

Investigate quality factor of single tuned passive filter to reduce harmonic of LED lamp

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Abstract. The use of LED energy-saving lamps is proliferating in the world and ranging from homes, offices to government buildings. The main reason for this is because LED lights have relatively small electrical power consumption. Behind the advantage of saving energy, it turns out that LED lights have a high level of harmonic. Passive filter is recommended to eliminate harmonic. The Quality factor (Q) of a filter will determine its performance. If the Q value is significant, the value of R will be smaller, and the quality of the filter will also be getting better because the energy used by the filter is lowering. It indicates that the heat losses of the filter are small. This work has tested four single tuned passive filter designs on X brand LED lamps with nominal power values of 3W, 4W, and 7W. The inductor values (L) tested were 65mH, 78mH, 91mH, and 115mH, respectively. The test results show that the total harmonic distortion (THD) of voltage on the X brand LED lights does not exceed the IEEE 519-2014 standard limit which is a maximum of 5%, because the highest harmonic voltage is 2.7%. While the highest total harmonic distortion (THD) of current in the LED lamps tested was 154%. The results of installing the first filter (L = 65mH) can reduce THD current up to 90.91%, the second filter (L = 78mH) reduces THD current up to 89.81%, the third filter (L = 91mH) reduces THD current up to 89.57%, while the fourth filter (L = 115mH) reduces THD current up to 86.86%.

1. Introduction

The application of LED energy-saving lamps is overgrowing in life, varying from residences, factories, and public buildings. People tend to use LED lamps because they have relatively low electrical power consumption. However, it does not mean that LED lights do not have any drawbacks. They have a high level of harmonic. The installation of rectifiers causes harmonic as part of the LED lighting supply circuit [1]. Harmonics cause the quality of the electricity supplied to decrease because the voltage and current are distorted [2]. Several studies have been carried out to reduce harmonics by using passive filters [3,4,5,6,7]. This study focuses on using the famous brand LED lights in Indonesia to examine four single tuned passive filter designs.

Harmonic measurements on the LED lights were carried out to determine the voltage THD and current THD. Then it continues with designing the passive filter considering the quality factor. According to several references, combining two or more components of the inductor (L) and capacitor (C) can construct the passive filter [7]. This study has tested inductor (L) of 65mH, 78mH, 91mH, and 115 mH. It also investigates the quality factor of four filter designs with the predefined Inductor value on the X brand LED lamp. In this paper, quality factor (Q) is defined as the ratio of the inductance or



capacitance to resistance at the resonance frequency [8]. IEEE 519 – 2014 standard is used as reference limit of THDv and THDi [9].

2. Single tuned filter specification

In this paper, four types of filter designs with different quality factor values are investigated. Their specifications are listed below.

- 1st Filter ($L = 65\text{mH}$)
- 2nd Filter ($L = 78\text{mH}$)
- 3rd Filter ($L = 91\text{mH}$)
- 4th Filter ($L = 115\text{mH}$)

The values of the four inductors are the values that are available on the market.

3. Measurement Harmonic process

Power Quality Analyzer (PQA) HIOKI 3197 is used to find the dominant parameters of LED lamps such as voltage, current, power factor, real power factor, percentage of total harmonics distortion for voltage and current. The illustration of experimental circuit in general is shown in figure 1. The values of electrical parameters as the dominant parameters of LED lamps is read and recorded directly from PQA to personal computer by using USB.

