



A New Design of LED Driver for Electronic Ballast with Capacitor Clamped Current Sharing Circuit

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ABSTRACT: An LED driver with electronic ballast that are currently commercially used is newly proposed, which adopts a variable switched capacitor by controlling the switching duty cycle for LED power regulation. The resonant frequency of an LC resonant tank of electronic ballasts can be changed, which makes the proposed LED driver versatile for electronic ballasts for various switching frequencies. In this way, the fluorescent lamp is replaced with an LED lamp, where the electronic ballast in the lighting infrastructure remains unchanged. The ZVS is applied for the variable switched capacitor (VSC) in the electronic ballast. Neither an inductor nor a transformer is introduced in the proposed LED driver, which leads to compact size and high efficiency. Furthermore, no electrolytic capacitor is used, which is beneficial for the long lifetime of LED drivers. This paper also presents a simple and efficient capacitor clamped current-sharing method for LED strings.

KEYWORDS:Light Emitting Diode, Zero Voltage Switching, Variable Switched Capacitor.

I.INTRODUCTION

Lighting consumes almost 10-15% of global energy requirement. Given the increasing concerns about energy saving, the improvement for the overall efficiency of lighting systems is of significant importance. Fluorescent lamps are well known for decades to be an efficient light source, which are mainly used for home and office lighting. Recently, a new type of lamps: light emitting diode (LED) lamps are born. The LED lamps that are now available can reliably offer over 120 lumens from a one-watt device. Due to the high-efficiency, the LEDs are increasingly attractive in the world, especially for industrial applications such as the street light. Fluorescent lamps are gas discharge lamps with negative temperature coefficient and thus cannot be connected to a voltage source such as ac mains. There is a need to limit the lamp current and ballast is used for that. Output of ballast is AC currents. LED is a single directional device and also the power rating for fluorescent and LED for substitution is different. Thus direct application of LED to ballast is not possible. The solution is to replace only lamp to LED tube compatible with electronic ballast where the LED driver will be integrated in the LED tube. In this an adaptable LED driver compatible with various electronic ballasts is discussed, which adopts a variable switched capacitor by controlling the switching duty cycle for LED power regulation. The zero voltage switching is applied for the variable switched capacitor in the electronic ballast.

Neither an inductor nor a transformer is introduced in the proposed LED driver, which leads to compact size and high efficiency. Furthermore, no electrolytic capacitor is used, which is beneficial for the long lifetime of LED drivers. Due to negative temperature coefficient of LED and voltage drop tolerance, current imbalance issues arises. Capacitor clamped current sharing circuit is used in multistring LEDs for equalizing the currents.

II.SYSTEM MODEL AND ASSUMPTIONS

LED driver compatible with various electronic ballasts is discussed, which adopts a variable switched capacitor by controlling the switching duty cycle for LED power regulation. By controlling the switching duty cycle, the resonant frequency of an LC resonant tank of electronic ballasts can be changed, and the LED power can be appropriately modulated. This resonant-frequency-adjustment characteristic makes the proposed LED driver versatile for most electronic ballasts available in markets. The proposed variable switched capacitor is the first application to LED drivers

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and is different from the variable capacitors used for wireless power transfer applications to modulate load power by tuning or detuning the LC resonant condition.

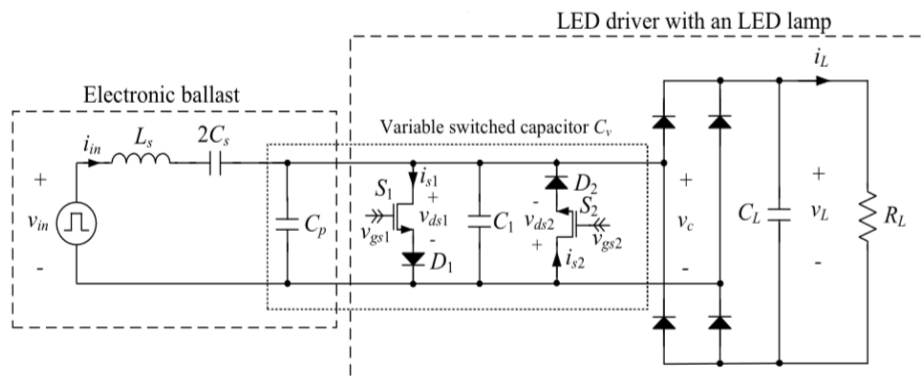


Fig (1)

