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Improving Power Quality in High-Rise Buildings with a Single-Tone Passive Filter and Capacitor Bank

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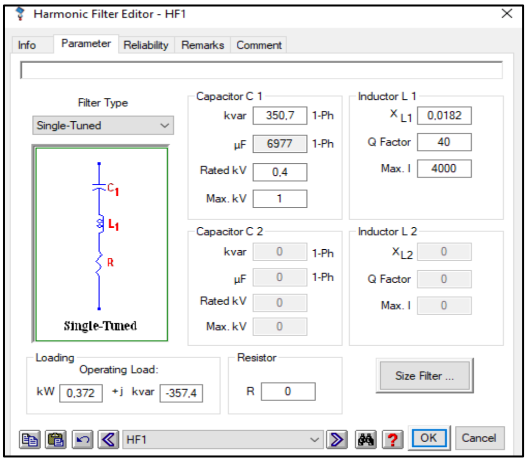
ABSTRACT



Filter Type: Single-Tuned

Capacitor C 1
kvar 350,7 1-Ph
μF 6977 1-Ph
Rated kV 0,4
Max. kV 1

Inductor L 1
X_{L1} 0,0182
Q Factor 40
Max. I 4000

Capacitor C 2
kvar 0 1-Ph
μF 0 1-Ph
Rated kV 0
Max. kV 0

Inductor L 2
X_{L2} 0
Q Factor 0
Max. I 0

Loading
Operating Load:
kW 0,372 +j kvar -357,4

Resistor
R 0

Total harmonic distortion and a low power factor are critical issues affecting power quality in modern high-rise buildings. Non-linear loads generated by highly efficient electrical equipment cause total harmonic distortion. On the other hand, low power factor is caused by induction machines, excessively long cables, and inefficient equipment. This research aims to design a single-tunable filter and capacitor bank to address power quality issues. Our method involves utilizing a single-line building design diagram and conducting load simulations using ETAP 19.0.1 software. Our method is a harmonic load flow analysis. We use this method to calculate the harmonic distribution at various points within the electrical network. Harmonic flow analysis aids in identifying the harmonic contributions from various non-linear loads within the system. For research, we implemented a single-tuned passive filter and capacitor bank in the building's electrical system. We initiate the study by analyzing the transformer's total harmonic distortion (THD) and then make iterative adjustments to parameter values until we achieve compliance with the IEEE 519-2014 standard. As a result, the study recommends the installation of two single-tuned filters for orders 5 and 7, as well as the inclusion of a capacitor bank with a capacity of XXX. This reduces the system's THDi value from 21.77% to 4.45% and 22.63% to 4.45%, respectively. The power factor increased from 85.78% to 99.69% and 88.68% to 99.41%, respectively.

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1. INTRODUCTION

Power quality issues are essential for high-rise managers. Paying attention to power quality can reduce the possibility of damage to sensitive equipment in high-rise office buildings [1][2]. A common problem found in modern buildings today is total harmonic distortion. Harmonics are signs of creating a sine wave with a frequency resulting from multiplying a whole number by the fundamental frequency [3]. If a frequency wave combines with a harmonic wave that has multiples of the fundamental frequency, a wave will arise whose frequency changes, causing the wave to lose its sinusoidal shape [4][5].

The extensive use of non-linear electrical loads on building equipment causes harmonic waves. The dominant electrical load in facilities such as offices, hospitals, shopping centers, universities, airports, factories, and other public places generally falls into the non-linear category [6][7]. The purpose of using non-linear loads is to save electrical energy. However, as a result, harmonic waves arise. The impact can be significant. The large harmonic content can cause the transformer to experience excessive heating even though it has not yet reached its nominal load [4][5][8][9]. Excessive heating is caused by increasing losses in the transformer, namely load losses, copper losses, eddy current losses, and hysteresis losses. The presence of harmonics in the current can increase temperatures in the transformer parts, resulting in increased power losses and reduced efficiency. This impact can then affect the power capacity that the transformer can handle [4][10]. Non-linear loads produce output waves that are not proportional to the voltage in each half cycle, so the resulting current and voltage waves are not similar to the original input waves, experiencing changes in shape or distortion [4]. The use of non-linear loads is due to their high efficiency, easy and smooth setup, small space dimensions, and flexibility. However, it has yet to be realized that the large number of non-linear load devices in the electric power system has distorted the system current by the percentage of harmonic content [8].

This research was conducted on the XYZ Building construction project at Jalan Letjen S. Parman, Tomang Village, Grogol Petamburan District, Jakarta. Building XYZ is an office building planned as a business center using non-linear loads such as VFDs (Variable Frequency Drives), inverters, LED lights, and other energy-saving equipment. The problem is that Building XYZ still needs to design a device that can overcome Total Harmonic Distortion due to non-linear loads [4][11].

