Simulation of passive filter design to reduce Total Harmonic Distortion (THD) in Energy-Saving Lamps (LHE) and Light Emitting Diodes (LED)

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Abstract. This paper discusses the design of a passive filter system for Energy-Saving Lamps (LHE) and Light Emitting Diodes (LED) using the MATLAB Simulink software. This type of lamp is a type of non-linear load that produces harmonics of current and voltage. However, this harmonic problem can be reduced using passive filters. To determine the size of the passive filter components, research was carried out in the form of measurements of power, power factor, voltage, current, THDi and THDv produced by the LHE and LED. The results of these measurements were simulated using MATLAB Simulink to determine the passive filter design that reduces the THD value on the LHE and LED. To reduce the level of current harmonics, a single tuned LC passive filter was designed. The filter, designed to work at a frequency of 50 Hz and is expected to reduce the level of harmonics in the 3rd, 5th, 7th, 9th, 11th harmonic orders so that the THD produced by LHE and LED meets the IEEE 519-2014 standards. The simulation results of single tuned LC passive filter design can reduce THDi by 46.78% from the initial THD of 84.55% so that it becomes 37.77%.

1. Introduction

With the development of science and technology today, humans are competing to produce various kinds of new discoveries to meet their own needs. New inventions made by humans include sophisticated and energy-efficient electronic devices and electrical appliances, the most commonly used are LHE and LED. LHE and LED are power electronics based self-ballast lights that are proven to save energy. However, LHE and LED cause non-sinusoidal current and contain harmonics.

The purpose of this study, among others, was to analyze the amount of Total Harmonic Distortion (THD) on LHE and LED, so that a passive filter can be designed to reduce THD on LHE and LED using the MATLAB Simulink program. Furthermore, to analyze the comparison of THD on LHE and LED before and after filter installation in a passive filter design simulation using the MATLAB Simulink program. Based on the results of research conducted by Putra et al., it is concluded that the results of the implementation of the low pass filter succeeded in reducing the THDi% by 70%, from 93% to 29% [1].
2. Methods

2.1. Single tuned passive filter calculation

The steps for designing a single tuned passive filter are [2,3]:

- Determine the power capacity of the capacitor $Q_c$, based on equation (1):
  \[ Q_c = P \left[ \tan(\cos^{-1} p_{f_1}) - \tan(\cos^{-1} p_{f_2}) \right] \]  
  \[ (1) \]

- Determining the capacitance of the capacitor can be determined based on equation (2):
  \[ C = \frac{Q_c}{2\pi f V^2} \]  
  \[ (2) \]

- Determine the inductance of the inductor based on equation (3):
  \[ L = \frac{X}{(2\pi f)} \]  
  \[ (3) \]

- Determine the reactance based on equation (4):
  \[ X = \frac{1}{2\pi f h C} = \sqrt{(L/C)} \]  
  \[ (4) \]

- The amount of resistance used in the filter is determined based on equation (5):
  \[ R = \frac{1}{(2\pi f C)} \]  
  \[ (5) \]

2.2. Determine the type and amount of lamp power used

In the passive filter design simulation, 60 LHE and LED were used, with power variations: 8 W, 9 W, 14.5 W, 16 W, 18 W, 19 W, 20 W, 23 W, as in Table 1.

| No | Lamp Brand | Type of Lamp | Watt | Total | Total Watts |
|----|------------|--------------|------|-------|-------------|
| 1  | A          | LHE          | 8    | 5     | 40          |
| 2  | A          | LHE          | 18   | 5     | 90          |
| 3  | A          | LHE          | 23   | 5     | 115         |
| 4  | A          | LED          | 8    | 5     | 40          |
| 5  | A          | LED          | 14.5 | 5     | 72.5        |
| 6  | A          | LED          | 19   | 5     | 95          |
| 7  | B          | LHE          | 8    | 5     | 40          |
| 8  | B          | LHE          | 18   | 5     | 90          |
| 9  | B          | LHE          | 23   | 5     | 115         |
| 10 | B          | LED          | 9    | 5     | 45          |
| 11 | B          | LED          | 16   | 5     | 80          |
| 12 | B          | LED          | 20   | 5     | 100         |

| SUM |                                            | 922.5 |

There are 60 pcs of LHE and LED lamps with a combination of power quantities, arranged according to Figure 1.
2.3. Measurement of real power (S), active power (P), reactive power (Q), voltage (v), power factor (pf) and frequency (f) in energy saving lamps (LHE) and LED

Figure 2 shows the magnitude of S, P, Q, V, PF and f on LHE and LED.

The measuring instrument used to measure the magnitude of S, P, Q, V, PF and f on the LHE and LED in Figure 2 is the KYORITSU Power Quality Analyzer.

