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Power factor improvement on LED lamp driver using BIFRED converter

Moh. Zaenal Efendi, Farid Dwi Murdianto, Fito Ardli Fitri, Luluk Badriyah
Department of Electrical Engineering, Politeknik Elektronika Negeri Surabaya,
PENS Campus, Indonesia

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ABSTRACT

This paper presents the implementation of a power converter to improve power factor for LED lamp driver. The power converter which used in this system is the integration of boost and flyback converter (boost integrated flyback rectifier energy storage DC-DC/BIFRED). The boost converter as power factor correction (PFC) works on discontinuous conduction mode (DCM) operation to make the resistive converter. Thus, when a rectifier circuit supplies a resistive load, the load current that flows back to the source will have the same waveform as the voltage and it makes the power factor value next to 1 (unity). According to experiment results, the BIFRED converter as LED lamp driver can improve power factor from 0.84 to become 0.98 and this driver circuit also meets the line-current harmonic limits set by IEC61000-3-2 class C.

Corresponding Author:

Moh. Zaenal Efendi,
Department of Electrical Engineering,
Politeknik Elektronika Negeri Surabaya,
PENS Campus, Surabaya, Indonesia.
Email: zen@pens.ac.id

1. INTRODUCTION

At this time the development of technology is very rapid, one of it is the use of LED lamps with little power but can provide bright light. All over the world LED lamps have been applied and have a significant impact on decreasing power consumption. Unfortunately, the LED lamp is included in non-linear load which can reduce power factor so a tool is needed to repair or increase the power factor. LED lamp usually requires a driver circuit consisting of a rectifier that converts AC voltage source to DC voltage, one of which is a single-phase full wave rectifier circuit. On this circuit, there is an enough large capacitor which is used as filter and reduces output voltage ripple. However, installing a capacitor on a rectifier circuit can cause the input current to be distorted and the waveform not to become a sinus. It also increases the number of current harmonics into the grid [1] and that will produce a low power factor. High harmonic and low power factor are quite an important problem for electric power supply. For this reason, some efforts must be made to overcome this problem.

The right way to overcome this problem is to add a converter as power factor improvement on LED lamp, it is called power factor correction (PFC) Converter. So the PFC converter becomes most important and very attractive issue. Many converters can be used to improve power factor and all have the ability to reach or approach unity. The development of research on power factor correction is very rapid because we often encounter problems with the reduction of power factor in all places due to non-linear loads. Several types of research on power factor correction are the soft-switching AC-DC power factor correction converter which discusses the improvement of power factor using soft switching technique [2-4]. Development is also carried out by adding a source of renewable energy on the input side and an inverter is used to supply non-linear loads so that it is needed power factor improvement in a system that is integrated through passivity-based control [5]. Research on high efficiency in improving power factor using frequency multiplier technique proves that through frequency multiplier technique can increase efficiency from power factor improvement [6]. A new architecture of improving the power factor from AC to DC at high frequency operation has also been carried out and achieved good results [7]. The next development in power factor improvement was done with a single-stage wireless-power transfer resonant converter with a combination of bridgeless power boost factor correction by using a rectifier as a nonlinear load so that it can be proven that the power factor improvement has been successfully carried out [8].

The development of power factor improvement has arrived at the smart grid system, smart grid is a research theme that is very rapidly developing now and is a research of the future, through enhancement in residential smart grid using power factor correction stage then the power factor in the smart grid system can be improved [9]. On the side of power quality mitigation on unidirectional AC-DC using versatile control power factor improvement can be done so that it impacts on power quality [10]. Improvement of power quality on the SMPS (switch mode power supply) system can be improved through the power corrected zeta converter [11]. In LED lamp applications, that is applied to everyday life throughout the world on a single-phase system and with lower processing [12].

