Harmonics filter design for energy saving lamps based on EMC standard

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Abstract. Lighting devices, for instance, electric lamps hold an essential role in wide range application either for industrial or household applications which mostly for illuminating purposes. Energy Saving Lamp (ESL) gaining the scientific attention replacing outdated lighting technology such as an incandescent lamp or Glass Lighting Splinter (GLS) due to some reasons. However, in their practice, the use of ESL technology remains challenging regarding its low efficiency which arises from the high harmonic current. According to Electromagnetic Compatibility (EMC) Standard class C IEC- 61000-3-2, there is a maximum permissible limit of the harmonic current that being emitted by lighting equipment during their operational time. Thus, we attempt to analyse the Harmonic Current Emissions (HCE) that is generated by a specific brand of ESL. We employed some filters and run a performance test to solve the aforementioned problem. To optimize the investigation outcomes, we applied insertion loss analysis in the filter selection. The key finding in our observation is LC-LPF filter shows the most suitable filters fulfilling the EMC standard which potentially can be applied in ESL technology.

1. Introduction
Electromagnetic Compatibility (EMC) is a branch of science that studies the emission and immunity of electronic equipment to function in the manner intended in the electromagnetic field [1]. Along with technological developments, the number of frequencies circulating in the environment of electronic equipment is increasing. The number of frequencies that circulate in the environment can disrupt and degrade the reliability of electronic equipment. Low-frequency noise due to the nonlinear load will cause harmonics; damaging equipment such as overcurrent on wires, transformer heating, and others, being high-frequency interference may cause malfunctions of equipment, errors reading sensor data, a trip out of control, and others. Therefore, the design effort required for equipment EMC, including the filtering system design to suppress electromagnetic interference (EMI).

One of the equipment that have some EMC problem is Energy Saving Lamps (ESL). ESL has integrated electronic circuit components to replace the function of the ballast, starter, and compensation capacitor in one unit. ESL excellence is to have a higher lighting efficiency than incandescent lamps or Lighting Glass Splinter (GLS), and it has a longer lifespan which is about 8-10 times. The weakness of ESL is a smaller power factor and higher harmonic current emissions [2]. Several previous studies have shown that almost all the ESLs do not meet IEC 61000-3-2 EMC standards [3]. An example, in such a way research for several brands of ESL, i.e., Chiyoda, Focus,
Milion, and Optima with the nominal real power of 8 watts, the total harmonics distortion for current are 109.2%, 112.7%, 103.4%, and 96.3% respectively [4].

This study intended to test the filters that mainly work at lower frequencies to comply with applicable EMC standards. The filter is a single tone harmonic filter to dampen the additional frequencies that appear on the grid especially at the third harmonic (150 Hz). The filters were designed for electronic equipment such as ESL. In this study, we designed a low-pass filter (LPF) to reduce harmonic current emission (HCE) of ESL to comply with EMC requirements. LPF with higher HCE reduction and lowest insertion loss (IL) would be chosen as the best result.

2. Method and Formulation
The research methods can be seen in Fig. 1. Determination of passive filter components L and C is the part that is strongly emphasized. Measurement, testing, and analysis of the performance of the filter in the form of IL would be done through the parameters of impedance, admittance, and transmission. The filter’s circuits used in this study comprise two types i.e. harmonic filter and BPF filter [5]. Expected outcomes of the filter can reduce emissions HCE comply with applicable EMC standards IEC-61000-3-2.

![Figure 1. Research Methods.](image-url)
IL values is the important parameter of filter for characterization that used to measure the capability of passive power filters and its components to suppress EMI level [5]. The value of IL can demonstrate the effectiveness of the filter. Lower IL value result in a better performance of filter circuit. Equation (1) explains that IL is the ratio of power before and after the filter is inserted. Power is proportional to the square of the voltage across or current that flow in the filter circuit. Units of IL expressed with decibel (dB). There are several ways to determine the value of IL, through equations or from measurements. IL also can be determined by the formula as written in (2). Table parameters transformation also will be used for calculation IL that formulated in T parameters.

\[ IL = 10 \log \left( \frac{P_I}{P_L} \right) = 20 \log \left( \frac{V_I}{V_L} \right) = 10 \log \left( \frac{I_I}{I_L} \right) \]  

(1)

\[ IL = 20 \log \left| \frac{A + B + CZ_L + DZ_G}{Z_L + Z_G} \right| \]  

(2)

Where \( P_I \) and \( P_L \) is output power before and after the filter installed, \( V_I \) and \( I_I \) are voltage or current output before inserting the filter, \( V_L \) and \( I_L \) are output voltage or current after the filter installed. Through the concept of IL, impedance, admittance and transmission parameters that exist in communication system will be applied to analyses the performance of the combination of the filter [5].

The other term shown in equation (3) is called the distortion factor and is due to the harmonic distortion of the current.

\[ D = \sqrt{S^2 - (P^2 - Q^2)} \]  

(VAD)

Where \( D \) is the distortion power, \( S \) is the apparent power, \( P \) and \( Q \) are the real and reactive power, respectively.

