

The Analysis of Harmonics on LED Lamps

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Abstract. The development of the era affects the technological advances that currently appear two types of loads, those are linear and non-linear loads. LED lamp included non-linear loads so causes harmonics. For that reason, the comparison of power consumption between LED lamp load and the combination of TL-D and XL LED lamps to find which one is better to use. Due to the occurrence of harmonics by the LED lamp load, it is necessary to improve the harmonics by designing a Single Tuned Filter passive filter with the help of ETAP Power Station 12.6 applications. This research method with literature study, measurement, load data processing due to harmonics to the comparison of TL LED and TL-D lamps in New FPEB Building, and the design of passive filter design so that can get the desired result. The current and voltage harmonics on the SDP are not compliant with IEEE 519-2014 standard, that is current harmonics on each floor of it ranges above 45.95% to 94.73%, in contrast to voltage harmonics ranging from 2.2% to 2.8% which still within the standards allowed that is under 5%. As a result of harmonics causing total power loss before exposed to harmonics of 7715.11 Watt and total harmonized power of 9639.92 Watt. So the total loss of power due to harmonics of LED lamp loads of 1924.81 Watt. At investment cost, lamp replacement cost based on lifetime, and lower power consumption cost of LED type lamp compared to combination of TL-D and XL LED lamps. In Single Tuned Filter type filter simulation designed to reduce 3rd, 5th, and 7th harmonics can decrease THDi respectively R, S, and T phases of 7.19%, 7.01%, and 10.95%.

1. Introduction

The development of the era has an effect on the technological advancement that nowadays there are various objects and electrical appliances, thus the load on electric power system is classified into two types namely linear load and non-linear load. Linear load is a load having a current waveform equal to its voltage waveform while the non-linear load is a load whose current waveform is not equal to its voltage waveform [1], with both types of load affecting the quality of the Power System (STL). Power System Quality is related to Power Quality. LED lamps can be classified into non-linear load, because in the LED lamp components, there are non-linear components such as diodes, transistors, and others that can affect the quality of Power System harmonics. So the researcher will analyze the harmonics of LED lamps in FPEB new building because in the building all the lighting using LED type of lights and to compare which one is better between LED lights that are small powerless but the price is expensive, or ordinary type of lights with greater power but the price is cheap. In that comparison, the researcher will compare the type of TL LED lamp to TL-D or usual TL.

Non-linear load harmonization especially lighting using LED lamp can affect the power quality at New FPEB Building after harmonic measurement is obtained that the harmonics of voltage on each



floor is 2.5% thus the harmonic stress of the building is still in IEEE 519-2014 standard different from current harmonics on the SDP on each floor of the building does not meet the standard that is above 45.95% to 94.73% and on the MDP current harmonics flows over 27.26% to 36.70% where the grounding of the building is 0.1Ω , hence the improvement of harmonics by using filter is required. Hence, the researcher designs filter. For harmonics reparation, the researcher designs passive filter using a software that is ETAP 12.6.0, the researcher chooses passive filter because it is plentiful on the market and easy to find.

2. Theoretical Basis

2.1. Harmonics

Harmonics of voltage or current waves arising in the alternating current (AC) voltage system are influenced by the non-linear load supplied by the power company. Harmonics is a sinusoidal or current waveform whose frequency is an integer multiple of the frequency at which the supply system is designed to operate (called the fundamental frequency, usually 50 or 60 Hz).

The distorted waveform can be decomposed to a number of fundamental frequencies and harmonic distortion harmonics derived from the non-linear load and load characteristics of the power system [2]. This nonlinearity is that the current is not proportional to the applied voltage. It can be seen in the figure 1.

