DC-DC converter Topologies for LED Driver Circuit: A Review

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Abstract—It has been noticed that in commercial lighting, in terms of efficiency light-lamps based on light-emitting diodes(LEDs) are far better as compared to those where traditional high-pressure sodium (HPS) lamps which are still in use in major underdeveloped and developing areas worldwide in specifically street lighting. The LED driver is an electrical device which controls power flow to the single LED or a string of the LEDs or controls to the current flowing through the LEDs. Available conventional topologies for LED drivers have several demerits such as flickering issues, high losses, luminance problems, low power factor, more number of switches etc. So, the need of the hour is to develop efficient, compact, long lifetime, high power factor and flicker-free LED drivers. The LED have numerous advantages such as high luminous efficiency, life span and it has no mercury in its composition. Therefore, recently researchers of this area has been setting a goal to utilize LED as a good alternative to save electricity from major parts of this planet.

In this paper, various topologies of LED drivers are presented. This paper also portrays simulation of a LED driver which is based on the combination of the buck-boost converter as power factor correction stage (PFC) and buck converter as dc-dc power conversion (PC) stage. Both the stages are integrated using single switch only so it is basically integrated LED driver circuit.

Keywords—About four key words or phrases in alphabetical order, separated by commas.

I. Introduction

THERE are more than 10 million Indian hawker/street vendors according to Ministry of Housing and Urban Poverty Alleviation [1], lighting is a major issue for them. Most of them are using 12 volt LED lights as they do not have the regular electrical supply. 12 volt LED is preferred as the 12 volt battery used in vehicles is easily available in the market. In the current scenario many researchers have been setting a goal to utilize LED lifespan with efficient and good driver circuit. Driver circuits provides the supply for the LED lamps, these circuits must be compatible enough so that they can convert electrical energy from the line and supply and process it with continuous current to the LED lights. Also, the driver lifespan and LEDs lifespan must be coherently maintained, so that lamps do not lose any of its main features, especially its own lifetime factor. **W. Yang** et al [2] presented a highly efficient multiple-output buck-type led driver which uses only single-inductor. Various buck converter based topology is also found in literature [3, 4, 5, 6, 7, 8, 9]. Power factor improvement is the main concern of the researcher working in this area, some of the researcher suggested topologies with improved power factor [9, 10]. Electrolytic Capacitor-Free topology is also available in literature which improves the lifetime of the driver [11, 4, 12, 13, 10, 14, 15, 16]. Amongst the esteemed researcher **Cassio Gobbato** et al [17] presented Integrated Topology of DC-DC Converter for LED Street Lighting System. This topology has been simulated and presented in this paper for 12 Volt LED lights. Topology presented in [17] is implemented as it is but the design parameters has been modified in accordance with the Indian scenario.

II. Topologies for LED Driver Circuit

In literature various topologies for LED drivers has been reported till date. In this paper these topologies have been presented.

A. Integrated buck – flyback converter topology

Guirguis Z. Abdelmessih, et al. [18], an integrated buck – flyback converter topology is used to design the LED driver. The flyback converter is working in DCM mode to achieve high power factor. Parameters are redesigned in such a way that it has higher the efficiency, less output current ripple, Low THD and high – power factor than conventional IBFC converter. The efficiency achieved by this topology is 89%, power factor 0.96, THD is 16%.

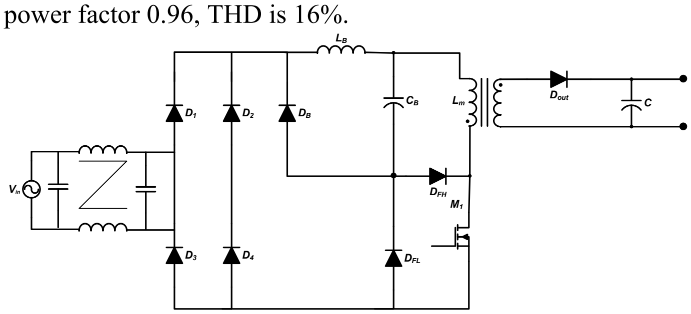

Fig. 2.2. Circuit of Integrated Buck Flyback LED driver with EMI Filter [18]