More specifically, improving the power factor using a power converter can be divided into two types, such as a two-stage PFC circuit and a one-stage PFC circuit. A two-stage PFC circuit is a circuit consisting of two converters, one converter as a PFC and another for a dc regulator connected in a series circuit. The second type of PFC circuit is a one-stage PFC that combines two converters into one stage and has multiple functions, such as PFC and dc regulator. The difference from a one-stage PFC circuit with a two-stage PFC circuit lies in higher level converter efficiency, lower cost usage, and less use of components. There are many two-stage converters used to increase power factors, some of which are boost converter and buck converter [13-16], sepic converter [17], flyback converter [18]. For PFCs with single-level converters that have been issued, some of them include flyback-boost (flyboost) [19], boost-flyback converter (BIFRED) [20], and flyback-forward converter [21].

In this paper, we will discuss the implementation of the BIFRED converter as an LED lamp driver. BIFRED converter contains boost converter as a power factor correction converter that works on discontinuous conduction mode (DCM) and flyback converter which can work on CCM or continuous conduction mode (CCM). One application of the BIFRED converter is as a BLDC motor driver [22]. So, in this paper, the BIFRED converter is applied to lighting loads (LED lamps) and discussed its use for increasing power factor and reducing harmonics to meets the line-current harmonic limits set by IEC61000-3-2 class C [23] as shown in Table 1.

Table 1. The line-current harmonic limits set by IEC61000-3-2 class C [12]

Harmonic order (*n*)	Maximum permissible harmonic current expressed as a percentage of the input current at the fundamental frequency (%)
2	2
3	30 * circuit power factor
5	10
7	7
9	5
$11 \leqslant n \leqslant 39$	3

2. RESEARCH METHOD

The basis of this research is the design of a system that is described in the block diagram that contains the system workflow. An overview of the utilization of BIFRED converter as an improvement of the power factor for LED lamp loads is shown in Figure 1. One of the proposed converter to reduce the number of components, costs and complexity issues of a two-stage converter is BIFRED (boost integrated flyback rectifier energy storage DC-DC) converter. The circuit of the LED lamp driver using BIFRED converter is shown in Figure 2.

A BIFRED Converter as shown in Figure 2 is an integration of boost-flyback converters using a single stage (single-switch) and one controller to achieve PFC input and output voltage regulators simultaneously. A BIFRED converter contains Boost Converter that works on discontinuous conduction to serve as PFC and the output stage is a flyback converter for setting the output voltage. The active switch is shared by the two stages. Capacitor C_b is the energy storage capacitor and sees the low-frequency (e.g. 100Hz) and the high-frequency switching ripple, while C_o is the output capacitor which sees only the high-frequency switching ripple. This configuration is potentially a low-cost solution since there are only one switch and one control circuit. Boost converter on BIFRED circuit as power factor correction (PFC) can be seen in Figure 3 and it has an inductor current waveform as shown in Figure 4. This Boost converter is modeled as having input resistance (r_s) calculated from the input voltage and input current at one switching period.