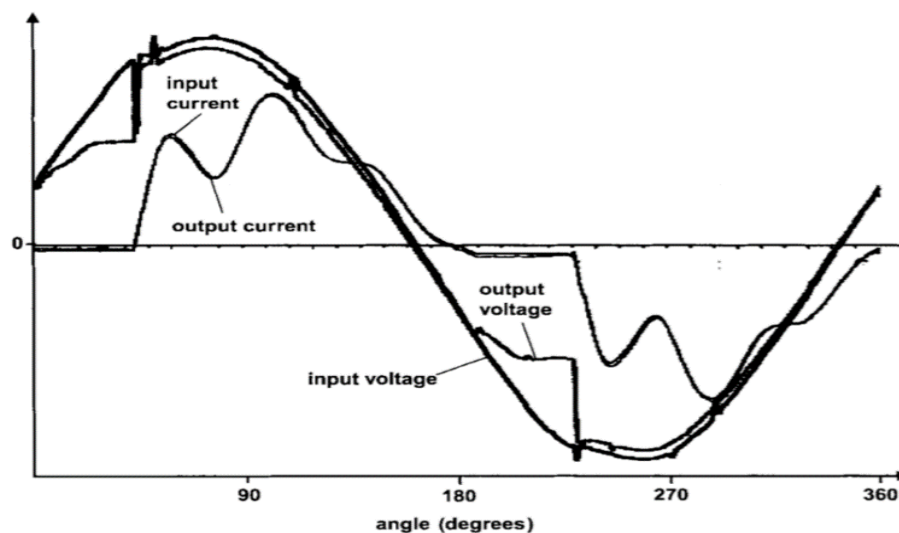


Figure 1. Waves affected by harmonics [3].

2.2. The influence of Harmonics

The effect of harmonics negatively impacts the equipment for instance the emergence of mechanical vibrations in electrical panels, harmonics may cause additional torque on kWh meters of electromechanical type using rotating induction disks, frequency interference on load-bearing telecommunication systems.

The load breaker may work under its rated current or may not work at rated current, reducing the efficiency of the electrical system and its utilities, reducing the isolation life of power supply equipment, increasing resonance of the power system [4]. The impact of voltage and current harmonics on the power system (STL) is increased harmonic level due to resonance parallel relationship, generator power, transmission, and other tools decreased efficiency, errors on the meter of energy measuring plate [5].

2.3. THD (Total Harmonic Distortion)

To measure the effective value of the harmonic components of the defective wave (distorted) the amount of THD (Total Harmonic Distortion) is used is the ratio of the rms value of the harmonic component of

a quantity (current or voltage) to the rms value of the current or voltage at its fundamental frequency and is usually calculated in percent that can be seen in equation 1.

$$THD = \frac{\sqrt{\sum_{h>2}^{hmax} M_h^2}}{M_1} \quad (1)$$

Where M_h is the rms value of the harmonic component to h of a magnitude of M . The rms value itself can be obtained if it is known that the rms value of the first harmonic component and its THD value can be seen in equation 2:

$$RMS = \sqrt{\sum_{h=1}^{hmax} M_h^2} = M_1 \sqrt{1 + THD^2} \quad (2)$$

For the THD value of current in equation 3:

$$THD_I = \frac{\sqrt{I_2^2 + I_3^2 + I_4^2 + \dots + I_n^2}}{I_1} \quad (3)$$

For the THD value of the voltage in equation 4:

$$THD_V = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2}}{V_1} \quad (4)$$

THD currents vary from a few percent to over 100%. THD voltages are usually smaller than 5%. Below 5% is generally acceptable but if above 10% then this is unacceptable and will cause problems for sensitive loads and equipment [6].

At the IEEE 519-2014 harmonic standard there are two criteria used to evaluate harmonic distortion ie the limits for current harmonics and constraints for voltage harmonics. For current harmonic standards, is determined by the ratio of I_{sc} / I_L . I_{sc} is the maximum short-circuit current available on the PCC (Point of Common Coupling) or at the measuring point, whereas I_L is the maximum load current at the fundamental frequency. Meanwhile for the standard harmonic voltage is determined by the voltage of the system used.

2.4. LED Light (Light Emitting Diode)

LED (Light Emitting Diode) or often abbreviated as LED is an electronic component that can emit monochromatic light when is given forward voltage. LED is a family of Diodes made of semiconductor materials. Block diagram of LED electronic ballasts can be seen in the figure 2.

