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Enhancing Power Factor on LED Light Driver with Boost and Fly Back Converter Integration

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Abstract: This paper describes the practical application of a power converter in order to enhance the power factor of an LED light driver. The power converter employed in this system is a combination of a boost converter and a fly back converter. The power factor correction functionality of the boost converter is achieved by the implementation of discontinuous conduction mode operation, which enables the converter to function as a resistive converter. Hence, in the case of a rectifier circuit providing power to a resistive load, the current flowing back to the source will exhibit the same waveform as the voltage. Consequently, this results in a power factor value close to unity (1). Based on the findings of the conducted experiment, it has been seen that the use of the BIFRED converter as a driver for LED lamps yields a notable enhancement in power factor, elevating it from 0.84 to 0.98. Furthermore, it has been determined that this particular driver circuit adheres to the prescribed line-current harmonic thresholds established by the IEC61000-3-2 class C standards.

Keywords: LED – Light Emitting Diode, PFC – Power Factor Correction, BIFRED- Boost Integrated Flyback Rectifier Energy storage DC-DC , DCM - Discontinuous Conduction Mode

I. INTRODUCTION

Currently, there is a significant advancement in technology, shown by the emergence of low-power LED lights that offer high luminosity. LED lights have been widely implemented globally and have had a substantial influence on reducing power consumption. Regrettably, the LED light is categorized as a non-linear load, hence having the potential to diminish the power factor. Consequently, an apparatus is required to rectify or enhance the power factor. The operation of an LED lamp often necessitates the utilization of a driver circuit, which comprises a rectifier responsible for converting an alternating current (AC) voltage source into a direct current (DC) voltage. One commonly employed rectifier configuration is the single-phase full wave rectifier circuit. Within this electrical circuit, there exists a capacitor of significant magnitude that serves the purpose of functioning as a filter. Its primary role is to diminish the occurrence of output voltage ripple. Nevertheless, the incorporation of a capacitor into a rectifier circuit has the potential to induce distortion in the input current and prevent the waveform from assuming a sinusoidal shape. Additionally, the integration of this technology results in an augmented quantity of current harmonics being introduced into the electrical grid [1], therefore leading to a diminished power factor. The issues of high harmonic distortion and poor power factor are of significant concern in the field of electric power supply. Therefore, it is necessary to undertake certain measures in order to address this issue.

The best solution to address this difficulty is to put a converter as power factor improvement on LED light, it is called power factor correction (PFC) Converter. As a result, the PFC converter has emerged as a significant concern. Power factor may be increased with a variety of converters, all of which can go close to 1 in terms of efficiency. Due to the widespread prevalence of issues with the degradation of power factor caused by non-linear loads, research into methods of power factor correction is rapidly progressing. The soft-switching AC-DC power factor correction converter is one form of power factor correction study that focuses on the topic of improving power factor through the use of soft switching. Integration of a renewable energy source on the input side and the usage of an inverter to serve non-linear loads for power factor enhancement via passive control are also part of the development process. Studies showing increased efficiency from power factor enhancement utilizing the frequency multiplier approach provide credence to this hypothesis. In addition, successful tests of a novel design for boosting the power factor from alternating current to direct current have been conducted. The next step in power factor improvement was accomplished with a single-stage wireless-power transfer resonant converter that incorporated bridgeless power boost factor correction by employing a rectifier as a nonlinear load.

Power factor improvement has reached the smart grid system. Smart grid is a research topic that is currently and will likely develop very quickly. By utilizing power factor correction to enhance residential smart grid systems, the power factor in these systems can be improved.

In terms of mitigating power quality in unidirectional AC-DC, power factor enhancement through flexible control may be implemented to influence power quality. Power corrected zeta converters can be used to improve power quality in switch mode power supply (SMPS) systems. Applications for LED lamps are used in single-phase systems with less processing in daily life all across the world. More precisely, there are two types of power converters that may be used to increase the power factor: one-stage and two-stage PFC circuits. A two-stage PFC circuit is made up of two converters linked in series, one for use as a PFC and the other for a dc regulator. The second kind of PFC circuit is a one-stage PFC, which may be used as both a PFC and a dc regulator. It combines two converters into a single stage. A two-stage PFC circuit differs from a one-stage PFC circuit in that it uses fewer components, cheaper costs, and a better level of converter efficiency. In order to raise power factors, a variety of two-stage converters are employed, including flyback, sepic, and boost converters. Boost-flyback converter (BIFRED), flyback-forward converter, and flyback-boost (flyboost) are a few of the single-level converters that have been released for PFCs.

