Harmonic Testing Analysis of Light Emitting Diode (LED) Lamps based SNI IEC 61000-3-2 Standard

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Abstract. The use of LED lamps in Indonesia has increased since 2013 because of low power consumption and high efficiency. LED lamps are non-linear loads that cause harmonic distortion in the electric power system. Harmonic distortion can impact to overheating in magnetic core electrical equipment. Therefore, it is necessary to standardize the limits of the harmonic emission limits of LED lamps. In this study, the harmonics measurements of LED lamps of 22 samples from 10 brands, which include different types of EMI filters in the LED drivers, are carried out to analyze harmonic currents. Measurements in this study conducted using Teseq ProfLine 2105. The results of parameter testing of third and fifth-order harmonic currents, peak current phase angle, beginning current flow at 60 degrees, and end current at 90 degrees were analyze based on the criteria for class C SNI IEC 61000-3-2 standard. The results showed that the three samples used EMI filter inductor in the LED driver can minimize third-order harmonic currents and comply with all parameters.

1. Introduction
Public policies in many countries, which are in line with environmentally friendly technology, encourage the use of energy-efficient lamps as the lighting in various applications indoors and outdoors [1]. Energy Saving lamps are increasingly used are LED lamps with various residential applications, office buildings, roads, vehicles, emergencies, entertainment, and plant grow light [2, 3]. According to data from The Indonesian Electrical Lighting Industry Association (APERLINDO), the full use of LED lamps in Indonesia in 2013 reached 3.4% of the total consumption of electric lamps. This figure continues to increase every year, wherein 2018, it has dominated with a percentage reaching 42.8%.

The main purpose of using LED lamps for low energy consumption is to produce energy-efficient and environmentally friendly because there are no toxic substances than other energy-saving lamps. LED lamps can be classified in energy-saving lamps (LHE). In addition to the advantages possessed by these LED lights, LED lights also have disadvantages such as harmonic emissions caused by the driver device contained in the LED light circuit.

Harmonics are disturbances caused by non-linear loads resulting distortion in the voltage and current waves resulting in the formation of waves with a frequency that is a round multiple of the fundamental frequency [4]. The harmonic phenomenon shows in Figure 1. Harmonic distortion can harm household electrical systems to electric power distribution systems. The negative impact of third-order harmonic distortion generated by single-phase electronic equipment can cause losses in neutral
wire conductors, transformers, electric motors, and protection systems. The protection system that works as a load breaker operates abnormality because it cannot detect the true-RMS current [5].

![Figure 1. The phenomenon of harmonics [5].](image1)

This paper presents a data individual harmonics analysis of LED lamps by measurement test, using different brand LED lamps. In this research, a total of 22 samples of LED lamps from 10 brands is tested. This paper analyzes the effect of using different component EMI filters in the LED lamp to the harmonic emission limit. The measurements are carried out in an accredited laboratory with ISO/IEC 17025:2017. The test results were analyzed based on the criteria for class C requirements of SNI IEC 61000-3-2 harmonic standard.

2. Theoretical Base

2.1. Harmonic Emission Limits

The limits of harmonics are different for each class. The LED lamps are classified as Class C electrical and electronic equipment. The limits of SNI IEC 61000-3-2 are the same as those of IEC 61000-3-2. Harmonic emission limits in Class C are consist of two active input power criteria. These are input power less than or equal to 25 Watt and exceeding 25 Watt. LED lamps with active input power less than or equal to 25 Watt shall comply one of the two conditions. One of the conditions consists of five parameters. These parameters are: third-order harmonic current should not exceed 86% (parameter 1), the fifth-order harmonic current should not exceed 61% of the fundamental current (parameter 2), current peak before or at 65 degrees (parameter 3), beginning of the current flow it reaches the 5% current threshold before or at 60 degrees (parameter 4), and end of the current flow does not fall below the 5% current threshold before 90 degrees (parameter 5) [6]. If there is not comply one of the five parameters, then the LED lamp's test result fails (not comply). Five parameters are shown in Figure 2 and Table 1.

![Figure 2. Illustration of requirements related to peak value of the current waveform. The 5% current threshold is defined to be 5% of the maximum absolute peak value (I_p(abs)) [6].](image2)
Table 1. Harmonic limits of class C requirements active power below 25 Watt [6].

| Parameter                     | Limit                        | Code   |
|-------------------------------|------------------------------|--------|
| Third order harmonics         | Max. 86% fundamental current | I_h-3  |
| Fifth order harmonics         | Max. 61% fundamental current | I_h-5  |
| Peak current phase angle      | Before or at 65 degree       | Current peak |
| Beginning current flow        | Before or at 60 degree       | I_p(abs) at 60° |
| End of the current flow       | 90 degree or after           | I_p(abs) at 90° |

2.2. Mains Operated of LED Lamps

LEDs need a constant current source to monitor the output current and adjust the current amount by turning output off and quickly (switching). The constant current source regulates how long the output is on and how long it is off (duty cycle). The circuit diagram of the LED lamp driver shows in Figure 3. EMI (electromagnetic interference) is a significant problem with LED drivers. Inconstant currents are the most likely to generate EMI. Furthermore, there are many methods to minimize using EMI filters in the LED driver circuit [7].