It is important to have soft switching operations of $S_1 - D_1$ and $S_2 - D_2$ for reliable operation and high power efficiency of the proposed LED driver. Thus, each main switch S_1 or S_2 should be in on-state earlier than its zero-crossing point of V_c , as shown in Fig 3.3, so that the path $S_1 - D_1$ or $S_2 - D_2$ may be automatically turned ON as soon as the polarity of V_c changes, which corresponds to ZVS turn-on. As S_1 or S_2 is turned-off, V_c becomes nonzero and the switch is ZVS turn-off. In this application, V_{in} leads I_{in} , which meets the soft-switching condition of the inverter switches of the ballast. The maximum value of V_c is limited by the load capacitor voltage V_L .

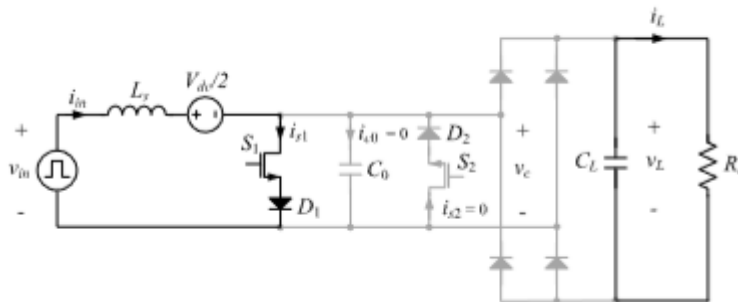


Fig (2)

Mode 1: At t_0 , the switch S_1 is just turned ON as a result of the polarity change of V_c from the negative to the positive. This mode ends when V_{in} changes to 0 at t_1 , where V_{in} is arbitrarily determined by given electronic ballast.

Mode 2: At t_1 , I_{in} decreases linearly, where the path $S_1 - D_1$ is still turned ON. This mode ends when S_1 , whose duty cycle is arbitrarily controlled to regulate the LED power, is turned OFF. It is shown in Fig 2.

Mode 3: At t_2 , the switch S_1 is just turned OFF. Then, V_c is determined, where I_{in} is assumed to be constant for a short time period of this mode. This mode ends when the detection signal V_{d2} toggles to zero, which corresponds to the positive slope of V_c , as a result of $V_c = V_{th}$.

Mode 4: At t_3 , both S_1 and S_2 are still turned OFF and C_0 is continuously charged just as in the previous mode. It is assumed that the inductor current is kept constant. It is shown in Fig 3.

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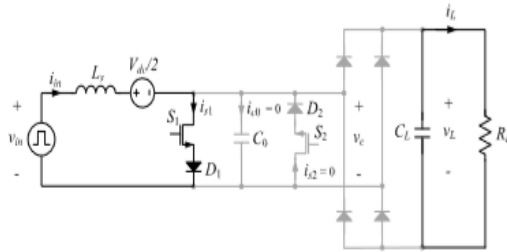


Fig (3)

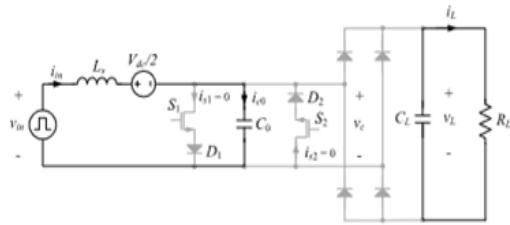


Fig (4)

Mode 5: The diodes D₃ and D₆ of the diode rectifier are turned ON, as a result of $V_c(t_4) = V_L$. Assuming that the LED lamp is mode led as a constant dc voltage source of V_L due to the very large time constant of C_L and R_L compared to a switching period. It is shown in Fig 4.

