor in the electrical system at PT. Sunrise Steel. In this industry there are 2 production sites for coated steel named Continous Galvalume Line 1 and Continous Galvalume Line 2. There are 6 transformers that supply power to the two places, but there are 2 transformers that have a very low power factor, where Transformer 1 (Continous Galvalume Line 2) a capacitor bank has been installed but the power factor is still low, which is 0.67 and Transformer 3 (Continous Galvalume Line 1) is 0.66. The addition of Capacitor Bank is of course very much needed to increase the value of the power factor in the two electrical systems. This research targets an increase in power factor to 0.98, where Transformer 1 (Continuous Galvalume Line 2) requires the addition of a 17.831 uF capacitor and Transformer 3 (Continous Galvalume Line 1) requires a 2948,81 uF capacitor using an automatic compensation technique. The compensation method used in both is the global compensation method, a capacitor will be installed on each main LVMDP. ETAP Power Station software is used to simulate the results of installing capacitor banks.

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Introduction

The industrial sector is a consumer of electricity service providers which absorbs a large enough amount of electrical energy. In general, the industry has inductive loads in the form of electric motors which require quite large active and reactive power (Zhou, et al., 2018). The need for reactive power which is quite large will cause the power factor to decrease, with a decrease in the power factor it will cause an increase in electrical losses in the system concerned, one example that occurs with a decrease in the power factor, causing the active power that can be provided by the system to decrease while the power reactivity will increase. The capacitor is one of the electrical devices that is often used to improve the power factor, to increase the low value of power factor is to reduce the phi angle so that the power factor approaches the value of 1 (Shanmugapriya, M. et al., 2021). Meanwhile, to reduce the φ angle, what is possible is to reduce the reactive power component. This means that the reactive power components that are inductive must be reduced and this reduction can be done by adding a reactive power source in the form of a capacitor (Téllez, A. Á., et al., 2018). This research will analyze the value of the capacitor needed to increase the power factor at PT. Sunrise Steel from the current power factor value of 0.66 to 0.98. Feasibility test for installing bank capacitors at distribution substations of PT. Sunrise Steel with the aim of improving the power factor in order to reduce operating costs, the effect caused by the installation of the capacitor bank.

Capacitor bank is an electrical equipment that has capacitive properties, consisting of a collection of several capacitors connected in parallel to obtain a certain capacitive capacity (Allagui, A., et al., 2018). The parameter that is often used is kVAr (Kilo Volt Amperes Reactive), although the capacitance itself is listed in farads. Capacitors have electrical properties that are capacitive (leading) so as to reduce / eliminate inductive properties (lagging) (Kabir, Y., et al., 2017). The capacitor units are mounted in galvanized steel racks to form a capacitor bank of single-phase capacitor units. The number of capacitor units in a bank is determined by the voltage and power required. For higher power and voltage, or according to power requirements, capacitors are arranged in series and parallel to form a capacitor bank. The capacitor to be used to increase pf is connected in parallel with the load circuit (De Araujo, L. R., et al., 2018). When the circuit is given a voltage then the 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 that at that time the capacitor generates reactive power (Saxena, N. K.., 2020).

By adding a bank of capacitors to the system, the reactive power generated by inductive loads can be compensated. The capacitor bank provides the reactive power needed to offset the reactive power generated by inductive loads. Thus, capacitor banks help improve power factor by reducing or eliminating the additional reactive power required from the main power source (Toupouvogui, J. O., et al., 2023). Benefits of adding capacitor banks in industry include: a) By eliminating or reducing additional reactive power, capacitor banks help increase the efficiency of electrical systems. This reduces power loss and increases system capacity, b) In some cases, electric utilities apply additional charges for reactive power that exceeds a certain limit. By using capacitor banks to compensate for reactive power, companies can reduce their electricity bills, c) Poor power factor can overload electrical equipment, reducing service life and increasing the risk of damage. By improving the power factor, capacitor banks help protect equipment and extend its operational life, d) When the reactive power is compensated, the system voltage becomes more stable. This reduces the voltage drop caused by poor power factor and ensures consistent power availability. Installation of Bank Capacitors at PT. Sunrise Steel will increase the power factor, so that it can maximize power consumption, save power and reduce reactive power components. Starting from the above, the need for research related to improving the power factor so as to optimize the production of steel.