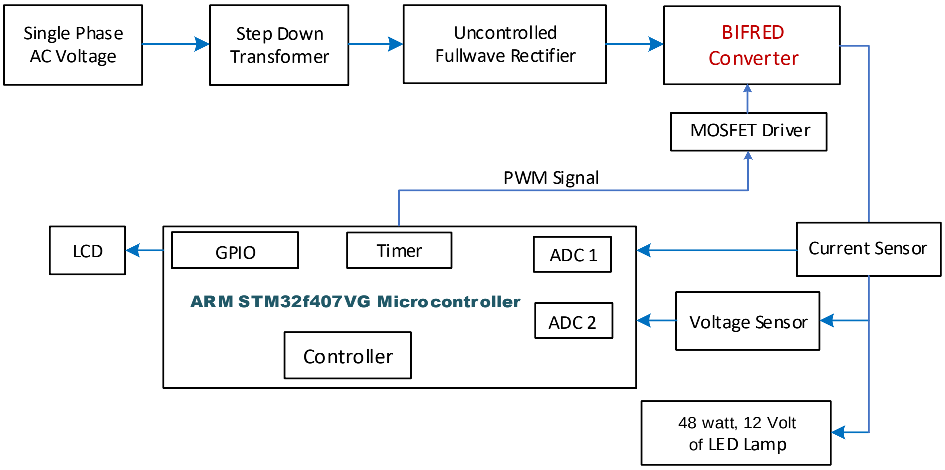

Figure 1. Block diagram system

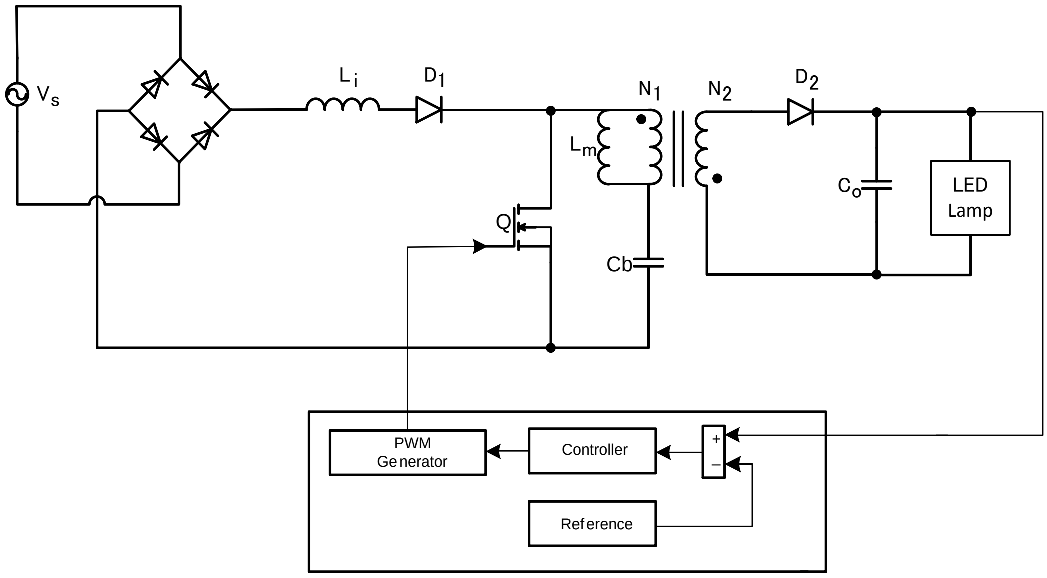

Figure 2. Circuit of BIFRED converter as LED lamp driver

According to Figure 3 and Figure 4, the input resistance of boost converter can be calculated as follows:

$$r_s(t) = \frac{v_s(t)}{i_s(t)} \tag{1}$$

and the equivalent resistance can be found as (2).

$$r_s = \frac{2L}{D^2T}\left(1 - \frac{V_s}{V_o}\right) \tag{2}$$

From (2), it is known that input resistance (r_s) depends on the value of the inductor, switching period and duty cycle. If the Boost Converter is sure to work on discontinuous conduction mode and the duty cycle is constant, then the input resistance (r_s) becomes constant. As a result, the current i_s (t) follows the form of input voltage and Boost Converter becomes a power factor improvement. Meanwhile, the flyback converter on BIFRED circuit operates on continuous conduction mode which is known from the magnetizing inductor current which depends on the magnitude of the transformer (L_m) magnetization. The relationship between the DC output voltage ($V_{o(dc)}$) with the source voltage is shown in (3).