The use of the BIFRED converter as an LED light driver will be covered in this article. The BIFRED converter consists of a flyback converter that may operate in either continuous conduction mode (CCM) or discontinuous conduction mode (DCM) and a boost converter that functions as a power factor correction converter (CCM). The BIFRED converter can be used as a BLDC motor driver, for example. In order to fulfill the line-current harmonic restrictions established by IEC61000-3-2 class C [23], as indicated in Table 1, the BIFRED converter is applied to lighting loads (LED lights) and presented in this work.

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
$11 \leq n \leq 39$	3

II. METHOD OF RESEARCH

The framework for this investigation is the system design delineated in the block diagram comprising the workflow of the system. Figure 1 illustrates a comprehensive summary of the application of the BIFRED converter in order to enhance the power factor of LED lamp loads. In order to minimize the number of components, costs, and complication issues associated with two-stage converters, one of the proposed converters is the BIFRED (boost integrated flyback rectifier energy storage DC-DC) converter. Figure 2 illustrates the circuit of the LED lamp driver utilizing the BIFRED converter.

For PFC input and output voltage regulation, a BIFRED Converter (shown in Figure 2) integrates boost-flyback converters into a single stage (single-switch) and a single controller. The input stage of a BIFRED converter is a flyback converter, which is used to establish the output voltage, and the output stage is a Boost Converter, which uses discontinuous conduction to function as PFC. The two levels share a same active switch. The output capacitor (Co) only experiences the low-frequency (e.g. 100Hz) switching ripple, while the energy storage capacitor (Cb) experiences both the low- and high-frequency switching ripple. Since there is just one switch and one control circuit, this setup has the potential to be inexpensive. Power factor correction (PFC) using a boost converter on a BIFRED circuit is seen in Figure 3, and its associated inductor current waveform is depicted in Figure 4. The input resistance (rs) of this modeled Boost converter is determined by the input voltage and input current during a single switching phase.