The hypothesis of installing capacitor banks to improve power quality is that by installing capacitor banks in the electrical system, power quality will improve. A capacitor bank is a series of capacitors connected in parallel to provide additional capacitance in the system. Several reasons that support this hypothesis are that capacitor banks can be used to compensate for reactive power factor in electrical systems. Poor power factor can cause excessive reactive load, resulting in energy loss and reduced efficiency. By installing a capacitor bank, the power factor can be improved, reducing reactive loads, and increasing overall system efficiency (Sahib, A., & Al-Baidhani, H., 2022). When the electrical load increases, the voltage in the system can decrease significantly. Capacitor banks can help reduce this voltage drop by providing capacitive reactance which improves voltage stability. Thus, installing a capacitor bank can help maintain a stable voltage in the system, which is essential for maintaining good power quality. Capacitor banks can also help reduce harmonic levels in an electrical system. Harmonics are unwanted frequency components that can cause interference to electrical equipment and the system. Capacitor banks can act as filters to reduce harmonic levels and maintain better power quality. However, it should be noted that the effectiveness of installing a capacitor bank in improving power quality may vary depending on the specific conditions of the electrical system, the load involved, and other factors (Melo, I. D., et al., 2020). Therefore, it is important to carry out careful analysis and planning before deciding to install a capacitor bank in an electrical system.

Method

This research uses a quantitative methodology or also known as the scientific method. The reason for using this method is because this method has adhered to the principles of science, which are systematic, clear, objective, measurable, and concrete. This research aims to help the problems that occur in PT. Sunrise Steel. At PT. Sunrise Steel has 6 transformers and 2 of them namely Transformer 1 (Continuous Galvalume Line 2) and Transformer 3 (Continous Galvalume Line 1) have a power factor below 0.85. This will have an impact on the electrical system. Therefore, the addition of capacitors here is needed to increase the power factor itself. The research data that will be used to design the required capacitor bank values are in the following table I.

Table 1. Data Low Voltage-MDP

Data	Transformator 1	Transformator 3
Current (A)	2230,5	353
Power Factor (Cos φ)	0,67	0.66
Voltage (V)	418.37	391
Specification of Capasitor	1200 kVAR (12 step) (50 kVAR per step)	Not Installed

Table 1 contains data on capacitor specifications and measurement results of current (I), voltage (V), and power factor (Cos φ) on the two main low voltage main distribustion panel (LVMDP) transformers 1 (Continous Galvalum Line 2) and transformer 3 (Continuous Galvalum Line 1). The data above is taken from the power meter of each of the low voltage main distribution panel (LVMDP).

Calculation of Active Power and Apparent Power

To determine the amount of capacitor to be installed to achieve the desired target power factor (Cos φ = 0.98). From observations made on the respective power meters of LVMDP Transformer 1 and Transformer 3, with the initial data in table 1, the active power and apparent power values are determined using the following equation (Nobile, G, et al. 2022):

$$S = \sqrt{3} \times V \times I \tag{1}$$

Where,

S = Apparent Power (VA)
V = Voltage (V)
I = Current (A)

$$P = S \times Cos\varphi \tag{2}$$

Where,

P = True Power (Watt)
$Cos\ \varphi$ = Power Factor

From the calculation of the active power and apparent power of transformer 1 and transformer 3, the values are written in table 2. From table 2, these values will later be used to calculate the reactive power value to determine the amount of compensation.

Table 2. Apparent Power and True Power Data

Data	Transformator 1	Transformator 3
Apparent Power (kVA)	1616,31	239,06
True Power (Watt)	1082,92	157,78

Calculation of Reactive Power

In this section the researcher calculates the initial reactive power (Q1) and the reactive power after (Q2) with the target Cos φ = 0.98 from the power calculation results for each transformer 1 and transformer 3 at PT. Sunrise Steel uses the following formula (Jurák, V., et al 2020) :

$$Q = S \times Sin\ \varphi \tag{3}$$

Where,

Q = Reactive Power (VAR)

S = Apparent Power (VA)

From the results of calculating the reactive power of transformer 1 and transformer 3, it is written in table 3. From table 3, these values will later be used to calculate the reactive power value to determine the value for the installed capacitor.