$$V_{o(\mathrm{dc})} = \frac{N_2}{N_1}\frac{D}{1-D}V_{in} \tag{3}$$

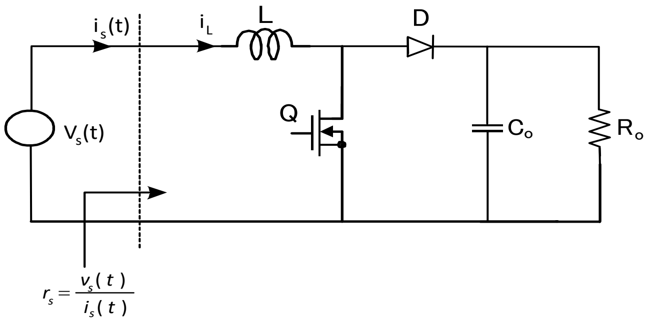

Figure 3. Boost converter circuit in DCM operation

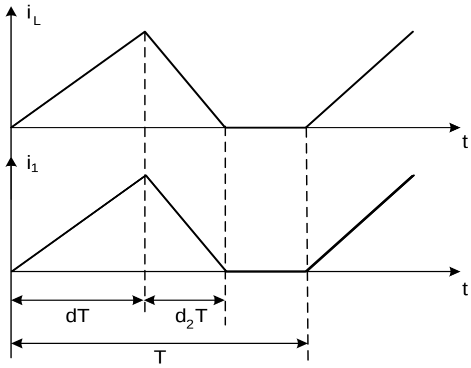

Figure 4. Inductor current waveforms of boost converter on discontinuous conduction mode operation

The (4) shows the boost inductor on CCM operation.

$$L_i = \frac{V_{in} \times D}{f_s \times \Delta I_{in}} \tag{4}$$

f_s is the switching frequency and ΔI_{in} is the ripple current on L_i. Ripple current for critical conduction mode can be calculated using (5),

$$\Delta I_{Li} = 2 \times I_{in} \tag{5}$$

so, the critical value of the inductor is:

$$L_{\mathrm{ic}} = \frac{V_{in} \times D}{2 \times f_s \times I_{in}} \tag{6}$$

boost inductor value on DCM operation can be calculated using (7):

$$L_i < L_{ic} \tag{7}$$

the (8) is used to determine the critical value of the magnetizing inductance L_{mc}:

$$L_{\mathrm{mc}} = \frac{(1-D)^2 R_l}{2 \times D \times f_s \times \left(\frac{N_2}{N_1}\right)^2} \tag{8}$$

while to operate in CCM mode use (9).

$$L_m >> L_{mc} \tag{9}$$

The calculation of bulk value of C_b uses (10):

$$C_b = \frac{V_{dc} \times D \times \left(\frac{N_2}{N_1}\right)}{RL \times f_s \times \Delta V} \tag{10}$$

the (11) is used to calculate the output capacitor.

$$C_o = \frac{D}{r \times R_L \times f_s} \tag{11}$$

The use of the capacitor must have a value with a maximum ripple of 2% which means that the value of the capacitor used must be greater than the value of the calculation.

3. RESULTS AND ANALYSIS

The first experiment of power factor improvement on LED lamp is testing the system without BIFRED converter to determine the value of power factor before improvement. In testing on a 12 Volt, 48 Watt of LED lamp, it produces a power factor value of 0.84. Figure 5 shows the input voltage and input current waveforms without PFC Converter. According to the experiment result, it is known that a system without PFC has a rather low power factor and the input current waveform is not sine.