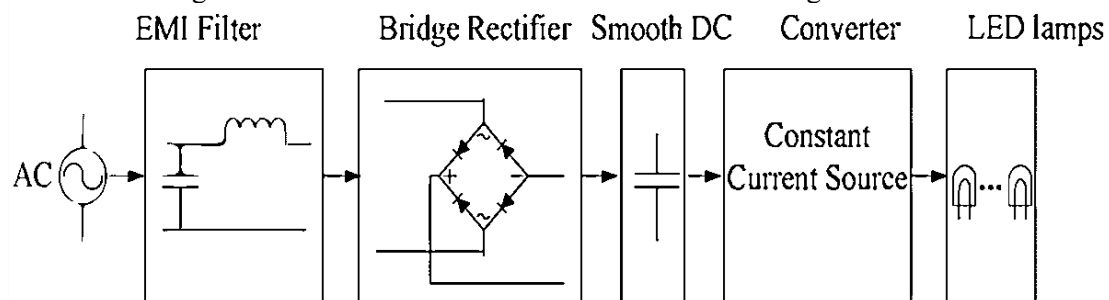


Figure 2. Block diagram of LED electronic ballasts [7].

LEDs require a constant current source from a low DC voltage source, but they should also operate from AC power. Therefore, it is necessary to use the converter to adjust the voltage and control the current applied to the LED [7].

2.5. Harmonic Filters

The main purpose of a harmonic filter is to reduce the amplitude of a particular frequency of a voltage or current. With the addition of a harmonic filter on a power system containing harmonic sources, the spread of harmonic current throughout the network can be minimized. In addition, harmonic filters at fundamental frequencies can compensate for reactive power and are used to improve the system power factor [8].

2.6. Passive Filters

Passive filters are an effective and economical solution for harmonic problems. Passive filters consist of R, L, and C sequences. Passive filters are ;mostly designed to provide a special section for diverting undesired harmonic currents in the power system. Passive filters are widely used to compensate for reactive power losses due to harmonics in the installation system. Passive filters are used as common and easy-to-find applications in the market for power system and designer techniques to reduce voltage distortion and harmonic current through electrical installations [9].

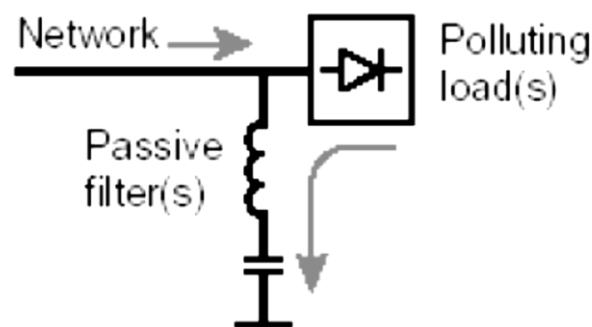


Figure 3. Passive Filters [10].

From the figure 3 the installation of passive filters are located after the source, in the circuit aims to harmonic flow that does not flow to the source but through the filter and grounded, there are some harmonic passive filter topology used, those are single tuned filter and high pass filter. Passive filter configuration can be seen in figure 4.

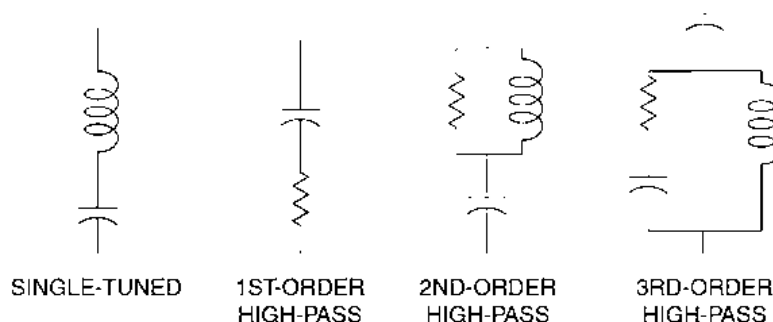


Figure 4. Passive Filter Configuration [2].

3. Methods

3.1. Harmonic Measurement Procedures

A series of harmonic testing on the installation of LED lights on each floor of the New FPEB Building can be seen in figure 5.

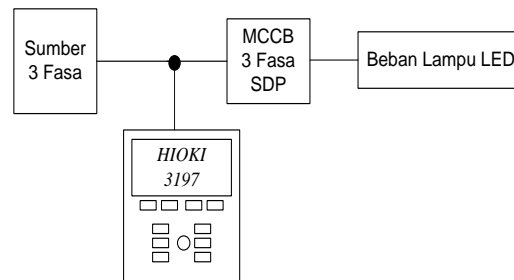


Figure 5. Series of harmonic measurements on LED lamp installations.

