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Performing power quality analysis of different LED lamps

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ABSTRACT

Lighting, which accounts for 20-30% of electricity use, is among the most important electricity consumption uses. Light Emitting Diode (LED) lamps are more durable, economical and environmentally friendly than incandescent, halogen and fluorescent lamps. One of the most important advantages of LEDs is their high efficiency. LEDs have become an important technology sector in lighting with their high efficiency and savings worldwide. When using LEDs, they need a driver circuit due to their operating characteristics, since it is necessary to limit the current flowing through them. Due to the power electronics elements contained in the driver circuits used in the LEDs, they draw harmonic current from the system. For this reason, it is very important to analyse and interpret the effects of LEDs on power quality. In this study, total harmonic distortion and power factor values, which are among the power quality problems caused by different power LEDs in the electrical network, were investigated. Measurement results were compared with IEC 61000-3-2 and IEEE 519-2014 harmonic standards. Compared with the standard, a passive harmonic filter is designed and added to the input of the LED lamp, since some harmonics exceed the maximum allowable harmonic limit. The designed passive low-pass filter is used to reduce the harmonics aroused from the driver of the LED lamp. The effect of the filter used in the system on harmonics was also investigated. As a result of the study, it has been seen that LEDs of different power values have significant effects on power quality.

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1. INTRODUCTION

Lighting, which accounts for 20-30% of electricity use, is among the most important electricity consumption uses [1]. The electricity consumed for lighting reaches 40% of the total electricity consumption in some cities. Electricity consumption in Turkey was reported as approximately 278.3 TWh in 2016. Street and tunnel lighting account for 2 to 4.6% of all electricity consumption in Turkey [2]. Since the energy used in lighting in our country corresponds to approximately one-fifth of the total electrical energy consumed, it is inevitable to work on increasing efficiency and savings in lighting systems. To use energy efficiently and to save energy, the elements used in lighting systems should be selected from those with high efficiency. With the developing technology due to electricity consumption and efficiency, LEDs are preferred in lighting systems. The reasons why LEDs come to the forefront more than other lighting elements are that the life of LEDs is longer than other lighting elements, they require less maintenance, the equipment takes up less space, that is, small size, color, and light diversity. They are more durable against vibrations and shocks and consume less power [3]. Therefore, LED lighting systems gain more importance as they provide a situation for more efficient use of electrical energy in areas such as homes, public lighting systems, transportation, commercial applications [4].

Due to their reduced cost and increased performance, LED lamps are among the most common environmentally friendly devices found in our daily lives. By 2030, it is expected that LEDs used in lighting will represent 83% of all residential lighting in the world, and as a result, lighting energy consumption will decrease by approximately 40% [5]. Electrical systems are designed to operate in sinusoidal form and at frequencies of 50 Hz and 60 Hz. Besides that, LED, etc. such loads produce currents and voltages with frequencies that are integer multiples of the 50 Hz and 60 Hz fundamental frequency. These high frequencies are a form of electrical pollution known as power system harmonics [6].

As a result of loads with nonlinear characteristics, harmonic currents and voltages occur. In electrical systems, harmonics can significantly affect the quality of the electrical system. Electronic devices are generally non-linear and therefore result in non-sinusoidal currents even when powered by a purely sinusoidal voltage. These currents can distort grid voltage [7]. As non-linear loads, LEDs also generate harmonics due to the converter that they contain in their drivers and semiconductor devices. In other words, they inject current and voltage harmonics that can disrupt power

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quality by acting as a harmonic source. Although the power of a single LED is quite low, their widespread use in lighting can affect power quality in distribution systems and cause significant additional harmonic losses in existing low voltage lines [8]. Therefore, it is very important to investigate the harmonic properties of power electronics-based lighting systems, which can provide useful information and recommendations for the reduction and control of harmonics, and evaluate their possible effects on the power network.

Numerous studies have been done on LEDs as energy-saving lamps. However, most of these studies are about internal driver circuit design or light distribution and the visual performance of LED lamps. Some studies are related to the harmonic states of LED lamps [9]. In some studies, it has been determined that LED lamps produce high current harmonics that exceed the limits of the IEC 61000-3-2 standard [10-12]. These harmonics can cause fundamental wave distortion, low power efficiency, and low Electromagnetic Compatibility (EMC) of devices [13]. The majority of the studies on the harmonic state of LED lighting elements in the literature are on the harmonic activities of LED drivers and lamps as a result of measurements and the research and development of solutions for reducing these activities. In some studies, the harmonic states of lighting elements of different structures and LED lighting elements were compared. In addition, in some studies, the effects of LED lighting elements that cause harmonic pollution on the grid have been investigated [14].

This article presents the harmonic and power parameter analysis of four different LED lamps with 40 W, 75 W, 100, W, and 150 W power ranges, which are commercially used and have higher power ratings than other studies. Eight different measurement parameters of four LED lamps of different power were examined. Measurements were made to observe voltage and current waveforms and analyze power values. In addition, the measurement results were compared with IEC 61000-3-2 and IEEE 519-2014 harmonic standards. Finally, harmonic filter design was carried out and suggestions were made to reduce the effect of harmonics. Since the practical application in the literature is very few compared to simulation applications, our ultimate aim in this study is to solve the problems caused by harmonics caused by LED drivers with passive filtering, which is one of the harmonics reduction methods.

2. MATERIALS AND METHODS

The Fourier series represents an efficient way to study and analyze harmonic distortion. It enables the various components of a distorted waveform to be examined by decomposition. In general, any periodic waveform can be expressed in the form of a Fourier series. With this method, the analysis of harmonics can be done easily. Total Harmonic Distortion (THD) indicates how many harmonic components the voltage and current waveforms contain and the extent of waveform distortion that occurs.

