Performance Analysis of LED Driver Circuit using DC-DC Converter Topology

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Abstract: High Pressure Sodium (HPS) lamp has been extensively employed in outdoor lighting. But the need of time is to save electricity since HPS has high consumption of electricity. Light Emitting Diodes (LEDs) are better choice to replace HPS. Since they are compact and with very low power ratings, they have very high illumination. The basic difference between LED and HPS is that, HPS works on normal AC voltage supply whereas LED requires low DC voltage to operate. Hence a converter circuit with low voltage rating is required for proper functioning of LED. In this paper, simulation and hardware implementation of an LED driver base on a permutation of the buck converter as the DC-DC power conversion (PC) stage and buck-boost converter as the power factor rectification (PFR) stage is presented. This paper presents the hardware implementation of LED driver circuit for 12 V LED lighting strip.

Keywords— High Pressure Sodium (HPS), Light Emitting Diode (LED), Power Conversion (PC), Power Factor Rectification (PFR).
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1. Introduction

THE High Pressure Sodium (HPS) lights were the most innovative and efficient technology developed in 1970s. Whereas Light Emitting Diodes (LEDs) are modern day saviour. The HPS lights were preferred due to its high efficiency, cheap, low maintenance cost and long lifespan. But with the advancement in solid state technology, LED proved to be better in all the above mentioned aspects in comparison to HPS. There are lot many reasons for replacement of HPS by LED like; high Colour Rendering Index (CRI), instantaneous ON/OFF response, dimming, Viable Light Emissions, failure characteristics directionality, shock resistance, heat emissions, etc. Hence LEDs have developed a wide market and HPS is being replaced by LEDs [1]. To control the functioning of LEDs a driver circuit is required which is essentially developed by using DC-DC converters [2-8]. Various buck converter based LED driver topologies are reported in literature [9-15]. Power factor improvement is the one of the key concern for the researcher working in this area; some of the researchers have been suggested topologies [16, 17] which improves the power factor.

Electrolytic capacitor free LED driver topology to increase the life span is also available in the literature [18–23]. The Integrated DC-DC Converter based driver topology for LED based street lighting system presented in [24], is also the scope of this paper. Topology presented in this paper is implemented in Indian context, so the simulation model is demonstrated in this paper for 12 Volt LED lights.

2. Driver Circuit Topology

As mentioned in previous section that a lot of work has been reported in literature for numerous topologies of driver circuit. Among the various topologies reported in literature broadly used are integrated type, isolated 2-channel topology, mixed topology single-stage driver circuit, self-oscillating topology, etc. the brief overview of theses topologies is presented in this section.

2.1 Integrated Buck-Flyback Converter based LED Driver Topology

To design the LED driver circuit, an integrated buck – flyback converter is employed as depicted in figure 1[25].

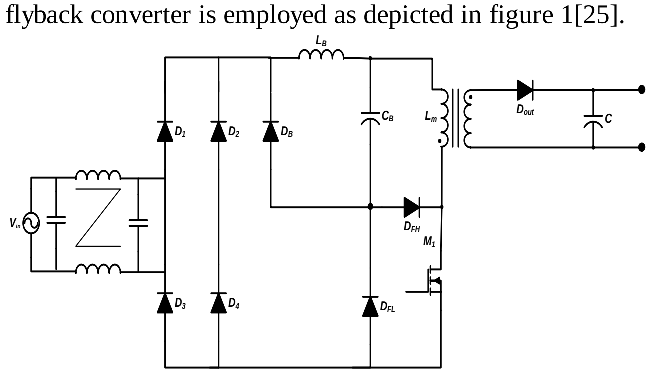

Figure 1. Integrated Buck Flyback LED driver topology [25]

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The flyback converter works on discontinuous conduction mode (DCM) as depicted in figure 1, to achieve high power factor. Parameters are redesigned in such a way that it has high power factor, fewer output current ripple, modest total harmonic distortion (THD) and higher efficiency than conventional IBFC converter. The efficiency achieved by this topology is 89%, power factor 0.96, THD is 16%.