At this harmonic measurement is taken when all the LED lights are turned on, the measurement of harmonics on the LED Lights in FPEB Building. The harmonic measurements on the SDP on each floor use HIOKI 3197 POWER QUALITY ANALYSER. The measured data are voltage (V), current (A), active power (Watt), reactive power (VAR), pseudo power (VA), power factor (PF), THDv voltage (%), and THDi current (%). The harmonic measurement circuit on MDP uses Clamp on Power Hitester HIOKI 3286 - 20 can be seen in figure 6.

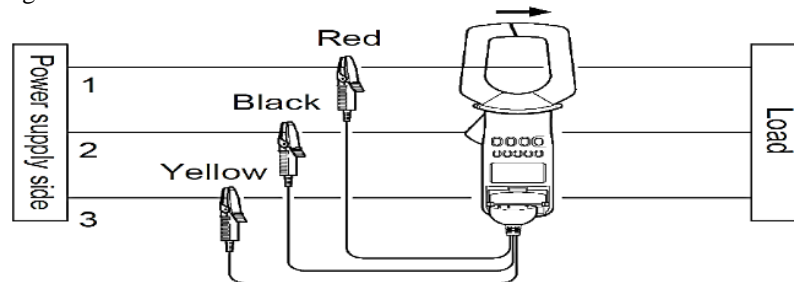


Figure 6. Series of harmonic measurements on MDP.

On MDP uses Clamp on Power HIOKI 3286 - 20 Hitester. The measured data are voltage (V), current (A), active power (Watt), reactive power (VAR), pseudo power (VA), power factor (PF) THDv voltage (%), and THDi current (%). All measured data are recorded.

3.2. Design of Passive Filter Design Single Tuned Filter Type

From the result of measurement in Table 3.6 that the current harmonics value at each of the 3, 5, and 7 phase exceeds 10.7% and below 22%, and the harmonic voltage is still within the allowed standard. So the passive filter will be designed to reduce the current harmonics. The filter designed will improve the power factor to 0.9.

After determining the order of harmonics to be repaired then the next step is to determine the capacitance capacitor, in the calculation for the filter design taken data from phase R, then performed the following calculation:

R Phase Filter

$$\begin{aligned}
 Q_C &= 16800 \cdot (\tan(51,9)) - (\tan(25,84)) \\
 &= 16800 (1,275 - 0,48) \\
 &= 16800 (0,795) \\
 &= 13356 \text{ VAR}
 \end{aligned}
 \tag{5}$$

The result of the calculation shows that to improve the power factor to 0.9, reactive power of 13356 VAR is needed, for single tuned filter to be installed that is 3rd order harmonic filter.

Furthermore, the capacitor reactance (X_C) can be found.

$$X_{C1} = \frac{V^2}{VAR} = \frac{380^2}{13356} = 10,81 \, \Omega
 \tag{6}$$

Furthermore, when the capacitor reactance (X_c) results can be found, so is the capacitance of the capacitor (C).

$$C = \frac{1}{2\pi f X_c} = \frac{1}{2(3,14)(50)(10,81)} = 0,00029 \text{ F} \quad (7)$$

After obtaining the capacitance of the capacitor, then reactance from the inductor (X_L) can be sought. The inductive reactance required at harmonic h is, in this case as follows:

$$\begin{aligned} X_{Lh} &= X_{ch} \\ X_{L3} &= X_{c3} \\ X_{L1} &= \left(\frac{1}{h}\right) X_{Lh} = \left(\frac{1}{h}\right) X_{L3} = \frac{3,6}{3} = 1,2 \Omega \end{aligned} \quad (8)$$

$$I_1 = \frac{(1,05)(V_{LN})}{(X_c - X_L)} = \frac{(1,05)(219,39)}{(10,81 - 1,2)} = 23,97 \text{ A} \quad (9)$$

$$I_3 = \frac{1}{h} \frac{KVA_{load}}{\sqrt{3} (13,8)} = \frac{1}{h} \left(\frac{27,2}{\sqrt{3} (13,8)} \right) = 0,379 \text{ A} \quad (10)$$

$$X_{c3} = \left(\frac{1}{h}\right) X_{c1} = \frac{10,81}{3} = 3,6 \Omega \quad (11)$$