Table 3. Reactive Power Value

Data	Transformator 1		Transformator 3	
	$Cos\varphi = 0.67$	$Cos\varphi = 0.98$	$Cos\varphi = 0.67$	$Cos\varphi = 0.98$
Reactive Power (kVAR)	1199,98	219,94	179,60	32,04

After calculating the reactive power, there was a decrease in the reactive power in transformer 1 from the original 1199.98 kVAR when cos phi 0.67 decreased to 219.94 kVAR with cos phi 0.98. In transformer 3, the reactive power value from the original 179.60 kVAR at cos phi 0.67 decreased to 32.04 kVAR.

Determination of Bank Capacitor Design

The determination of bank capacitor design involves several factors that need to be considered. Bank capacitors are commonly used in power systems to improve power factor and voltage stability. In determining the design of the capacitor bank value, because previously a capacitor with a capacity of 1200 kVAR was installed in 12 steps with 50 kVAR per capacitor, with the global compensation method on the main LVMDP of Transformer 1 (Continuous Galvalum Line 2). So it takes 20 additional 50 kVAR capacitors which are installed in parallel at each step to reach the target Cos φ = 0.98.

The initial step to determine the difference in reactive power before and after repair is expressed in compensated reactive power. The initial step to determine the difference in reactive power before and after repair is expressed in compensated reactive power, mathematically expressed as follows (Alsakati, A. A., et al., 2021):

$$Q_c = Q_1 - Q_2 \tag{4}$$

Where,

Q_c = Reactive Power Compensation (VAR)
Q_1 = Reactive Power before improvement (VAR)
Q_2 = Reactive Power after improvement (VAR)

When Cos φ = 0.98, the capacitive reactance (Xc) is obtained (Awadalla, M., et al., 2015) as:

$$X_c = \frac{V_{L-L}^2}{Q_c} \tag{5}$$

Where,

Xc = Capasitive Reactance (Ohm)
Q_c = Reactive Power Compensation (VAR)
$V_{L\text{-}L}$ = Line to Line Voltage (Volt)

After calculating the capacitive reactance value then calculating the value of the capacitor (Najmi, V., et al., 2014) needed for each transformer 1 and transformer 3 at PT. Sunrise Steel.

$$C = \frac{1}{\omega \times X_c} \tag{6}$$

Where,

C = Capasitor Value (Farad)
ω = Radian Frequency ($2\pi f$)
Xc = Capasitive Reactance (Ohm)

Table 4. Value for Capacitor Design

Data	Transformator 1	Transformator 3
Reactive Power Compensation (kVAR)	980,04	147,56
Capasitive Reactance (Ohm)	0,1786	1,03
Capasitor Value (uF)	17831	2948,81

After calculating the required capacitor value, the result is that transformer 1 requires 17832.5 µF while transformer 3 requires 2948.81 µF. So, later this value can be used by PT. Sunrise Steel to determine the need for capacitors that must be installed to improve power quality. Once the reactive power requirement is known, you can select the appropriate capacitor units to meet that requirement. Capacitors are rated in kVAR and typically come in standard sizes. You can choose individual capacitors or pre-assembled capacitor banks consisting of multiple capacitors connected in parallel or series-parallel configurations. Consider factors such as voltage rating, current rating, and the number of units required to meet the reactive power demand (Stanelyte, D., & Radziukynas, V., 2019). Consider the physical space available for capacitor installation, as well as factors such as cooling requirements, protection measures (e.g., fuses or circuit breakers), and accessibility for maintenance and inspection. Ensure that the selected capacitors and the overall bank design comply with relevant standards, regulations, and safety guidelines applicable to your location or industry.

Results and Discussion

The global compensation method, where the position of the capacitor bank is only in one place in the entire electrical system, both of which are installed on their respective LVMDP. The reason for using this method is because the average load used is a non-linear load or inductive load, namely 3-phase induction motors and welding machines.

Results Before Power Quality Improvement

The initial conditions a 1200 kVAR capacitor bank was installed with a unit of 50 kVAR per capacitor on LVMDP Transformer 1 (Continous Galvalume Line 2). However, the power factor on this channel is still below the SPLN standard, namely 0.67 (67%). The load power is assumed to be 45.12 kW per load, where the power is obtained from the total active power that was successfully measured at LVMDP at full load divided by the number of loads (1082.92 kW/24). In Figure 1 is the result of a simulation of the initial conditions of the channel system on Transformer 1 (Continous Galvalume Line 2) before power factor improvement.

