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Analysis of the Effect of Capacitor Bank Integration and Harmonic Filters on Improving Energy Efficiency and the Reliability of the Electrical System at Hotel Danau Toba Medan

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Hotel Danau Toba Internasional Medan consumes a large amount of electricity due to the use of inductive and non-linear loads, which can reduce power quality. This study aims to evaluate the existing power quality and assess the effect of installing capacitor banks and harmonic filters in improving the efficiency and reliability of the electrical system. The methods used in this study include direct measurements, analysis referring to the IEEE Std. 519-2014 standard, and simulations with ETAP software version 16.0.0. The measurement results show a low power factor of 0.759, with a voltage drop reaching 15.65 kV from a nominal voltage of 20 kV, and the highest voltage unbalance recorded at 2.64% on panel 1 during the weekend. Based on the simulation results, the installation of a capacitor bank with a capacity of 525.22 kVAR can improve the power factor to 0.972 and reduce the current from 2015.2 A to 1782.6 A. To prevent resonance caused by harmonics, a reactor detuned by 8% is used. This implementation has been proven to increase energy efficiency, maintain system stability, and generate operational cost savings of IDR 221,400,000 annually.

Keywords: : power quality, power factor, capacitor bank, harmonic filter, energy efficiency.

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1. Introduction

The hospitality sector is one of the industries with a high level of electricity consumption. Four- and five-star hotels are known to consume up to 380 kWh/m²/year (Rotimi et al., 2017). In Indonesia, the commercial building sector, including hotels, contributes approximately 30% of the total national energy consumption. (Kementerian ESDM, 2020).

The high level of energy consumption makes energy efficiency and the reliability of electrical systems crucial aspects, not only for reducing operational costs but also for supporting energy conservation policies and reducing greenhouse gas emissions. Energy efficiency in hotel electrical systems is not only related to the use of energy-efficient equipment but is also influenced by power quality. Poor power quality can lead to increased energy consumption, reduced equipment lifespan, and operational disruptions (Mahela & Shaik, 2019). Hotels that operate 24 hours a day require reliable and stable electrical systems to maintain service quality. Therefore, power quality improvement technologies such as capacitor banks and harmonic filters have become relevant solutions.

Hotel Danau Toba Medan is a four-star hotel with 213 rooms and various supporting facilities such as restaurants, conference rooms, and a fitness center (Siregar et al., 2021). Based on an energy audit by the Ministry of Energy and Mineral Resources (MEMR), four-star hotels in Indonesia have an average Energy

Consumption Intensity (ECI) of 300 kWh/m²/year (MEMR, 2019). With a building area of approximately 20,000 m², the estimated annual electricity consumption of Hotel Danau Toba Medan reaches 6,000,000 kWh, indicating significant energy-saving potential. The hotel's electrical distribution system uses a radial configuration with a voltage of 380/220 V, where the main loads come from air conditioning systems (40–50%), lighting (20–25%), elevators and escalators (10–15%), kitchen and laundry equipment (10–15%), and other loads (Prasetyo & Winardi, 2020).

These nonlinear load characteristics have the potential to cause power quality issues such as low power factor (0.75–0.80), high harmonic distortion (current THD of 18–22%), and excessive reactive power, exceeding the IEEE 519-2014 standard (Balasubramaniam & Singaravelu, 2018; Ferraro et al., 2020). The implementation of capacitor banks has been proven to improve the power factor up to 0.95 and generate energy savings of 3.2% per year (Liang et al., 2020), while harmonic filters can reduce current THD to below 5% (Sharma & Mahela, 2020). A study in Europe shows that integrating these two technologies can achieve average energy savings of 7.5% and increase the Power Quality Index by 22% (Papathanassiou et al., 2019). However, in Indonesia, only about 35% of four- and five-star hotels have implemented comprehensive power quality improvements (Center for Electricity Research and Development, 2020). Therefore, research on the integration of capacitor banks and harmonic filters in the electrical system of Hotel Danau Toba Medan is highly relevant to improve energy efficiency and the reliability of the hotel's electrical system.