The peak voltage (V_{peak}) and rms voltage (V_{rms}) on the capacitor,

$$\begin{aligned} V_{c \text{ peak}} &= \sqrt{2} (V_{c1} + V_{c3}) \\ V_{c \text{ peak}} &= \sqrt{2} (X_{c1} I_1 + X_{c3} I_3) \\ V_{c \text{ peak}} &= \sqrt{2} ((10,81 \times 23,97) + (3,6 \times 0,379)) \\ V_{c \text{ peak}} &= \sqrt{2} (259,16 + 1,37) = 368,44 \text{ Volt} \end{aligned} \quad (12)$$

$$V_{c \text{ rms}} = \sqrt{V_{c1}^2 + V_{c3}^2} = \sqrt{259,16^2 + 1,37^2} = 259,16 \text{ V} \quad (13)$$

If 219.39 V (neutral phase voltage to 380 V on the system).

$$\frac{V_{c \text{ rms}}}{V_{c \text{ peak rated}}} = \frac{259,16}{219,39} = 1,181 \text{ p.u.}$$

(Limit of IEEE-18 below 1.1 p.u.)

$$\frac{V_{c \text{ peak}}}{V_{c \text{ peak rated}}} = \frac{368,44}{\sqrt{2} (219,39)} = 1,1867 \text{ p.u.}$$

In the calculation for 3rd order harmonics, is still not in accordance with IEEE-18 standards. After the inductive reactance is known, then the inductance of the inductor (L) can be sought.

$$L = \frac{X_L}{2\pi f} = \frac{1,2}{2(3,14)(50)} = 0,0038 \text{ H} \quad (14)$$

Obtaining the inductor, and the capacitor, then the resistance (R) can be found.

$$R = \frac{\sqrt{L}}{\sqrt{C}} = \frac{\sqrt{0,0038}}{\sqrt{0,00029}} = 0,045 \Omega \quad (15)$$

Having known the value of each component for 3rd order filter then the filter specification for the order of 5 and 7 can be seen in table 1 is a single tuned filter model specification used.

Table 1. Specification Model Single Tuned Filter Design Results.

Fasa R				
orde	3	5	7	
Qc	13356	13356	13356	
Xc1	10,81	10,81	10,81	
Xc3	3,60	2,16	1,54	
C	0,00029	0,00029	0,00029	
XLh=Xch	XL3=Xc3	XL5=Xc5	XL7=Xc7	
XL1	1,20	0,43	0,22	
I1	23,97	22,19	21,75	
I3	0,379	0,228	0,163	
Xc3	3,60	2,16	1,54	
Vc1	259,16	239,96	235,16	
Vc3	1,37	0,49	0,25	
Vpeak	368,44	340,05	332,92	
Vrms	259,16	239,96	235,16	
p.u limit	1,181	1,094	1,072	
p.u limit IEEE-18	1,187	1,096	1,073	
L	0,0038	0,0014	0,0007	
R	0,045	0,027	0,019	
Fasa S				
orde	3	5	7	
Qc	12684	12684	12684	
Xc1	11,38	11,38	11,38	
Xc3	3,79	2,28	1,63	
C	0,00028	0,00028	0,00028	
XL=Xch	XL3=Xc3	XL5=Xc5	XL7=Xc7	
XL1	1,26	0,46	0,23	
I1	22,76	21,08	20,66	
I3	0,261	0,156	0,112	
Xc3	3,79	2,28	1,63	
Vc1	259,16	239,96	235,16	
Vc3	0,99	0,36	0,18	
Vpeak	367,90	339,86	332,83	
Vrms	259,16	239,96	235,16	
p.u limit	1,181	1,094	1,072	
p.u limit IEEE-18	1,095	1,073	0,000	
L	0,0040	0,0015	0,0007	
R	0,047	0,028	0,020	
Fasa T				
orde	3	5	7	
Qc	3605,8	3605,8	3605,8	
Xc1	40,047	40,047	40,047	
Xc3	13,35	8,01	5,72	
C	0,00008	0,00008	0,00008	
XL=Xch	XL3=Xc3	XL5=Xc5	XL7=Xc7	
XL1	4,45	1,60	0,82	
I1	6,47	5,99	5,87	
I3	0,215	0,129	0,092	
Xc3	13,35	8,01	5,72	
Vc1	259,16	239,96	235,16	
Vc3	2,87	1,03	0,53	
Vpeak	370,56	340,82	333,31	
Vrms	259,17	239,96	235,16	
p.u limit	1,181	1,094	1,072	
p.u limit IEEE-18	1,194	1,098	1,074	
L	0,0142	0,0051	0,0026	
R	0,167	0,100	0,072	

Table 1 is the result of calculations to find passive filter specifications. The calculations of order 5 and 7 are the same as calculating the filter specifications for the order of 3. The filter specifications for the 5th and 7th order can be found in table 1.