In this due to negative temperature coefficient of LED and voltage drop tolerance the current through the LED strings are not equally shared. In this scenario current imbalance problem is rectified by using capacitor clamped current sharing circuit as shown in fig 5.

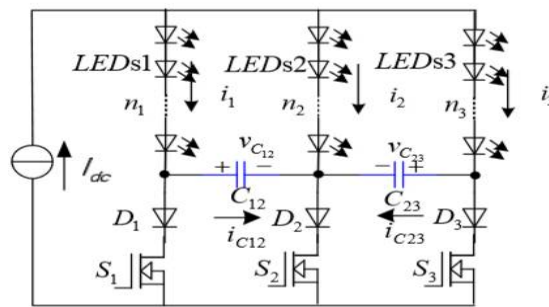


Fig (5)

Take three branches for example to analyse the linear type current sharing principle. Take the charging and discharging process for linearity as the circuit works in high frequency. I_{dc} is the input constant current, i_1, i_2, i_3 is the forward current through led strings. V_{C12}, V_{C23} are the voltages crossing C_{12} and C_{23} .

During first mode S_1 is on. The charging and discharging of C_{12} and C_{23} is given below.

$$\Delta V_{C12} = \frac{-(i_2+i_3)}{C_{12}} T_{ON}$$

$$\Delta V_{C23} = \frac{i_3}{C_{23}} T_{ON}$$

During mode 2 S_2 is on. The charging and discharging of C_{12} and C_{23} is as below.

$$\Delta V_{C12} = \frac{i_1}{C_{12}} T_{ON}$$

$$\Delta V_{C23} = \frac{i_3}{C_{23}} T_{ON}$$

During mode 3 S_3 is on. The charging and discharging of C_{12} and C_{23} is as below.

$$\Delta V_{C12} = \frac{i_1}{C_{12}} T_{ON}$$

$$\Delta V_{C23} = \frac{(i_1+i_2)}{C_{23}} T_{ON}$$

During the whole cycle, by the law of charge conservation $i_1=i_2=i_3$.

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III.SYSTEM DESIGN

The boost Converter is designed based on the following parameters:

Input voltage (V_{in}) = 23V

Output voltage (V_o) = 40 V

Switching frequency (f_s) = 1 kHz

Power (P_o) = 1.2W

Design equations:

The Duty ratio D is, $D = \frac{V_o - V_{in}}{V_o}$

Load resistance is, $R = \frac{V_o^2}{P_o}$

Inductor value is, $L = \frac{V_{in}(V_{out} - V_{in})}{\Delta I_L \times f_s \times V_{out}}$

Current output value is, $I_o = \frac{V_o}{R}$

Capacitor value is, $C = \frac{I_o \times D}{f_s \times \Delta V}$

The resonant parameters are designed as follows.

$V_{lamp} = 110V$

$$C_s = 15 \frac{V_{lamp}}{V_{in}} \frac{1}{R \omega_{switching}}$$

$$R = \frac{V_{lamp}^2}{P_o}$$

$$C_p = \frac{C_s}{15}$$

$$L_r = \frac{16}{C_s (\omega_{switching})^2}$$

IV. SIMULATION AND RESULTS

The Simulink model LED driver is shown in figure 6. The input is 23V_{ac} and is connected to electronic ballast. The output of electronic ballast is given to a variable switched capacitor and the rectified output is given to load as shown in figure.