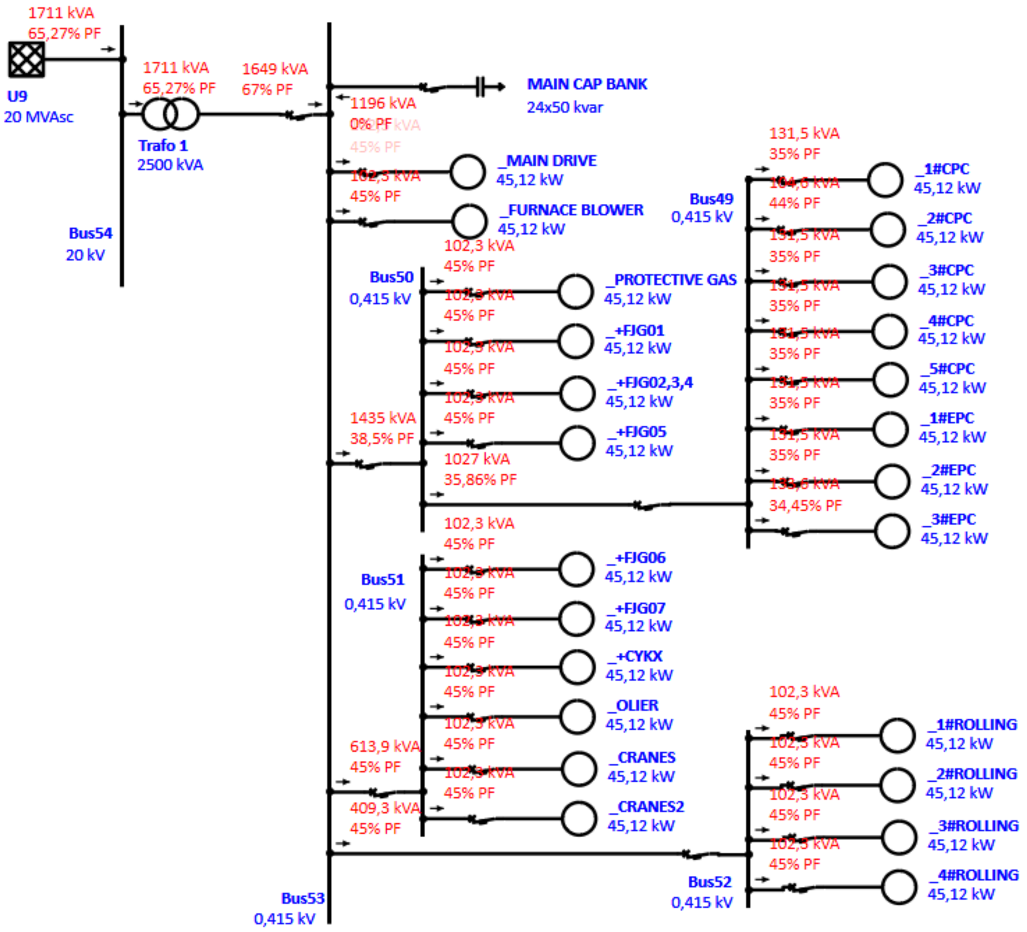

Figure 1. Simulation on Transformer 1 Before Power Factor Improvement

In Figure 2 is the result of a simulation of the initial conditions of the channel system on Transformer 3 (Continuous Galvalume Line 1) before power factor improvement. Where in the initial conditions the capacitor bank has not been installed. The power factor on this channel is still below the SPLN standard, namely 0.66 (66%). The total active power on this channel is 157.8 kW, this result is obtained from the calculation of the existing data on the LVMDP power meter at full load.