This research aims to design a single-tuned passive filter to overcome total current harmonic distortion and voltage harmonic distortion in the XYZ Building's electrical system. The method used is Harmonic Load Flow Analysis, which is used to help design using ETAP 19.0.1 software. The loads used in the simulation are based on a single-line diagram of the building. The contribution of this research is in the form of a passive filter design that is suitable for Building XYZ. With an appropriate filter, you can anticipate poor power quality. The standard used to measure THD_V and THD_I is the IEEE 519-2014 standard.

2. METHODS

Several researchers have previously carried out similar research on improving energy quality. A study showed that the total harmonic distortion (THD) in the voltage of various brands of LED lamps did not exceed the limit set by the IEEE 519-2014 standard, namely a maximum of 5%, because the highest voltage harmonic detected was 2.9%. However, on the other hand, the total harmonic distortion (THD) in the current from various brands of LED lamps shows a more significant value, with the highest THD reaching 170.6%. These findings provide valuable information about the level of harmonic distortion produced by LED lamps of certain brands. [1],[11]-[14].

Non-linear loads were developed to reduce electrical energy consumption and increase efficiency. This is achieved by applying semiconductor components that can be regulated in their use [15]. From the results of the research and discussions that have been carried out, several conclusions can be drawn, such as in homes that have much modern equipment with the majority using SMPS (Switch Mode Power Supply) type resources, such as computers, the strange changes that most often appear are in the order of -3, 5, and 7. Meanwhile, other researchers measured the transformer's power reduction due to the presence of harmonics. The method used to design passive filter simulations for distribution transformers involves ETAP software. The results of this research are that after the passive filter was installed, there was a reduction in harmonic currents by reducing the previous initial value of 26.29% on transformer 1, 14.36%, then on transformer two by 24.42%, on transformer three the value exceeds the maximum limit of the IEEE 519-2014 standard, by adding a single tuned passive filter it can reduce the THD_I value in each order to 10.82% on transformer one which is 10.17% while on transformer two it becomes 11.25% and then on transformer three already below the IEEE 519 – 2014 standard. Power losses decreased to 14.23 kW on transformer 1, then 13.23 kW on transformer 2, and 13.7 kW on transformer 3 [16].

2.1. Total Harmonic Distortion (THD)

Harmonics can be explained as part of a periodic wave with a sinusoidal shape and a frequency that is a multiple of the fundamental frequency. For example, if the fundamental frequency of an electrical system is 50 Hz, then the second harmonic will have a wave with a frequency of 100 Hz, the third harmonic will have a wave with a frequency of 150 Hz, and so on. For a more detailed explanation, we can refer to Table 1.

Table 1. Fundamental frequencies and their multiples

Frequency (Hz)	**Term**
50	Fundamental Frequency
100	Second Harmonic
150	Third Harmonic
200	Fourth Harmonic
⋮	⋮

To get the THD value for voltage (THD_V), calculations can be carried out using Equation (1) [5]. Where, THD_V is the Total Harmonic Distortion voltage (%) and V_n is the n-th harmonic voltage value.

$$THD_V = \frac{\sqrt{{V_2}^2 + {V_3}^2 + {V_4}^2 + \ldots + {V_n}^2}}{V_1} \tag{1}$$

Meanwhile, we can calculate the current THD (THD_I) value using Equation (2). Where, THD_I is the Harmonic Distortion Total current (%) and I_n is the N-th harmonic current value.

$$THD_I = \frac{\sqrt{{I_2}^2 + {I_3}^2 + {I_4}^2 + \ldots + {I_n}^2}}{I_1} \tag{2}$$

Harmonics themselves have a limiting value that must be maintained to maintain the power quality of the electrical system. The IEEE 519-2014 contains the maximum value limits for total harmonic voltage distortion in electrical systems, as seen in Table 2.

Table 2. Voltage harmonic distortion limit standards (IEEE 519-2014)

Bus Voltage	**IHD_V (%)**	**THD_V (%)**
V ≤ 1 KV	5.0	8.0
1 KV < V < 69 KV	3.0	5.0
69 KV < V < 161 KV	1.5	2.5
161 KV < V	1.0	1.5

Meanwhile, the standard maximum limits for current harmonic distortion can be seen in Table 3 for operating voltages below 69 kV. Because this research uses an operating voltage of 400 V, the IEEE 519-2014 standard with Vn ≤ 69 kV is used.