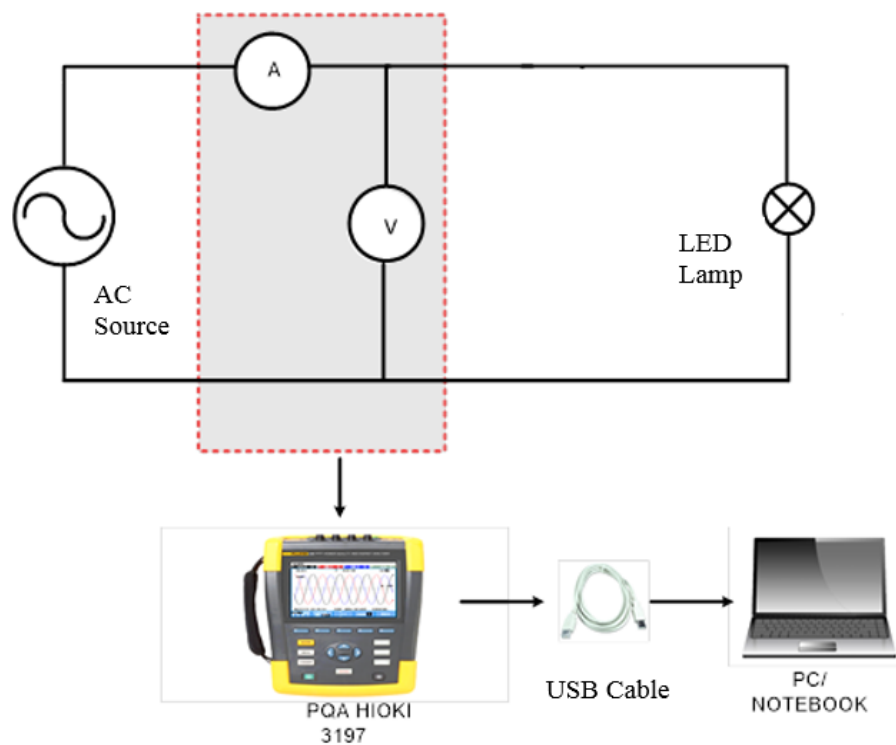


Figure 1. Harmonic measurement LED lamp

Result of measurement LED lamp to get the value of voltage and current harmonic shown in table 1. It is shown that the largest harmonics of voltage is 2.8% and the largest of harmonics of current is 154%.

Table 1. Percentage of Total Harmonic Distortion Of Current (THDI) and Voltage (THDv)

No	Rating power (W)	THDv (%)	THDi(%)
1	3	2.7	154
2	4	2.8	148.6
3	7	2.8	128.9

4. Experiment and Result

This study has found that the tested LED lamp was a capacitive load, so it should get a large inductor value. In this study 4 inductor values were used, i.e. 65mH, 78mH, 91mH and 115 mH, respectively. The next step to do is to calculate the value of the capacitor needed concerning the principle of resonance.

$$C = \frac{1}{(2\pi f)^2 h_0^2 L} \quad (1)$$

where h_0 is the 3rd order frequency, that will be tuned because of the highest harmonic level. From the above equation, it can be calculated as follows:

- For $L = 65$ mH, then the value of $C = 17.3 \mu F$
- For $L = 78$ mH, then the value of $C = 14.4 \mu F$
- For $L = 91$ mH, then the value of $C = 12.4 \mu F$
- For $L = 115$ mH, then the value of $C = 9.8 \mu F$

After calculating and obtaining possible filter values, the following step is to measure the reactance values of L , C , and R on each filter using the LCR meter. Result measurement shown in table 2. It is shown that value of R depends on value of L . The smallest value R is the smallest inductor value.

Table 2. Filter values tested

No	$(2\pi f)^2$	$(h_0)^2$	L (mH)	C (μF)	R (Ohm)
1	98596	9	65	17,3	232
2	98596	9	78	14,4	498
3	98596	9	91	12,4	509
4	98596	9	115	9,8	586

The value of the inductor resistance R can be determined by the quality factor (Q). Equation (2) expresses how to obtain the amount of Q value:

$$Q = \frac{x_L}{R} = \frac{\sqrt{L/C}}{R} \quad (2)$$

- The Q value calculation for first filter design ($L=65$ mH, $C=17,3\mu F$)

In the same way, the Q value can be calculated for the other filter design. Quality factor (Q) value will be obtained:

- 2nd Filter design ($L=78$ mH, $C=14,4\mu F$), $Q = 0,1477$
- 3rd Filter design ($L=91$ mH, $C=12,4\mu F$), $Q = 0,1683$
- 4th Filter design ($L=115$ mH, $C=9,8\mu F$), $Q = 0,1848$

Table 3. Quality Factor (Q) Value

No	L (mH)	C (μ F)	R (Ohm)	Q
1	65	17,3	232	0.2642078
2	78	14,4	498	0.1477710
3	91	12,4	509	0.1683031
4	115	9,8	586	0.184858

Table 3 shown that quality factor value based on calculation method. The smallest quality factor value get from inductor with value is 78mH.