Figure 3. Circuit Diagram LED driver [8, 9].

The types of EMI filter circuits as contained in the LED lamp driver can be observed from the resulting current waveforms. Some of the filters' types using LED lamp drivers are shown in Figure 4 and Figure 5 [10, 11]. In this paper, an analysis of harmonics current of the effect by LED lamps using EMI filter type passive will be carried out.

Figure 4. The types of current waveforms various LED lamps tested. Using EMI filter type valley fill (blue line) and without filter (orange line).

Figure 5. Type of other current waveforms from different LED lamps tested using EMI filter type passive (blue line).
3. Methodology

3.1. Experiment Setup

The research system is tested in an electrical testing laboratory using measuring equipment following SNI ISO/IEC 61000-3-2 specifications and has accredited with ISO/IEC 17025:2017 standard. The experimental set-up in Figure 6 was conducted to obtain accurate harmonic current value. The measurement in Figure 6 consists of three main components. There are: (1) ProfLine 2105 for measuring of harmonic, (2) the LED lamp is device under tested (DUT), and (3) a personal computer to perform harmonic voltage and current signal analysis. Each test of the harmonic current of the LED lamp takes at least 3 minutes to obtain parameter values [6]: (1) third-order harmonic current, (2) fifth-order harmonic current, (3) current peak, (4) beginning current flow, and (5) end of the current flow.

The ProfLine 2105 brand TESEQ combines a programmable for 5 kVA power source, power analyzer, DAQ card, interface cable, and WIN 2100 harmonic and flicker test software requirements of SNI IEC 61000-3-2 and SNI IEC 61000-3-3 specifications. The ProfLine 2105 TESEQ equipment can be used to measure harmonics ranging from order 1 to order 40 and can isolate the measurement system from electrical network noise and ensure that the voltage supply for measurement is stable and in the form of pure sine without distortion so that the harmonics measured are purely caused by lamp loads LED tested.

The measurement method is shown in Figure 2 refers to the distortion of voltage and current, which means that even though the voltage source line is pure sinusoidal, the non-linear load will attract harmonically distorted currents. The distorted current passing through the power delivery line's impedance will produce a harmonically distorted voltage on the load path. The value depends on the impedance and current of the line [5]. The input voltage was set at 230 Volts on the ProfLine 2105 programmable power source in this research.

3.2. LED Lamps Sample

In this paper, ten brands of LED lamps with different active input power are analyzed. Their samples are:
- Brand A: 3 Watt (A 3 W), 5 Watt (A 5 W), 7 Watt (A 7 W), and 11 Watt (A 11 W).
- Brand B: 3 Watt (B 3 W), 5 Watt (B 5 W), 7 Watt (B 7 W), and 11 Watt (B 11 W).
- Brand C: 5 Watt (C 5 W) and 7 Watt (C 7 W).
- Brand D: 15 Watt (D 15 W).
- Brand E: 15 Watt (E 15 W).
- Brand F: 3 Watt (F 3 W) and 5 Watt (F 5 W).
• Brand G: 7 Watt (G 7 W).
• Brand H: 5 Watt (H 5 W), 7 Watt (H 7 W), 11 Watt (H 11 W), and 15 Watt (H 15 W).
• Brand I: 3 Watt (I 3 W) and 11 Watt (I 11 W).
• Brand J: 7 Watt (J 7 W).

4. Results and Discussions
Table 2 shows the testing result of the measurement of individual harmonic for LED lamps sample. An Individual LED lamp is measured the 3rd and fifth-order harmonic current in terms of percentage to the fundamental current, current peak, beginning current flow at 60 degrees, and the end of the current flow at 90 degrees. When the third and fifth-order harmonic values for lamps brand A 5 W, A 7 W and A 11 W, it can be observed that the third-order harmonic value generally ranges between 73 to 79 %, while brand B with active input power B 5 W, B 7 W and B 11 W leading of third-order harmonics value generally range between 85 to 90 %. It is caused these LED lamps to use different component EMI filters in the LED driver circuit.