THD is found by dividing the root mean square (RMS) of the harmonic components by the effective value of the fundamental component and is usually expressed as a percentage. For an ideal system, THD is equal to zero. In other words, as it can be understood from Equation (1-2), the THD will be zero in systems without harmonics. In the standards that aim to keep the harmonic values within certain limits, THD, which is very commonly used, is calculated for current and voltage as in Equation (1-2) [15], respectively.

$$THD_I = \frac{\sqrt{\sum_{n=2}^{N} I_n^2}}{I_1} = \frac{\sqrt{I_2^2+I_3^2+I_4^2+\ldots+I_n^2}}{I_1} \tag{1}$$

$$THD_v = \frac{\sqrt{\sum_{n=2}^{N} V_n^2}}{V_1} = \frac{\sqrt{V_2^2+V_3^2+V_4^2+\ldots+V_n^2}}{V_1} \tag{2}$$

V_n and I_n represent the RMS voltage and current at the n^{th} harmonic. In other words, the effective value of the n^{th} order harmonic of the voltage applied to the circuit and the current passing through the circuit, N the maximum harmonic order, V_1, and I_1 represent the neutral RMS voltage and current of the line, that is, the RMS value of the voltage applied to the circuit and the current passing through the circuit at the fundamental frequency [15].

Active power (P) is the power dissipated by the load. This is the power used to produce torque in the engine. Reactive power (Q) is the power stored and discharged by the inductive and capacitive components of the system. This is the force that produces the magnetic flux that causes the motor to rotate. Apparent power (S) is the complex sum of active and reactive power. Due to non-linear loads, harmonics affect the power factor. Therefore, the THD should also be considered when calculating the actual power factor. Power factor (PF) is the ratio of real (active) power to apparent power. In other words, the PF is expressed as the product of displacement power factor (dPF) and distortion power factor (distortion PF) as in Equation (3-5) [16].

$$PF = \frac{P}{S} = \frac{P}{S_1} \cdot \frac{1}{\left(\sqrt{1+THD_v^2}\,\sqrt{1+THD_i^2}\right)} \tag{3}$$

$$PF = cos\varphi \cdot \frac{1}{\left(\sqrt{1+THD_v^2}\,\sqrt{1+THD_i^2}\right)} \tag{4}$$

$$PF = dPF \,.\, distortion\ PF \tag{5}$$

Where P is the total active power, S is the total apparent power, and S_1 is the apparent power at the fundamental frequency.

dPF is the PF resulting from the phase shift between voltage and current at the baseline frequency. For pure sinusoidal currents, the dPF is the same as the apparent power factor. The dPF is defined as in Equation 6 [16]:

$$dPF = \frac{P}{S} = \cos(\delta_1 - \theta_1) = cos\varphi \tag{6}$$

where δ_1 is the phase angle of the voltage, θ_1 is the phase angle of the current; φ is the PF angle.

The dPF is the distortion component associated with the harmonic voltages and currents present in the system. The dPF is calculated as in Equation 7 [16]:

$$distortion\ PF = \frac{1}{\left(\sqrt{1+THD_v^2}\cdot\sqrt{1+THD_i^2}\right)} = \frac{V_{1rms}}{V_{rms}} \cdot \frac{I_{1rms}}{I_{rms}} = \frac{S_1}{S} \tag{7}$$

where THD is the total harmonic distortion for current and voltage [16]. A driver circuit is required to condition the voltage applied to the LEDs. Some of the low-cost LED lamps have high harmonics that exceed the requirements specified in the IEC 61000-3-2 and IEEE 519-2014 standards. In some of the tests performed on LEDs, it has been found that the PF approaches 0.6 and the THD_I for the current varies between 100% and 140% [17].

The traditional approach to solving the harmonic problem is to use a passive harmonic filter. Nowadays, passive harmonic filter applications can be used as a common application. These filters typically provide an alternating impedance path for the harmonic currents produced by the non-linear load and lower harmonic current components in the mains current. A passive harmonic filter can be created with three components: an inductor (L), a capacitor (C), and a resistor (R). The filter can cause series or parallel resonance from high or low impedance at the tuned frequency. To reduce the harmonic magnitude, the resonant frequency Equation 8 [1] is an important parameter to be considered.

$$f_r = \frac{1}{2\pi\sqrt{LC}} \tag{8}$$

Where f_r is the resonant frequency in Hertz (Hz). L is the inductor in the harmonic filter, in Henry (H). C is the capacitor in the harmonic filter in Farad (F) [1].

In this study, measurements were carried out at 220 V voltage and 50 Hz frequency. Power quality parameters were measured with the Amprobe Energy Test Power Analyzer. The power analyzer is a three-phase measuring device that can analyze current and voltage harmonics, active, reactive, and apparent powers. It allows accurate analysis of power consumption with high storage capacity and long power records. LED lamps with 40 W, 75 W, 100, W, and 150 W are energized and the power parameters of each LED voltage (V), current (I), apparent power (S), active power (P), reactive power (Q), current and voltage total harmonic distortion (THD_I-THD_V), power factor (PF) and displacement power factor (dPF) values were connected and measured as in Figure 1.

In addition, the voltage and current graph are drawn by the LEDs, as well as the harmonic spectrum is given. The characteristics obtained by the harmonic spectrum power analyzer of the current drawn by the LEDs are transferred to the computer environment with the help of the driver of the device, thus providing a more detailed examination opportunity. The measurement results were compared with IEC 61000-3-2 and IEEE 519-2014 harmonic standards, and filter design and application were carried out to reduce and filter harmonics.