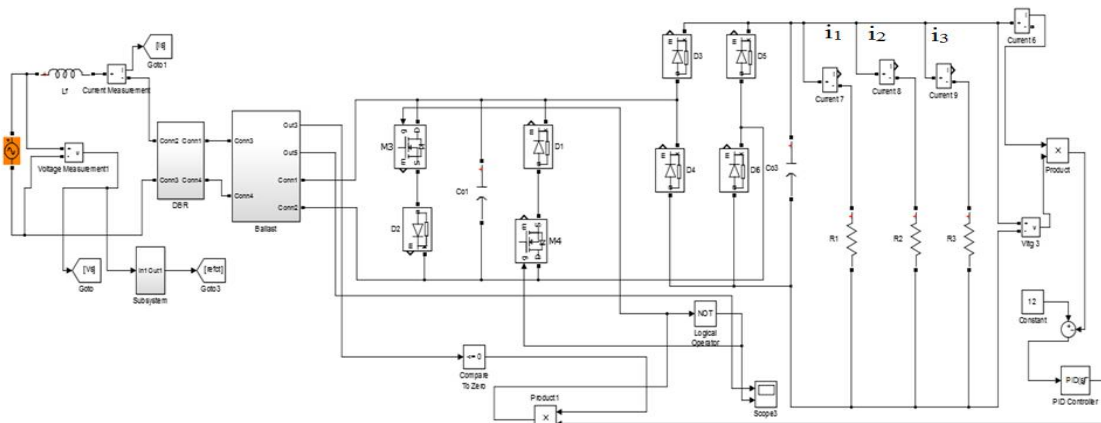


Fig (6)

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The subsystem in this Simulink model is Electronic ballast. The output of boost converter is designed for 40V. A dc voltage of 40V is obtained as boost converter output.

Electronic ballast consists of a diode bridge rectifier where ac is converted into dc. Then comes the power factor correction circuit and here it is a boost converter. The output of boost is then given to resonant inverter and the output obtained is ac. This ac output is given to variable switched capacitor. It is important to have soft switching operations of $S_1 - D_1$ and $S_2 - D_2$ for reliable operation and high power efficiency of the proposed LED driver. The current through the loads are not equally shared.

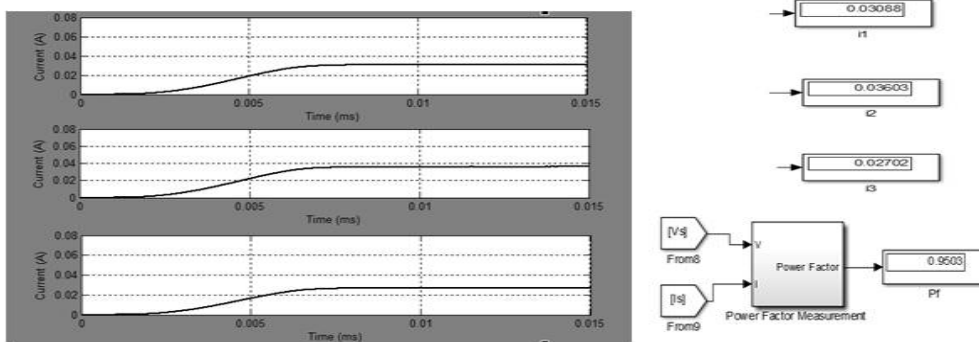


Fig (7)

The current through the loads are shown in figure7. The current is not equal and in order to equalize the current capacitor clamped current sharing circuit can be used.

The Simulink model LED driver with capacitor clamped current sharing circuit is shown in fig 8.

