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COMPARISON OF SINGLE PHASE BUCK-BOOST AND SEPIC LED DRIVER

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ABSTRACTS

This paper presents the comparison of LED driver topologies that include buck-boost and SEPIC converters. Both topologies are connected to grid over single phase diode rectifier and designed for 8W power. Furthermore, buck-boost and SEPIC converters operate with 63 kHz switching frequency and inductors of SEPIC are wounded as coupled. By means of the implementations, power factor (PF) and total harmonic distortion (THD) of current and voltage, power LED voltage and current are shown for both topologies. Comparison is also made between IEC61000–3–2 standard, buck-boost and SEPIC converters. Besides, electrical circuit model of power LED is derived by using its current-voltage characteristic.

Keywords: LED driver, PFC, buck-boost converter, SEPIC converter, power factor, THD

1. INTRODUCTION

Recently, power LEDs in illumination have been taking much attention due to their high efficiency feature with respect to other illumination methods such as fluorescent, incandescent and metal halide bulbs. However, power LEDs need dc power for their operation. This dc power can be mostly obtained after rectification process of single phase AC power. In this rectification process if uncontrolled rectifiers are directly used, this will cause harmonics on grid current and reducing power factor. Furthermore, grid current harmonics are limited by international standards such as IEC61000–3–2. To avoid this problem, high power factor or power factor correction (PFC) circuits can be used as a LED driver. Besides, PFC circuits in single phase can be realized by using any dc-dc converters after uncontrolled bridge rectifier. In literature, some studies are conducted on this topic as follows.

Using PFC converters as LED driver that include buck and buck-boost converter is designed in [1]. In [2], the implementation of Cuk converter based LED driver presented. LED drivers that consist of Flyback and SEPIC converter are realized in [3–4]. Also in [5], combination of buck and Flyback converters as an LED driver is implemented. AC-DC and DC-DC converters are used as an LED driver in [6]. PFC converters that include basic dc-dc converters are presented and compared by their advantages and disadvantages in [8–10]. Besides, detailed analysis, design and operation of dc-dc converters are clarified in [11]. Comparison of basic dc-dc converters that includes buck, boost, buck-boost, SEPIC and zeta with PFC for supplying high pressure sodium lamps is presented [12]. Also, another comparison in [13] is made for buck-boost, SEPIC, Cuk dc-dc converters that drive power LEDs.

In this paper, comparison of LED driver topologies that include buck-boost and SEPIC converters are presented. Both topologies are connected to grid over single phase diode rectifier and designed for 8W power. Besides, they operate with 63 kHz switching frequency and use easily found integrated circuits (IC). With implementations, PF and THD of grid current and voltage, power LEDs current and voltage are shown for both topologies. Furthermore,

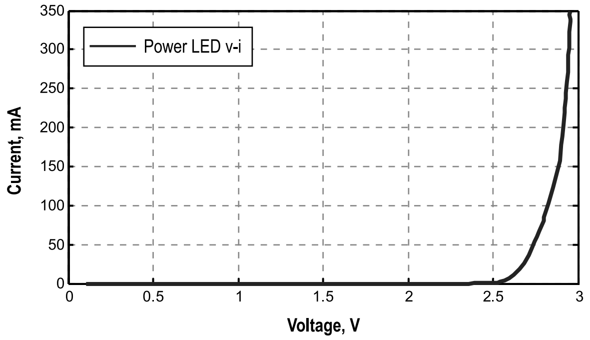


Fig.1. Voltage-current characteristic of power LED

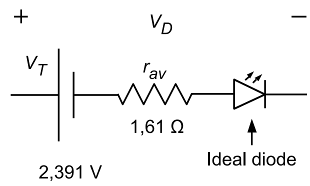


Fig.2. Electrical equivalent model of power LED

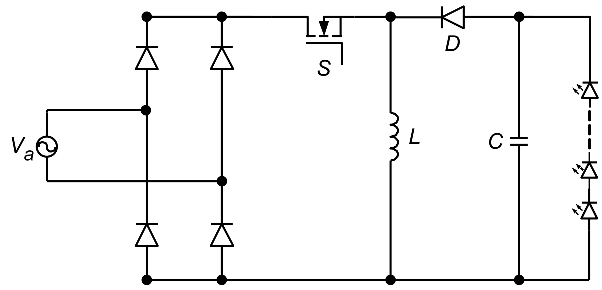


Fig.3. PFC Buck-Boost Converter

comparison between IEC61000–3–2 standard and results of implementations is made. Electrical circuit model of power LED is also derived.