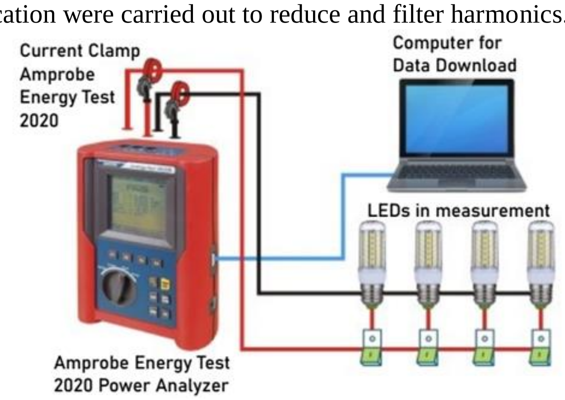
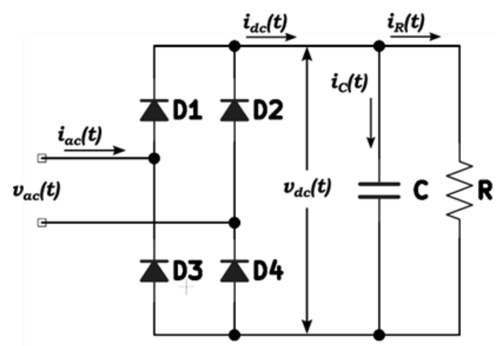
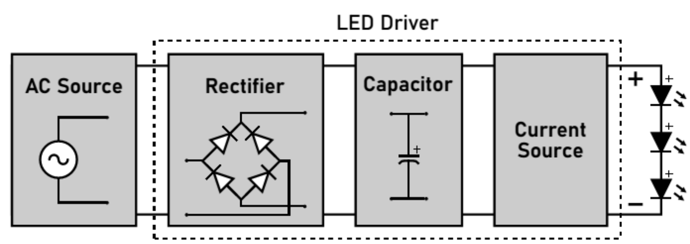


Fig. 1. Schematic diagram of measurement of LEDs with power analyzer.

LED lamps inherently require a non-linear power electronics driver. Depending on the quality of the driver circuit, LED lamps can draw significant non-sinusoidal current and produce harmonic pollution. Harmonic pollution has adverse effects on power system infrastructure and user equipment. LED devices with high harmonic effect drivers can have a huge impact on the power system infrastructure and electricity bills. High penetration of low-quality LED lamps can cause the power system to become unstable. The LED driver circuit is essentially a single-phase capacitor filtered uncontrolled AC/DC converter [18]. The LED driver is a power supply switch that supplies a constant current to the LEDs. Power supply switching is a non-linear load that causes harmonics. The general LED driver circuit and the block diagram of the LED driver are shown in Figure 2. Line input voltage 230 V AC at 50 Hz frequency, a rectifier with smoothing capacitor, pulse width modulation (PWM) controlled constant current source converter for DC to DC conversion are connected to the LEDs.



(a)



(b)

Fig. 2. (a) General LED driver, (b) Block diagram of LED lamp circuit.

Harmonics can be reduced using filtering techniques. To effectively reduce the harmonic currents from LED lamps, standards defining the acceptable harmonic level for harmonic filter design are taken into account.

Table 1 shows the harmonic current limit of lighting equipment (Group C) according to IEC 61000-3-2 (TS EN 61000-3-2) standard. The standard specified in the table includes the electromagnetic compatibility (EMC) emission limits of harmonic currents injected into the electrical network system for electrical electronic devices with an input current of ≤ 16 A per phase and to be connected to low voltage distribution systems. The harmonics being in the specified standards ensures that the sensitive electrical/electronic equipment or the lamp is not affected by the harmonics produced. The maximum allowable harmonic current is calculated as a percentage compared to the baseline size.

Table 1. The harmonic current limit of lighting equipment (Group C) according to IEC 61000-3-2 Standard [19].

Harmonic Degree (n)	*Maximum allowable harmonic current*
2	2
3	30 x power factor
5	10
7	7
9	5
$11 \leq n \leq 39$ (odd harmonics only)	3

Considering the regulations and standards that lighting elements must comply with, high-performance drivers are needed in most cases. The LED driver system does not only provide AC-DC conversion but also LED current control, Power Factor Correction (PFC), and input current THD control [4].

In transmission systems, the presence of a distorted current produced by a non-linear load also disrupts the grid voltage due to the interaction between source impedance and harmonic currents. This deterioration in the mains voltage adversely affects other loads at the common connection point, which is the point that connects the mains and the consumer, who is the end-user. In the IEEE 519-2014 harmonic standard, limits are introduced for current and voltage harmonics to evaluate harmonic distortion. Current harmonic standards are determined by the I_{SC}/I_L ratio. I_{SC} is the maximum short-circuit current available at the Common Coupling Point (PCC) or measuring point, while I_L is the maximum load current at the fundamental frequency. According to the IEEE 519-2014 standard, it recommends that the THD value should not exceed 5% for current and voltage [20].

3. FINDINGS AND DISCUSSION

To obtain data on current harmonic content, and power values of LED lamps with four different powers, measurements were made utilizing the setup as shown in Figure 1. The power quality analyzer consists of four elements, the current clamp, the LED lamps being measured, and a laptop to analyze the signals. The basic power parameter values obtained from the measurements performed on four LED lamps of different power are given in Table 2.