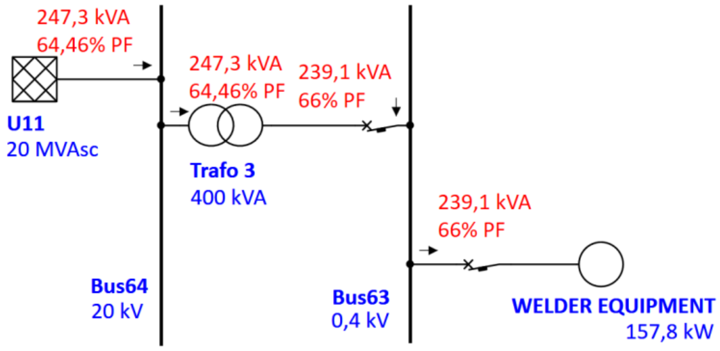

Figure 2. Simulation on Transformer 3 After Power Factor Improvement

Results Before Power Quality Improvement

To find out the effect of installing a capacitor bank that has been calculated previously, it is necessary to make a one-line system diagram and enter the system components with data according to the calculation findings, both before and after adding the capacitor bank to each line. This simulation uses ETAP Power Station Software (Electric Transient and Analysis Program) version 19.0.1. Table 5 is the simulation result of adding a capacitor bank, which is installed on LVMDP Transformer 1 using the global compensation method with a 10-step manual compensation technique. Figure 3. shows that after adding a 1000 kVAR capacitor bank, the total will be 2200 kVAR with 50 kVAR units per capacitor on the low voltage main distribution panel (LVMDP) of Transformer 1 (Continuous Galvalume Line 2). The power factor which was originally 0.67 has increased to 0.98 (98.19%), where the results of manual calculations target 0.98, which means that the simulation results and manual calculations are close to the target with a difference of less than 1%. Figure 4 shows after adding a 150 kVAR capacitor bank with 25 kVAR units per capacitor on the main LVMDP of Transformer 3 (Continuous Galvalum Line 1). The power factor which was originally 0.66 has increased to 0.98 (98.18%), where the calculation results target 0.98, which means that the simulation results and manual calculations are close to the target with a difference less than 1%.

Table 5. Simulation Results of Adding Bank Capacitors to Transformer 1

Step	Power Factor	Capasitance (µF)	Qc (kVAR)
0	0,67	0	0
1	0,7035	1822	100
2	0,7332	3644	200
3	0,7699	5465	300
4	0,8009	7287	400
5	0,8392	9109	500
6	0,8692	10931	600
7	0,9052	12753	700
8	0,9388	14574	800
9	0,9604	16396	900
10	0,9828	18218	1000