4. Results and Discussion

4.1. THD Value on LED Lights Installation of New FPEB Building

At this harmonic measurement by turning on all LED lights that are in FPEB Building. Measurement is carried out to determine the current harmonics value and the voltage generated by the LED light and the effect on the power consumption due to harmonics produced by the non-linear component on the LED lamp. Here are the measurements of each floor using a HIOKI 3197 Power Quality Analyzer.

Table 2. THDi Measurement on LED Lamp Installation.

Floor	THDi %			THDv %		
	R	S	T	R	S	T
1	58,00	78,97	87,36	2,50	2,50	2,30
2	93,75	73,70	75,27	2,50	2,60	2,40
3	80,40	75,36	59,07	2,70	2,80	2,30
4	82,67	73,70	90,55	2,30	2,50	2,30
5	84,06	78,69	60,85	2,40	2,50	2,30
6	68,37	94,74	45,95	2,40	2,40	2,20

From Table 2 the measurement data of each floor can be seen harmonic current and voltage, on the harmonic measurement data that is not in accordance with IEEE 519-2014 standard that is harmonic current in each floor harmonic current ranges above 45.95% to 94.73%, unlike the harmonic voltage ranging from 2.2% to 2.8% is still within the allowed standard of under 5%. The influence of the harmonics can have an impact on power losses.

4.2. Effect of Harmonics on Power Loss

From the harmonic measurement results can be seen that the influence of harmonics can cause loss of power. It can be seen from the current measured after exposure to harmonics and before harmonics. The current which is not affected by harmonics can be seen on the harmonic value of 1st order current. In this case we can know the loss of power generated due to harmonics and comparison of power consumption before exposed and after exposed to harmonics with real power calculation (Watt).

Calculation of real power (P) for 1st floor before exposed to harmonics:

$$P = (V) (I_{\text{orde 1}}) \cos \phi$$

$$P = (228,8) (5,1) 0,817$$

$$P = 953,34 \text{ Watt}$$

Table 3. Total Power before Affected by Harmonics.

Power (W)	Lt 1	Lt 2	Lt 3	Lt 4	Lt 5	Lt 6	Amount of P Fasa
R	953,34	410,11	380,24	523,06	308,08	234,75	2809,57
S	271,11	239,59	233,25	235,56	508,13	305,33	1792,97
T	430,96	417,09	452,35	423,09	199,30	1189,78	3112,57
Amount of P	1655,4	1066,78	1065,84	1181,71	1015,50	1729,86	7715,11
Amount of P kW	1,66	1,07	1,07	1,18	1,02	1,73	7,72

Calculation of real power (P) for 1st floor before affected by harmonics:

$$P = (V) (I_{\text{rms}}) \cos \phi$$

$$P = (228,8) (5,9) 0,817$$

$$P = 1102,88 \text{ Watt}$$

Table 4. Total Power after Affected by Harmonics.

Power (W)	Lt 1	Lt 2	Lt 3	Lt 4	Lt 5	Lt 6	Amount of P Fasa
R	1102,8	560,48	482,61	676,90	406,10	288,92	3517,89
S	348,57	306,14	298,04	300,99	651,04	427,46	2332,25
T	568,87	525,22	572,98	573,22	234,47	1315,02	3789,78
Amount of P	2020,3	1391,8	1353,6	1551,1	1291,6	2031,4	9639,92
Amount of P kW	2,02	1,39	1,35	1,55	1,29	2,03	9,64

From the data table 3 and 4 can be known the difference in power values before and after affected by harmonics. The impact of the harmonics on the loss of power from the actual known value on the calculation of the power of 1st floor phase R before harmonized of 953.34 Watt and the value of power calculation after harmonization of 1102.88 Watt. The difference in power loss at the R phase of 149.54 Watt, so that harmonics can be detrimental in terms of power consumption and costs borne.