The graph of current and voltage are drawn by A (40 W) LED lamp is given in Figure 3 and Figure 4. It can be seen that the voltage waveform in Figure 3 is quite close to the sinus form, but the current waveform in Figure 4 is far from the sinusoidal form. When the harmonic spectrum for the current in Figure 5 is examined since the value of the 3rd harmonic is approximately 10%, the THD value is measured as 10.131 and the PF value is 0.634, as seen in Table 2. In addition, the dPF value was determined as 0.639.

Table 2. Measured basic parameters of A (40 W), B (75 W), C (100 W), and D (150 W) LED lamps.

Parameter	*A (40W)*	*B (75W)*	*C (100W)*	*D (150W)*
V_{rms} (V)	221.621	228.831	228.826	224.752
I_{rms} (A)	0.117	0.291	0.395	0.417
P (W)	16	33	82	66
S (VA)	26	67	90	94
Q (VAr)	-20	-58	-38	-67
dPF	0.639	0.909	0.919	0.706
PF	0.634	0.5	0.909	0.699
THD_I (%)	10.131	150.836	13.174	12.111

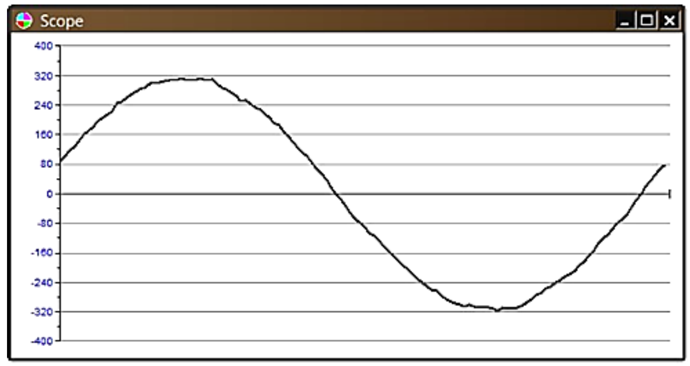


Fig. 3. The voltage waveform of A (40 W) LED lamp.

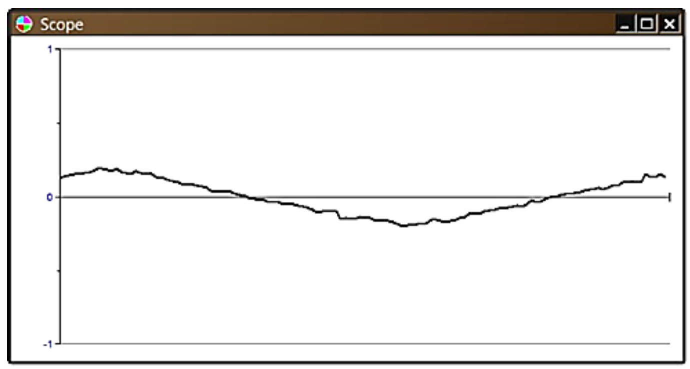


Fig. 4. The current waveform of A (40 W) LED lamp.

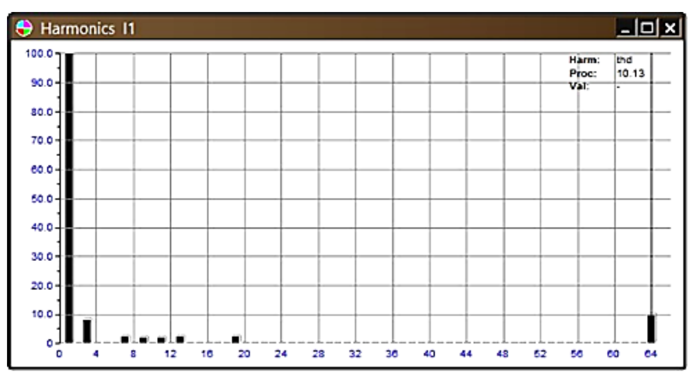


Fig. 5. Current harmonic spectrum of A (40 W) LED lamp.

The graph of current and voltage are drawn by the B (75 W) LED lamp is given in Figure 6 and Figure 7. It can be seen that the voltage waveform in Figure 6 is quite close to the sinus form, but the current waveform in Figure 7 is quite far from the sinusoidal form. When the harmonic spectrum for the current in Figure 8 is examined, the 3rd harmonic value is approximately 90%, the 5th harmonic value is 80%, the 7th harmonic value is 60%, the 9th harmonic value is 45%, the 11th harmonic value is 25%, the 13th and 17th harmonic value is approximately the THD value is 150.84%, and the PF value is 0.5 since the value of the first harmonic is 10%, the 19th and 21st harmonic value is 15%, the 23rd harmonic value is 12%, the 25th harmonic value is 9%, and the 35th harmonic value is 7% measured. In addition, the dPF value was determined as 0.909.

The LED driver circuit draws current from the network that is not in a sinusoidal waveform. This current drawn is obtained as the sum of the harmonic component multiples of the low to high order fundamental component signal according to the Fourier series expansion. Therefore, there are harmonic currents from low to high order in the current drawn.

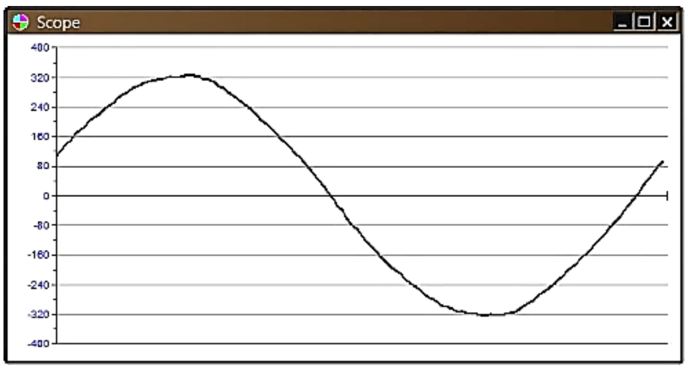


Fig. 6. The voltage waveform of B (75 W) LED lamp.