This paper is organized as follows. Power LED current-voltage characteristic and electrical circuit model are derived in Section 2. LED driver topologies applied are reviewed in Section 3. Applications of LED drivers are presented in Section 4. THDs, power factor and power LED current-voltage of each topology are shown in Section 5. Some conclusions are given in Section 6.

2. POWER LED

In this chapter, current-voltage characteristics and electrical circuit model of power LED that are used for this study are derived by using Fluke 15B and Fluke 17B.

Fig.1. shows voltage-current characteristic of a power LED. The characteristic is obtained by increasing voltage on a single power LED and plotting voltages versus each current. It is seen from the figure that LED voltage and current has exponential relation and LED current increase extremely after LED conducts. Also, LED voltage doesn't change much after and up to 340 mA current [14].

By using Fig.1, electrical circuit model of power LED is derived as in Fig.2. It is understood by this model that threshold voltage and conductance resistance of power LED are 2.391 V and 1.61Ω, respectively.

3. LED DRIVER

In this chapter, PFC buck–boost and SEPIC converters as a LED driver are introduced. Both drivers are connected to grid over single phase diode rectifier. By changing duty cycle of each converter dc voltage on power LED can be set to the desired value while obtaining naturally high power factor on grid. Furthermore, both topologies can give lower or higher voltage with respect to input voltage.

A. Buck-Boost Converter

Fig.3. shows the buck-boost converter that consist of inductor L, capacitor C, diode D and S switch.

Buck-boost converter is connected to grid over diode bridge and with high frequency operation of the switch; dc voltage that feeds power LEDs is obtained. This converter works on principle of transferring energy of inductance and can

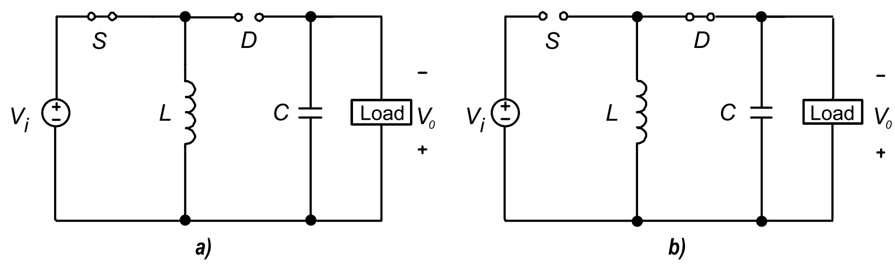


Fig.4. Switching state a) open, b) closed

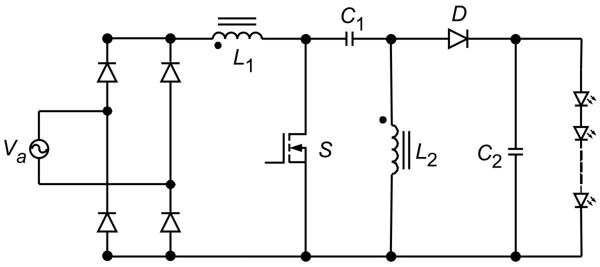


Fig.5. PFC SEPIC converter

be analyzed by the state of the switch that is seen in Fig.4. If the switch turned on, inductance stores energy and the switch turns off inductance transfer this energy to the load.

Furthermore, the voltage on power LEDs can be adjusted to less or more with respect to input voltage by changing pulse width modulation (PWM). Besides, high frequency operation also provides high power factor [8]. However, dc voltage on power LEDs is reverse polarity with input voltage and to avoid high frequency noise, input filter needs to be added.