2.2 Isolated 2 – Channel LED Driver Topology with Automatic Current Balance

In [26], LED driver circuit for an isolated 2 – channel automatic current balance using capacitor as well as zero DC-magnetizing current. In this topology, a transformer is provided for the isolation and also each winding has capacitor connected in series as depicted in figure 2. Because of this the dc magnetization current is zero. Also, the capacitor in secondary winding works as current balancing in LED driver. This topology can be utilized for multi – channel LED driver without raising the output voltage. The MOSFET experiences less voltage stress in this topology. The maximum efficiency achieved with this topology is 98.85%.

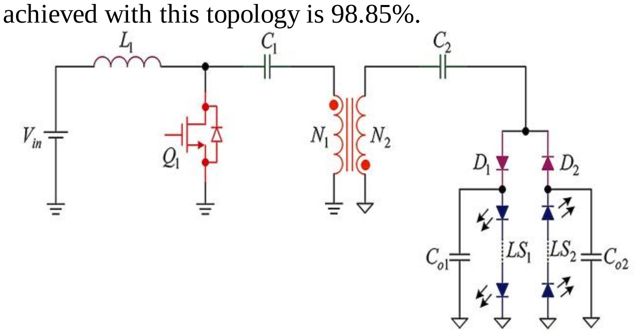

Figure 2. Isolated 2 – Channel LED driver topology [26]

2.3 Single Stage LED DriverTopology

The driver for LED having single stage with DCM is presented in [27]. The primary side have regulated characteristics to achieve high performance of the system. The performance is account for high-power density, high reliability, high PF, high efficiency and low input current THD. 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%.

2.4 Single – Stage LED Driver Topogoly with Boost Converter

In [28], a LED driver single – stage circuit as depicted in Figure 3 featuring a half-bridge LLC resonant and boost converter. In this topology, the PFR is obtained by operating boost-converter in discontinuous conducting mode in order to have low THD and high PF. For providing isolation as well as soft switching LLC resonant converter is used so that less switching losses is obtained. This LED driver can be employed for industrial lighting on full load has achieved 91.5% of efficiency. The PFR is also recognized as PFC (Power Factor Correction).

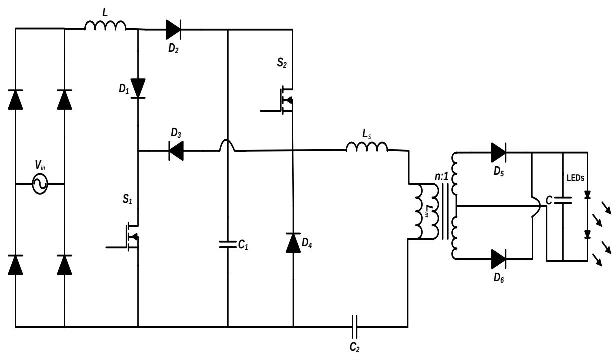

Figure 3. Single – Stage LED Driver Topology with Boost Converter [28]

2.5 Single Stage Series Type LED Driver Topology

For applications such as mixed color LED lighting system, driver require constant current through LED strings also current flowing through each string should be independently controlled to obtain good performance efficiency. For giving effect to this, LED driver topology with self-regulating control of N- channel output current is developed. The working principle for this uses 3-channel output LED driver which is realized in [29], which is depicted in Figure 4. The design parameters for the implemented topology are elaborated in [29].

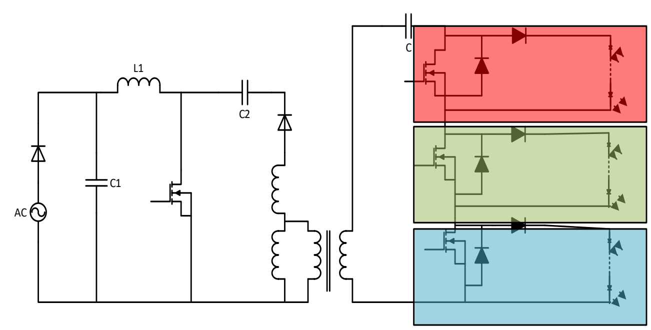

Figure 4. Single stage series type LED driver topology [22]

2.6 Self Oscillating -Soft Switched LED DriverTopology

In [30] a LED driver with self – oscillating soft switched topology depicted in figure 5 which implements zero current switching (ZCS) at turn off instant of the switch.