After getting the required filter values, the next step is to install the filters on the load of the LED lamp that are tested.

The results of testing each filter are as follows:

- 1st Filter with value L = 65,10 mH, C = 17,3 μ F, Rd = 232 ohm.

Table 4. Measurement value 1st filter

Lamp Power	before				after			
	P (W)	I _{rms} (mA)	THD _I (%)	THD _V (%)	P (W)	I _{rms} (A)	THD _I (%)	THD _V (%)
3w	2,9	26,1	154	2,7	10	1,281	11,9	1,8
4w	3,4	29,6	148,6	2,8	9	1,266	12,9	1,7
7w	7	57	128,9	2,8	6	1,281	14	1,8

According to table 4, the measurement results of the first filter design show that this filter is able to reduce THDI significantly. On 3 watt LED lamp before installing the filter THDI content of 154%, after this filter installed THDI becomes 11.9%.

- 2nd Filter with value L = 78 mH, C=14,4 μ F, Rd = 498 ohm.

Table 5. Measurement value 2nd filter

Lamp Power	before				after			
	P (W)	I _{rms} (mA)	THD _I (%)	THD _V (%)	P (W)	I _{rms} (A)	THD _I (%)	THD _V (%)
3w	2,9	26,1	154	2,7	8	1,009	13,8	1,7
4w	3,4	29,6	148,6	2,8	7	1,011	14	1,6
7w	7	57	128,9	2,8	4	1,022	15,7	1,7

Table 5 shows that the second filter is also able to reduce THDI significantly. On LED lamp 3 watts before the THDI filter is installed at 154%, after this filter the THDI becomes 13.8%.

- 3rd Filter with value L = 91 mH, C=12,4 μ F, Rd = 509 ohm

The results of the third filter design, as shown in table 6, declares that this filter is also able to reduce THDI significantly. On LED lamp 3 watts before the THDI filter is installed at 154%, after this filter the THDI becomes 14%.

Table 6. Measurement value 3rd filter

Lamp Power	before				after			
	P (W)	I _{rms} (mA)	THD _i (%)	THD _v (%)	P (W)	I _{rms} (A)	THD _i (%)	THD _v (%)
3w	2,9	26,1	154	2,7	6	0,885	14	1,7
4w	3,4	29,6	148,6	2,8	6	0,886	14,5	1,7
7w	7	57	128,9	2,8	2	0,899	16	1,7

- 4th Filter with value L = 115 mH, C = 9,8 μ F, R_d = 586 ohm.

Table 7. Measurement value 4th filter

Lamp Power	before				after			
	P (W)	I _{rms} (mA)	THD _i (%)	THD _v (%)	P (W)	I _{rms} (A)	THD _i (%)	THD _v (%)
3w	2,9	26,1	154	2,7	8	0,714	19,1	2,8
4w	3,4	29,6	148,6	2,8	8	0,715	18	2,8
7w	7	57	128,9	2,8	8	0,719	19,2	2,7

From table 7, the results of the fourth filter design show that this filter is also able to reduce THDI significantly. On LED lamp 3 watts before the THDI filter is installed at 154%, after this filter the THDI becomes 19,1%.

From the four filters tested on LED lamp, all of which can reduce THDi values very significantly. The first filter with smallest Q value can works best among others. For example, THDi decrease from 154% to 11,9 %. While the fourth filter with the biggest quality factor is the worst filter in reducing THDi.

5. Conclusion

Passive filters are an effective and economical settlement method for reducing voltage and current harmonics. A single tune passive filter is one of the most recommended filters to reduce harmonic in non-linear loads.

The quality factor of a filter is very influential on the filter's performance. The smallest resistance (R) at the quality factor value of a filter, the filter performance will be more optimal in reducing THDi

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