Passive equipment can be chosen by using following equations (1–2) as in [11]. In equation (1), L_{max} is the maximum inductance value for discontinuous conduction mode (DCM) operation. R_{Lmin} is minimum load resistance. D_{max} is maximum duty cycle. f_s is switching frequency.

$$L_{max} = R_{Lmin}(1\text{-}D_{max})^2 \big/ 2f_s. \quad (1)$$

$$C_{min} = D_{max}V_o \big/ f_s.R_{Lmin}.V_{ripple}. \quad (2)$$

In equation (2), C_{min} is the minimum capacitor value, D_{max} is also maximum duty cycle, R_{Lmin} is again minimum load resistance, V_o is output voltage, V_{ripple} is the ripple voltage on output of converter and f_s is also switching frequency.

B. SEPIC CONVERTER

Fig.5. shows the PFC SEPIC converter circuit that has two inductors and two capacitors. Furthermore, inductors in SEPIC converter are wounded as coupled that means on the same core.

Switch states are shown in Fig.6 when S is turned on, L_1 is energized by power source, and L_2 is energized by C_1. When S is turned off, C_1 is charged by power source and L_1, also currents of L_1 and L_2

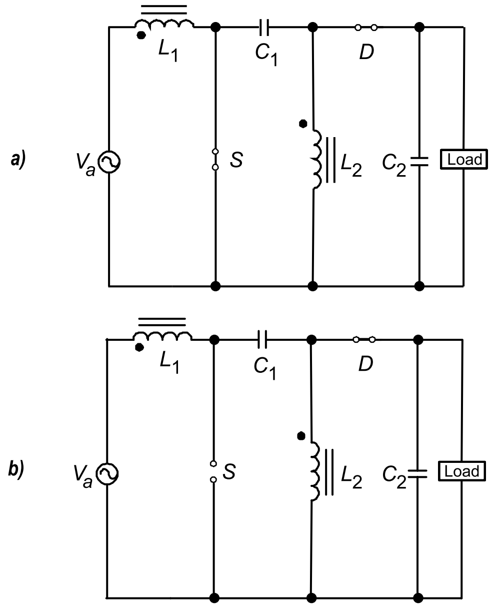


Fig.6. Switching state: a) open, b) closed

flow through D and load, C_2 is also charged [15–16]. Furthermore, by operating the switch with high frequency, PFC process is obtained naturally.

The most important advantage of SEPIC converter over buck-boost converter is to provide output voltage with the same polarity of input voltage. However, number of passive elements is more than buck-boost converter. But, having inductor on the input side provides continuous input current and helps the reduction of noise [15].

Passive elements in SEPIC converter can be chosen by using equations (3–5) as in [16–17]. In equation (3), L_{1min} and L_{2min} are the minimum L_1 and L_2 inductance values. D_{max} is maximum duty cycle. V_{in} is input voltage. ΔI_L is the ripple current on inductors. f_{sw} is switching frequency.

$$L_{1min} = L_{2min} = D_{max}.V_{in} \big/ 2 \cdot I_L \cdot f_{sw}. \quad (3)$$

$$C_2 \geq I_{out}.D_{max} \big/ V_{ripple}.f_{sw}. \quad (4)$$

In equation (4), C_2 is the value of C_2 capacitor, I_{out} is output current, V_{ripple} is the output voltage ripple, D_{max} is maximum duty cycle, f_{sw} is duty cycle.

$$C_1 = I_{out}.D_{max} \big/ \Delta V_{C_1} \cdot f_{sw}. \quad (5)$$

In equation (5), C_1 is the value of capacitor C_1, I_{out} is output current, D_{max} is maximum duty cycle,

ΔV$_{C1}$ is voltage ripple across C_1,
f_{sw} is switching frequency.

