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Analysis of Capacitor Bank Installation for Improving Power Factor in PA Jemursari Prapen Pump House, Surabaya

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Abstract*—This study aims to analyze and evaluate power factor correction (cos φ) in the electrical installation of the PA Prapen pump house in Surabaya City, with the goal of reducing penalty charges incurred from excessive reactive power consumption (kVArh) imposed by the national utility company, PLN. Based on initial data obtained from measurements and electricity usage records, the pump house has an average power factor of 0.70 with an active power load of 707.95 kW. This low power factor results in high reactive power consumption and leads to significant monthly penalty costs. On average, the facility pays approximately IDR 31 million per month in penalties, which becomes a substantial operational expense. To address this issue, a simulation and reactive power compensation analysis were conducted using ETAP version 19.0.1 software. The simulation proposed the installation of capacitor banks to supply capacitive reactive power and improve the overall power factor closer to the ideal value. The target power factor was set at 0.95, in accordance with PLN regulations, in order to eliminate or minimize penalties. The simulation results indicate that the required reactive power compensation is approximately 488.485 kVAr. To meet this requirement, capacitor banks with a total capacitance of around 9507.8 μF need to be installed. The installation of these capacitor banks is expected to effectively improve the power factor, reduce power losses, and result in significant cost savings for the operation of the PA Prapen pump house in Surabaya City.

***Keywords*— Capacitor Bank, ETAP Simulation, Power Factor Correction, Reactive Power Compensation**

I. INTRODUCTION

Low power factor problems in industrial electrical systems and public facilities are a major issue that directly affects energy efficiency and operational costs. A low power factor leads to high reactive power consumption, increased line losses in distribution networks, reduced system efficiency, and penalty charges imposed by utility companies such as PLN [1], [2].

Many studies have examined reactive power compensation methods using capacitor bank installation as an effective and economical solution to improve system power factor [3], [4]. Installing capacitor banks has been proven to reduce reactive power drawn from the source, improve voltage profiles, and lower distribution losses [5], [6]. Additionally, power system design standards generally require a power factor of at least 0.95 to achieve optimal efficiency and minimize operational expenses [7], [8].

The use of simulation software such as ETAP for designing reactive power compensation systems has also grown significantly. ETAP facilitates detailed power flow analysis, short-circuit studies, and planning of capacitor bank installations with higher precision [3], [9]. Several studies have utilized ETAP to analyze capacitor bank requirements in processing industries [4], commercial buildings [5], and medium-voltage distribution networks [6].

Mahdavi et al. [10] reported a 20% reduction in electricity costs following the installation of capacitor banks in a processing plant. Permadi [11] successfully increased the power factor of a commercial building from 0.72 to 0.96 using ETAP simulation. Soma [12] demonstrated reduced power losses in distribution networks through optimal capacitor placement. Meanwhile, Rofii et al. [13] analyzed the reduction of reactive power charges in high rise buildings, while Rohouma et al. [14] performed simulations for capacitor requirements in low-voltage distribution systems.

International research also highlights the optimization of capacitor placement to reduce losses and improve voltage quality [11], [12]. Tang [15] and Schavemaker [16] discuss power system stability theory and the role of reactive compensation. Ten & Hou [17] cover power system design and power electronics supporting reactive power compensation in various applications.

However, most existing research has focused on industrial systems, commercial buildings, or distribution networks with relatively stable load characteristics. Studies on municipal pump house electrical systems with large induction motor loads and fluctuating operating patterns remain limited. Therefore, this study addresses that gap through a comprehensive analysis and ETAP 19.0.1 simulation of capacitor bank installation at the PA Prapen Pump House in Surabaya City, targeting a power factor of 0.95 in compliance with PLN requirements, to provide a practical and specific solution for public facility managers.

II. METHODS

This research adopts a quantitative analytical approach using simulation-based modeling to evaluate power factor correction in the PA Prapen Pump House electrical system. Data on active and reactive power consumption are collected from operational records and field measurements. ETAP 19.0.1 software is used to simulate the addition of capacitor banks, calculate reactive power compensation requirements, and assess improvements in power factor from 0.70 to the target 0.95. The methodology includes load flow analysis, capacitor sizing, and economic evaluation to determine potential penalty cost reductions, offering practical recommendations for optimizing the pump house's electrical efficiency.