Table 3. Standard limits for current harmonic distortion with Vn ≤ 69 kV

IS/IL	**Individual Harmonic Order (odd harmonics)**					**THD**
Ratio	**3≤ h<<11**	**11<h<17**	**17<h<23**	**23<h<35**	**35<h≤50**	**(%)**
<20	4	2	1.5	0.6	0.3	5
21-50	7	3.5	2.5	1	0.5	8
51-100	10	4.5	4	1.5	0.7	12
101-1000	12	5.5	5	2	1	15
>1000	15	7	6	2.5	1,4	20

To determine the maximum distortion limit value for each order, first, calculate the I_{SC}/I_L. The I_{SC} value can be calculated using Equation (3) [5] To find out the I_{SC}. Where, I_{SC} is the Short circuit current (A), S is the Apparent power (VA), V is the Voltage (V), and Z is the Transformer impedance (%).

$$I_{SC} = \frac{S}{\sqrt{3 \times V \times Z(\%)}} \tag{3}$$

After getting I_{SC}, the I_L value is needed as a comparison value. I_L is obtained using Equation (4), assuming $I_L = I_{FL}$ [5]. Where, I_{FL} is the Full load current (A), S is the Apparent power (VA), and V is the Voltage (V).

$$I_{F_L} = \frac{S}{\sqrt{3} \times V} \tag{4}$$

The primary purpose of using a harmonic filter is to overcome the impact of harmonics by reducing the wave level at a specific frequency of current or voltage. One type of passive filter that is most often used is the single-tuned filter. Figure 1 shows several types of passive filters.

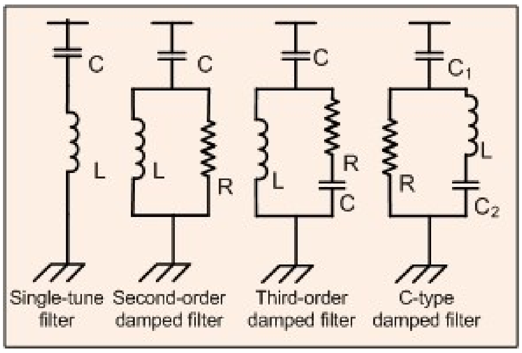


Figure 1. Types of passive filters

Passive filters are designed to improve the power factor. The compensated reactive power can be calculated using Equation (5) [17]. Where, ΔQ is the Reactive power (VAR), $\phi_{initial}$ is the Initial power factor, and ϕ_{Terget} is the The desired power factor.

$$\Delta Q = P[tan(cos^{-1}\phi_{initial}) - tan(Cos^{-1}\phi_{Terget})] \tag{5}$$

The next step is calculating the value of the capacitor (C) used in the filter. The capacitor value can be calculated using Equation (6) [17]. Where, C is the Capacitor, ΔQ is theReactive power (VAR), V is theVoltage, Ω is the $2\Pi f$, and f is the Fundamental frequency (50 Hz).

$$C = \frac{\Delta Q}{V^2 \times \omega} \tag{6}$$

After knowing the value of the capacitor needed, we can find the value of the inductor needed to be used as a filter circuit. We can calculate the value of the required inductor using Equation (7) [17]. Where, L is the Inductor and n is the Reduced harmonic order.

$$L = \frac{1}{\omega \times n^2 \times C} \tag{7}$$

The inductive reactance value is calculated using Equation (8) [17]. We can get the resistance value by (assuming Q = 40) calculations using Equation (9) [18]. Where, X_L is the Induktive Reactance and Q is the Quality Factors.

$$X_L = \omega \times L \tag{8}$$

$$R = \frac{X_L}{Q} \tag{9}$$

The impedance of a single-tuned passive filter can be calculated using Equation (10).

$$Z = R + j(\omega L = \frac{1}{\omega C}) \tag{10}$$

Two factors must be considered in determining the values of R (resistor), L (inductor), and C (capacitor), namely Quality Factor (Q) and Relative Frequency Deviation (δ). Filters with a high Q value are adapted to handle low-frequency harmonics, such as fifth-order harmonics. The range of Q values usually ranges from 30 to 60. In single-tuned type filters, the quality factor Q is the ratio of the inductance or capacitance at the resonant frequency to the found resonance value. To calculate the Q value, you can use Equation (11) and Equation (12). Where, X_0 is the impedance of the filter and R is the Resistance of reactor.

$$Q = \frac{X_0}{R} \tag{11}$$

$$X_0 = \sqrt{\frac{L}{C}} \tag{12}$$

2.2. The electrical system in XYZ Building

The electrical system in the building is used to store all loads installed on the building. Table 4 is data from the transformer used in the building.

Table 4. Transformer data

ID	Capacity
Transformer 1	2500 kVA
Transformer 2	2500 kVA

The working voltage on the primary side is 20 kV, and then the transformer reduces the voltage to 0.4 kV. The new voltage can be distributed to each load using the required working voltage. The data on the load installed on the building is written as the overall capacity. Details of the load will be attached to this final project, while the general load can be found in Table 5.