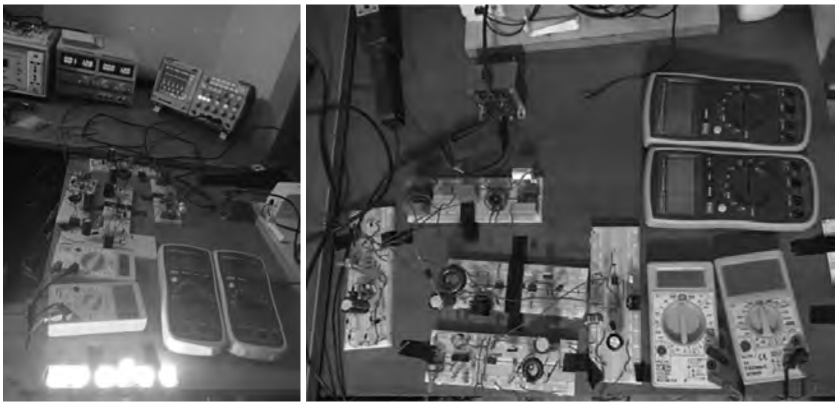


Fig.7. Experimental setup

4. APPLICATION

In this chapter applications of LED drivers that use buck-boost and SEPIC PFC as converter are realized. Fig.7. shows the experimental setup. Both converters are connected to grid over step down transformer 220/24 50Hz. Furthermore, as a load, three series connected power LEDs tied with two parallel branches. It is understood from Figs.1,2 that maximum 3V is required for best operation, therefore in applications, power LEDs are supplied up to 10V. Also, applications are conducted by easily found and cheap ICs that are SG3524, IR2117, TC4427 and LM317.

4.1. PFC Buck-Boost Converter

Application circuit of buck-boost PFC based LED driver is shown in Fig.8. It is understood that open loop operation is realized and SG3524 IC is used for PWM signals. Besides, EMI filter, IRF540N Mosfet, IR2117 Mosfet driver, Mur460 fast diode, 100μH inductor, 1000 μF capacitor are included in the application circuit [18–21].

The duty cycle is changed by the potentiometer connected to SG3524 and PWM frequency is set to 63 kHz. To reduce high frequency noise and avoid discrete current on grid, π type of EMI filter is used as in [22]. Besides, passive elements are used after calculation by equations (1,2).

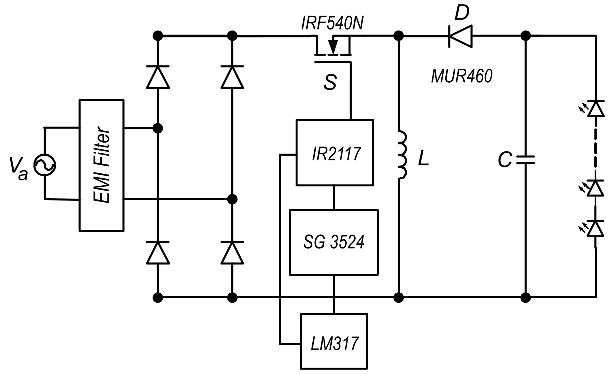


Fig.8. Application circuit of PFC buck-boost converter

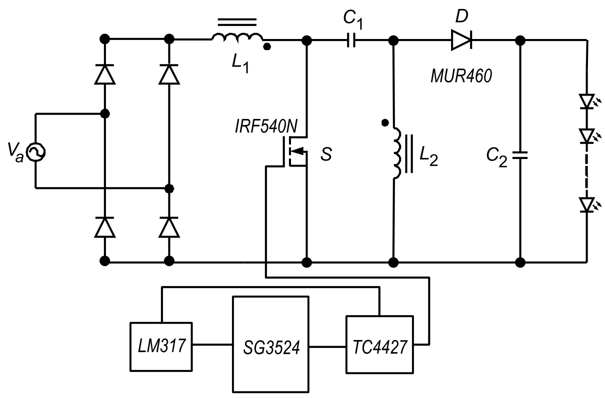


Fig.9. Application circuit of PFC SEPIC converter

4.2. PFC SEPIC Converter

Fig.9. shows the application circuit of SEPIC PFC based LED driver. This application is also realized by open loop algorithm. Furthermore, SG3524 IC is used for PWM signals and IRF540N Mosfet, TC4427 Mosfet driver, Mur460 fast diode, 100μH inductor, 1000 μF capacitor are used in the application circuit [18–23].

The duty cycle is also changed by the potentiometer connected to SG3524 and PWM frequency is again used as 63 kHz. The same load is used with buck-boost PFC LED driver. By using equations (4–5), passive elements are chosen. Without using an EMI filter, SEPIC PFC LED driver can give the desired results.

5. MEASUREMENT RESULTS

In this section, THDs of grid current and voltage, power factors, power LEDs voltage and current are measured for both buck-boost and SEPIC based LED drivers. For measurement, TPS2024B oscilloscope and TPS2PWR1 power application software are used.