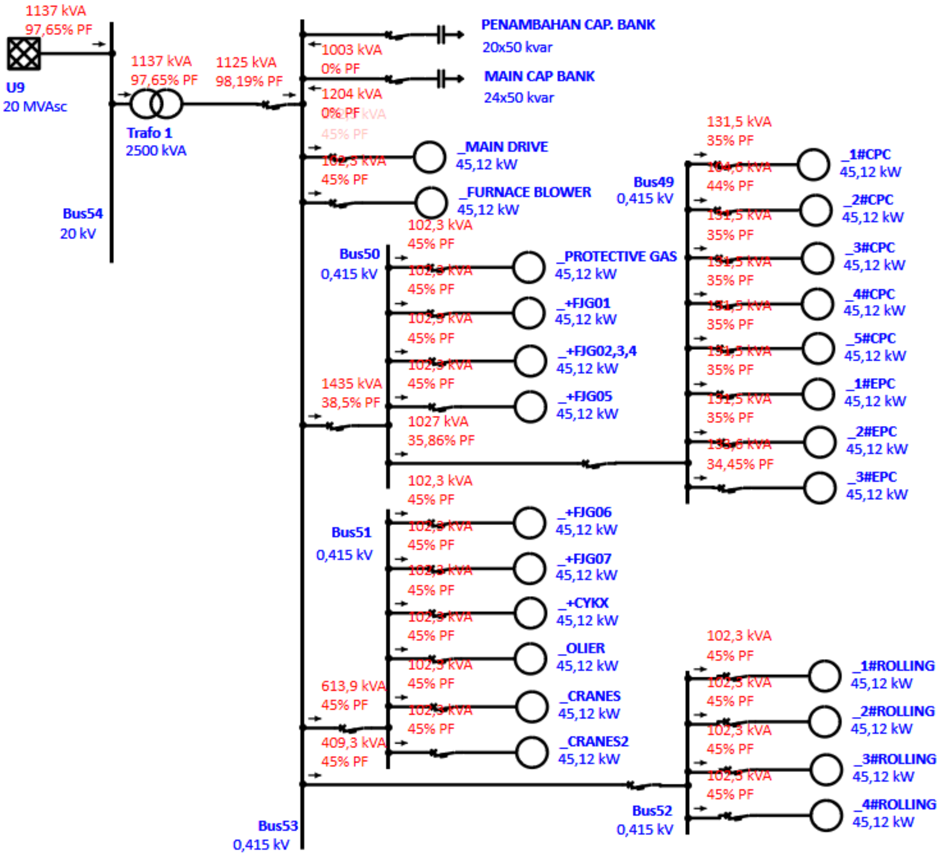

Figure 3. Simulation on Transformer 1 After Power Factor Improvement

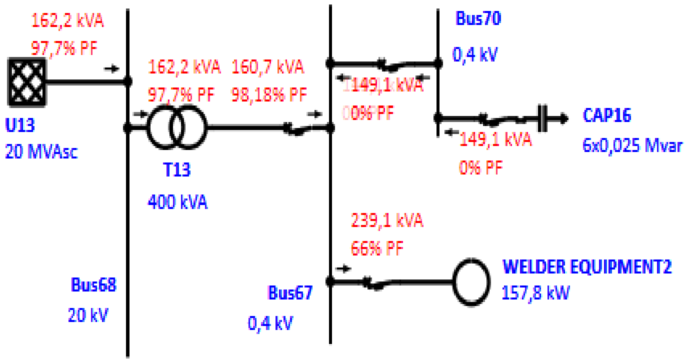

Figure 4. Simulation on Transformer 3 After Power Factor Improvement

Table 6 shows the simulation results of adding a capacitor bank, which will be installed on LVMDP Transformer 3 (Continous Galvalume Line 1) using the global compensation method with a manual compensation technique of 6 steps. Where at each step using a 25 kVAR capacitor mounted in parallel.

Table 6. Simulation Results of Adding Bank Capacitors to Transformer 3

Step	Power Factor	Capasitance (µF)	Qc (kVAR)
0	0,66	0	0
1	0,7144	497,4	25
2	0,7726	994,7	50
3	0,8325	1492	75
4	0,8935	1989	100
5	0,9447	2487	125
6	0,9818	2984	150

Installing a capacitor bank can have a significant positive impact on power quality at PT. Sunrise Steel. Capacitor banks are used to compensate for the reactive power generated by inductive loads such as electric motors and transformers. By reducing the reactive power, the power factor increases, which means that the active power and reactive power become more balanced (Petrov, A., & Shurov, N., 2017). This reduces energy wastage and increases system efficiency, thereby reducing operating costs. Bank capacitors help reduce energy losses in the electrical system at PT. Sunrise Steel. By reducing reactive power, electric current flows through power lines more efficiently, reducing power losses in cables and transformers. This means more active power is available for use in steel smelting, reducing the required energy costs. Capacitor banks help maintain a stable voltage in the steel industry's electrical systems. When there is a varying load, the capacitor bank can provide additional reactive power to keep the voltage at the desired level. This prevents voltage fluctuations that could damage equipment and disrupt production processes. By reducing the reactive power load, capacitor banks free up additional capacity in the electrical system (AlDahmi, M., et al., 2019). By designing and operating the capacitor system properly, PT. Sunrise Steel can optimize power quality, reduce operating costs, improve energy efficiency, and increase productivity.

Conclusion

Based on the results of research and calculations at PT. Sunrise Steel that have been carried out, the following conclusions can be drawn. The power factor in the electrical system at PT. Sunrise Steel can be increased by installing a capacitor bank. Where in LVMDP Transformer 1 to achieve a power factor from originally 0.67 to 0.98 it requires a 1000 kVAR reactive power compensation and a capacitance of 18218 μF using a manual compensation technique of 10 capacitor steps. At each step, the power factor increases by 0.031 and requires a capacitance of 1822 μF. Whereas in LVMDP Transformer 3 to achieve a power factor from originally 0.66 to 0.98 requires a 150 kVAR reactive power compensation and a capacitance of 2984 μF using a manual compensation technique of 6 step capacitors. At each step, the power factor increases by 0.05 and requires a capacitance of 497.4 μF.

Referensi

AlDahmi, M., Al Ahmad, O., & Ahmad, E. (2019, April). Assessment of Al Ain Distribution Network Capacitor Banks and Power Factor Enhancement Study. In *2019 IEEE 2nd International Conference on Power and Energy Applications (ICPEA)* (pp. 159-162). IEEE.