Fig. 7. The current waveform of B (75 W) LED lamp.

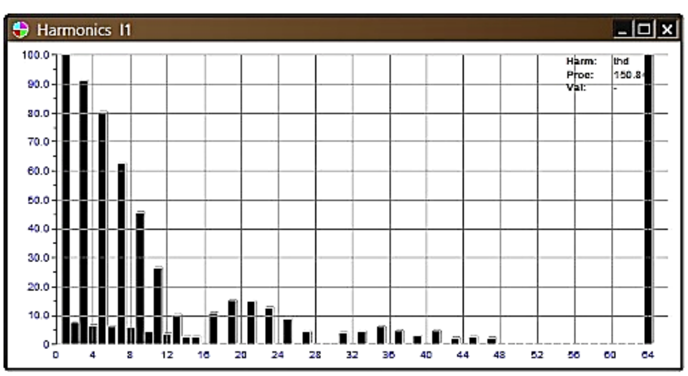


Fig. 8. Current harmonic spectrum of B (75 W) LED lamps.

The graph of current and voltage are drawn by the C (100 W) LED lamp is given in Figures 9 and Figure 10. It can be seen that the voltage waveform in Figure 9 is quite close to the sinusoidal form, but the current waveform in Figure 10 is far from the sinusoidal form. When the harmonic spectrum for the current in Figure 11 is examined, the harmonic distortion value is measured as 13.17%, and the PF value is 0.909 since the 3rd and 5th harmonic value is close to 10% and the 7th harmonic value is close to 5%. In addition, the dPF value was determined as 0.919.

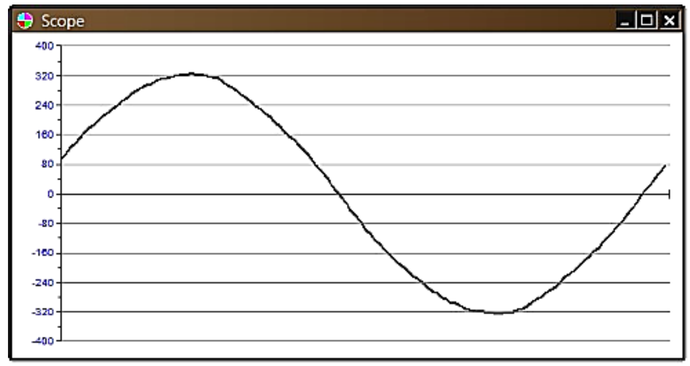


Fig. 9. The voltage waveform of C (100 W) LED lamp.

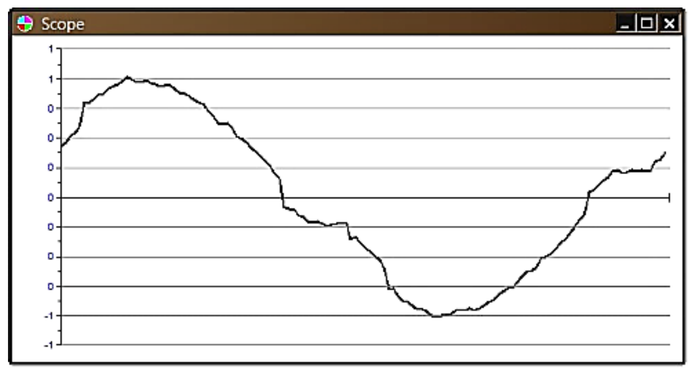


Fig. 10. The current waveform of C (100 W) LED lamp.

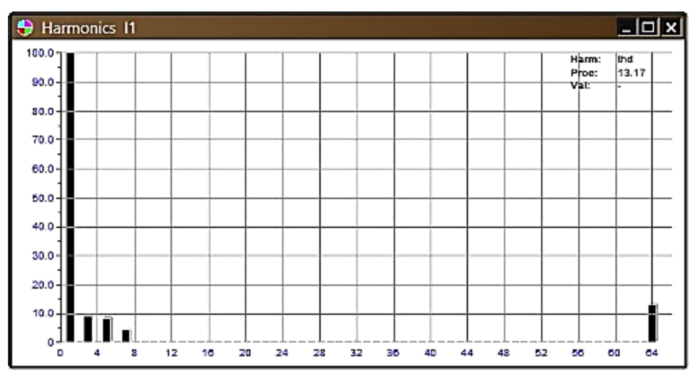


Fig. 11. Current harmonic spectrum of C (100 W) LED lamps.

The graph of current and voltage are drawn by the D (150 W) LED lamp is given in Figure 12 and Figure 13. It can be seen that the voltage waveform in Figure 12 is quite close to the sinus form, but the current waveform in Figure 13 is far from the sinusoidal form. When the harmonic spectrum for the current in Figure 14 is examined since the 3rd harmonic value is approximately 10% and the 9th harmonic value is approximately 4%, as seen in Table 2, the THD value is 12.11 % and the PF value is 0.699. In addition, the dPF value was determined as 0.706.