B. Isolated 2 – channel LED driver with automatic current balance using capacitor

K. Hwu and W. Jiang [19], suggested an isolated 2 – channel LED driver with automatic current balance using capacitor and zero dc magnetizing inductance current. In this topology, a transformer is provided for the isolation and also each winding has capacitor connected in series. Because of this the dc magnetization current is zero. Also, the capacitor in secondary winding works as current balancing in LED driver. This LED driver can be used for multi – channel LED driver without increasing the output voltage. The voltage stress on the MOSFET is less in this topology. The maximum efficiency achieved with this topology is 98.85%.

C. Single stage LED driver

Y. Wang et al. [20], have designed single stage LED driver working in discontinuous conduction mode with primary side regulated characteristics to achieve high performance of the system such as high power density, high accuracy, high reliability, high power factor, high efficiency and low input current distortion. The calculation for different parameters, used in the implementation of the topology, is presented in this paper. For the variation in the input voltage from 90V to 260V, power factor always remains greater than 0.95 and efficiency varies between 85% and 90.8%.

D. Single – stage LED driver featuring boost converter

J. Ma et al. [21], depicted a single – stage LED driver featuring boost converter and a half-bridge LLC resonant converter. In this topology, the power factor correction is done by operating boost converter in discontinuous mode of conduction so that the driver has low THD and high pf. LLC resonant converter provides isolation as well as soft switching so that less switching losses are there. This LED driver can be employed for industrial lighting. This topology on full load has achieved 91.5% of efficiency.

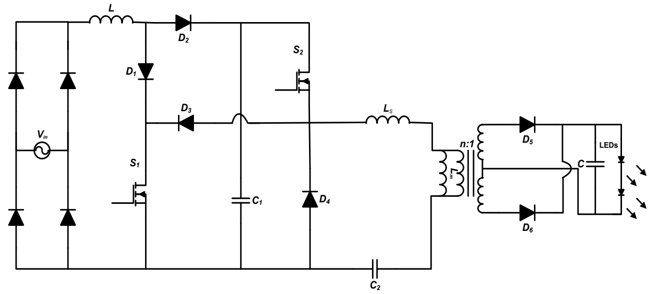

Fig. 2.1. Circuit of LED driver based on Boost circuit and LLC converter [21]

E. Mixed color LED lighting system

J. Huang, et al. [22], have shown that LED drivers used in applications such as the mixed color LED lighting system require constant current through each LED string and current flowing through each LED string should be controlled independently. For giving effect to this, a single stage LED driver with independent control of N- channel output current is developed. The working principle and independent current loop control strategy (ICCS) for 3-channel output LED driver is implemented in this paper. The design parameters for the implemented topology are elaborated in the paper.

F. Self – oscillating soft switched LED driver

B. M. Tehrani, et al. [23], have presented a self – oscillating soft switched LED driver which implements zero current switching (ZCS) at turn off instant of the switch. When variation in output voltage is around 33% then variation in current is only 10% it means output current flowing through LEDs remains almost constant when there is wide variation in output voltage so this topology does not require any current feedback. The topology presented in this paper does not need any power supply for control circuit. The main drawbacks of the topology are that it can operate for only low power applications i.e. less than 25W and input current does not remain sinusoidal.

S. Zhang, X. Liu, Y. Guan, Y. Yao and J. M. Alonso [24], have depicted a LED driver topology in which switches are turned on and off by a modified ZVS control scheme. It is a single stage topology of LED driver based on Flyback and Class E converter. Class E converter is a resonant type of converter, so it has inherently soft switching. The Flyback converter is operated in discontinuous mode of conduction so that high power factor (pf) can be achieved with this topology and LED load is supplied by the Class E converter with wide range of duty cycle so that output current can be regulated at a constant frequency. Conventionally, the Class E converter has high drain – source voltage of the switch. To overcome this problem the converter is operated with variable duty cycle.