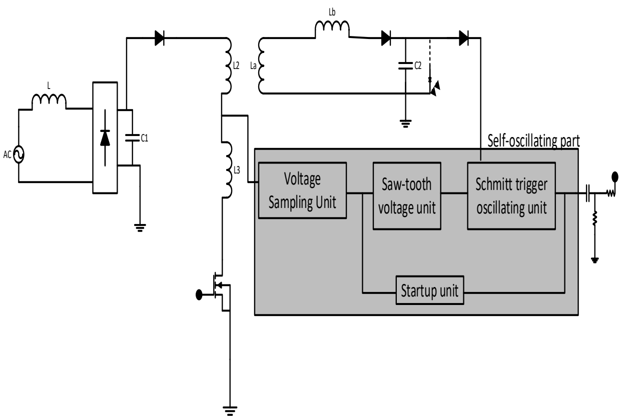

Figure 5. LED driver with Self-oscillating soft-switched topology [30]

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 topology does not require any power source 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.

2.7 Class E Converter based LED Driver Topology

In [31], a LED driver topology in which switches are turned on and off by a modified ZVS control scheme. It is a single stage of LED driver topology on Flyback and Class E converter depicted in figure 6. Class E converter is a resonant type of converter, so it has inherently soft switching. The Flyback converter is operated in DCM, so that high power factor can be realized with this topology and the Class E converter feeds LED load with a broad range of duty cycle which results regulated output current at a steady frequency. Conventionally, the Class E converter has high drain – source voltage at the switch. To conquer this problem the converter is operated with variable duty cycle.

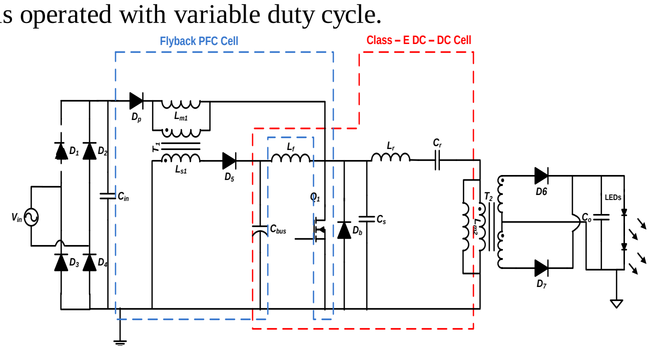

Figure 6. Class E Converter based LED Driver Topology [31]

3. Comparison of LED Driver Circuit Topologies

The comparison of various topologies presented in section II is depicted in Table I 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, PF and THD.

Table I. Comparison of LED Driver Topologies

Topology	**Converter type**	**No. of switches**	**Efficiency**	**PF**	**THD**
Integrated Buck-Flyback Converter based LED Driver Topology [25]	Integrated Buck-Flyback	MOS-FET (x1)	89%	0.96	16
Isolated 2 – Channel LED Driver Topology with Automatic Current Balance [26]	Boost Converter	01	98.85%	-	-
Single Stage LED Driver Topology [27]	Flyback converter	01	91%	0.997	8.3
Single – Stage LED Driver Topology with Boost Converter [28]	Boost Converter and LLC Converter	02	91.5%	0.94 – 0.98	-
Single Stage Series Type LED Driver Topology [29]	Buck-boost converter	04	-	-	4.78
Self Oscillating -Soft Switched LED Driver Topology [30]	Boost converter	04	90%	0.95	3.2
Class E Converter based LED Driver Topology [31]	Fly-back and Class E converter	01	91.6%	0.995	5