| Type of EMI Filter | Test Results | A 3 W | 15 | 86.07 | 74.20 | 70 | 0.00 | 23.35 | Passive filter | Not comply |
|--------------------|--------------|------|----|--------|--------|----|------|--------|----------------|-------------|
| B 3 W              |              | 15   | 83.80 | 72.47 | 75 | 0.00 | 0.00 | Passive filter | Not comply |
| F 3 W              |              | 14   | 81.86 | 67.00 | 76 | 0.00 | 0.00 | Passive filter | Not comply |
| I 3 W              |              | 19   | 71.89 | 60.05 | 70 | 0.00 | 23.52 | Passive filter | Not comply |
| A 5 W              |              | 29   | 73.03 | 55.41 | 64 | 93.51 | 14.91 | Passive filter | Comply |
| B 5 W              |              | 21   | 85.06 | 72.67 | 76 | 0.00 | 32.96 | Passive filter | Not comply |
| C 5 W              |              | 24   | 87.50 | 78.95 | 80 | 0.00 | 0.00 | Passive filter | Not comply |
| F 5 W              |              | 25   | 81.96 | 65.44 | 75 | 60.90 | 0.00 | Passive filter | Not comply |
| H 5 W              |              | 39   | 35.00 | 16.10 | 179 | 36.45 | 0.00 | Valley fill | Not comply |
| A 7 W              |              | 35   | 79.22 | 60.80 | 62 | 91.90 | 14.96 | Passive filter | Comply |
| B 7 W              |              | 33   | 87.48 | 70.24 | 67 | 83.72 | 15.10 | Passive filter | Not comply |
| C 7 W              |              | 32   | 86.90 | 70.93 | 72 | 84.48 | 5.31 | Passive filter | Not comply |
| G 7 W              |              | 35   | 87.25 | 75.25 | 76 | 0.08 | 5.26 | Passive filter | Not comply |
| H 7 W              |              | 29   | 92.96 | 89.37 | 81 | 0.00 | 7.07 | No filter | Not comply |
| J 7 W              |              | 34   | 80.06 | 56.73 | 68 | 64.27 | 4.36 | Passive filter | Not comply |
| A 11 W             |              | 59   | 76.10 | 53.35 | 56 | 85.52 | 16.42 | Passive filter | Comply |
| B 11 W             |              | 48   | 90.39 | 77.06 | 70 | 0.00 | 27.71 | Passive filter | Not comply |
| H 11 W             |              | 43   | 23.39 | 14.72 | 80 | 2.96 | 0.00 | Valley fill | Not comply |
| I 11 W             |              | 51   | 84.70 | 65.25 | 60 | 87.61 | 12.15 | Passive filter | Not comply |
| D 15 W             |              | 72   | 92.15 | 82.11 | 75 | 0.00 | 13.14 | No filter | Not comply |
| E 15 W             |              | 109  | 21.81 | 14.81 | 178 | 11.91 | 0.09 | Valley fill | Not comply |
| H 15 W             |              | 70   | 14.30 | 13.64 | 102 | 0.00 | 0.00 | Valley fill | Not comply |

Meanwhile, LED lamps that use a valley fill EMI filter can produce lower third-order harmonics values than passive EMI filters. Brand of H 5 W, H 11 W, E 15 W, and H 15 W generate low levels of third-order harmonics value generally range between 14 to 35 %. However, the valley fill filter cannot increase the peak current phase angle before 65 degrees because of the ripples in the resulting current waveforms. The resulting waveform is shown in Figure 7 to Figure 10.
Even though in Figure 8 and Figure 10, using the same type of EMI filter, the components used by each brand have different specifications. Figure 11 shows the EMI filter used by the brand of A (left) and the B (right) LED lamps 5 Watt. In the implementation brand of A, two inductors (suppression of the common-mode noise) [12, 13] in LED drivers such as inductor create by using a transformer (green arrow) and inductor radial leaded type (orange arrow). The EMI filter that uses two inductors of the common-mode can minimize third order of harmonic current value to below 86% of the fundamental current, while the EMI filter that uses one inductor [14, 15] (suppression of the differential-mode noise) causes up to 86% of the fundamental current. It is because there is lacking ventilation in the LED lamps to remove heat in the resistor. Whereas, the inductor does not generate heat, resulting in the lowest voltage ripple factor [16] and increasing the value of the peak current phase angle before 65 degrees.
less source impedance. Single section inductor can inductor saturate at the peak ripple current, so output current while still having enough to sufficiently reduce the noise signal [17] and third-order harmonic current still up to 86%.

5. Conclusions
The results of 22 samples from 10 brands of LED lamps show that 3 samples comply with all parameters, and 19 samples only comply with some of the standard parameters of SNI IEC 61000-3-2. The details are as follows: 14 samples comply the third order of harmonic current parameters, 9 samples comply the fifth order of harmonic current parameters, 3 samples comply the peak current phase angle parameters, 10 samples comply the initial current parameters of current flow parameters, and 13 samples comply the final current parameters. A sample of an LED lamp complying with all parameters uses an EMI filter to have more than one inductor (multi-section inductor).

EMI filters in LED drivers that use two inductors (common-mode suppression) can be placed third-order harmonic currents to below 86% of the fundamental current. The use of a multi-section inductor in the EMI filter can prevent the peak ripple currents’ saturation so as not to overheat the LED driver circuit. As a result, the peak current angle occurs before 65 degrees and minimizes the current ripple factor.

6. References
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Acknowledgments

The authors thank the Ministry of Research and Technology of The Republic of Indonesia, Saintek and National Standardization Agency for Indonesia (BSN). This research’s early works are supported under a collaboration between the Department of Electrical Universitas Indonesia and Electromagnetic Compatibility Laboratorium Centre of Electronics Technology (PTE) Indonesian Agency for the Assessment and Application of Technology (BPPT). While the publicity of this work is support by Research Grant "Hibah Publikasi Terindeks Internasional (PUTI) 2020 (NKB-1128/UN2.RST/HKP.05.00/2020)", Universitas Indonesia. (Corresponding author: Purnomo Sidi Priambodo)