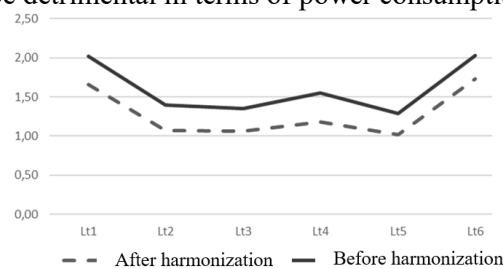
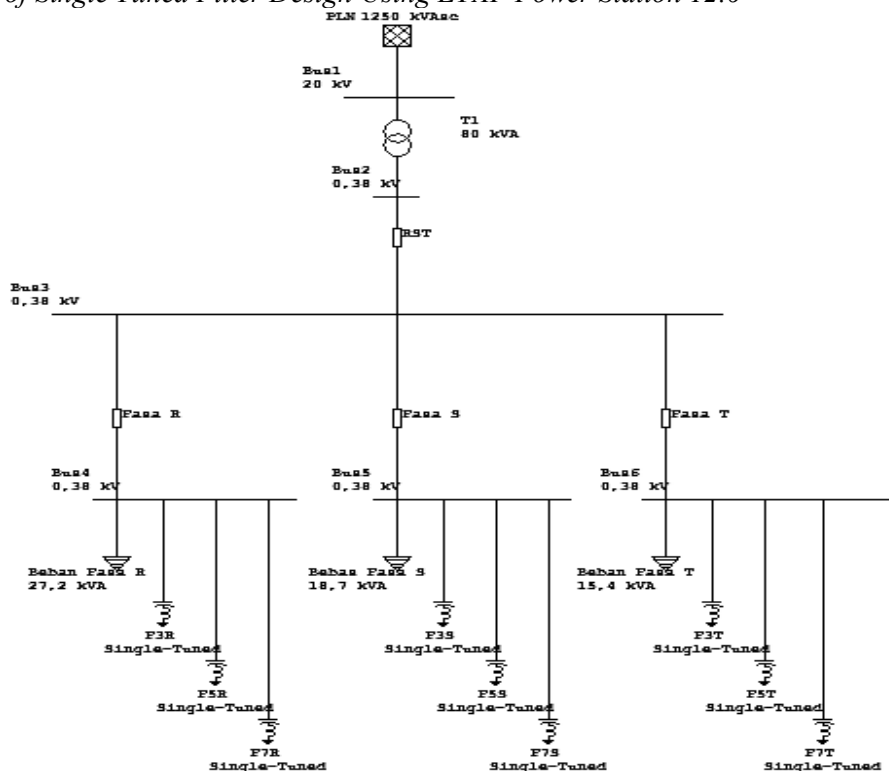
**Figure 7.** Graph of comparison of power consumption before and after harmonization.

Figure 7 shows the difference in power consumption of LED lamp installations before and after affected by harmonics. So the consequences of harmonics can affect the loss of power of a system.

4.3. Design of Single Tuned Filter Design Using ETAP Power Station 12.6

**Figure 8.** Installing 3, 5, and 7 single tuned filters.

In figure 8 installation of 3rd, 5th, and 7th order filters to reduce current harmonics (THDi) at 3rd, 5th, and 7th order, after the installation of 3rd, 5th, and 7th order filters, the results are as follows.

Table 5. Data of Harmonic Flow of Fitting Results of 3rd and 5th Order Filter.