4. Topology Implemented

The topology given in [24] is implemented in this paper as it is, but the design parameters has been customized in accordance with the Indian state of affairs. The reason is to adopt and implement this topology is it requires only one switch which make it's driver modular, also it is compatible with LED street lighting system. The controller is realized through an Arduino UNO which is capable of controlling any number of modules. The LED driver demonstrated in this paper utilizes 12 V output to accomplish the lighting requirement of hawkers. The 12 volt LED strip can be employed directly with 12V battery when grid power is out, and once the grid power is in than it can be used with driver to light the same LED strip. The proposed work is implemented in MATLAB Simulink and simulation model of this topology is depicted in Figure 7.

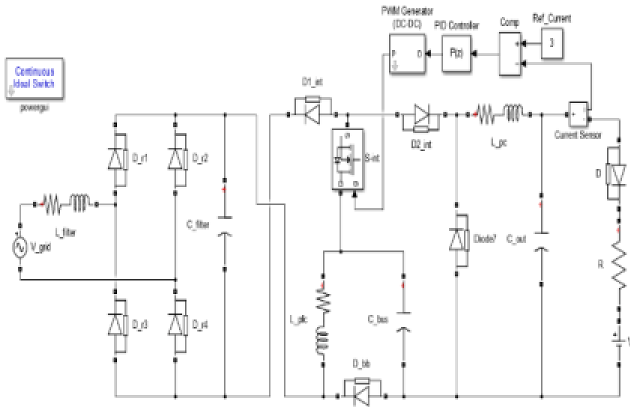

Figure 7. Simulink model of integrated DC-DC converters [24].

The LED in MATLAB Simulink is represented in figure 8 as a series combination of an ideal diode (D), a resistor (R) and a voltage source (V).

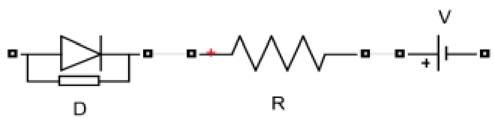

Figure 8. An LED representation in MATLAB Simulink

Integrated topology [24, 32] is a single-stage AC-DC LED Driver topology. It is a combination of two DC-DC converters in which First unit is PFC -Buck-Boost converter which operates in DCM and second unit is a Buck converter with a voltage rectifier. This integration is feasible by allocating the same power switch for both. Additionally, both the converters must operate in same switching frequency with the same duty ratio.

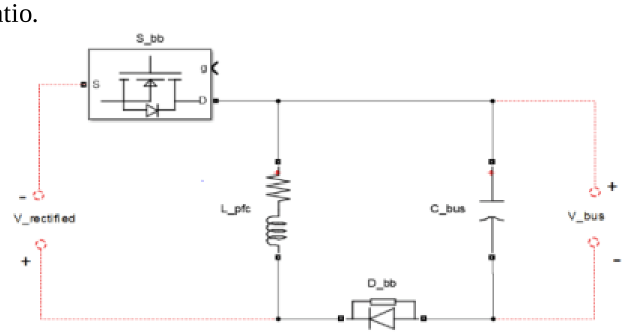

Figure 9. Buck-boost converter

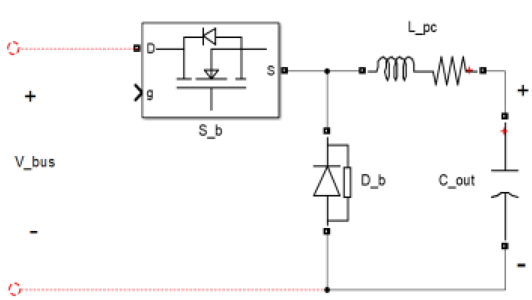

Figure 10. Buck converter

The series connection of buck-boost and buck converters depicted in Figure 9 and Figure 10 together introduces the T-type inverted topology as it is presented in [24, 32] and depicted in Figure 7. In this T-type inverted topology the drains of the switches S_{bb} of buck-boost converter and S_b of buck converter allocated for same node thus substituting the S_{bb} and S_b switches by a single switch S_{int} and includes two diodes D_{1int} and D_{2int}.