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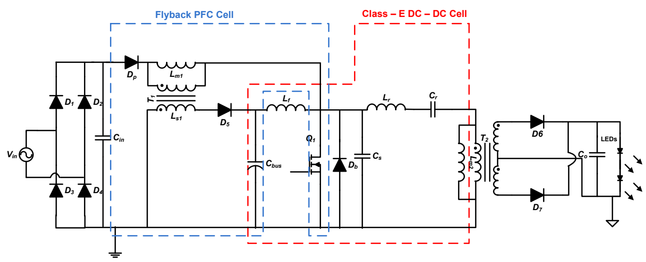

Fig. 2.3. Circuit of LED driver based on Flyback and Class – E converter [24]

III. Comparison of LED Driver Topologies

The comparison of various topologies presented in section II is presented in this section on the basis of various parameters: Converter type (represents the available topology of converter), number of switches (total number of switches used in the topology), efficiency power factor and total harmonics distortion (THD).

Table- I: Comparison of LED Driver topologies

Topology	*Converter type*	*No. of switches*	*Efficiency*	*pf*	*THD*
Loss analysis for efficiency improvement of the IBFC LED driver [18]	Integrated Buck-Flyback	MOSFET (x1)	89%	0.96	16
2-channel LED Driver [19]	Boost Converter with galvanic isolation	01	98.85%	-	-
Primary side regulated LED driver [20]	Flyback converter	01	91%	0.997	8.3
LED driver based on Boost circuit and LLC converter [21]	Boost Converter with LLC Resonant Converter	02	91.5%	0.94 – 0.98	-
Single stage series type LED drivers [22]	Buck-boost converter	04	-	-	4.78
Self-oscillating soft switched LED drivers [23]	-	04	90%	0.95	3.2
LED driver based on class E converter [24]	Flyback and Class E converter	01	91.6%	0.995	5

IV. Topology Implemented

The topology given in [17] is implemented in MATLAB Simulink in this paper and the circuit diagram of this topology is given in Fig. 1.

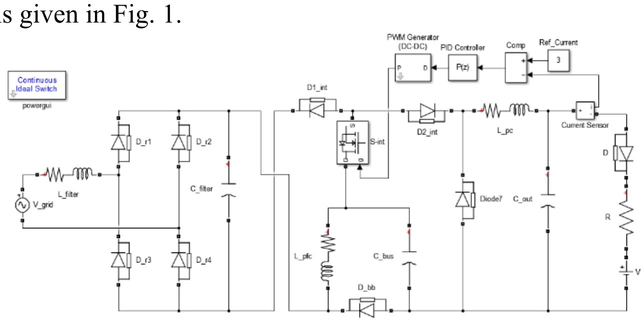

Fig. 1. Circuit diagram of integrated DC-DC converters [17].

The electrical modeling of LED as shown in the Fig. 2 is a series connection of an ideal diode (D), a resistor (R) and a voltage source (V). Voltage source characterizes the minimum voltage required to make LED forward biased .

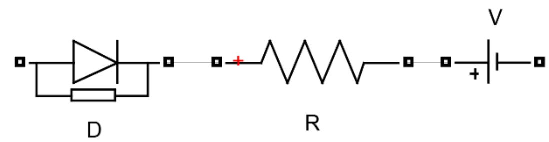

Fig. 2. Electrical modeling of LED in MATLAB Simulink

Integrated topology [17, 25]: Quanming Luo et al [25] present Single-Stage AC-DC LED Driver which is integration of two DC-DC converters. First power factor correction (PFC) unit which is Buck-Boost converter operating in discontinuous conduction mode (DCM) and second is an isolated DC-DC unit with a voltage rectifier. This integration is possible by sharing the same power switch and both the converters must operate in same duty ratio and same switching frequency.