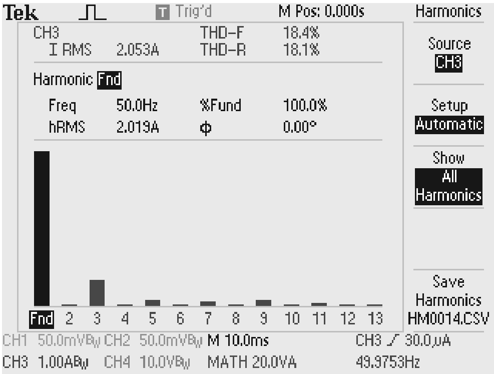


Fig.10. THD of grid current

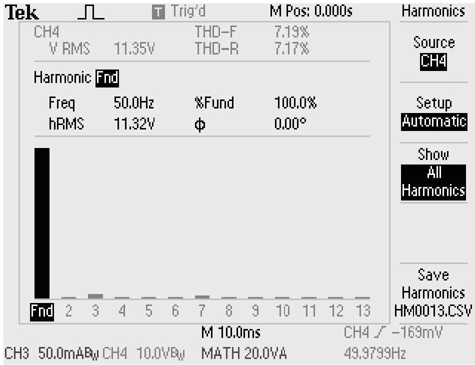


Fig.11. THD of grid voltage

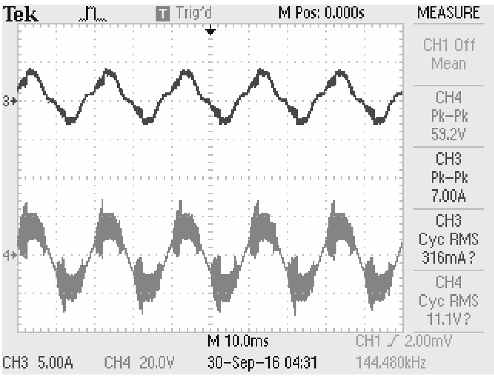


Fig.12. Grid current and voltage

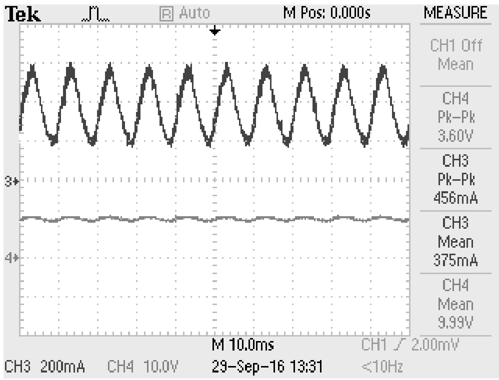


Fig.13. Power LED voltage and current

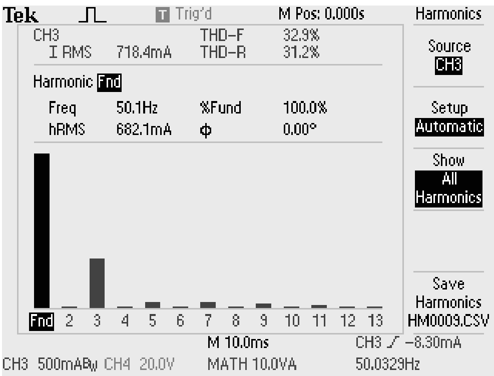


Fig.14. THD of grid current

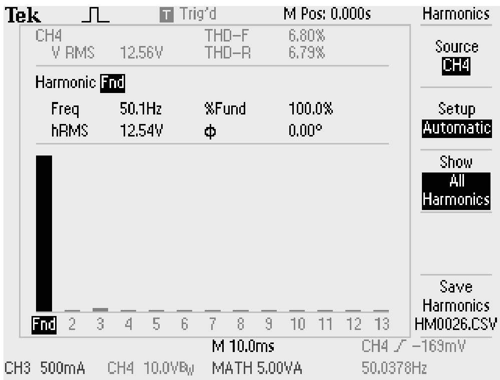


Fig.15. THD of grid voltage

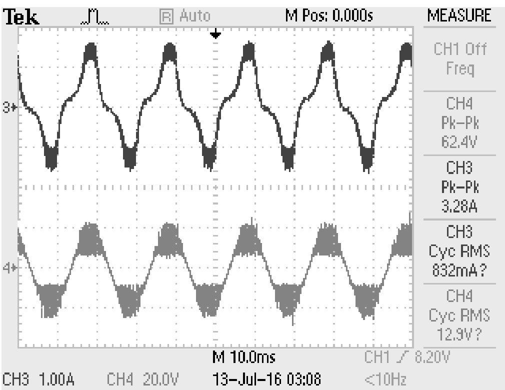


Fig.16. Grid voltage and current

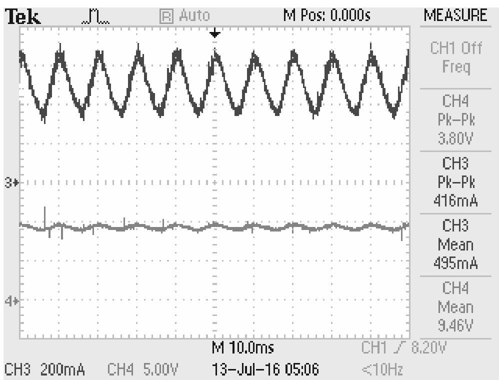
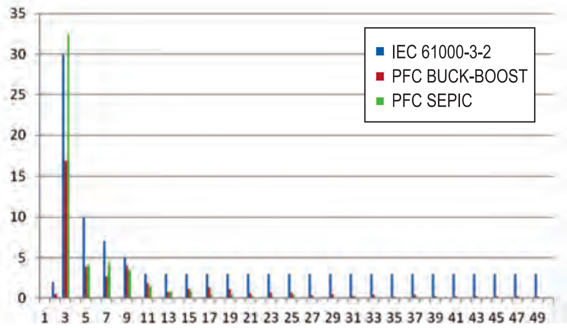


Fig.17. Power LED voltage and current

Table1. Comparison of grid Current THD's



5.1. PFC Buck-boost Converter

Grid current THD of PFC buck-boost converter that is 18.4 % is shown in Fig.10. Also, PF is measured as 0.925. THD of grid voltage is measured as 7.19 % and shown in Fig.11.

Grid current and voltage are shown in Fig.12. The shape of grid current is similar to grid voltage, and they are both sinusoidal.

Power LEDs voltage and current are shown in Fig.13, and it is seen that LED current is not dc and it has oscillation with 400mA.

5.2. PFC SEPIC converter

Fig.14. shows grid current THD of PFC SEPIC converter that is 32.9 %. P.F. is also measured as 0.912.

THD of grid voltage is shown in Fig.15 and it is 6.80 %.

Grid current and voltage are shown in Fig.16. The shape of grid current is similar to grid voltage, and they are both sinusoidal.

Power LEDs voltage and current are shown in Fig.17, and it is seen that LED current has oscillation with 200mA.