A. Power Factor Improvement Using Reactive Power Compensation

This study employs a quantitative analytical approach with simulation to design reactive power compensation for the PA Prapen Pump House electrical system. Active and reactive power consumption data are collected from field measurements and operational records. ETAP 19.0.1 software is used to perform load flow simulations, determine the required capacitor bank size, and predict the improvement in power factor from 0.70 to 0.95.

The process includes load analysis, capacitor sizing calculations, and evaluation of penalty cost savings, resulting in practical recommendations for implementing power factor correction in public facility electrical systems. The method of power factor improvement in the PA Prapen Pump House electrical system is based on reactive power compensation through capacitor bank installation to increase the power factor toward 0.95, in accordance with PLN regulations [6], [7]. The data used include active power (P), voltage (V), and total current (I) obtained from field measurements. The apparent power before correction is calculated using:

$$S = \sqrt{3} \times V_{L-L} \times I \qquad (1)$$

The initial reactive power is determined with:

$$Q = \sqrt{S^2 - P^2} \qquad (2)$$

The initial power factor is calculated by:

$$\cos\varphi = \frac{P}{S} \qquad (3)$$

For example, if $\cos\varphi = 0.70$ then the phase angle is:

$$\varphi_1 = cos^{-1}(0{,}70) = 45{,}57^0$$

The target power factor is 0.95, so:

$$\varphi_2 = cos^{-1}(0{,}95) = 18{,}19^0$$

The required reactive power compensation is calculated as:

$$Q_C = P \times (\tan\varphi_1 - \tan\varphi_2) \qquad (4)$$

The capacitor bank size is determined using:

$$C = \frac{Q_C}{2\pi f V_{L-L}^2} \qquad (5)$$

The capacitor bank controller module is designed with 12 steps, so the capacity per step is:

$$\text{Capasitor per steps} = \frac{Q_C}{12} \qquad (6)$$

These calculations yield values for apparent power (S), initial reactive power (Q), initial power factor ($\cos\varphi_1 = 0.70$), and the required reactive compensation (Q_C) to achieve the target power factor ($\cos\varphi_2 = 0.95$). The resulting capacitor bank specifications are used as design inputs for ETAP 19.0.1 simulation to verify compensation requirements and project penalty cost savings.

B. Single Line Diagram (SLD) modeling at the PA Jemursari Prapen Pump House

The initial data for this study were obtained from two primary sources. The first source consists of records documented in the E-Maintenance system or the pump house technician application, which includes operational history and logged electrical parameters. To validate and strengthen the accuracy of this data, structured interviews were conducted with the pump house staff or operators. In addition, direct on-site measurements were carried out using a Hioki 3286-01 to obtain real-time readings of current, voltage, and pf. The following section presents the initial data used as the basis for calculations and simulation.

Table 1 shows the specifications of the generator and transformer used in this study. The generator, labeled Perkins, has a power rating of 520 kW / 650 kVA, a voltage of 230 V / 400 V, and a current of 983.194 A. The transformer, labeled Trafindo, has a higher power capacity of 1000 kW / 1250 kVA, with the same voltage levels (230 V / 400 V) and a current of 1804 A.

TABLE 1. TRANSFORMER AND GENERATOR SPECIFICATIONS

Information	Generator	Transformer
Label	Perkins	Trafindo
Power	520 kW / 650 kVa	1000 kW / 1250 kVa
Voltage	230 V / 400 V	230 V / 400 V
Current	983,194 A	1804 A

TABLE 2. LOAD MEASUREMENT DATA

Load	Voltage (V)	Current (A)	Power (kW)	Power Factor
P. Sludge 1	408,8	109,3	68,9	0,89
P. Sludge 2	398,2	74,4	41,5	0,80
P. Flood 1	405,8	265	172,1	0,92
P. Flood 2	405,7	301,7	161	0,75
P. Flood 3	402,5	389,1	264,4	0,97