2. Theoretical Study

Hotel Electrical System

A hotel's electrical system is a complex network consisting of various components to distribute electrical power throughout the hotel's facilities. According to Zhuang et al. (2020), this system must be designed to handle varying and fluctuating loads, ranging from lighting and HVAC to elevators and kitchen equipment. Lu et al. (2019) emphasize the importance of efficient distribution system design. To estimate the total hotel load, IEEE Std 241-1990 recommends the following formula:

$$\text{Total Load} = \sum(Ai \times Di \times Fi)$$

Where:
Ai = Area for each type of room
Di = Load density for each room type (W/m²)
Fi= Diversity factor for each load type

Chen et al. (2022) proposed a more sophisticated approach by taking temporal variations into account:

$$P(t) = Pb(t) + \sum(Pv,i(t) \times fi(t))$$

Where:
P(t)= Total load at time t
Pb(t) = Basic load at time t
Pv,i(t) = Variable load of type i at time t
fi(t)= Variable load of type i at time t

Power Quality

Power quality is crucial for hotel operations. Wakileh (2021) defines power quality as the ability of an electrical system to provide stable, uninterrupted energy. Power quality issues can lead to equipment damage, operational disruptions, and increased energy costs. According to Fuchs & Masoum (2018), some key parameters in power quality include harmonics, voltage fluctuations, phase imbalance, and power factor. They highlight the importance of monitoring and controlling these parameters to ensure efficient operation and minimize disruptions. One important parameter in power quality is Total Harmonic Distortion (THD). According to IEEE Std 519-2014, THD for voltage is calculated using the formula:

$$THD\_V = \sqrt{(\sum(Vn^2) / V1^2)} \times 100\%$$

Where :
Vn = Nth harmonic voltage
V1 = Fundamental stress

And for the current:

$$THD\_I = \sqrt{(\sum(In^2) / I1^2)} \times 100\%$$

Where :
Vn, In = Nth harmonic components for voltage and current
V1, I1= Fundamental components of voltage and current

Fuchs & Masoum (2018) emphasize that in the hotel context, the main sources of harmonics include electronic equipment, lighting systems, and variable frequency motor drives (VFDs) used in HVAC systems.

Bank Kapasitor

Capacitor banks are devices used to improve power factor and reduce losses in electrical systems. Sharma & Mahela (2020) explain that capacitor banks can significantly improve the efficiency of hotel electrical distribution systems by reducing reactive current. Research by Ahmed et al. (2021) shows that proper use of capacitor banks can result in energy savings of up to 5-10% in hotel electrical systems. They also discuss the importance of optimal capacitor bank placement and control to maximize their benefits. To calculate the required capacitor capacity, the following formula is used:

$$Qc = P \times (\tan \varphi 1 - \tan \varphi 2)$$

Where :
Qc = Required capacitor capacity (kVAR)
P = Active power (kW)
φ1 = Initial power factor angle
φ2 = Desired power factor angle

Ahmed et al. (2021) developed an optimization model for capacitor bank placement in a hotel distribution system:

$$\text{Min } F = \sum(Ci \times Xi) + Ke \times \sum(PLi)$$

With limitations:
Where :

$$Vmin \le Vi \le Vmax \; ; \sum Qci \le Qtotal$$

F= Total cost objective function
Ci = Capacitor cost at bus i
Xi = Binary variable (1 if capacitors are installed, 0 otherwise)
Ke = Energy cost per kWh
PLi = Power losses at branch i Vi = Voltage at bus i
Qci = Capacitor capacity at bus i
Qtotal = Total available capacitor capacity

Harmonic Filter

Harmonics in electrical systems can cause various problems, including overheating of equipment and reduced efficiency. Akagi et al. (2017) explain that harmonic filters are an effective solution to address these issues. They discuss various types of harmonic filters, including passive, active, and hybrid filters.