Table 5. Data on several building loads

ID	Capacity (kVA)
SDP PARKIR	189.7
SDP EMG PARKIR	30.6
PP CHILLER	780
PP CHWP	320
SDP POMPA	164,7
DP	14.254.28
PP VAC	484.4
MDP EMERGENCY	601.5

The XYZ building is a high-rise building consisting of 32 floors. To connect each floor to the building using an elevator, each elevator uses a variable frequency drive, which is used as a motor speed control device, as shown in Table 6.

Table 6. Variable frequency drive data

ID	Capacity (kVA)	ID	Capacity (kVA)	ID	Capacity (kVA)
VFD lift (LS 01)	48	VFD lift (HZ-03)	100	VFD lift (P-01)	12
VFD lift (LS 02)	48	VFD lift (HZ-04)	100	VFD lift (P-02)	12
VFD lift (LS 03)	18	VFD lift (HZ-05)	100	VFD PP Chiller 1	585
VFD lift (LS 04)	12,5	VFD lift (LZ-01)	27	VFD PP Chiller 2	585
VFD lift (LS 05)	12,5	VFD lift (LZ-02)	27	VFD PP Chiller 3	315
VFD lift (HZ-01)	100	VFD lift (LZ-03)	27	VFD PP Chiller 4	315
VFD lift (HZ-02)	100	VFD lift (LZ-04)	27	UPS	118

2.3. Standard IEEE-519-2014

The IEEE-519-2014 standard has different values for each I_{SC}/I_L, as shown in Table 3. To determine the maximum distortion limit value for each order, first calculate the I_{SC}/I_L. The ISC value can be calculated using Equation (8).

$$I_{SC} = \frac{20.000}{\sqrt{3} \times 400 \times 7\%} = 412.393$$

So to get the I_{SC}, the I_L value is needed using Equation (9) then, $I_L = I_{FL},$ So:

$$I_{FL} = \frac{20.000}{\sqrt{3} \times 400} = 28{,}87$$

After calculating the ISC value and IL value using the equation below, the I_{SC}/I_L results are obtained as follows.

$$\frac{I_{SC}}{I_L} = \frac{412.393}{28.87} = 14.28$$

After carrying out the calculations, the I_{SC}/I_L ratio result is 14.28; a value of 14.28 is in the < 20 categories, so the THDi standard must be followed in the I_{SC}/I_L category with a ratio value of < 20. In the I_{SC}/I_L ratio category < 20, the permitted value in the 3rd to 11th order is 4%, while the THD_I is set at a maximum value of 5%.

2.4. Initial Simulation

An initial harmonic load flow simulation was conducted to analyze the building's power quality conditions before installing the filter. The software used is ETAP 19.0.1. The initial THD simulation results on the transformer are given in Table 7. Meanwhile, detailed current harmonic values are shown in Table 8. A single-tuned passive filter is used because this filter works in the desired order. Based on the data in Table 8, capacitor and inductor values were calculated for filter design. Filters are used to dampen the 5th and 7th orders.

Tabel 7. Harmonic load flow simulation data

ID	THD_i (%)	THD_v (%)	Standard (%)
Transformer 01	21.77	0.94	5
Transformer 02	22.63	0.96	5

Tabel 8. IHD_i on the transformer

Order	Transformer 01	Transformer 02	Standard
5	20.315%	21.043%	4%
7	6.783%	7.067%	4%
11	3.242%	3.635%	4%
13	1.276%	1.458%	2%
17	1.309%	1.459%	2%
19	0.799%	0.886%	1.5%
23	0.625%	0.845%	1.5%
25	0.377%	0.512%	0.6%

2.5. Single-Tuned Passive Filter Design

Based on initial simulations, it is known that the reactive power requirement needed to compensate for the electrical system on Transformer 01 is 701.4 kVAR. In the first design in the 5th order, with the assumption of dividing evenly by the number of filters, the result is 350.7 kVAR. Using Equation (6), the capacitor value is obtained.

$$C = \frac{\Delta Q}{V^2 \times \omega} = \frac{350.700\,VAR}{400^2 \times 2 \times 3.14 \times 50} = 6977\,\mu F$$

To obtain the value of C, you can find the value of the inductor using Equation (7),

$$L = \frac{1}{\omega n^2 \times C} = \frac{1}{(2 \times 3.14 \times 250)^2 \times 6977} = 5.815 \times 10^{-11} = 5.815 \times 10^{-5}\mathrm{\mu H}$$

After getting the L value, you can find the value of the inductor reactance using Equation (8),

$$X_L = \omega \times L = (2 \times 3.14 \times 50) \times 5.815 \times 10^{-5} = 0.0182\,\Omega$$

In the second design for the 7th order, with the assumption of dividing evenly by the number of filters, the result is 350.7 kVAR. Using Equation (6), the capacitor value is obtained at:

$$C = \frac{\Delta Q}{V^2 \times \omega} = \frac{350.700\,VAR}{400^2 \times 2 \times 3.14 \times 50} = 6.977\ \mathrm{\mu F}$$