Based on Table 2, measurements of the electrical load at the P.A Prapen Pump House installation show a total active power of 707.95 kW, derived from six main loads comprising five pump units and one household load. Sludge Pump 1 operates at 408.8 V with a current of 109.3 A, producing 68.9 kW of active power with a relatively good power factor (cos φ) of 0.89. Meanwhile, Sludge Pump 2 delivers a lower power of 41.5 kW at 398.2 V and 74.4 A, with a power factor of 0.80. The two main flood pumps, Flood Pump 1 and Flood Pump 2, generate 172.1 kW and 161 kW of active power, respectively. Flood Pump 1 has a high pf of 0.92, while Flood Pump 2 shows lower efficiency with a cos φ of only 0.75, indicating a greater need for reactive power compensation. Flood Pump 3 is the largest load, with an active power of 264.4 kW, a current of 389.1 A, and a very good power factor of 0.97, demonstrating highly efficient performance. Finally, the household load, although small at just 0.45 kW, also has a power factor of 0.80. Measurements for Sludge Pumps 1 and 2 were taken while both pumps operated simultaneously, while measurements for Flood Pumps 1, 2, and 3 were performed alternately because during measurement, the water elevation or flow rate was below 1 meter.

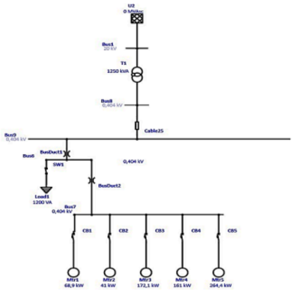

Figure 1. SLD before Installing the Capacitor Bank

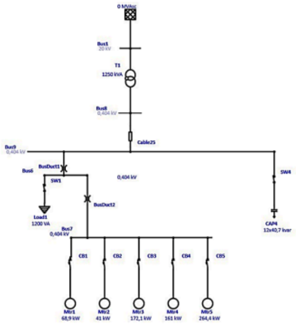

Figure 2. SLD after Installing the Capacitor Bank

Figures 1 and 2 illustrate the SLD of the pump house electrical system before and after installing the capacitor bank. Figure 1 shows the existing configuration without any reactive power compensation, where all loads are connected directly to the busbar. Figure 2 depicts the improved configuration after installing the capacitor bank, which is connected in parallel to the busbar to improve power factor and reduce reactive power demand from the source.

III. RESULT AND ANALYSIS

A. *Reactive Power Compensation Results Analysis*

This section presents the calculation to determine the required capacitor bank capacity to improve the system power factor from 0.70 to 0.95. The initial power factor is assumed to be 0.70**.** This assumption is used to simulate the worst-case load condition in ETAP 19.0.1 software, where the power factor of each load is expected to be below the standard value of 0.85 before correction. Power factor improvement aims to reduce the system's reactive power demand, decrease current flow, minimize power losses in conductors, and enhance overall supply efficiency. Based on measurement data in Table 2, the following system calculation is given:

$$S = \sqrt{3} \times V_{L-L} \times I$$

$$S = \sqrt{3} \times 404.5 \times 1.73 = 1010{,}16\ kVA$$

Thus, the apparent power before power factor correction is approximately 1010.16 kVA, which reflects the total load on the system. Next, the reactive power (Q) corresponding to this apparent power is calculated. Reactive power represents the non-working power component that does not produce useful work but causes extra current flow in the system.

$$Q = \sqrt{S^2 - P^2} = \sqrt{(1010{,}16)^2 - (707{,}95)^2}$$

$$Q = 720{,}35\ kVAR$$

This result shows that the system's reactive power before correction is 720.35 kVAR, indicating a significant reactive demand that needs to be compensated. To understand the relationship between active and reactive power in the apparent power triangle, the phase angle φ_1 is calculated.

$$\cos \varphi_1 = 0.70$$

$$\varphi_1 = cos^{-1}(0.70) = 45.57^0$$

The phase angle φ_1 of 45.57° shows the degree of phase lag between voltage and current at the initial power factor of 0.70. For improved system efficiency, the power factor target is set at 0.95. The new phase angle φ_2 corresponding to this target is calculated as follows:

$$\cos \varphi_1 = 0.95$$

$$\varphi_1 = cos^{-1}(0.95) = 18.19^0$$

The smaller phase angle 18.19° indicates that after correction, the current will be more in phase with the voltage, resulting in reduced reactive power. Next, the required reactive power compensation (Q_C) needed to correct the power factor from 0.70 to 0.95 is calculated using the following formula:

$$Q_C = P \times (\tan \varphi_1 - \tan \varphi_2)$$

$$Q_C = 707.95 \times (\tan 45.57^0 - \tan 18.19^0)$$

$$Q_C = 488.485\ kVAR$$

This calculation indicates that approximately 488.485 kVAR of reactive power compensation is required from the capacitor bank to achieve the target power factor of 0.95. To determine the physical specification of the capacitor bank, the total capacitance value is calculated using:

$$C = \frac{Q_C}{2\pi f V^2} = \frac{488.485}{2 \times 3.14 \times 50 \times 404.5^2} = 9507.8\, uF$$

Therefore, the total required capacitance for the compensation is 9507.8 µF. For operational flexibility, the capacitor bank is typically divided into multiple steps. In this design, 12 steps are planned, so the capacity per step is calculated as:

$$Q_C\ per\ step = \frac{9507.8}{12} = 40.7\ kVAR$$

Thus, the capacitor bank will consist of 12 steps, each rated at approximately 40.7 kVAR. In practice, this value can be adjusted to standard commercial sizes, such as 40 kVAR per step. In conclusion, to improve the power factor from 0.70 to 0.95, a capacitor bank with a total capacity of 488.485 kVAR and total capacitance of 9507.8 µF is required. The bank is planned in 12 steps of around 40 kVAR each to enable flexible adjustment according to the load variations.

B. Simulation Result Before Compensation

The analysis of capacitor bank planning is carried out to improve the electrical system's power factor, making it more efficient, reducing reactive power losses, and lowering electricity billing costs associated with low power factor penalties. In this study, the ETAP was used to simulate and analyze the system's behavior. Based on initial data, the system had a total active power of 707.95 kW with an initial power factor of approximately 0.70. Using the Power Flow and Load Flow Analysis, calculations were performed to determine the actual apparent power (S) and reactive power (Q) needed to achieve the target power factor improvement to 0.95. The results showed that achieving this target required a reactive power compensation of 488.5 kVAR. This value was then used to determine the appropriate capacitor bank capacity, which was set at 488.5 kVAR and divided into 12 steps of approximately 40.7 kVAR each for flexibility in responding to load variations.

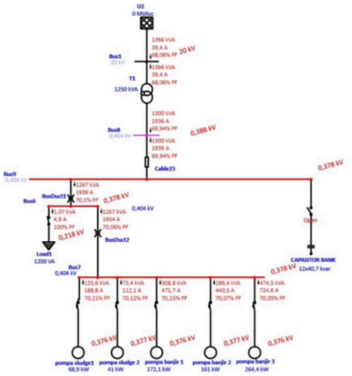

Figure 3. Power Flow before Reactive Power Compensation

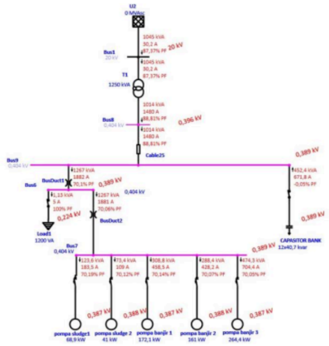

Figure 4. Power Flow after Reactive Power Compensation

In this simulation, the power factor control switch was disabled to observe the actual system behavior without compensation. The cos φ (power factor), reactive power (kVAR), and apparent power (kVA) values at each bus were recorded under the condition that all pumps were operating simultaneously, with their individual power factors reduced to 0.70. The ETAP 19.0.1 simulation of the Surabaya City Pump House electrical system showed that the external power source (Power Grid) at a nominal voltage of 20 kV connected to Bus1 supplied 929.8 kW of active power and 1001 kVAR of reactive power. The system's power factor before compensation was recorded at 68.06% (equivalent to 0.6806). This value indicates the system has a highly inductive load characteristic, with reactive power nearly equal to active power. Such conditions result in low system efficiency and higher current loading on the distribution network. The simulation also showed the current drawn from the source was 39.44 A.