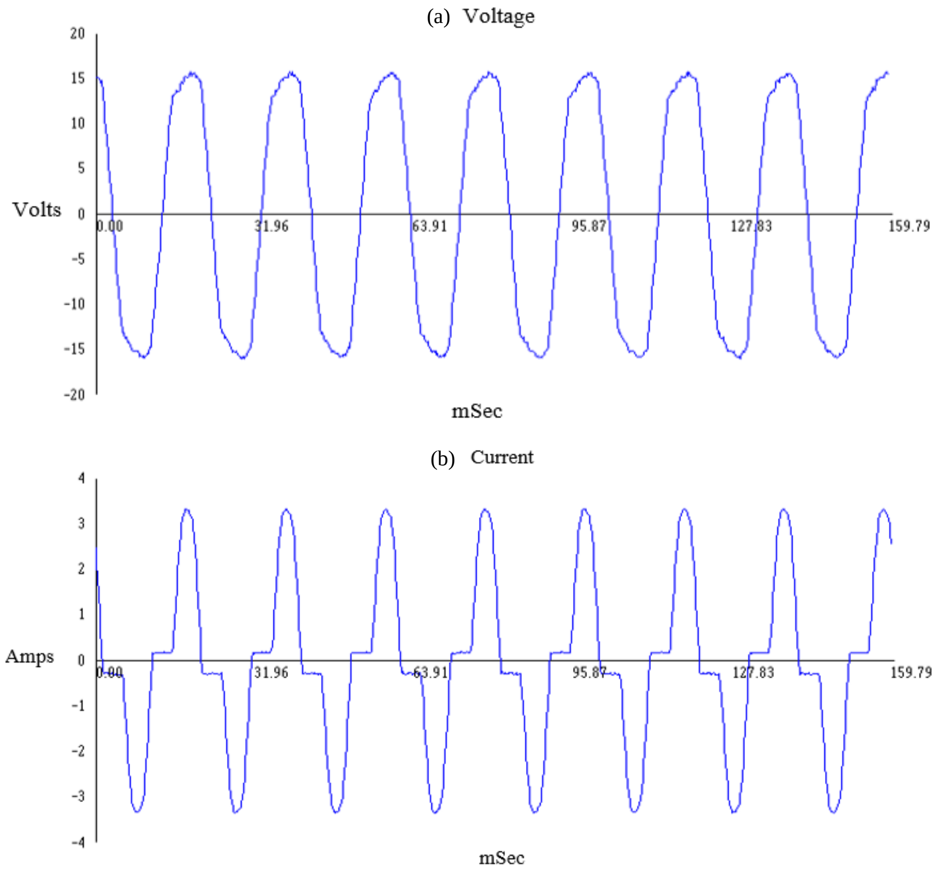

Figure 5. Test results of the system without PFC using 12 V, 48 W of LED lamp: (a) the waveform of input voltage of converter without PFC, (b) the input current waveform on the system without PFC

Further experiment is the implementation of LED lamp driver using BIFRED converter as power factor correction with the parameters as shown in Table 2. Based on the parameters in Table 2, we can make a BIFRED converter that has two functions such as power factor correction (PFC) and voltage regulator. BIFRED converter is driven using the FOD3182 circuit and the STM32f4VG ARM of microcontroller. PFC system testing is a whole system test which means combining each part of the PFC system into one. The purpose of this test is to determine the magnitude of the increase in power factor and decrease in harmonics by using a BIFRED converter. The PFC converter system is supplied by a 110 Volt of AC voltage source with a DC rectifier that produces 99.03 Volt. The output rectifier voltage is used as a BIFRED converter supply and produces a 12 Volt of the output voltage. Table 3 shows the experimental data of BIFRED converter using a variable resistor and Table 4 shows the experimental data of BIFRED converter using a 12 Volt, 48 Watt of

LED lamp. Figure 6 shows the input voltage and input current waveforms which are almost in phase so that the resulting power factor reaches 0.98.

Table 2. Parameters of BIFRED converter

Parameter	Value
The input voltage of the rectifier	110 Volt
The input voltage of BIFRED converter	99 Volt
Output voltage (V_o)	12 Volt
Switching frequency (f_s)	40 kHz
Inductor (L_1)	300 μH
Ratio of transformer	$N_1 : N_2 = 99 : 12$
L_m of transformer	12.25 mH
Diode D_1	STTH 60L06CW
Diode D_2	STTH 60L06CW
Switch (Q)	MOSFET IRFP460
Bulk capacitor	1 μF
Output capacitor (C_o)	2500 μF

Table 3. Experimental data of BIFRED converter using a variable resistor

V_{inac} (volt)	V_{indc} (volt)	V_{out} (volt)	I_{out} (A)	Load (ohm)	Duty cycle (%)	PF
110.3	96.9	11.94	0,51	24	29	0.97
111.2	97.6	12.06	1,02	12	34	0.98
110.6	97	11.97	1,51	8	35	0.98
110.5	96.8	12.05	2	6	36	0.98
111	96.9	11.86	2,57	4,8	37	0.98
110.6	96.5	11.95	3.3	4	39	0.98
110.6	96.6	12.01	4.3	3.43	41	0.99
110.1	95.8	12.02	4.8	3	43	0.99