For passive filters, the resonant frequency is calculated as:

$$fr = 1 / (2\pi\sqrt{(LC)})$$

where :
fr = Resonant frequency
L = Inductance
C = Filter capacitance

In the hotel context, Jain & Singh (2022) demonstrated that the use of harmonic filters can significantly improve power quality and energy efficiency. They recommend an integrated approach to harmonic filter design that takes into account the hotel's specific load characteristics.

$$\text{Min } F1 = \sum(THD\_Vi) \text{ Min } F2 = \sum(Ci \times Xi)$$

With limitations:
Where :

$$THD\_Vi \leq THD\_max \; Ii \leq Imax$$

F1 = Objective function for minimizing THD
F2 = Objective function for minimizing cost
THD_Vi = THD voltage at bus i
Ci = Filter cost at bus i
Xi = Binary variable (1 if filter installed, 0 otherwise) Ii = Harmonic current in branch

Energy Efficiency

Energy efficiency is a crucial aspect of modern hotel management. Según Pérez-Lombard et al. (2018) reported that the hotel sector consumes approximately 2-3% of total global energy. They emphasized the importance of a comprehensive energy efficiency strategy that includes improvements to HVAC systems, lighting, and other electrical equipment.
Energy Use Intensity (EUI) is a common metric for measuring a building's energy efficiency:
EUI = Total Annual Energy Consumption / Total Floor Area
For HVAC systems, efficiency is often measured using the Coefficient of Performance (COP):

$$COP = Qc / W$$

Where :
Qc = Cooling capacity
W = Input work

Kang et al. (2020) proposed a multifaceted approach to improving energy efficiency in hotels, including the use of smart building technology, IoT-based energy management systems, and renewable energy utilization. Implementing this strategy can result in energy savings of up to 30%.
With limitations:
Where :

$$\text{Min } E = \sum(Ei \times Pi)$$

$$Tmin \leq Ti \leq Tmax; \; Lmin \leq Li \leq Lmax$$

E = Total energy consumption
Di = Device energy consumption
Di = Device operating status (0 or 1) Ti = Room temperature (i)
Li = Room illumination level

System Reliability

Electrical system reliability is crucial for smooth hotel operations. Billinton & Allan (2017) define electrical power system reliability as the system's ability to provide a continuous, high-quality supply of electricity to customers. Some reliability metrics include:

1. System Average Interruption Duration Index (SAIDI):

$$SAIDI = \sum(ri \times Ni) / NT$$

2. System Average Interruption Frequency Index (SAIFI):

$$SAIFI = \sum(\lambda i \times Ni) / NT$$

Where :
ri = Recovery time for each outage
λi = Outage frequency
Ni = Number of customers affected for each outage
NT = Total number of customers served

In the hotel context, Chen et al. (2023) emphasize the importance of redundant system design and the use of uninterruptible power supplies (UPS) to ensure electricity availability.

$$R(t) = \exp(-\lambda t)$$

Where :
R(t) = System reliability at time t
λ = System failure rate

3. Research Methods

Time and Place of Research

The research was conducted at the Danau Toba Hotel Medan from July to August 2024. The selection of this location was based on the availability of a complex and representative hotel electrical system for the analysis of the integration of capacitor banks and harmonic filters.

Research Variables

1. Power Factor. Measures the ratio of active power to apparent power before and after integration.
2. Total Harmonic Distortion (THD). Calculates the level of harmonic distortion in the system before and after the installation of a harmonic filter.
3. System Losses. Analyzes the reduction in power losses in the system after the integration of capacitor banks and harmonic filters.
4. Bus Voltage. Monitors changes in the voltage profile on the system buses after integration.
5. Energy Efficiency. Calculates the overall energy efficiency improvement of the system reliability index. Measures changes in reliability indices such as SAIDI.