TABLE 3. BUS 1 SIMULATION DATA BEFORE COMPENSATION

ID	Terminal Bus	Type	Rated Voltage (V)	Active Power (kW)	Reactive Power (kVAR)	Current (A)	% PF
U2	Bus1	Power Grid	20,000	929.8	1001	39.44	68.06

TABLE 4. BUS-BY-BUS SIMULATION DATA BEFORE COMPENSATION

Bus ID	Nominal Voltage (kV)	Type	Voltage (V)	Active Power (kW)	Reactive Power (kVAR)	Current (A)
Bus 1	20	Swing	20000	929.8	1001	39.44
Bus 6	0.404	Load	378	888.4	903.8	1936
Bus 7	0.404	Load	378	887.4	903.8	1934
Bus 8	0.404	Load	387.8	909.3	929.2	1936
Bus 9	0.404	Load	378	888.4	903.8	1936

TABLE 5. LOAD DATA BEFORE COMPENSATION

Load	Rating/Limit	Voltage (V)	Active Power (kW)	Reactive Power (kVAR)	Current (A)	% PF	Terminal Voltage (V)
Lighting	1.2 kVA	231	1.07	0	4.908	100	218.3
Flood Pump 1	172.1 kW	400	215.1	219.5	471.7	70	376.2
Flood Pump 2	161 kW	404	201.2	205.3	440.5	70	376.8
Flood Pump 3	264.4 kW	404	330.5	337.2	724.6	70	376.2
Sludge Pump 1	68.9 kW	404	86.12	87.87	188.8	70	376.2
Sludge Pump 2	41 kW	380	51.25	52.29	112.1	70	377

TABLE 10. VOLTAGE DROP AND POWER LOSS BEFORE CAPACITOR BANK INSTALLATION

ID	Bus 1	Bus 2	Voltage Drop (%)	Real Power Loss (kW)	Reactive Power Loss (kVAR)
Cable 7	Bus 7	Sludge Pump 1	0.44	0.664	0.169
Cable 9	Bus 7	Sludge Pump 2	0.26	0.234	0.0597
Cable 15	Bus 7	Flood Pump 1	0.46	1.52	0.642
Cable 20	Bus 7	Flood Pump 2	0.3	0.846	0.446
Cable 23	Bus 7	Flood Pump 3	0.46	1.86	1.44
Cable 25	Bus 8	Bus 9	2.42	20.85	25.46
T1	Bus 1	Bus 8	4.01	20.51	71.79

Figures 3 and 4 illustrate the system's power flow conditions before and after the implementation of reactive power compensation, respectively. In Figure 3, prior to compensation, the network exhibits higher reactive power flows throughout the system branches, leading to elevated current levels and increased apparent power transfer from the main supply. These conditions contribute to significant voltage drops along the feeder lines and an overall reduction in voltage quality at the load terminals. The pronounced reactive power demand observed in this scenario imposes a substantial burden on the supply infrastructure, reducing operational efficiency and increasing transmission losses.

In contrast, Figure 4 demonstrates the improved system performance achieved after reactive power compensation. The introduction of capacitor banks significantly reduces the reactive power demand across the network, resulting in lower current magnitudes and decreased apparent power flows. Consequently, voltage profiles across all buses are enhanced, exhibiting less deviation from nominal values, which ensures better power quality for end-users. This improvement also leads to reduced real and reactive power losses within the system, confirming the effectiveness of reactive power compensation strategies in stabilizing voltage levels, improving power factor, and optimizing overall system efficiency.

Referring to the simulation results presented in Table 3 through Table 6, it is evident that the electrical system at Bus 1, as shown in Table 3, operates at a rated voltage of 20 kV, delivering an active power of 929.8 kW and a reactive power of 1001 kVAR. The resulting current reaches 39.44 A, with a low power factor of approximately 68.06 percent. This condition reflects a significant inductive load characteristic within the system.

As illustrated in Table 4, the voltage profile across each bus indicates a reduction, particularly in the low-voltage load buses (Bus 6 to Bus 9), where measured voltages range from 378 V to 388 V, deviating from the nominal 404 V. This suggests the presence of considerable voltage drops across the distribution network. Further insights from Table 5 show that the primary electrical loads, including flood and sludge pumps, exhibit poor power factors averaging around 70 percent, accompanied by high current demands. For instance, Flood Pump 3 registers a current of 724.6 A and a terminal voltage of only 376.2 V. These values confirm the presence of substantial inductive loads that necessitate reactive power compensation to enhance overall system performance and efficiency. Additionally, Table 6 presents data on voltage drop and power loss, revealing voltage drops ranging between 0.26 and 4.01 percent.