5. Simulation Model and Result

In this paper an integrated DC-DC converter topology is realized for LED driver circuit by means of MATALB software. The design parameter as given in base paper is presented in table II.

Table II. Design Parameter employed in Base Paper

Symbol	Design Parameters	Value
V_{GRID}	Supply voltage (RMS)	127V
f_r	Supply frequency	60Hz
f_s	Switching frequency	60 kHz
P_o	Output power	25W (each module)
I_{leds}	Output current	500mA (average)
ΔI_{leds}	LEDs current ripple	100mA - 20%
V_{bus}	PFC output voltage	170V (average)
ΔV_{bus}	PFC output voltage ripple	85V - 50%
V_{out}	PC output voltage	51V (average)
ΔV_{out}	PC output voltage ripple	1.02V - 2%

Design parameters customized according to Indian hawker/street vendors lighting necessities represented in table III.

Table III. Design parameter for proposed work

Symbol	Specification	Value
V_{GRID}	Supply voltage (RMS)	230V
f_r	Supply frequency	50Hz
f_s	Switching frequency	60 kHz
P_o	Output power	25W
I_{leds}	Output current	2.2A (average)
ΔI_{leds}	LEDs current ripple	100mA - 20%
V_{bus}	PFC output voltage	85V (average)
ΔV_{bus}	PFC output voltage ripple	85.6 to 87.6V (2.35%)
V_{out}	PC output voltage	12V (average)
ΔV_{out}	PC output voltage ripple	12.356 to 12.346–(0.08%)

As discussed in the introduction section the 12 volt LED strip can be employed directly with 12V battery when grid power is out, and once the grid power is in than it can be used with driver to light the same LED strip. The LED driver demonstrated in this paper utilizes 12 V output to accomplish the lighting requirement of hawkers. The MATLAB Simulation model of the integrated topology is depicted in Figure 7; results are discussed in this section. Figure 11 depicts the time response of load current, it depicts the current is stable at the value of 2.25A.

Figure 12 depicts the output voltage after PCR stage and Figure 13 depicts the ripple in voltage after PCR stage. Figure 14 depicts 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.