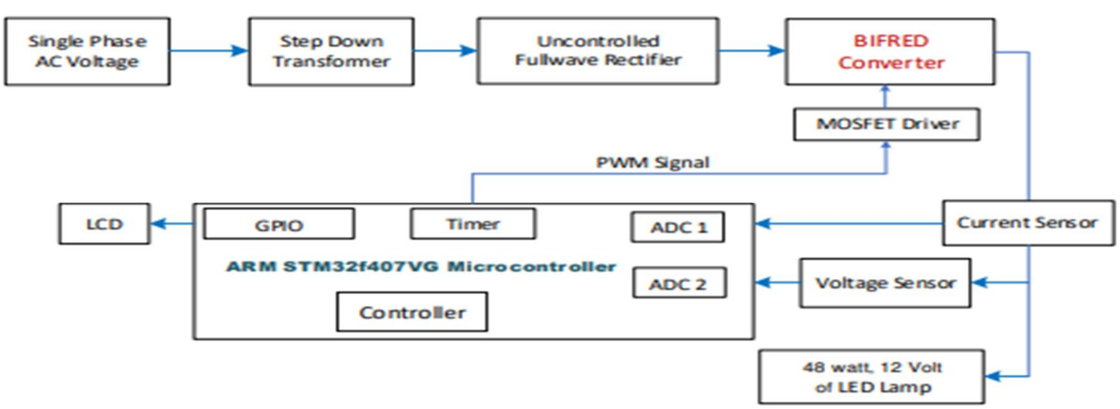

Figure 1. Block diagram of proposed system

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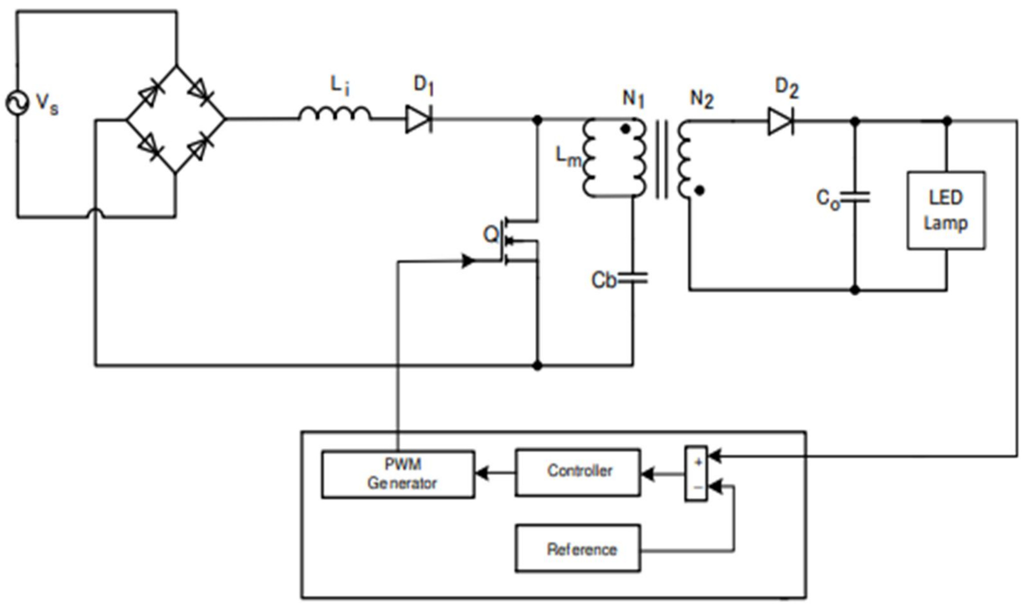

Figure 2. Circuit of BIFRED converter as LED lamp driver

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

$(t) = v(t) / \ is(t)$ (1)

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

$rs = 2L / D^2T\ (1 - Vs/Vo)$ (2)

It is clear from Equation (2) that the value of the input resistance, denoted by rs, is dependent on the switching time, as well as the duty cycle. If it can be established that the Boost Converter operates in the discontinuous conduction mode and that the duty cycle remains unchanged, then the input resistance (rs) will also remain unchanged. As a consequence of this, the shape of the current, denoted by t, follows the form of the input voltage, and the power factor of the Boost Converter is improved. In the meanwhile, the flyback converter on the BIFRED circuit runs in continuous conduction mode. This mode may be determined from the magnetizing inductor current, which is determined by the magnitude of the transformer's (Lm) magnetization. (3) illustrates the connection that exists between the DC output voltage, also known as Vo(dc), and the source voltage.

(dc) = $(N2/\ N1\ )$ x $(D/1 - D)$ x Vin (3)

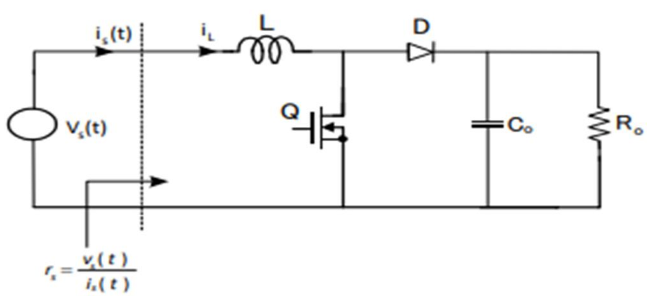

Figure 3. Boost converter circuit in DCM operation

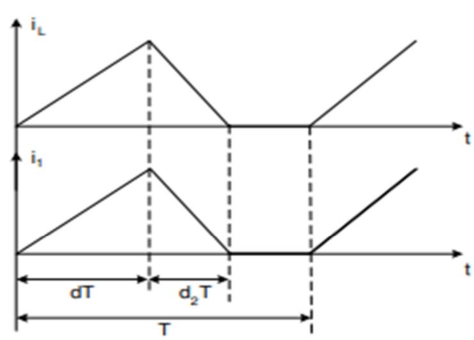

Figure 4. Inductor current waveforms of boost converter on discontinuous conduction mode operation

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

$$L_i = (V_{in} \times D) / (f_s \times \Delta\ ) \quad (4)$$

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),

$$\Delta I_{Li} = 2 \times Iin \quad (5)$$

so, the critical value of the inductor is:

$$L_{ic} = (V_{in} \times D) / (2 \times f_s \times I_{in)} \quad (6)$$

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

$$L_i < L_{ic} \quad (7)$$

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

$$L_{mc} = (1 - D)^2 R_l \ \ / 2 \times D \times f_s \times (N_2\, N_1)^2 \quad (8)$$

while to operate in CCM mode use (9).

$$L_m >> L_{mc} \quad (9)$$

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

$$C_b = V_{dc} \times D \times (N_2 / N1) / R_L \times f_s \times \Delta V \quad (10)$$

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

$$C_o = \ \ / \ \ \times RL \times fs \quad (11)$$

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.