Notably, the transformer line from Bus 1 to Bus 8 experiences the highest voltage drop of 4.01 percent, along with significant power losses amounting to 20.51 kW (real) and 71.79 kVAR (reactive). In summary, the simulation results prior to the installation of capacitor banks highlight several key issues, including low power factor, excessive current flow, significant voltage deviations, and high power losses. These conditions strongly indicate the need for reactive power compensation through the implementation of capacitor banks in order to improve power factor, reduce energy losses, and stabilize the voltage profile in accordance with acceptable operational standards.

C. Simulation Result After Compensation

Prior to the installation of the capacitor bank, the system recorded 929.9 kW of active power, 1001.2 kVAR of reactive power, 39.44 A of current, and a low power factor of 68.05%, indicating high reactive demand and energy inefficiency. After reactive power compensation using the capacitor bank, simulation results showed clear improvements. Active power slightly decreased to 917.3 kW, while reactive power was reduced significantly to 509.9 kVAR. The current dropped to 30.3 A, reducing the load on the system. The power factor improved substantially to 87.4%, moving closer to the ideal level typically targeted for efficient distribution networks.

Tables 7 until Table10 present a comprehensive summary of the simulation results after the installation of the capacitor bank for power factor correction in the electrical distribution system. Table 7 shows the Bus 1 simulation data after compensation, indicating a significant improvement in power factor from its previous low value. The power factor has improved to 87.37%, with the reactive power at Bus 1 reduced to 508.3 kVAR from its initial higher value. This reduction in reactive power demand leads to a lower current of 30.16 A compared to the uncompensated scenario, highlighting the direct impact of capacitor bank installation on lowering current flow and improving system efficiency.

Table 8 presents bus-by-bus simulation data after compensation, detailing voltage levels, active and reactive power, and currents at multiple buses. Bus 1 maintains its rated voltage of 20 kV with 912.9 kW active power and 508.3 kVAR reactive power. The 0.404 kV load buses (Bus 6, Bus 7, Bus 8, and Bus 9) exhibit voltage regulation around 388.8 V to 395.7 V. Active power at these load buses is generally high, approaching or exceeding 887 kW in many cases, while reactive power remains in the 466 – 903 kVAR range, accompanied by large load currents exceeding 1400 A up to 1882 A. The simulation suggests that even after compensation, the load-side demand remains substantial, requiring careful system design for cable sizing and voltage drop management.

Table 9 provides load data after compensation, listing individual loads and the effect of the installed capacitor bank. The capacitor bank itself is sized to provide -488.4 kVAR of compensation, with a measured reactive power output of approximately -452.5 kVAR at 404 V, helping offset much of the system's lagging reactive demand. Loads such as Flood Pumps 1–3 and Sludge Pump 1 operate at around 70% power factor, indicating that while overall system power factor at the main bus has improved, local loads still exhibit significant reactive demand that needs to be managed. The smaller Load 1 shows a near-unity power factor of 100%, reflecting balanced operation.

Table 6 details voltage drops and power losses on specific cables after capacitor bank installation. Voltage drops are minimal on most cables, with the highest observed at Cable 25 (1.7% drop between Bus 8 and Bus 9). Real power losses vary from small values such as 0.216 kW on Cable 5 to significant losses of 12.19 kW on Cable 25. Similarly, reactive power losses range up to 14.89 kVAR on Cable 25. This table underscores the importance of reactive power compensation in reducing overall system losses and voltage variations, demonstrating that strategic placement of capacitor banks can improve both voltage regulation and efficiency across the network. Overall, these tables collectively illustrate the benefits and remaining challenges of power factor correction in complex electrical distribution systems in PA Jemursari Prapen Pump House, Surabaya.