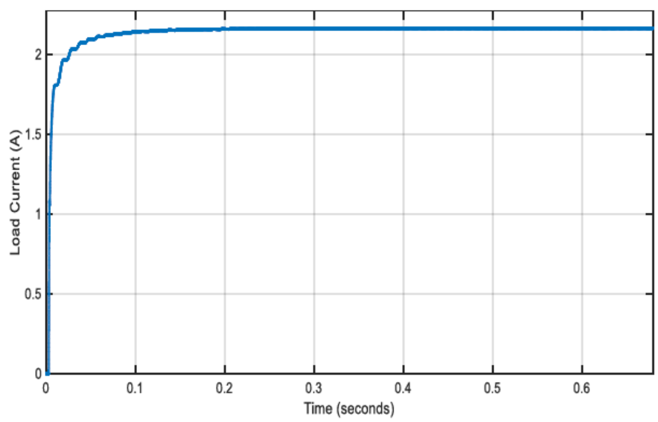

Figure 11. Load current vs time curve

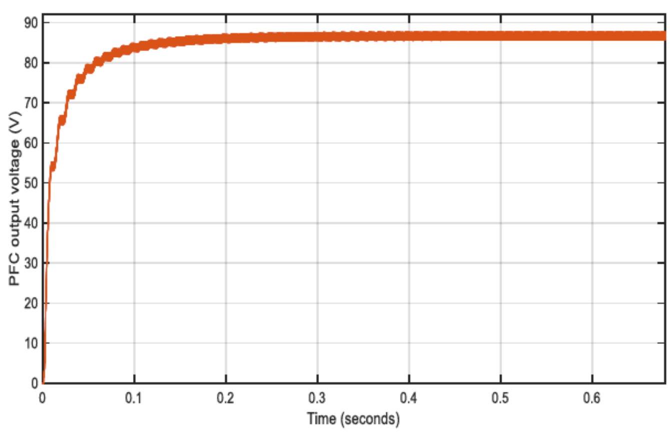

Figure 12. PCR output voltage vs time curve

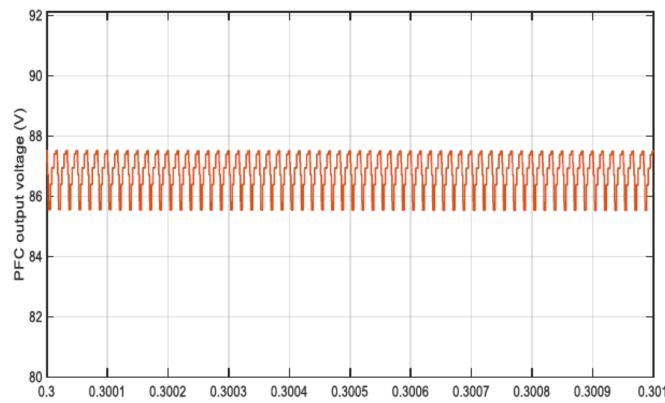

Figure 13. Ripple in PCR output voltage.

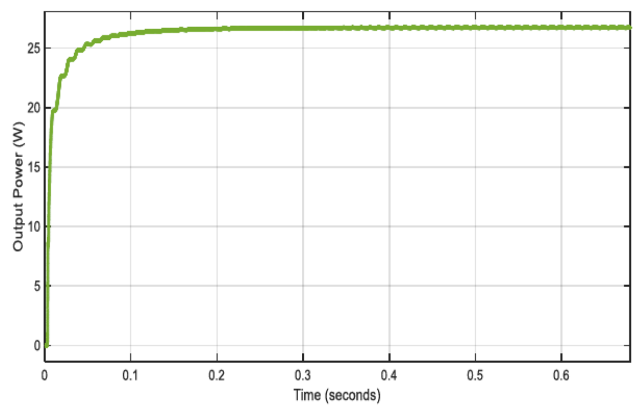

Figure 14. Output power vs time curve.

At the LED end the output voltage is constant at 12 volts as depicted in Figure 15. The ripple in the output voltage is less than 1% as depicted in Figure 16, hence the flicker is lowest in the LED light.

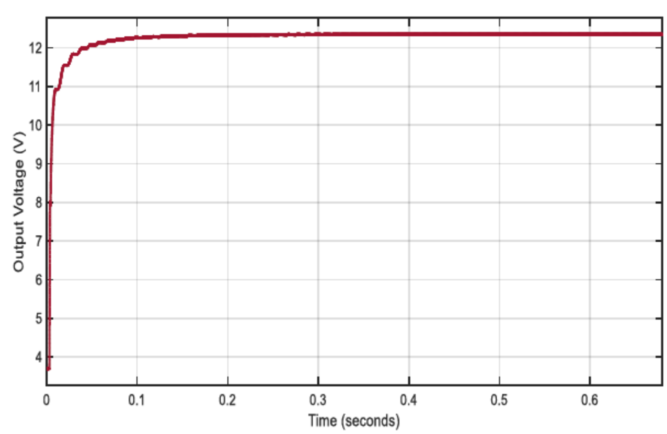

Figure 15. Output voltage vs time curve.