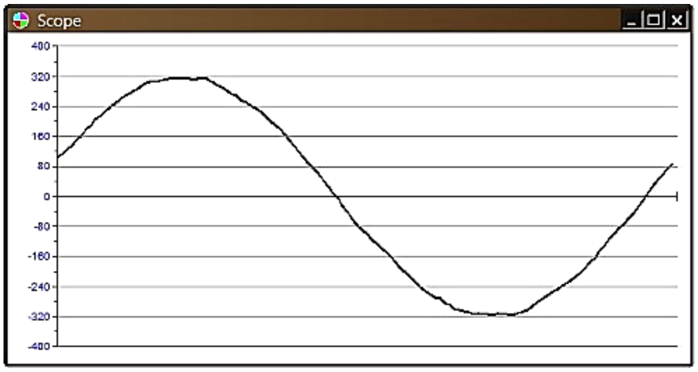


Fig. 12. The voltage waveform of D (150 W) LED lamp.

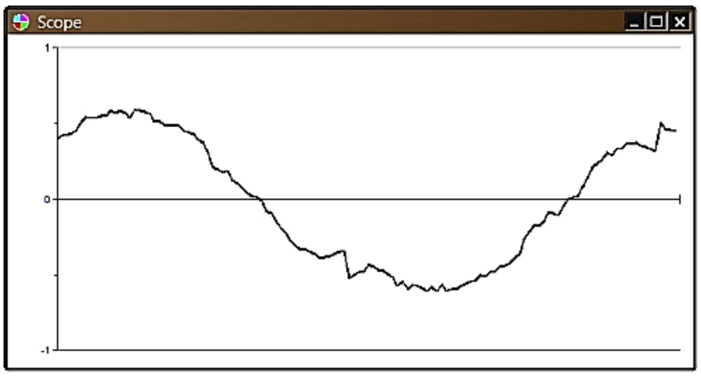


Fig. 13. The current waveform of D (150 W) LED lamp.

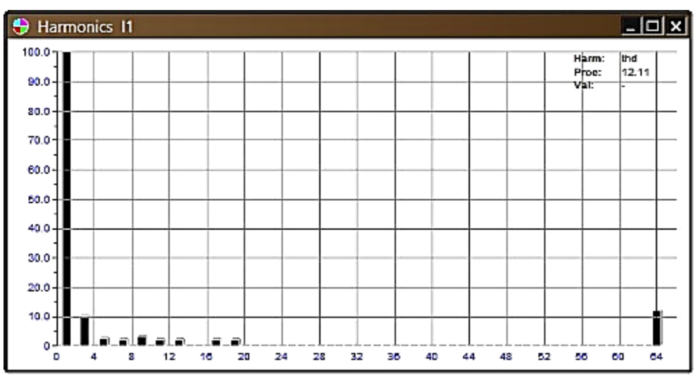


Fig. 14. Current harmonic spectrum of D (150 W) LED lamp.

As a result of the measurements, it was determined that the 3rd, 5th, 7th, 9th, 11th, 13th, 17th, 21st, and 23rd harmonics exceeded the standards, especially by the B (75 W) LED. Especially due to harmonics, it would be appropriate to connect a passive harmonic filter designed as in Figure 15 to the LED driver input.

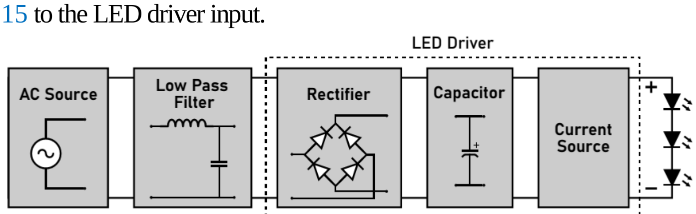


Fig. 15. Low pass filter placement in the LED lighting system.

As seen in Figure 16, the filter will simply consist of an inductor and a capacitor. Also, a resistor can be added to the capacitor to discharge the electrical charge. The mentioned structure corresponds to the low-pass filter which has its advantages. Considering the resonance frequency Equation 8 to reduce the harmonic magnitude; For the 3rd harmonic, the resonance frequency of the harmonic filter is fixed at 150 Hz, and the value of the capacitor is fixed at 11 μF, the value of the inductor is 102.44 mH. Since the low-pass filter is designed as a series toroidal inductor and five capacitors connected in parallel, each capacitor will be 2.2 μF, and its total value will be 11 μF. This is because the rated voltage is limited. The resistor in the passive harmonic filter is not optionally added.

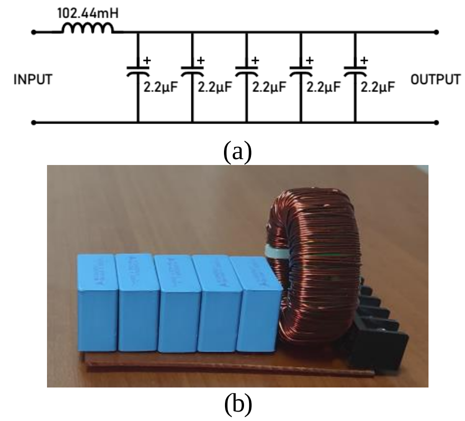


Fig. 16. The low pass filter used in this study; is (a) circuit, (b) filter.

Figure 17 shows the single line diagram of low-pass filter placement and measurement in the LED lighting system. The supply voltage is single-phase at 230 V, and the fuse is used as a protective device. A power analyzer was used for the measurement of electrical parameters and harmonics.