3. Results and Discussion

Table 1 shows the result of testing for two ESL types. The HCE of the 1st lamp (SL ATAMA 5 Watt) exceeds the standard limit specified, except the 2nd harmonic. The 3rd harmonic is very high at 67% whereas it should not exceed 30% x 0.64 = 19.2%. The HCE of type-2 lamps (LED HOLIC 18 Watt) almost meet the set standard limits, except the 2nd harmonic. The 5th, 9th, and 13th harmonics should less than 5 % and 3% thus it still doesn’t meet the standard requirements.

| Harmonic Current Emission (%) | Type 1; \( Pf = 0.64 \) | Type 2; \( Pf = 0.24 \) |
|-------------------------------|-----------------|------------------|
| Order                        |                 |                  |
| 2                            | 1               | 0.3              |
| 3                            | 67              | 13.4             |
| 5                            | 29.7            | 12.8             |
| 7                            | 24              | 1.1              |
| 9                            | 18.5            | 14               |
| 11                           | 19.4            | 3.6              |
| 13-39                        | 21.2            | 5.2              |
| THD                          | 90              | 26.7             |

Table 2 shows the results of subsequent measurements, emission of harmonic currents absorbed by type 1 ESL lamp. The amount of current before and after the installation of filters 1, filter 2 and
filter 3 as follows 35.4; 74.7; 62.2; 45.5 milliampere. The value of THD are 101.3%; 47.8%; 33.0% and 25.9% respectively. Use of filters 3. Type LPF RC can reduce THD significantly; it can meet the requirements of EMC standards. The problem is an increase in current from 10.1 mA so that it can generate heat on resistor R (1500 Ohm), power losses caused approximately 0.15 Watt. So we still look for another type filter.

Table 2. Harmonic Current Emission of SL ATAMA 5 Watt

| Order | Harmonic Current Emission (%) | Standard Class C | Before Filter | Filter 1 (RLC) | Filter 2 (BSF) | Filter 3 (RC) | Filter 4 (LC) |
|-------|-------------------------------|------------------|--------------|----------------|---------------|---------------|---------------|
| n     | Harmonic Current Emission (%) | Before Filter    | After Installation | After Installation | After Installation | After Installation | After Installation |
| 2     | 19.8*                         | 68               | 43.6         | 25.2           | 16            | 0             | 0             |
| 3     | 10                            | 39               | 13.5         | 16.5           | 1             | 16.1          | 17.7          |
| 4     | 36                            | 4.1              | 8.5          | 4.4            | 5             | 4.8           |              |
| 5     | 26                            | 5.5              | 8.9          | 4.8            | 4.8           |               |              |
| 7     | 4.7                           | 4.5              | 4.5          | 1.3            | 4.1           |               |              |
| 9     | 13.3                          | 4.9              | 2.1          | 1.1            | 1.6           |               |              |
| 11    | 3.3                           | 5.5              | 1.7          | 1.4            | 1.4           | 1.4           |               |
| 13    | 3.3                           | 5.5              | 1.7          | 0.3            | 0.7           | 0             |               |
| 17-39 | 3                             | 5.5              | 1.7          | 0.3            | 0.7           | 0             |               |

Table 2 shows the testing results of LC-LPF filter that inserted on lamp type 1, with the value of LC are 1.87 H & 0.3μF). The type filter can reduce THD significantly and meet the requirements of the EMC standard. The second and the odd harmonic value (3, 7, 9, 11, 13, 15, and so on) meets IEC 61000-3-2 standards except the 5th harmonic. The effective current reduces from 168.4 mA to 102.9 mA. Meanwhile, active power increased from 17.8 Watt to 22.2 Watt. The value of power distortion (D) before inserting a filter of 35.14 VAD and after inserting a filter of 5.57 VAD which are reduced significantly.

Figure 2 display the IL using equation 1 and 2 for a standard value of Zg and ZL. The IL value at f = 50 Hz (∼314 rad/s as frequency of source) are 17.8 dB and 24.1 dB. At normal frequency Insertion loss, RC LPF is bigger than LC LPF. Thus LC LPF is developed to become a prototype.

![Figure 2. Calculation of RC-LPF Filter](image-url)
4. Conclusion
The ability of filter resonance series and BSF filter in decreasing HCE level is undeniable but that is incomparable to RC-LPF & LC-LPF filter performance which is more efficient. The RC-LPF1 filter suppresses the emission of harmonic current related to the high heat problem. While, of the same type filter LC-LPF2 showed a better performance reducing the emission of the harmonic current based on the IL analysis with the source and the standard load impedance, for the same R, L, and C values. The IL calculation giving a further confirmation that the changing of L and C values which obviously affected the value of L. The L value is proportionally related IL value, the higher the value of L, the greater the IL value is to be, and vise versa, the higher value of C and the L value becomes smaller. Using the IL filter calculation as the baseline to justify the optimum operational condition, LC LPF needs to be tested in real-time instrument operation in subsequent research, by applying the standard and worst-case scenarios with the value $Z_g/Z_L$ of 0.1 $\Omega$ /100 $\Omega$.

5. References
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