Research Flowchart

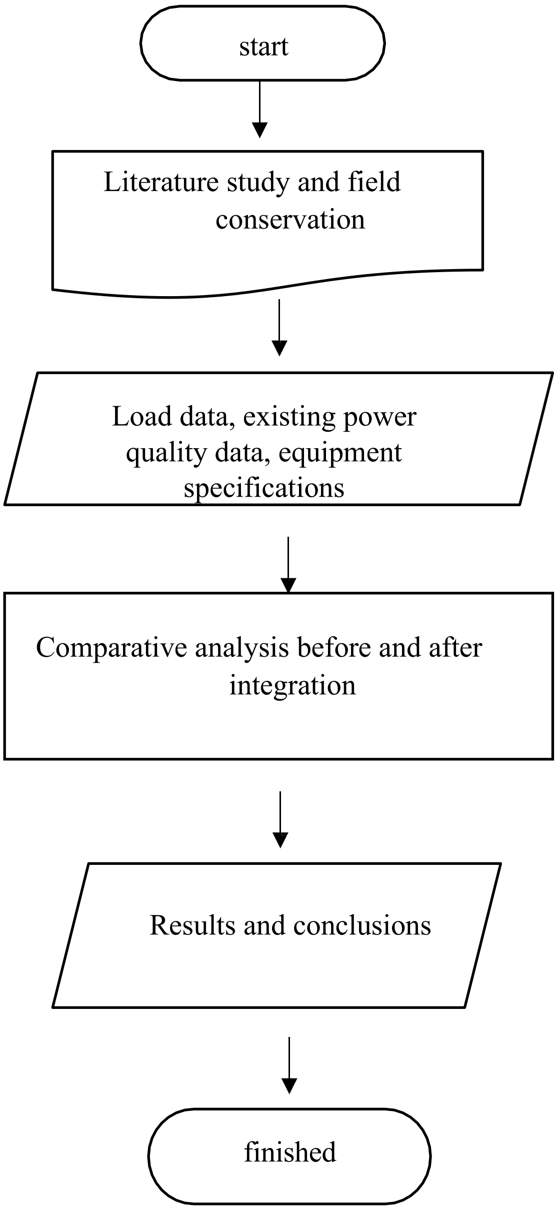

Figure 1. Research Flowchart

4. Results and Discussion

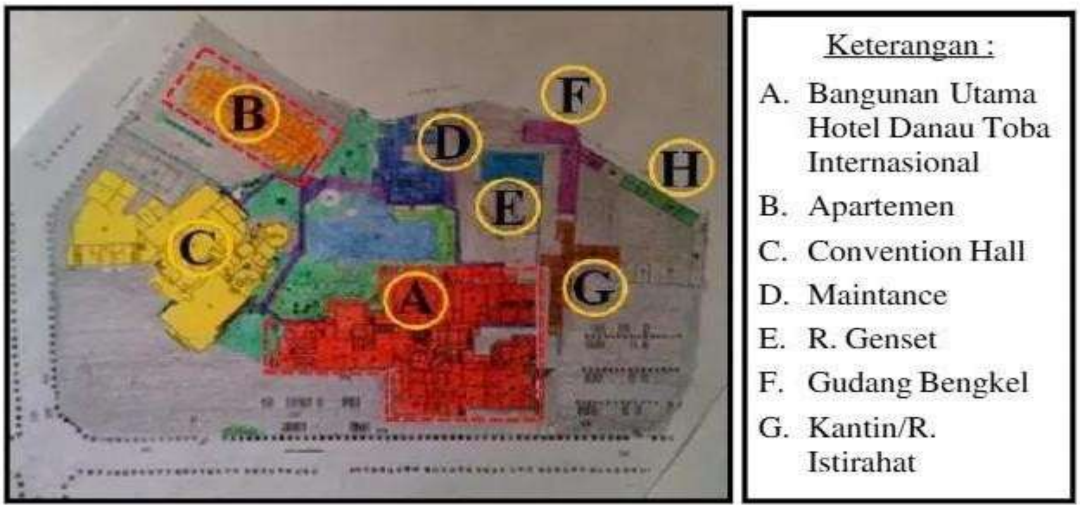

Figure 2. Site plan of Hotel Danau Toba International

Lake Toba International Hotel Electrical System

The electrical system at the Danau Toba International Hotel obtains its energy supply from PLN and can be categorized into the S-3 tariff (> 200kVA) and uses a backup energy supply generator set connected to a 20 kV step-down power transformer with a capacity of 380 kVA.