T-type inverted presented in [17] and [25] shown in Fig. 1 is the series connection of buck-boost and buck converters shown in Fig. 3 and Fig. 4. In this topology the drains of the switches S_{bb} and S_b share the same node thus replacing the S_{bb} and S_b switches by S_{int} switch and adding two diodes D_{1int} and D_{2int} as shown in Fig. 1.

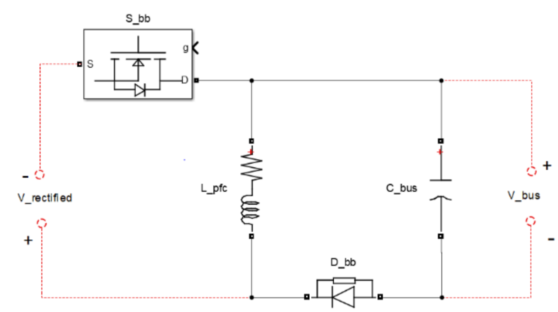

Fig. 3. Buck-boost converter

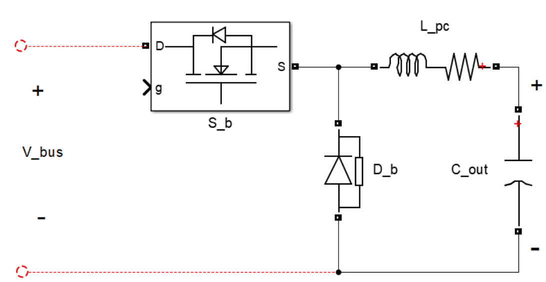

Fig. 4. Buck converter

V. Design Parameters

Design parameters used in the base paper [17] is shown in table 2 below:

Table- II: Design parameters used in [17]

Symbol	Specification	Value
V_{GRID}	Mains voltage (RMS)	127V
fr	Mains frequency	60Hz
Po	Output power (each module)	25W
Ileds	Output current (average)	500mA
Vbus	PFC output voltage (average)	170V
Vout	PC output voltage (average)	51V
ΔIleds	LEDs current ripple	100mA - 20%
ΔVbus	PFC output voltage ripple	85V - 50%
ΔVout	PC output voltage ripple	1.02V - 2%
fs	Switching frequency	60 kHz

Design parameters shown in table 1 are modified according to Indian hawker/street vendors lighting requirements. As discussed in the introduction section Indian hawkers already using 12 V LED lights which are directly connected to a 12 V battery. The LED driver presented in this paper also uses 12 V output to fulfill the hawkers lighting demand. The LED strip or light can be used directly with 12V battery when grid is unavailable and once the grid is available one can used this driver to light the same LED. The modified design parameters used in this paper is shown in table 3.

Table- III: Design parameters used in this paper

Symbol	Specification	Value
V_{GRID}	Mains voltage (RMS)	230V
fr	Mains frequency	50Hz
Po	Output power	25W
Ileds	Output current (average)	2.2A
Vbus	PFC output voltage (average)	85V
Vout	PC output voltage (average)	12V
ΔIleds	LEDs current ripple	100mA - 20%
ΔVbus	PFC output voltage ripple	85.6 to 87.6V (2.35%)
ΔVout	PC output voltage ripple	12.356 to 12.346 – (0.08%)
fs	Switching frequency	60 kHz

VI. Simulation and Results

MATLAB Simulation of the integrated topology is presented in Fig. 1; results are discussed in this section. Fig. 5 shows the time response of load current, it shows the current is stable at the value of 2.25A.