III. RESULTS AND ANALYSIS

Testing the system without the BIFRED converter is the initial experiment in the process of improving the power factor of an LED light. The goal of this test is to ascertain the value of the power factor before the improvement. An LED bulb of 12 volts and 48 watts was used for testing, and the device produced a power factor value of 0.84. Waveforms of the input voltage and current are depicted in Figure 5, which does not include a PFC Converter. According to the findings of the experiment, it is common knowledge that a system that lacks PFC possesses a power factor that is not very high and that the waveform of the input current is not sine.

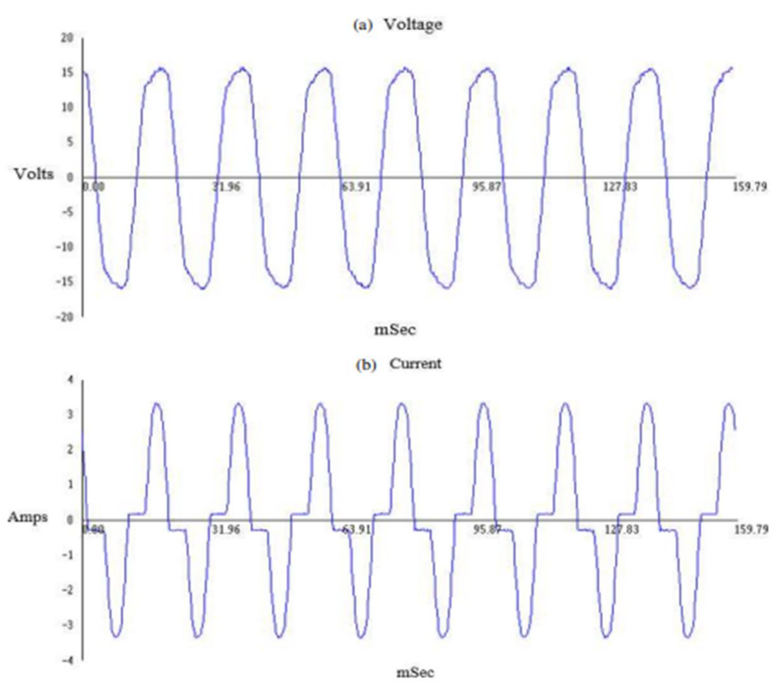

Figure 5. Test results of the system without PFC using 12 V, 48 W of LED lamp: (a) the waveform of input voltage of converter without PFC, (b) the input current waveform on the system without PFC

The next stage of testing will involve the installation of an LED light driver that makes use of a BIFRED converter for power factor correction. The parameters for this test may be found in Table 2. We are able to create a BIFRED converter that possesses two functions by using the parameters that are shown in Table 2. These functions include power factor correction (PFC) and voltage regulator. The BIFRED converter is powered by the FOD3182 circuit, which is then controlled by the ARM microcontroller STM32f4VG. When testing the PFC system, it is necessary to do a full system test, which involves bringing together all of the components of the PFC system into a single unit.

By utilizing a BIFRED converter, the objective of this test is to ascertain the degree to which the power factor has improved while simultaneously reducing the number of harmonics. The power for the PFC converter system comes from an AC voltage source that is 110 Volts, and it utilizes a DC rectifier that generates 99.03 Volts. The output voltage of the rectifier is utilized as the power supply for the BIFRED converter, which results in a voltage of 12 Volts being produced. Table 3 presents the experimental results of the BIFRED converter when it was connected to a variable resistor. Table 4 presents the experimental results of the BIFRED converter when it was connected to a 12 Volt, 48 Watt LED bulb. Waveforms of the input voltage and current are depicted in Figure 6; these waveforms are almost in phase with one another, which enables the power factor to approach 0.98 as a consequence.