Table 4. Experimental data of BIFRED converter using a 12 volt 48 watt of LED lamp

V_{inac} (volt)	V_{indc} (volt)	V_{out} (volt)	I_{out} (A)	load	Duty cycle (%)	PF
112.1	97.8	12.07	1.2	12 Volt, 48 Watt of LED Lamp	34	0.98

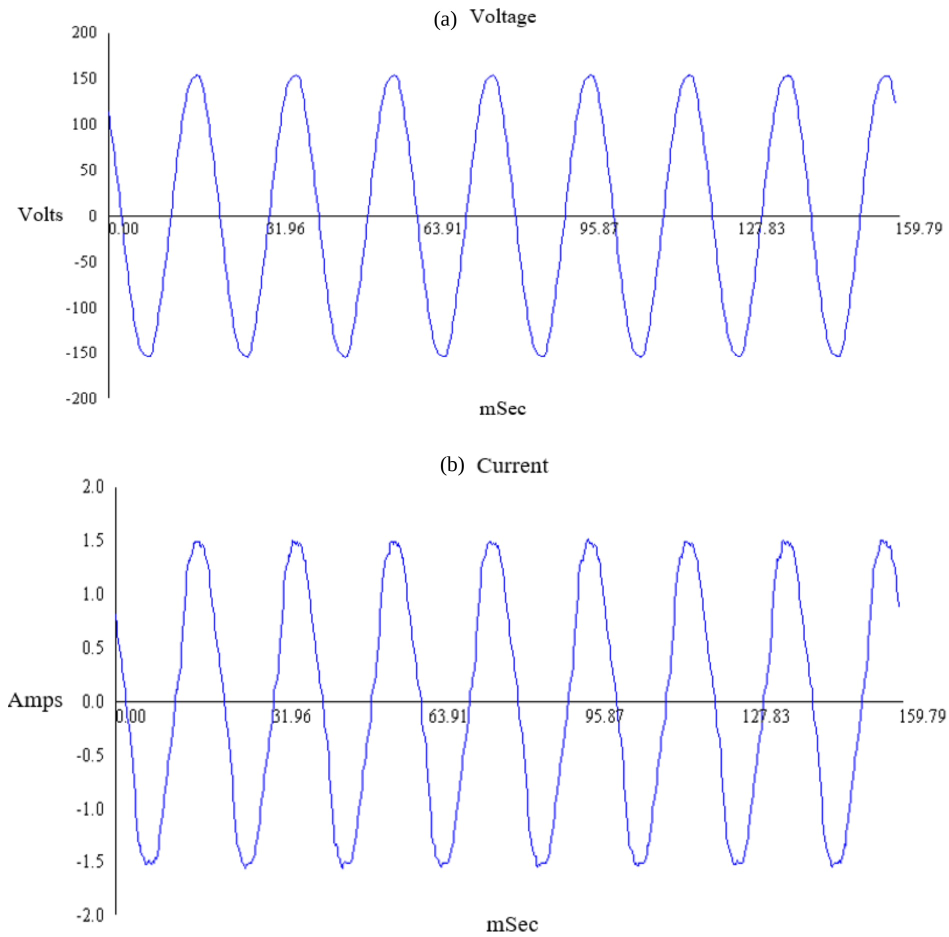

Figure 6. Test results of the system with PFC using 12 V, 48 W of LED lamp: (a) the waveform of input voltage of converter with PFC, (b) the input current waveform on the system with PFC

Based on the type of equipment used, the class classification used in this system is in accordance with the line-current harmonic limits set by IEC61000-3-2 which belongs to class C, where class C classification is lighting equipment. From the explanation of class C classification, the 12 Volt, 48 Watt of LED lamp used in this system is one part of class C. Table 5 shows the comparative harmonic current comparisons of systems that have used PFC with the line-current harmonic limits set by IEC61000-3-2 class C. In class C of IEC61000-3-2, the parameter which has been specified as the standard is the maximum value expressed as a percentage of the fundamental current, so it can be calculated each of the harmonic sequences with (12).