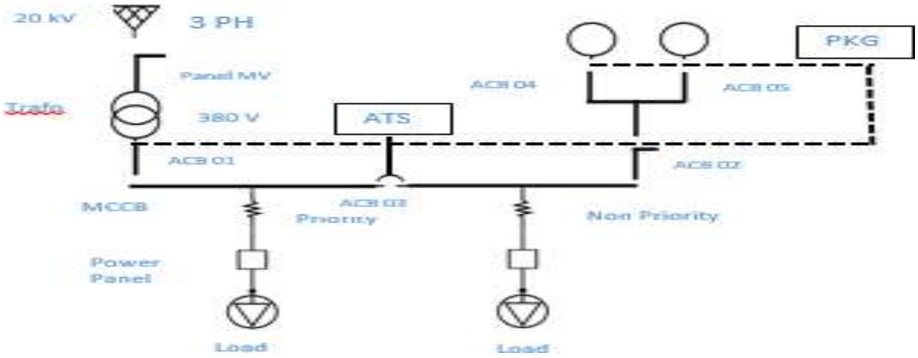

Figure 3. Single Line Diagram of the Electrical System of the International Lake Toba Hotel

Table 1. Electrical System of the International Lake Toba Hotel

Load	kVA	Power Factor (PF)	kVAR	kW
Floor 1	268	0.812	156	218
Floor 2	249	0.824	141	205
Floors 3–10	287	0.860	146	246
Floor 11	282	0.822	128	243
PLN (Utility Supply)	±435	—	—	—
Transformer	70 kV → 20 kV	—	—	—
Hotel Danau Toba International Transformer	20 kV → 220/380 V	0.759	—	—

Bus Loading Summary Report

0.759

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic					
ID	kV	Rated Amp	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Percent Loading
1st Floor	0.380		0	0	0	0	0	0	0	0	0.268	81.2	498.1	
2nd Floor	0.380		0	0	0	0	0	0	0	0	0.249	82.4	462.0	
3rd Floor	0.380		0	0	0	0	0	0	0	0	0.287	86.0	532.7	
4rd Floor	0.380		0	0	0	0	0	0	0	0	0.282	87.4	524.6	
Bus01	70.000		0	0	0	0	0	0	0	0	1.326	75.9	10.9	
Bus02	20.000		0	0	0	0	0	0	0	0	1.326	75.9	38.3	
Bus03	0.380		0	0	0	0	0	0	0	0	1.084	84.5	2015.2	
Bus14	0.380		0.042	0.031	0	0	0	0	0	0	0.052	80.0	155.1	
Bus17	0.380		0.008	0.006	0	0	0	0	0	0	0.011	80.0	19.7	
Bus19	0.380		0.029	0.022	0	0	0	0	0	0	0.036	80.0	69.4	
Bus21	0.380		0.056	0.042	0	0	0	0	0	0	0.069	80.0	136.4	
Bus23	0.380		0.026	0.019	0	0	0	0	0	0	0.032	80.0	61.1	
Bus25	0.380		0.001	0.001	0	0	0	0	0	0	0.002	80.0	3.2	

Figure 4. ETAP Report: Hotel Danau Toba Internasional's electrical system

Simulation results for Bus 1 and Bus 2 show a low power factor of 0.759 (PF < 0.90), caused by high power consumption and the dominance of inductive loads. This condition leads to inefficient use of electrical energy due to increased reactive power, which results in increased current, conductor losses, and increased kVA capacity of electrical equipment. Furthermore, a low power factor can potentially result in sanctions from PLN if reactive power consumption exceeds 62% of active energy (kWh) in a single month. Therefore, efforts to improve energy efficiency are needed to reduce Hotel Danau Toba Internasional's operational costs.