Allagui, A., Elwakil, A. S., Maundy, B. J., & Freeborn, T. J. (2016). Spectral capacitance of series and parallel combinations of supercapacitors. *ChemElectroChem*, *3*(9), 1429-1436.

Alsakati, A. A., Vaithilingam, C. A., Prakash, K. S., Gamboa, R. A., Jagadeeshwaran, A., & Alnasseir, J. (2021). Mitigation of power quality issues in distribution systems using harmonic filters and capacitor banks. *Facta Universitatis, Series: Electronics and Energetics*, *34*(4), 589-603.

Awadalla, M., Omer, M., & Mohamed, A. (2015, September). Single-tuned filter design for harmonic mitigation and optimization with capacitor banks. In *2015 International Conference on Computing, Control, Networking, Electronics and Embedded Systems Engineering (ICCNEEE)* (pp. 242-247). IEEE.

De Araujo, L. R., Penido, D. R. R., Carneiro Jr, S., & Pereira, J. L. R. (2018). Optimal unbalanced capacitor placement in distribution systems for voltage control and energy losses minimization. *Electric Power Systems Research*, *154*, 110-121.

Jurák, V., Bukvišová, Z., Ptáček, M., Topolánek, D., & Orságová, J. (2020, October). Compensation of reactive power in LV network and its impact on reactive power flow through distribution grid. In *2020 21st International Scientific Conference on Electric Power Engineering (EPE)* (pp. 1-5). IEEE.

Kabir, Y., Mohsin, Y. M., & Khan, M. M. (2017, February). Automated power factor correction and energy monitoring system. In *2017 Second International Conference on Electrical, Computer and Communication Technologies (ICECCT)* (pp. 1-5). IEEE.

Melo, I. D., Pereira, J. L., Variz, A. M., & Ribeiro, P. F. (2020). Allocation and sizing of single tuned passive filters in three-phase distribution systems for power quality improvement. *Electric power systems research*, *180*, 106128.

Najmi, V., Wang, J., Burgos, R., & Boroyevich, D. (2014, September). High reliability capacitor bank design for modular multilevel converter in MV applications. In *2014 IEEE Energy Conversion Congress and Exposition (ECCE)* (pp. 1051-1058). IEEE.

Nobile, G., Cacciato, M., & Vasta, E. (2022). Measuring Active Power as the Difference between the Peak Value of Instantaneous Power and the Apparent Power. *Sensors*, *22*(9), 3517.

Petrov, A., & Shurov, N. (2017, July). Reactive power compensation and high-frequency distortions correction in Metro. In *International Conference" Actual Issues of Mechanical Engineering" 2017 (AIME 2017)* (pp. 604-608). Atlantis Press.

Sahib, A., & Al-Baidhani, H. (2022, December). Power Factor Improvement by Shunt Capacitor Bank at 33 Kv Busbar in a Distribution Substation. In *2022 3rd Information Technology to Enhance e-learning and Other Application (IT-ELA)* (pp. 206-209). IEEE.

Saxena, N. K. (2020). Voltage control by optimized participation of reactive power compensation using fixed capacitor and STATCOM. *Optimization of Power System Problems: Methods, Algorithms and MATLAB Codes*, 313-363.

Shanmugapriya, M., Sijini, A. C., Srinivas, V. T., Karthick, M., & Pavan, S. (2021, May). Inductive load power factor correction using capacitor bank. In *Journal of Physics: Conference Series* (Vol. 1916, No. 1, p. 012140). IOP Publishing.

Stanelyte, D., & Radziukynas, V. (2019). Review of voltage and reactive power control algorithms in electrical distribution networks. *Energies*, *13*(1), 58.

Téllez, A. Á., López, G., Isaac, I., & González, J. W. (2018). Optimal reactive power compensation in electrical distribution systems with distributed resources. Review. *Heliyon*, *4*(8), e00746.

Toupouvogui, J. O., Camara, M. A., Sakouvogui, A., & Keita, M. (2023). Optimal Sizing of Capacitor Bank for Increasing Substation Capacity of Mamou. *World Journal of Engineering and Technology*, *11*(2), 217-233.

Zhou, X., Wei, K., Ma, Y., & Gao, Z. (2018, August). A review of reactive power compensation devices. In *2018 IEEE International Conference on Mechatronics and Automation (ICMA)* (pp. 2020-2024). IEEE.