TABLE 7. BUS 1 SIMULATION DATA AFTER COMPENSATION

ID	Terminal Bus	Type	Rated Voltage (V)	Active Power (kW)	Reactive Power (kVAR)	Current (A)	% PF
U2	Bus1	Power Grid	20,000	912.9	508.3	30.16	87.37

TABLE 8. BUS-BY-BUS SIMULATION DATA AFTER COMPENSATION

Bus ID	Nominal Voltage (kV)	Type	Voltage (V)	Active Power (kW)	Reactive Power (kVAR)	Current (A)
Bus1	20	SWNG	20000	912.9	508.3	30.16
Bus6	0.404	Load	388.8	888.5	903.8	1882
Bus7	0.404	Load	388.8	887.4	903.8	1881
Bus8	0.404	Load	395.7	900.9	466.3	1480
Bus9	0.404	Load	388.8	888.7	903.8	1882

TABLE 9. LOAD DATA AFTER COMPENSATION

ID	Rating/Limit	Measured Voltage (V)	Active Power (kW)	Reactive Power (kVAR)	Current (A)	% PF
Capacitor Bank	-488.4 kVAR	404	0	-452.5	671.8	0
Load 1	1.2 kVA	231	1.13	0	5.048	100
Flood Pump 1	172.1 kW	400	215.1	219.5	458.5	70
Flood Pump 2	161 kW	404	201.2	205.3	428.2	70
Flood Pump 3	264.4 kW	404	330.5	337.2	704.4	70
Sludge Pump 1	68.9 kW	404	86.12	87.87	183.5	70

TABLE 10. VOLTAGE DROP AND POWER LOSS AFTER CAPACITOR BANK INSTALLATION

ID	Bus1	Bus2	Voltage Drop (%)	Real Power Loss (kW)	Reactive Power Loss (kVAR)
Cable 5	Bus9	Capacitor Bank	-0.02	0.216	0.0812
Cable 7	Bus7	Sludge Pump 1	0.43	0.628	0.16
Cable 9	Bus7	Sludge Pump 2	0.26	0.222	0.0565
Cable 15	Bus7	Flood Pump 1	0.45	1.43	0.606
Cable 20	Bus7	Flood Pump 2	0.29	0.8	0.422
Cable 23	Bus7	Flood Pump 3	0.45	1.76	1.37
Cable 25	Bus8	Bus 9	1.7	12.19	14.89

D. Discussion

Under conditions prior to the installation of the capacitor bank, the electrical distribution system exhibited characteristics of poor efficiency. The active power load was recorded at 929.9 kW, while the reactive power demand was extremely high at 1001.2 kVAR. The current flowing through the system was also substantial, measured at 39.44 A. The power factor at this stage was only 68.05%, which is considered low. A low power factor indicates a dominant inductive load and high consumption of reactive power that does not perform useful work, leading to wasted energy. This condition increases power losses in the distribution network and reduces the capacity of the lines to deliver useful active power. Additionally, operating with a low power factor can result in financial penalties from the electricity supplier and requires the use of oversized distribution equipment to handle the higher current. After installing the capacitor bank as a reactive power compensation measure, simulation results showed significant improvements. The active power decreased slightly to 917.3 kW, which is considered a minor variation likely due to dynamic conditions or simulation tolerances. More importantly, reactive power demand dropped sharply to 509.9 kVAR. This substantial reduction in reactive power directly led to a decrease in current to 30.3 A, indicating a reduced load on the PA Jemursari Prapen Pump House, Surabaya.

IV. CONCLUSION

A comparative analysis of the simulation results before and after capacitor bank installation reveals clear benefits of reactive power compensation in improving system performance. Initially, as seen in Tables 3 through 6, the system at Bus 1 operated with an active power of approximately 929.8 kW and a high reactive power of around 1001 kVAR, resulting in a low power factor of roughly 68.06% and significant current flow of 39.44 A. This was compounded by voltage drops along the network most notably up to 4.01% between Bus 1 and Bus 8 leading to poor voltage profiles on low-voltage buses (down to 378 V). The primary loads, such as flood and sludge pumps, exhibited poor power factors around 70%, and demanded very high currents exceeding 700 A in some cases. These findings underscored the system's inefficiency, elevated losses, and operational stresses. After capacitor bank installation, simulation data showed marked improvement. Reactive power at Bus 1 was reduced to about 509.9 kVAR, lowering the current to 30.3 A and raising the power factor to 87.4%, aligning with industry standards.

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