Power Quality

Power quality indicates the degree to which voltage, frequency, and waveform conform to established standards. Measurements on January 10, 2025, showed a voltage drop of up to 15.65 kV on a 20 kV system for 0.5 seconds, exceeding the voltage tolerance limit of ±5%. The ETAP 16.0.0 simulation used a loading assumption of 40% of the total load of 20,520 MVA. Simulation and measurements of the existing network showed a power flow of 7,525 MVA. The power quality parameters analyzed included overvoltage, undervoltage, and voltage imbalance, which were used as the basis for evaluating the condition of the existing network.

Table 2. Overvoltage Measurements on the MDP Panel at the Danau Toba International Hotel

No	MDP Panel	Overvoltage (Volt)	Voltage Increase (%)	Remarks
1	Panel 1 (Weekend)	228.99	4.34	Compliant
2	Panel 1 (Weekday)	239.59	4.16	Compliant
3	Panel 2 (Weekend)	239.85	3.34	Compliant
4	Panel 2 (Weekday)	221.80	3.82	Compliant

Based on the table above, it is known that the overvoltage at the Danau Toba International Hotel on two MDP panels at different times, on weekdays and weekends, remained within the standard limit of >5% (Fuchs & Masoum, 2018). The monitoring data obtained can be used as parameters in analyzing undervoltage (L-N) problems.

Table 3. Undervoltage Measurements on the Danau Toba International Hotel MDP Panel

No	MDP Panel	Undervoltage (Volt)	Voltage Change (%)	Remarks
1	Panel 1 (Weekend)	218.21	-3.99	Compliant
2	Panel 2 (Weekend)	223.11	-1.67	Compliant

No	MDP Panel	Undervoltage (Volt)	Voltage Change (%)	Remarks
3	Panel 1 (Weekday)	231.22	-1.11	Compliant
4	Panel 2 (Weekday)	245.32	-2.03	Compliant

Based on the table, it can be seen that the undervoltage at the Danau Toba International Hotel on two panels at different times, on weekdays and weekends, remained within the standard limit of >-10% (Fuchs & Masoum, 2018). The monitoring results obtained can be used as parameters in analyzing voltage imbalance (L-L) problems.

Table 4. Voltage Unbalance Calculation for the Danau Toba International Hotel MDP Panel

No	MDP Panel	Voltage Unbalance (%)	Remarks
1	Panel 1 (Weekend)	2.54	Non-compliant
2	Panel 2 (Weekend)	1.52	Compliant
3	Panel 1 (Weekday)	1.44	Compliant
4	Panel 2 (Weekday)	1.94	Compliant

The table above shows that the voltage imbalance at the Danau Toba International Hotel at two different times, namely, panel 1 on weekends, exceeded the standard voltage imbalance limit of >2%. However, panel 1 on weekdays and panel 2 on weekends and weekdays still met the standard of >2% according to IEEE Std 519-2014. Reactive Power Compensation (Qc) Calculation:

Based on the results in Figure 4, the lowest power factor values are found at buses 1 and 2. Bus 1 represents the power flow from the PLN transformer to the Danau Toba International Hotel transformer, and bus 2 represents the power flow from the hotel transformer to the buses and main panel.
Note:
Initial active power value = 1007.63 kW
Initial apparent power = 1325 kVA
($Q_c = P \times (\tan \varphi 1 - \tan \varphi 2)$)
Initial reactive power = 823.00 kVAR
Active power value = 1007.63 kW
Apparent power value = 1,059.79 kVA

Thus, the reactive power value is 297.78 kVAR. With cos φ 0.90. With a difference of 525.22 kVAR, therefore the required capacitor bank capacity value for bus 3 is 528.980 kVAR.

Capacitor Bank

After the power factor improvement is carried out, the next step is to use a capacitor bank to simplify and increase the power factor to 0.90 (>0.90) by adding it to the main bus, namely bus 3. The following are the simulation results in the ETAP software:

ETAP
16.0.0

Bus Loading Summary Report

0.972

Figure 5. ETAP Report of the Electrical System of Hotel Danau Toba International After the Use of Capacitor Banks

From the program simulation results, it can be seen that the electrical system simulation of Hotel Danau Toba International (as shown in Figure 4.4) at Bus 1 and Bus 2 initially had a power factor of 75.9%, which was successfully improved through the use of a capacitor bank with a capacity of 525.22 kVAR. After the simulation process in the ETAP software (Figure 4.6), the power factor increased to 97.2%. This improvement was due to the addition at Bus 3, which proved to be efficient as indicated by the reduction in current from 2015.2 A to 1782.6 A.