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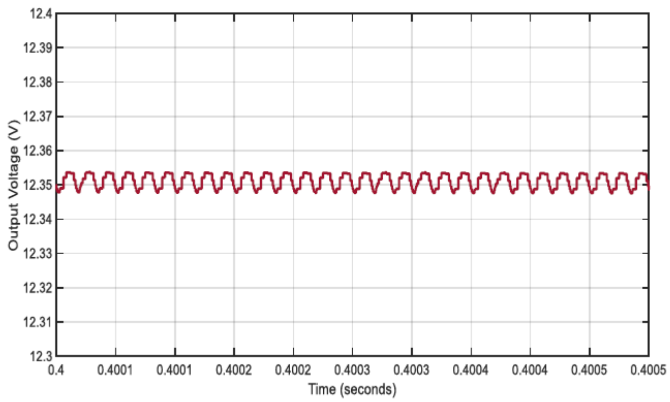

Figure 16. Ripple in output voltage

6. Hardware Implementation

The hardware implementation of the integrated topology depicted in figure 7 is presented in figure 17 and 18, figure 17 depicted the hardware circuit of integrated topology and figure 18 depicts its complete functioning set up. The control signal for hardware is produced by the Arduino UNO. A variable supply is given for regulation and air-core inductors are used.

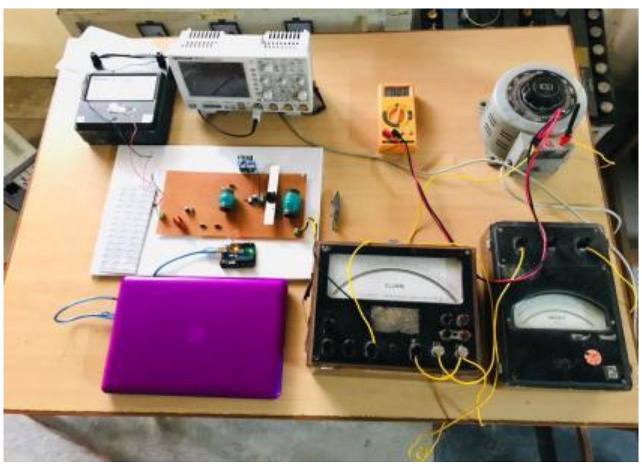
Figure 17. Integrated topology hardware circuit

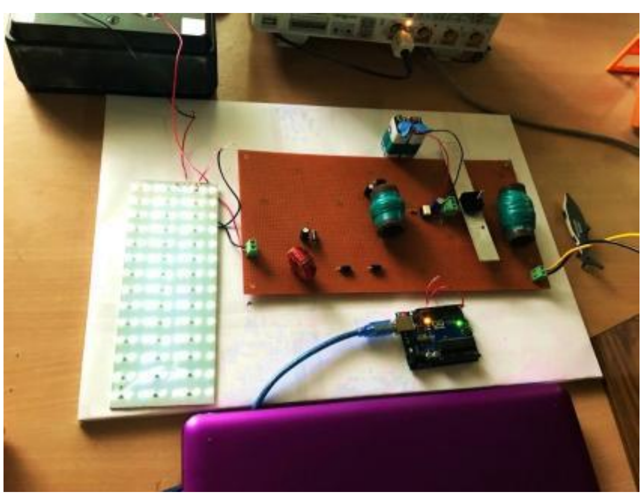
Figure 18. Integrated topology (Functioning Set-Up)

To measure the various parameters Ammeter, Voltmeter, Multimeter and digital signal oscilloscope (DSO) are used. The results of this topology are discussed in this section, all the results displayed in the HAMEG digital signal oscilloscope. Figure 19 depicts the input voltage waveform of supply without harmonics (LED module not connected), that is given through the variac. The RMS value of the input voltage given in the base paper [17] is 127V RMS and for this paper 170 V RMS employed. The output we get from the input 170V is 8V DC as shown in Figure 20, the topology design is further tested for 230V AC Supply which can offer 12V DC output for appropriate illumination. The ripple in the output voltage is less than 1% as depicted in Figure 21; hence the flicker is lowest in the LED light.