After getting the C value, you can find the value of the inductor using Equation (7),

$$L = \frac{1}{\omega n^2 \times C} = \frac{1}{(2 \times 3.14 \times 350)^2 \times 6977} = 2.967 \times 10^{-5}\mu H$$

After getting the L value, you can find the value of the inductor reactance using Equation (8),

$$X_L = \omega \times L = (2 \times 3.14 \times 50) \times 2.967 \times 10^{-5} = 0.0093\ \Omega$$

Next, calculate the filter requirements for Transformer 02. The reactive power requirement needed to compensate the electrical system for Transformer 02 is 493.6 kVAR. The filter design for the 5th order, with the assumption of dividing evenly by the number of filters, results in 246.8 kVAR. By using Equation (6), the capacitor value is obtained as follows:

$$C = \frac{\Delta Q}{V^2 \times \omega} = \frac{246{,}800\ VAR}{400^2 \times 2 \times 3.14 \times 50} = 4910\ \mu F$$

By obtaining the C value, the inductor value can be found using Equation (7),

$$L = \frac{1}{\omega n^2 \times C} = \frac{1}{(2 \times 3.14 \times 250)^2 \times 4910} = 8.263 \times 10^{-11} = 8.263 \times 10^{-5} \mathrm{\mu} H$$

Next, the L value can be found for the inductor reactance value using Equation (8),

$$X_L = \omega \times L = (2 \times 3.14 \times 50) \times 8.263 \times 10^{-5} = 0.0259\ \Omega$$

In the following design, namely the filter design for the 7th order, with the assumption of dividing it equally by the number of filters, the result is 246.8 kVAR. Using Equation (7), we get a capacitor value of.

$$C = \frac{\Delta Q}{V^2 \times \omega} = \frac{246.800\ VAR}{400^2 \times 2 \times 3.14 \times 50} = 4910 \mu F$$

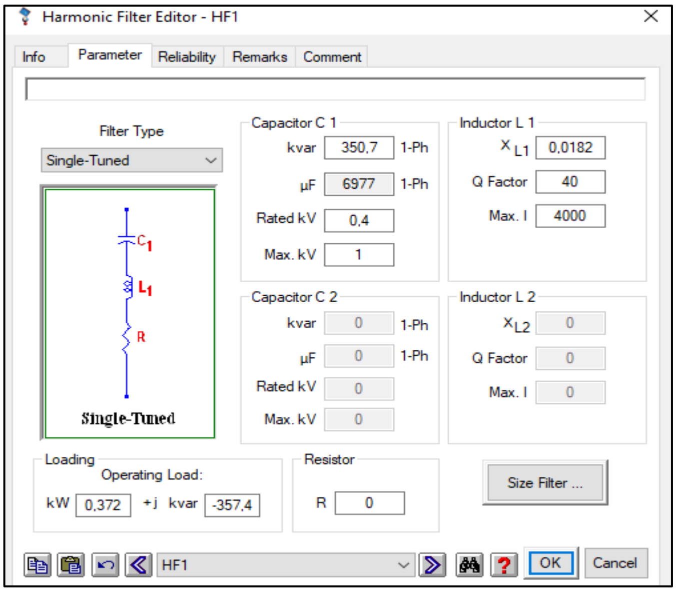
The inductor value L is calculated by Equation (7):

$$L = \frac{1}{\omega n^2 \times C} = \frac{1}{(2 \times 3.14 \times 350)^2 \times 4910} = 4.216 \times 10^{-11} = 4.216 \times 10^{-5} \mathrm{\mu} H$$

The value of the inductor reactance uses Equation (8),

$$X_L = \omega \times L = (2 \times 3.14 \times 50) \times 4.216 \times 10^{-5} = 0.0132\ \Omega$$

The low-voltage main panel bus is connected to a single-tuned filter, calculated according to Table 8. The PUTR is connected to a single-tuned filter of order five and other orders. The software's execution process is given in Figure 2. This setting applies to filters of order 7.



Filter Type: Single-Tuned

Capacitor C 1
kvar 350,7 1-Ph
µF 6977 1-Ph
Rated kV 0,4
Max. kV 1

Inductor L 1
X_{L1} 0,0182
Q Factor 40
Max. I 4000

Capacitor C 2
kvar 0 1-Ph
µF 0 1-Ph
Rated kV 0
Max. kV 0

Inductor L 2
X_{L2} 0
Q Factor 0
Max. I 0

Loading
Operating Load:
kW 0,372 +j kvar -357,4

Resistor
R 0

HF1

Figure 2. Setting the 5th-order filter parameters

3. RESULT AND DISCUSSION

3.1. Load Flow Analysis Simulation of Filter Installation

The simulation describes the electrical system's condition as closely as possible to the data obtained. The simulation results are given in Figure 3 and Figure 4. Figure 3 and Figure 4 are the results of the load flow simulation, which was carried out so that data was obtained that the power factor of the electrical system with a single tuned passive filter installed is still not close to number 1, as shown in Table 9 [14], [16]–[18].