Calculation of Cost Savings from Capacitor Bank Optimization: The calculation and simulation results show that the use of capacitor banks in the electrical system of Hotel Danau Toba International provides positive impacts, including current reduction, decreased power losses, and improved power factor. Although the installation of capacitor banks requires initial investment and maintenance costs, economic analysis indicates that the resulting electricity cost savings are significantly greater, making it a feasible long-term investment.

Hotel Danau Toba International is categorized as an S3 customer group (above 200 kVA). Before the use of capacitor banks, electricity consumption was recorded at 10,000 kWh with an annual cost of IDR 523,500,000. After the implementation of capacitor banks, electricity consumption decreased to 8,231 kWh with an annual cost of IDR 302,100,000. Thus, the total electricity cost savings amount to IDR 221,400,000 per year, or approximately IDR 10,070,000 per month under stable load conditions.

These results indicate that capacitor bank optimization is highly effective in reducing operational costs and provides significant economic benefits in both the short and long term. Therefore, the use of capacitor banks is considered efficient and feasible to implement, and it should be followed by the design of harmonic filters to anticipate potential resonance in the electrical system.

Table 5. Cost Calculation Results

Before Capacitor Bank	After Capacitor Bank	Cost Savings Result
IDR 523,500,000	IDR 302,100,000	IDR 221,400,000

Harmonic Filter

Based on the power factor data and total load, the electrical system was modeled with a focus on power flow analysis, power factor evaluation, and the impact of capacitor bank implementation. The electrical system of Hotel Danau Toba International operates at a frequency of 50 Hz. The presence of nonlinear loads generates harmonic currents at multiples of the fundamental frequency, which leads to current distortion and may cause voltage distortion when these currents pass through system impedance.

To protect the capacitor bank from harmonic effects, the system employs a detuned reactor connected in series with the capacitor bank. The use of a detuned reactor is effective in preventing resonance; however, it causes an increase in voltage across the capacitor, requiring appropriate adjustment of the capacitor voltage rating used in the system.

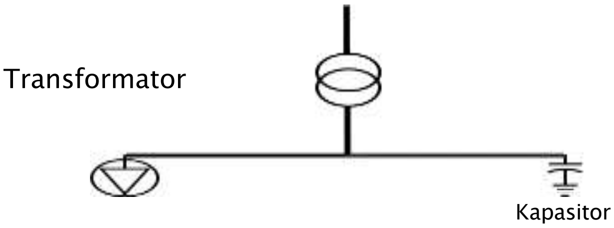

Figure 6. 400 V Capacitor in the System

As shown in the figure above, a voltage of 400 V is observed on a 380 V capacitor with a rating of 50 kVAR per step. To improve the performance of the capacitor, an 8% detuned reactor is used, resulting in a configuration as shown in the following figure.

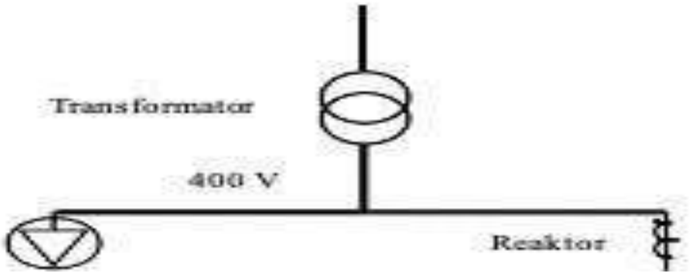

Figure 7. Adding a Detuned Reactor to a Capacitor

To determine the magnitude of the voltage increase that occurs after adding the reactor, calculate it using the following formula:

$fr = 1 / (2\pi\sqrt{(LC)}$
$fr = 1/(400(1-0,08)$ $fr =$
$400 / 0,92$
$fr = 434.78$