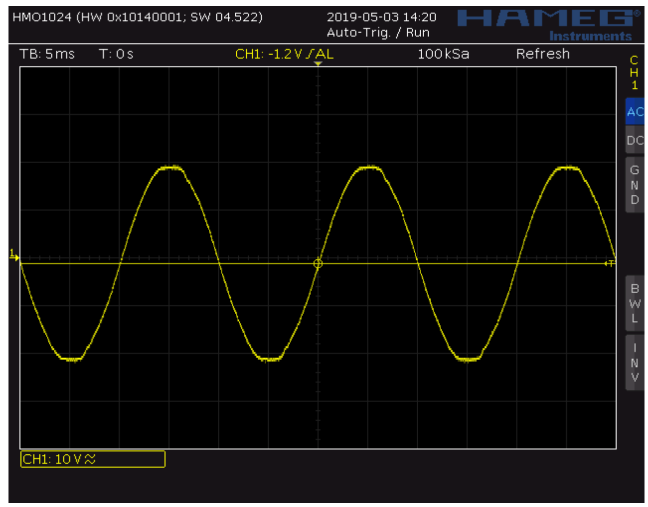

Figure 19. Input voltage waveforms voltage, peak value of voltage = 240V (10V/div probe setting 10x)

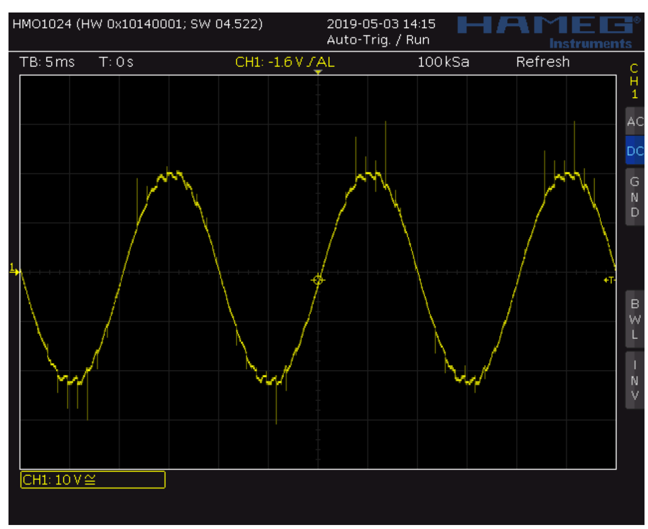

Figure 20. Output voltage (8 volt) at LED end

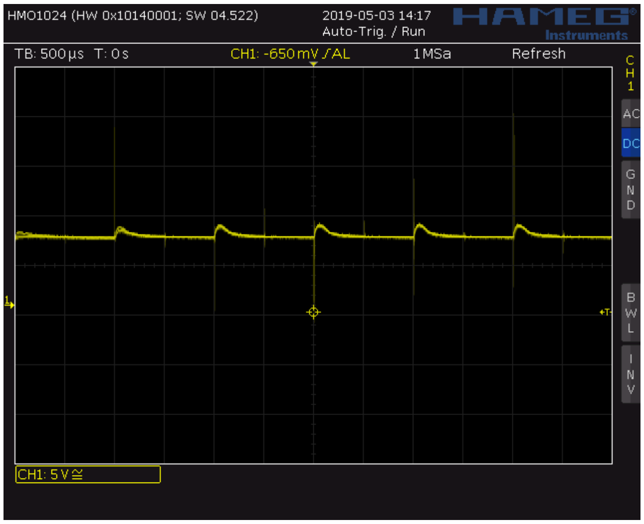

Figure 21. Output voltage waveforms at LED, peak value of voltage = 8V (voltage 5V/div probe setting 1x).

7. Conclusion and Future Work

In this paper a design of integrated LED driver topology for 12 V LED lightening is presented. A comparative analysis of the topology with base paper is presented. In context with the Indian hawker/street vendors, the designed parameters have been customized. The topology designed is customized in accordance with as approximately 10 million Indian hawker/street vendors suffer the issue of irregular power supply. The output voltage of this topology is stabled at 12Volt DC which can fulfil their lighting requirements with lowest ripples in the output that is less than 1 %. The results obtained from MATLAB simulation software are also verified using hardware implementation of integrated DC-DC converter topology whose control is generated using Arduino UNO and air core inductors.

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