6. CONCLUSIONS

This paper compares the LED drivers that include buck-boost PFC and SEPIC PFC converters. Also, voltage-current characteristics and electrical equivalent circuit of power LED are derived. With applications that are realized by using easily found and cheaper ICs, THDs of grid current and voltage, power factor, power LEDs current and voltage are measured. THD's of grid currents are 18.4, 32.9 % and THD's of grid voltages are 7.19 and 6.80 % for PFC buck-boost and SEPIC LED drivers, respectively. Furthermore, PF is also measured as 0.925 and 0.912 for buck-boost and SEPIC LED drivers, respectively. Besides, power LED current oscillations are 400mA and 200mA for buck-boost and SEPIC based drivers. PFC buck-boost converter provides IEC61000 3–2 standard C.

As a result, grid current THD and PF of buck-boost PFC are better than SEPIC PFC. However, grid voltage THD and oscillation level of power LED current in buck-boost PFC are worse than SEPIC PFC.

Furthermore, in Table1 comparison of grid current THD's between IEC61000–3–2 C class, PFC buck-boost and PFC SEPIC LED drivers is given. It is seen from that table, both LED drivers provides actual standard IEC61000–3–2. However, 3rd harmonic of PFC SEPIC is little bit higher than the limit of that standard. On the other hand, PFC SEPIC LED driver application is realized without using input filter. After adding an input filter, it is assumed that actual standard will be realized completely.

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