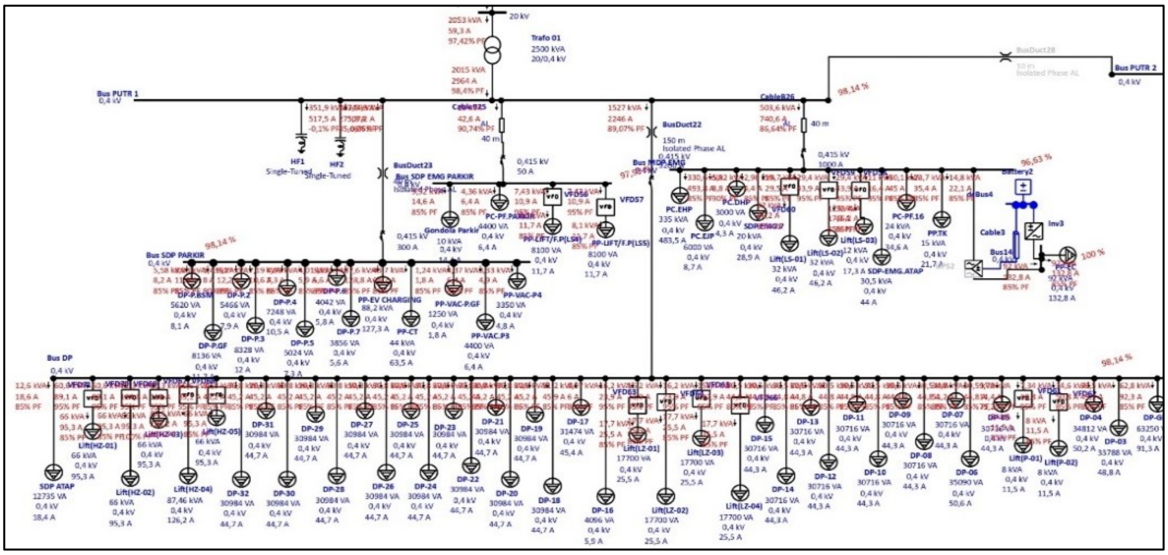


Figure 3. Load flow analysis of transformer 01 with filter

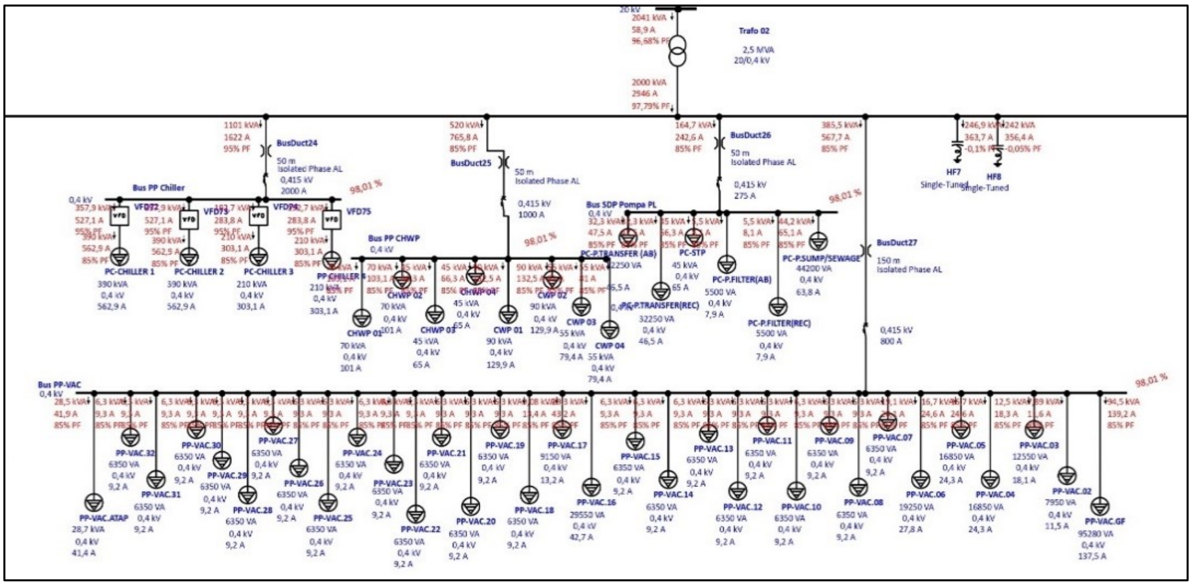


Figure 4. Load flow analysis of transformer 02 with filter

Table 9. Power factor before installing capacitor banks

ID	Power Factor
Transformer 01	97.42%
Transformer 01	96.68%

The following power factor data obtained after carrying out a load flow analysis simulation is in Table 9. Meanwhile, Table 10 contains data from the bus obtained after a load flow analysis simulation of the electrical system's condition connected to a single-tuned passive filter. Based on the standard (SPLN 1:1995), the permitted operating voltage value is +5% for the tolerance limit for voltage increases (over-voltage). The allowable limit for voltage drops is -10%; however, from ETAP itself, there is a marginal limit of ± 2% (95 – 102%), so it would be better if we used a limit of ± 2%.