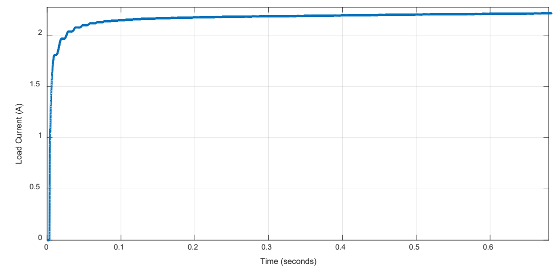

Fig. 5. Load current vs time curve

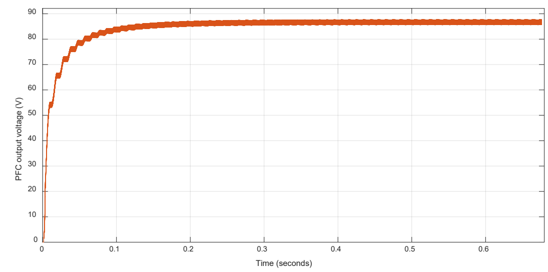

Fig. 6. PFC output voltage vs time curve

Fig. 6 shows the output voltage after PFC stage and Fig. 6 shows the ripple in voltage after PFC stage.

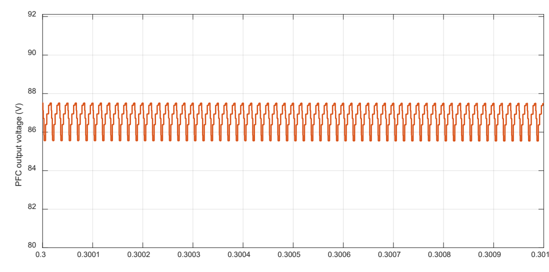

Fig. 6. Ripple in PFC output voltage.

Fig. 7 shows the output power with respect to time plot which is stable near the 25.25 watts. This power is sufficient for the lighting purpose of the Indian hawkers.

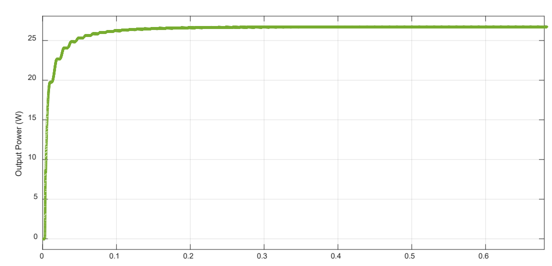

Fig. 7. Output power vs time curve.

Fig. 8 shows the output voltage at the LED end which is stabled at 12Volts.

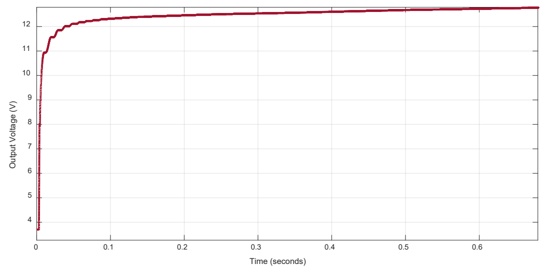

Fig. 8. Output voltage vs time curve.

Fig. 9 shows the ripple in the output voltage which is less than 1% hence the minimum flickering occurs in the LED light.

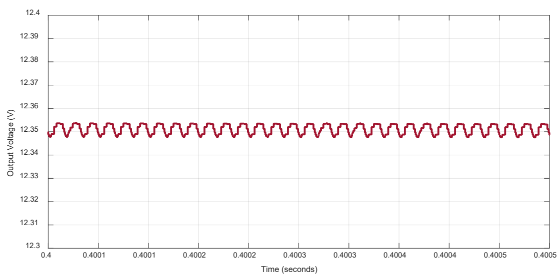

Fig. 9. Ripple in output voltage.

VII. CONCLUSION

In this paper integrated topology of DC-DC converter is presented for LED driver circuit, this topology has been presented by Cassio Gobbato et al however the designed parameters have been changed in accordance with the Indian hawker/street vendors. About 10 million Indian hawker/street vendors in India having irregular power supply. The topology is modified in accordance with them and the output voltage is stabled at 12Volt DC which can fulfill their lighting needs with less than 1 % ripples in the output.

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