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

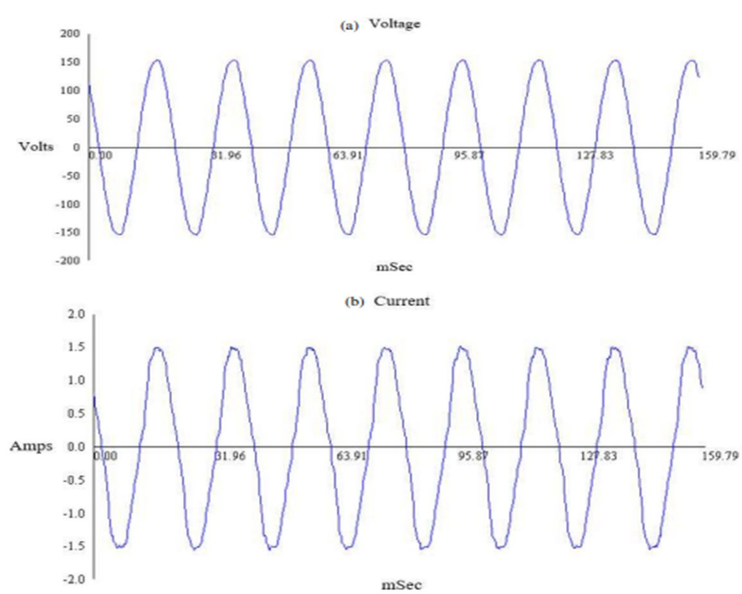

Figure 6. Test results of the system with PFC using 12 V, 48 W of LED lamp: (a) the waveform of input voltage of converter with PFC, (b) the input current waveform on the system with PFC

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The line-current harmonic limitations defined by IEC61000-3-2 are in accordance with the class classification that is used in this system. This system belongs to class C, which is classified as lighting equipment. Based on the type of equipment that is used, the class classification that is used in this system is in accordance with these limits. According to the description of the class C classification, the LED bulb that operates at 12 Volts and 48 Watts that is utilized in this system is an example of a component of class C. The line-current harmonic limitations that have been established by IEC61000-3-2 class C are displayed in Table 5, along with the comparative harmonic current comparisons of systems that have implemented PFC. The maximum value represented as a percentage of the fundamental current has been given as the standard for the parameter that has been established as the standard in class C of IEC61000-3-2. Because of this, it is possible to compute each of the harmonic sequences with the number twelve.

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

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

By using the formula (12), it is possible to compute and determine whether or not the harmonic current that is being produced by this converter system is in compliance with the line-current harmonic restrictions that have been established by the IEC61000-3-2 class C. When taking into account 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 is possible to conclude 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). This conclusion can be reached after considering the results of the comparison. The results of a comparison of the harmonic current produced by the BIFRED converter with the line-current harmonic limitations specified by IEC61000-3-2 class C are presented in Table 5.

To further simplify the process of comparing the readings of the converter's harmonic current 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 a BIFRED converter as PFC that uses a 3 ohm of nominal resistive load and a 12 volt, 48 watt LED lamp, it still meets to IEC 61000-3-2 standard,

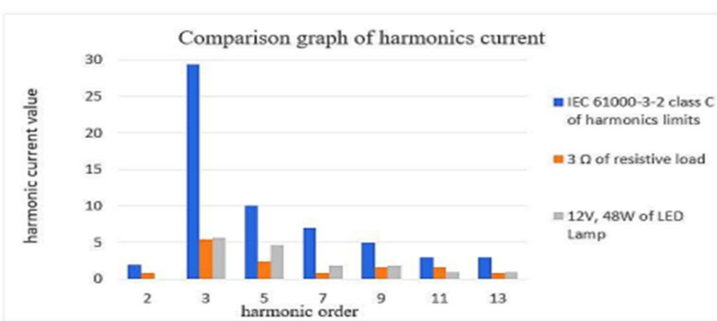

Figure 7. Comparison graph of system harmonics current with PFC with the line-current harmonic limits set by IEC61000-3-2 class C

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IV. CONCLUSION

The use of a power converter for an LED light driver's Power Factor Correction (PFC) circuit has already been covered in this work. The BIFRED converter, which operates in DCM-CCM mode, is what the system relies on for its conversion needs. The BIFRED converter combines the functions of a boost-flyback converter and a voltage regulator in a single device, consisting of a single switch and a single controller. With the BIFRED converter acting as Power Factor Correction (PFC), the power factor of a notional resistive load was raised from 0.89 to 0.99, while that of a 12 V, 48 W LED bulb was raised from 0.84 to 0.98. On both loads, this driver circuit fulfills the line-current harmonic restrictions established by IEC61000-3-2 class C.

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