2.4. THDi measurement before using the filter

Figure 3 shows the magnitude of the harmonic currents in each harmonic order and the magnitude of the harmonic currents at H3, H5, H7, H9 and H11 is quite high on the LHE and LED before using the filter. The IEEE 519-2014 harmonic standard recommends 5% for the limit of the harmonics [4,5], so a filter is needed to reduce the amount of harmonics on H3, H5, H7, H9 and H11.

3. Results and discussion

This study uses a load of 60 LHE and LED lamps, with a combination of varying power sizes (power sizes for the same five energy-saving lamps) of 8 W, 9 W, 14.5 W, 16 W, 18 W, 19 W, 20 W, 23 W. The filters are designed for six pieces and made for six times tuning in the order H3, H5, H7, H9, H11,
H13 based on frequencies of 149.85 Hz, 249.75 Hz, 349.65 Hz, 449.55 Hz, 549.45 Hz, 649.35 Hz.

Next, test the passive filter that has been designed using the MATLAB Simulink program. Figure 4 shows the simulation circuit before or without using a single tuned LC passive filter. Based on the results of research that has been conducted by Heryana et al. shows that the effect of THD will cause losses in the form of a decrease in power quality in the LHE. Data of the six samples of Compact Fluorescence Lamp (CFL) testing, namely with a source voltage of 220-234 volts, a voltage THD of less than 2%, a current THD of 63.8-72% rms, a power factor of 0.57-0.76 and a Displacement Power Factor (DPF) 0.73-0.85 [6].

Therefore, in this study, a passive filter design will be made using MATLAB Simulink as a passive filter design aid against a combination of LHE and LED loads, to improve DPF and reduce THDi after installing the passive filter.

**Figure 4.** Simulation circuit without single tuned LC passive filter.

Figure 5 shows the simulation circuit with single tuned LC passive filter.

**Figure 5.** Simulation circuit with single tuned LC passive filter.
Table 2 shows the THD of LHE and LED currents before using a single tuned LC passive filter.

**Table 2.** Total harmonic distortion of current without single tuned LC passive filter.

| Order of Harmonics | H1  | H3  | H5  | H7  | H9  | H11 | H13 |
|--------------------|-----|-----|-----|-----|-----|-----|-----|
| Current (A)        | 4.203 | 3.103 | 1.566 | 0.347 | 0.378 | 0.321 | 0.047 |
| THD (%)            | 100 | 74.03 | 37.74 | 8.45 | 8.81 | 7.82 | 1.32 |

Figure 6 shows the waveform and magnitude of THDi and the magnitude of the harmonic currents in each harmonic order on the LHE and LED before using the single tuned LC passive filter on the FFT Analysis in the list view.

Figure 6. Waveform and magnitude of THDi before using single tuned LC passive filter.

Figure 6 shows the amount of THDi before using a single tuned LC passive filter of 84.55%. Based on these data, the current harmonic values obtained in each harmonic order are the order H3 = 74.03%, the order H5 = 37.74%, the order H7 = 8.45%, the order H9 = 8.81%, the order H11 = 7.82% and the order H13 = 1.32%. And the highest current harmonics are in the order H3 = 74.03%.

Table 3 shows the THD of LHE and LED currents after using a single tuned LC passive filter.

**Table 3.** Total current harmonic distortion after using a single tuned LC passive filter.

| Order of Harmonics | H1  | H3  | H5  | H7  | H9  | H11 | H13 |
|--------------------|-----|-----|-----|-----|-----|-----|-----|
| Current (A)        | 4.203 | 3.103 | 1.566 | 0.347 | 0.378 | 0.321 | 0.047 |
| THD (%)            | 100 | 37.53 | 3.85 | 0.15 | 0.10 | 0.00 | 0.00 |

Figure 7 shows the waveform and magnitude of THDi and the amount of harmonic currents in each harmonic order on the LHE and LED after using a single tuned LC passive filter.
Figure 7. Waveform and magnitude of THDi after using single tuned LC passive filter.

Figure 7 shows the amount of harmonic currents in each harmonic order and the amount of THDi decreased by 37.77%. There was also a reduction in THDi of 46.78%, and a decrease in the amount of harmonic currents in each harmonic order, namely the order H3 = 37.54%, order H5 = 3.85%, order H7 = 0.15%, order H9 = 0.10%, order H11 = 0% and order H13 = 0%. However, it can be seen that the current harmonics are still high in the H3 order of 37.54%.

4. Conclusion

- The use of single tuned LC passive filters can reduce harmonics, thereby affecting the THDi of the load being tested in the form of LHE and LED.
- The use of a single tuned LC passive filter can reduce THDi by 46.78% from the initial THD of 84.55% so that the final THDi becomes 37.77%.
- The use of single tuned LC passive filter is still not in accordance with IEEE 519-2014 standards in this case for THDi which is still above 5%.

References

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