It can be seen that if the capacitor at an operational rating of 400 V is fitted with an 8% reactor, it can increase to 434.78 V. If ignored, it can shorten the use of the capacitor. This requires an appropriate capacitor replacement adjustment of 434.78 or more. Because it is very necessary to adjust to the voltage changes if there is an increase in harmonics, the previous capacitor value of 380 V, 50 Kvar/step needs to be readjusted to the new voltage of 434.78 V as follows:

$$Q' = \frac{Q}{1-p} = \frac{50}{1-0,08} = 54,34 \text{ kVAR/step}$$

In the following calculations, a new, more efficient capacitor is used when there is an increase in harmonics, namely 434.78 kVAR/step. However, the following data is based on the calculation results obtained at a fundamental frequency of 50 Hz.

Discussion

The existing electrical power quality conditions at Hotel Danau Toba International, Medan, show that the highest overvoltage occurs at Panel 1 during weekends at 4.34%, which is still within the IEEE Std. 519-2014 standard limit of ±5% of the nominal voltage. The lowest voltage condition also occurs at Panel 1 during weekends at −3.99%, which remains within the allowable tolerance. However, the highest voltage unbalance recorded is 2.64% at Panel 1 during weekends, which exceeds the IEEE Std. 519-2014 limit of 2%. This condition is influenced by increased energy consumption during weekends due to a higher number of guests, activities, and events at the hotel, resulting in an imbalance compared to weekday conditions.

Inductive and nonlinear loads dominating the hotel's electrical system lead to a low power factor and increased reactive power. The initial system power factor is recorded at 0.759, requiring improvement to reach a minimum target of 0.90, with a reactive power requirement of 2.917 MVAR. Based on ETAP simulation results, the installation of a 525.22 kVAR capacitor bank successfully improves the power factor to 0.972. In addition, system current is reduced from 2015.2 A to 1782.6 A, indicating improved electrical system efficiency.

Power factor correction using capacitor banks may introduce resonance issues due to harmonics; therefore, a detuned reactor installed in series is required. The electrical system of Hotel Danau Toba International operates at 50 Hz, and analysis indicates the need to adjust the capacitor from 50 kVAR at 400 V with an 8% reactor to 54 kVAR per step at 434.78 V to maintain system performance under harmonic conditions.

The integration of capacitor banks and harmonic filters has been proven to improve energy efficiency and the reliability of the hotel's electrical system. In addition to reducing reactive power and harmonic distortion, this system also results in electricity cost savings of IDR 221,400,000 per year. Harmonic filters also reduce voltage distortion, prevent resonance, extend the lifespan of electrical equipment, and maintain system stability. Therefore, the integration of capacitor banks and harmonic filters provides significant technical and economic benefits for Hotel Danau Toba International.

5. Conclusions

The electrical power quality at Hotel Danau Toba International generally still complies with the IEEE Std. 519-2014 standard. Overvoltage and undervoltage conditions remain within the allowable tolerance limits; however, voltage unbalance at Panel 1 during weekends reaches 2.64%, exceeding the standard limit.

The calculation and simulation results show that the integration of capacitor banks and harmonic filters is able to improve the efficiency of the electrical system, indicated by a reduction in reactive power from 863 kVAR to 232 kVAR and active power from 1007 kW to 962 kW. The application of capacitor banks supported by detuned reactors is effective in improving power factor, reducing harmonic distortion, maintaining system stability, and generating operational cost savings of IDR 221,400,000 per year. This combination of technologies also contributes to improved system reliability, protection of electrical equipment, and reduction of carbon emissions.

It is recommended to perform load balancing or install voltage compensators to address voltage unbalance issues, as well as to optimize the use of capacitor banks and harmonic filters to further improve the energy efficiency of the hotel's electrical system. Future research may employ other simulation software to obtain more specific results, accompanied by accurate harmonic filter design calculations. In addition, regular maintenance schedules and the assignment of competent technical personnel are necessary to maintain the reliability of the electrical system at Hotel Danau Toba International.

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