$$\%\ n^{th}\text{current} = \frac{\text{the } n^{th} \text{ harmonic current}}{\text{fundamental current}} \times 100 \tag{12}$$

Table 5. Comparative data of harmonic current of the BIFRED converter with the line-current harmonic limits set by IEC61000-3-2 class C

Harmonic order	Max value expressed as a percentage of the fundamental input current of the luminaries	3 Ω of resistive load		12 Volt, 48 Watt of LED lamp	
		Harmonic current value	% current	Harmonic current value	% current
2	2	0.01	0.78	0.00	0.00
3	29.4	0.07	5.46	0.06	5.60
5	10	0.03	2.34	0.05	4.67
7	7	0.01	0.78	0.02	1.87
9	5	0.02	1.56	0.02	1.87
11	3	0.02	1.56	0.01	0.93
13	3	0.01	0.78	0.01	0.93

Using (12), it can be calculated and known whether the harmonic current generated by this converter system is in accordance with the line-current harmonic limits set by IEC61000-3-2 class C. Considering the comparison of the harmonic current ratio of the system using PFC with the line-current harmonic limits set by IEC61000-3-2 class C in Table 5, it can be analyzed that the percentage of current of harmonic order on the fundamental current is still less than the standard percentage minimum current of each harmonic sequence in class C (IEC 6100-3-2). Table 5 shows the comparative data of harmonic current of the BIFRED converter with the line-current harmonic limits set by IEC61000-3-2 class C.

To further simplify the comparative readings of harmonic current of the converter with the line-current harmonic limits set by IEC61000-3-2 class C, a comparative graph can be shown in Figure 7, wherein the graph it can be seen that the resulting harmonic current of the system using BIFRED converter as PFC that uses a 3Ω of nominal resistive load and a 12 Volt, 48 Watt of LED lamp, it still meets to IEC 61000-3-2 standard and it means that this system can be used to improve power factor with a low harmonic current.

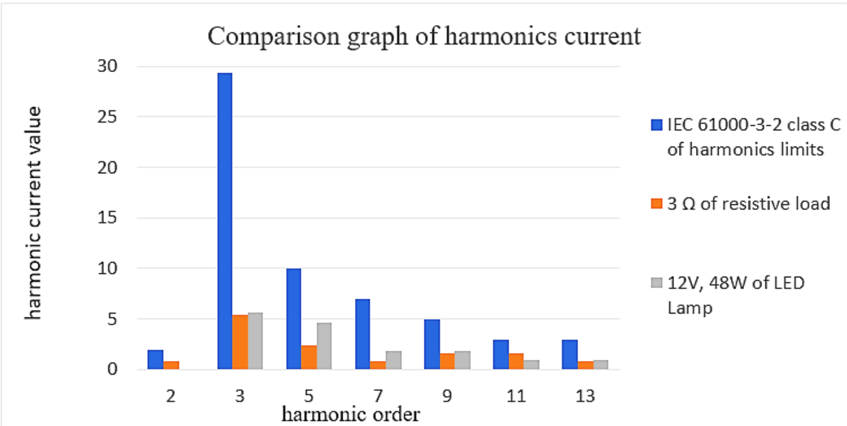

Figure 7. Comparison graph of system harmonics current with PFC with the line-current harmonic limits set by IEC61000-3-2 class C

4. CONCLUSION

This paper has already discussed the installing of the Power Factor Correction (PFC) circuit using a power converter for LED lamp driver. The converter used on the system is BIFRED converter which works in DCM-CCM mode. BIFRED converter is an integration of boost-flyback converters using a single switch and one controller that has the capability to see power factor on the input side and an output voltage regulator simultaneously. BIFRED converter as Power Factor Correction (PFC) has been able to improve power factor from 0.89 to 0.99 on the nominal resistive load and able to improve power factor from 0.84 to 0.98 on the 12 Volt, 48 Watt of LED lamp. On both loads, this driver circuit meets the line-current harmonic limits set by IEC61000-3-2 class C.

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