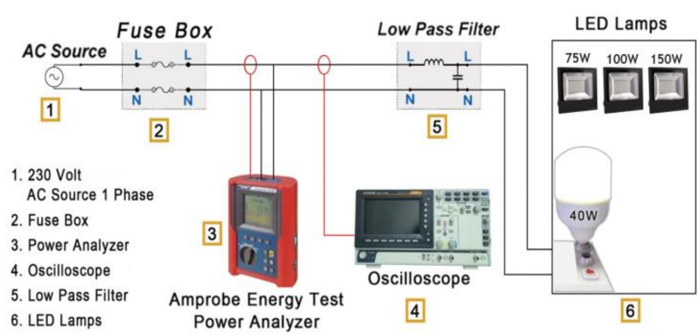


Fig. 17. Low-pass filter connection and single-line diagram of the circuit under measurement.

The graph of current and voltage was drawn by the B (75 W) LED after the passive harmonic filter is connected which is illustrated in Figure 18 and Figure 19. It can be seen that the voltage waveform in Figure 18 is sinusoidal, but the current waveform in Figure 19 is far from the sinusoidal form. When the harmonic spectrum for the current in Figure 20 is examined, the 3rd harmonic value, the THD, and the PF value are measured approximately 34.5%, 36.90%, and 0.7, respectively.

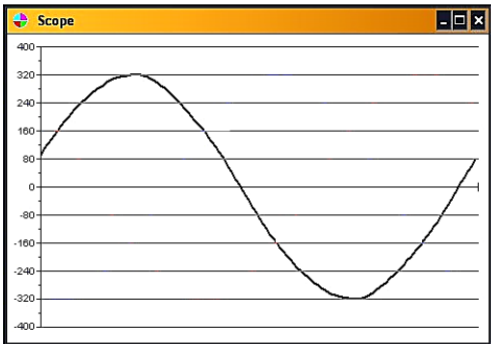


Fig. 18. The voltage waveform of B (75 W) LED lamp with filter.

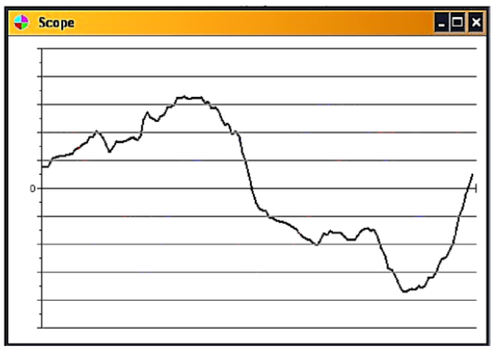


Fig. 19. The current waveform of B (75 W) LED lamp with filter.

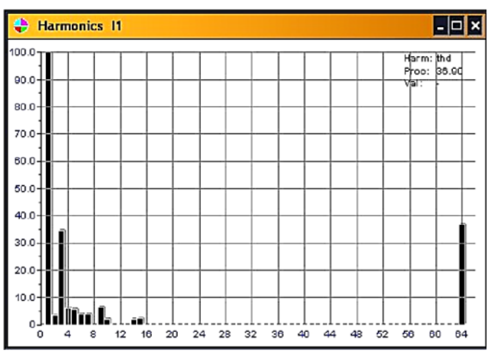


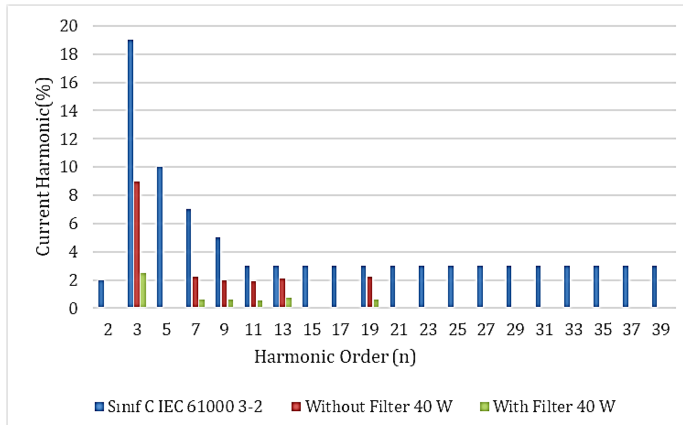
Fig. 20. Harmonic spectrum for current of B (75 W) LED lamp with filter.

The PF and the THD values of current are tabulated in Table 3 for 40 W, 75 W, 100 W, and 150 W LED lamps with and without a filter. As can be seen from the table, the THD_I value of LEDs for current without a filter is more than 5% compared to the IEEE 519-2014 standard. In the measurement made with the filter, the value of 40 W, 100 W, and 150 W LED lamps was lower than the IEEE 519-2014 standard, but the THD_I value for the 75 W LED lamp was more than 5% for the current.

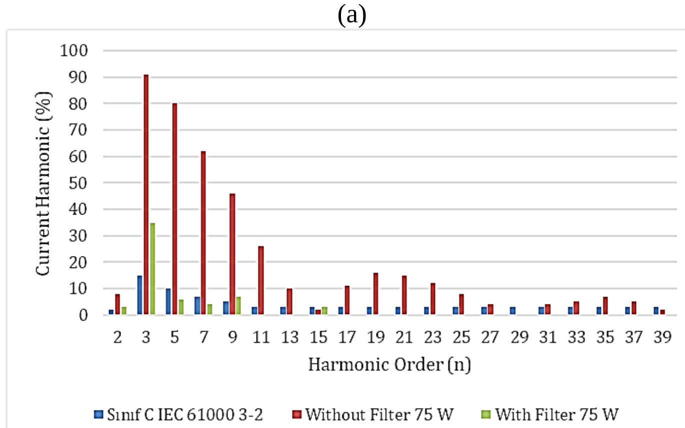
Table 3. Filtered and unfiltered PF and THD_I values.