Table 10. Results of load flow analysis

ID	Operating (%)
Bus PUTR 1	98.14
Bus SDP Parkir	98.14
Bus SDP EMG Parkir	97.99
Bus MDP EMG	96.63
Bus DP	98.14
Bus PUTR 2	98.01
Bus PP Chiller	98.01
Bus PP CHWP	98.01
Bus SDP Pompa PL	98.01
Bus PP.VAC	98.01

3.2. Capasitor Bank Design

Based on the data in Table 9 and Table 10, a capacitor bank is installed to increase the value of the power factor; the standard power factor value is at a number close to the perfect value, namely number 1; we assume the desired value of $cos\varphi$ is 1 [9][19][20]. Then, calculating the need for a capacitor bank can be done by:

$$S_1 = 2367 \text{ kVA}$$

$$P = S_1 \times \cos\varphi \text{ initial} = 2367 \times 0.85 = 2012 \text{ kW}$$

$$S_2 = \frac{P}{\cos\varphi\ target} = \frac{2012}{1.00} = 2012 \text{ kVA}$$

After getting the values of S_1, $S_{2,}$ and P, the next step is to find the value of Q_1 by rooting the subtraction value of S_1 with P, which has been squared below [21].

$$Q_1 = \sqrt{{S_1}^2 - P^2} = \sqrt{2367^2 - 2012^2} = 1.246.81$$

$$Q_2 = \sqrt{{S_2}^2 - P^2} = Q2 = \sqrt{2012^2 - 2012^2} = 0$$

$$Q_3 = Q_1 - Q_2 = 1.246.81 - 0 = 1.246.81\ kVAR$$

After calculations, the required capacitor capacity was 1,246.81 kVAR or 1,300 kVAR. We designed the capacitor bank in 12 steps, as shown in Table 11. We divided step capacitors into different sizes to adjust the KVAR value closer to requirements of up to 25 KVAR. Based on the data from the simulation results, the building's electrical system has a high content of individual harmonic distortion, namely in the 5th and 7th orders. The results are given in Table 12. After installing a single-tuned filter with this capacity, the harmonic load flow simulation was carried out again, and the results are shown in Table 13.

Table 11. Proposed Capacitor bank

Step	Capacitor Bank
1.	25 kVAR
2.	25 kVAR
3.	50 kVAR
4.	50 kVAR
5.	50 kVAR
6.	50 kVAR
7.	50 kVAR
8.	50 kVAR
9.	50 kVAR
10.	50 kVAR
11.	100 kVAR
12.	100 kVAR