Orde	Before Filter			Filter Orde 3,5,7		
1	0	0	0	0	0	0
2	2,8546	3,88196	2,40053	4,03874	4,3971	3,07648
3	20,152	18,147	17,3623	0,81638	0,7495	3,02102
4	0,93637	1,1907	1,96136	0,87579	1,3449	2,03651
5	22,312	16,6641	15,461	1,29543	0,89781	4,20688
6	0,88395	4,59412	2,46625	0,49778	2,23365	3,03624
7	18,261	10,7968	11,3327	0,924848	0,519492	2,59537
8	0,5268	2,83449	1,56918	0,314125	0,865434	1,61355
9	2,0558	9,50373	4,90581	0,898116	2,10395	4,43736
10	0,85666	4,26437	2,06841	1,03711	1,55832	1,74055
11	5,4471	5,90634	4,08292	3,98322	2,67024	4,37819
12	0,53288	0,993437	0,858778	0,341195	0,290031	0,82335
13	4,1474	1,86278	2,48619	2,79565	1,40272	2,54694
14	0,71168	1,08882	0,913395	0,632037	0,412226	1,11784
15	1,8958	1,23151	1,9366	1,09724	0,594073	2,07045
16	0,4012	1,30009	0,361039	0,336099	0,558437	0,91033
17	2,1622	1,74735	1,70422	1,41866	1,30041	1,7164
18	0,52975	1,2776	0,576837	0,309872	0,581673	0,81876
19	1,912	1,11662	1,38765	1,21489	1,06422	0,85557
20	0,50612	1,36017	0,954547	0,269866	0,771836	1,07875

In table 5 it can be seen that the current harmonic value at 3rd, 5th, and 7th order has decreased from the previous value. So THDi at each phase decreases THDi value on phase R, S, and T that is 7,20%, 7.01%, and 10,95%. Although the THDi value on each phase is decreasing, the THDi value still has not reached the 5% IEEE 519-2014 standard.

Table 6. Power Comparison Before and After Filter Installation.

Daya	P (kW)	S (kVA)	Q(kVAR)	I (A)
Sebelum di filter	37,3	61,3	47,5	102,9
Setelah di filter	33,79	37,54	16,37	98,8
Selisih	3,51	23,76	31,13	4,10

Table 6 summarizes the power ratio before and after the installation of passive filters in the simulation. The pre-filtered power of the filter is taken from the sum of the values recorded on the gauge, and the after-power filter is generated from the calculation of power with a voltage of 380 V, a power factor of 0.9, and a current of 98.8 A. The voltage, power, and current data Obtained from the simulation. For a clearer comparison of power can be seen in Figure 9.

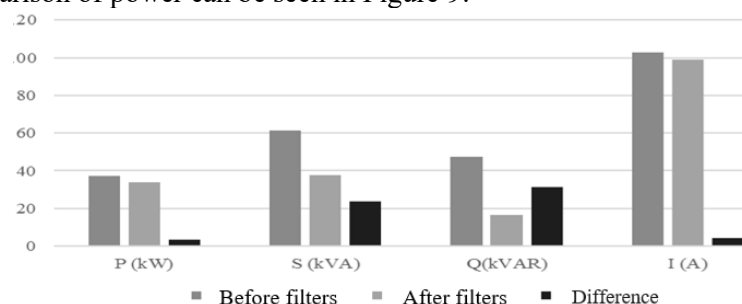


Figure 9. Power Comparison Before and After in Filters.

Figure 9 is a power comparison graph before and after the installation of passive filters. There is a difference between power consumption when harmonics are not filtered and when harmonics are filtered. The difference for real power (P) is 3.51 kW, apparent power (S) 23,76 kW, and reactive power (Q) 31,13 kW. So, for the filters installation can reduce power consumption.

5. Conclusions

From the results of the research that has been conducted can be drawn conclusion as follows:

- The use of LED lamps resulted in harmonics in the New FPEB Building is not meeting the IEEE 519-2014 current harmonic standards in the SDP of each current harmonic floor ranging above 45.95% to 94.73%, and at MDP the current harmonic over 27.26% up to 36.70%, in contrast to the voltage harmonics of the SDP and the MDP is still within the allowable standard of 5%,
- The results of large harmonic measurement data and not in accordance with the IEEE 519-2014 standards will have an effect on the quality of power resulting in loss of power, since the total power before the harmonics hit by 7715.11 Watt and the total harmonized power of 9639, 92 Watts. So the total loss of power due to harmonics of LED lamp loads of 1924.81 Watt.
- Installation of Single Tuned Filter type filter at each load is more effective for reducing current harmonics and filters can work on any perfume load, in Single Tuned Filter type filter simulation designed to reduce 3rd, 5th, and 7th harmonics can decrease THDi respectively - respectively R, S, and T phases are 7.19%, 7.01%, and 10.95%, since passive filters can attract harmonic currents so that harmonic currents do not enter the system resulting in loss of power.

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