LEDS	*Without Filter*		*With Filter*	
	PF	*THD_I*	*PF*	*THD_I*
A (40W)	0.634	10.131	0.75	2.86
B (75W)	0.5	150.836	0.70	36.90
C (100W)	0.909	13.174	0.95	3.65
D (150W)	0.699	12.111	0.80	3.44

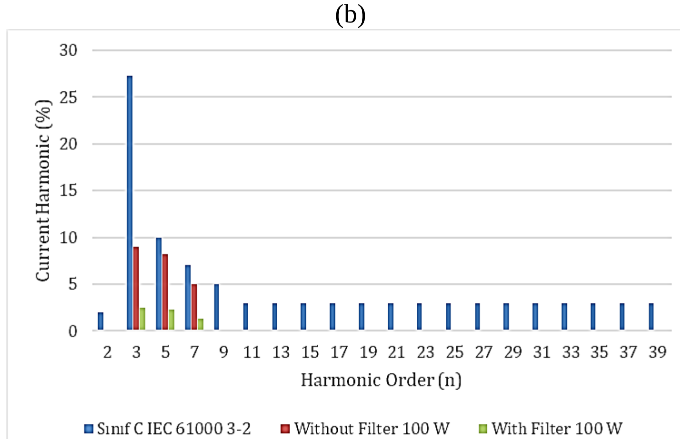
The obtained harmonic magnitudes with filtered and unfiltered are compared for present LEDs lighting systems with the IEC 61000-3-2 standard, and the graphs are shown in Figure 21. Figure 21(a-d) shows the comparison of the filtered and unfiltered harmonic current produced from 40 W, 100 W, and 150 W LED lamps, respectively, and IEC 61000-3-2 standard values. According to the results and the figure, 40 W, 100 W, and 150 W LED lamps have lower harmonic values than the standard allowable without a filter. It is seen that the values of the current harmonics in each row decrease significantly after the low-pass filter circuit is installed.



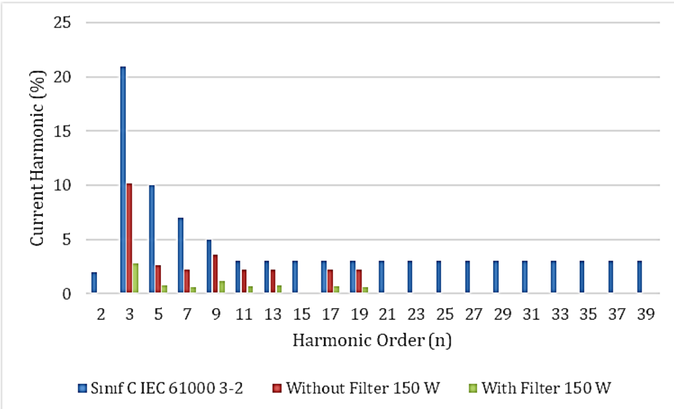
(a)



(b)



(c)



(d)

Fig. 21. Comparison of the harmonic magnitudes obtained from the filtered and unfiltered LED lighting systems with the IEC standard; (a) 40 W, b) 75 W, (c) 100 W, and (d) 150 W.

In the case of 40 W, 75 W, 100 W, and 150 W LED lamps, the focus is on the 75 W LED lamp due to the highest current harmonics. The comparison of the IEC 61000-3-2 standard value and the harmonic current produced from a filtered and unfiltered 75 W LED lamp is shown in Figure 21 (b). In the figure, it is shown that the LED lamp has current harmonic orders of magnitude greater than the allowable value. It is seen that the current harmonics in each row decrease significantly after the low-pass filter circuit is installed. However, although the proposed filter circuit significantly reduces the current harmonic, the current harmonic order values are higher than the IEC 61000-3-2 standard.

4. CONCLUSIONS

Efficient use of lighting is one way to support energy savings, and the application of new technologies and standards to reduce energy consumption has become an interesting topic. The use of LED lamps is increasing rapidly due to their low energy consumption and longevity. Due to this increasing use, there is a need to examine the effects of LEDs on power quality.

In this article, the THD_I values of the LEDs exceeded the IEEE 519-2014 harmonic standard in the measurements made without filters. When the harmonic orders are taken into consideration, the harmonic distortion values of only 75 W LED exceeded the IEC 61000-3-2 harmonic standard. To reduce harmonics, a low-pass filter circuit was designed and connected between the LED driver and the mains, and then measurements were made with a power analyzer. After adding the low-pass filter to the circuit, it has been observed that the harmonic value of the 75 W LED lamp can be reduced by about 75%, although it is above the standard value. Harmonics raised from LEDs may damage or cause a malfunction in other sensitive electrical equipment in the system. With the passive filter circuit, the harmonics occurring in the LEDs can be reduced, preventing them from flowing into the grid.

As a result, although LEDs are advantageous in terms of power saving and luminous intensity, the necessity of filtering (reducing) or controlling harmonic components has been revealed because they cause harmonics that affect power quality. For this reason, such studies on LED drivers will make significant contributions to the literature when power quality is considered.

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Biography

Faruk Kürker was born in Tarsus. He received his B.Sc. in Electrical and Electronics Engineering, his M.Sc. in Computer Engineering (2010), and his Ph.D. in Electrical and Electronics Engineering (2017) from Gaziantep University, Çukurova University, and Harran University, respectively. He is still working as an Assistant Professor at the Department of Electrical and Electronics Engineering at Adıyaman University. His areas of interest are electrical power quality, harmonics, power factor, and passive filters.

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