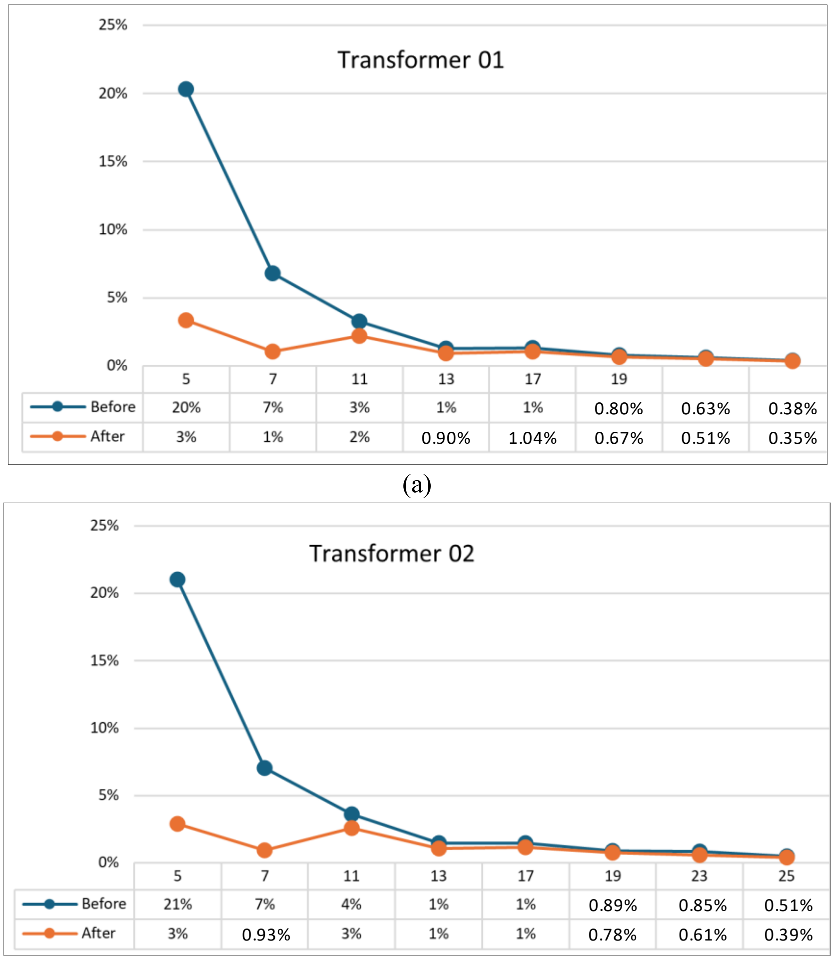
Table 12. Single-tuned filter capacity

Order	PUTR 01			PUTR 02		
	kVAR	C	X_L	kVAR	C	X_L
5	350.7	6977 μF	0.Ω	246.8	4910 μF	0.Ω
7	350.7	6977 μF	0.Ω	246.8	4910 μF	0.Ω

Table 13. Harmonic load flow simulation data after filtering

ID	THD_i (%)	THD_v (%)	Standard (%)
Transformator 01	4.41	1.18	5
Transformator 02	4.45	1.17	5

The total harmonic distortion content in the electrical system decreased after installing a single-tuned filter. The value initially exceeded the standard, but it has now fallen below the maximum standard figure, and the individual harmonic distortion content has significantly reduced, as shown in Figure 5. Apart from experiencing improvements in the decreasing harmonic content, there has also been an improvement in the existing power factor, but the value is still not optimal, namely not yet close to number 1; for this reason, it is necessary to add a capacitor bank to improve the power factor until it is close to number 1.



(a)

(b)

Figure 5. (a) THDI repair results on Transformer 01 (b) THDI repair results on Transformer 01

3.3. Load Flow Analysis

Based on the load flow analysis simulation, an improvement in power factor was obtained. Calculations were carried out using the assumption that the initial power factor provided by the state electricity company was 0.85 and assuming the desired power factor was 1, resulting in a result of 1,300 kVAR. The results are given in Table 14. Table 14 shows that the power factor value increases after installing filters and capacitors. The closer the power factor value is to 1, the better because the losses incurred will be minor to maximize power usage at the capacity value. In the existing condition, buses have also experienced improvements in their numerical values, as seen in Table 15. This research improves power quality and power factor, which are essential parameters in the operation of high-rise buildings. It can also overcome voltage drops due to installation too far away.

Table 14. Comparison of power factor before and after installing the capacitor bank

Transformer 01			**Transformer 02**		
Initial	filtered	filtered + Capacitor bank	Initial	filtered	filtered + Capacitor bank
85.78%	97.42%	99.69%	88.78%	96.68%	99.41%

Table 15. Comparison of power factors

ID	Before (%)	After (%)
Bus PUTR 1	98.14	98.9
Bus SDP Parkir	98.14	98.9
Bus SDP EMG Parkir	97.99	98.75
Bus MDP EMG	96.63	97.4
Bus DP	98.14	98.9
Bus PUTR 2	98.01	98.77
Bus PP Chiller	98.01	98.77
Bus PP CHWP	98.01	98.77
Bus SDP Pompa PL	98,01	98.77
Bus PP.VAC	98.01	98.77

4. CONCLUSIONS

The building's electrical system shows that THDi has exceeded the IEEE-519-2014 limit on transformer 01 of 21.77% and transformer 02 of 22.63%. A single-tuned passive filter is planned by designing in the 5th and 7th orders to reduce the total harmonic distortion value in independent IT buildings whose value has exceeded the maximum limit of the IEEE-519-2014 standard. The simulation results that were carried out after installing a single-tuned passive filter in the 5th and 7th orders significantly reduced the THDI. The single-tuned passive filter reduced the IHDI that occurred in transformer 01 order five from 20.315% to 3.329%, and then in order 7, the IHDI content fell from 6.783% to 1.061%. Meanwhile, in transformer 02, in order 5, it was initially 21.043%, then fell to 2.908%; in order 7, it was initially 7.067%, down to 0.925%. The power factor value in the conditions before the filter was installed and after the filter was installed increased quite well in transformer 01 from initially 85.78% to 97.42%. And on transformer 02, which was initially 88.68%, it became 96.68%, then experienced improvement again after installing a capacitor bank on transformer 01, it became 99.69%, while on transformer 02, it became 99.41%. In this research, we only reduced the total harmonic distortion current using a single-tuned passive filter. Suggestions for further research include using other types of filters and then comparing them to get better filter results.

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