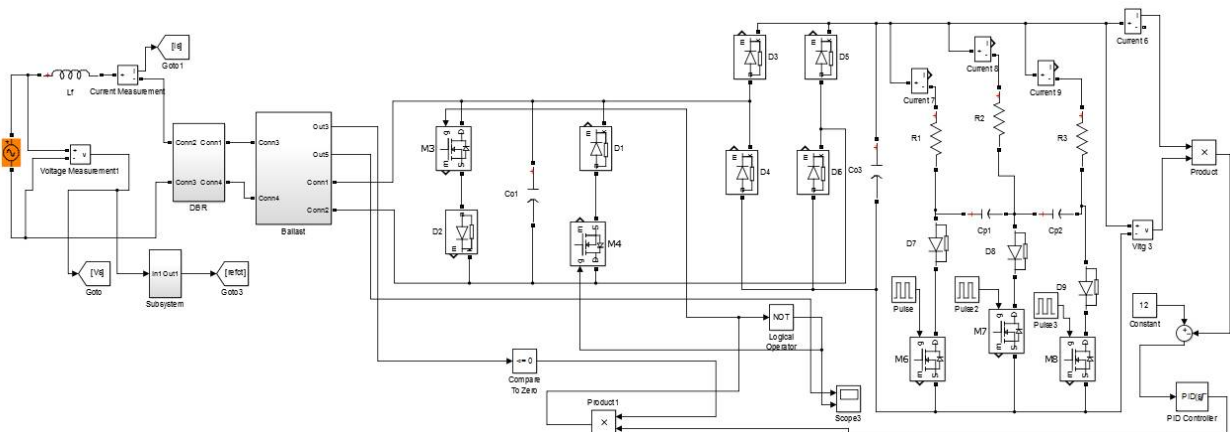


Fig (8)

The waveforms obtained from the simulation are discussed below. The output of boost converter is shown in Fig 9.

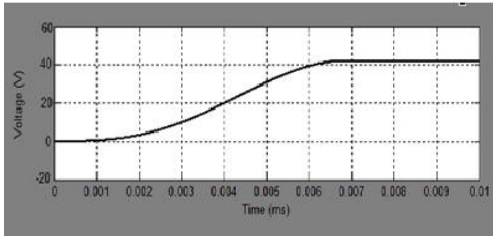


Fig (9)

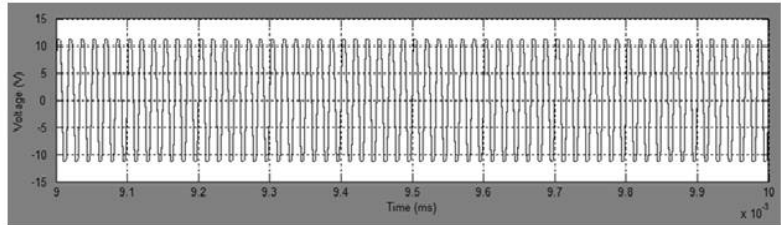


Fig (10)

The output of electronic ballast is 11V ac and is shown in Fig 16. The output of this electronic ballast is given to the input of variable switched capacitor. S_1 is on in the zero crossing point of positive half cycle of V_c . S_2 is on in the zero crossing point of negative half cycle of V_c . S_2 is on in the zero crossing point of negative half cycle of V_c .

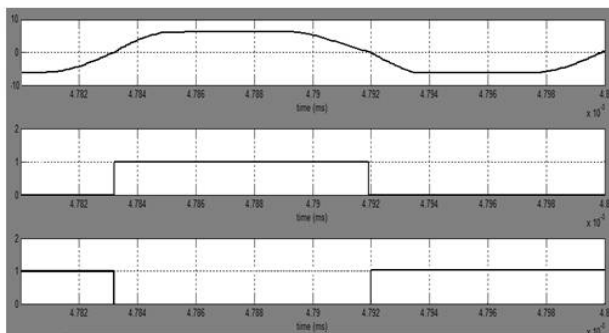


Fig (11)

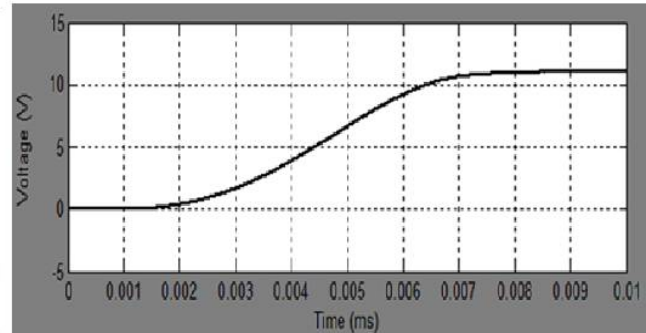


Fig (12)

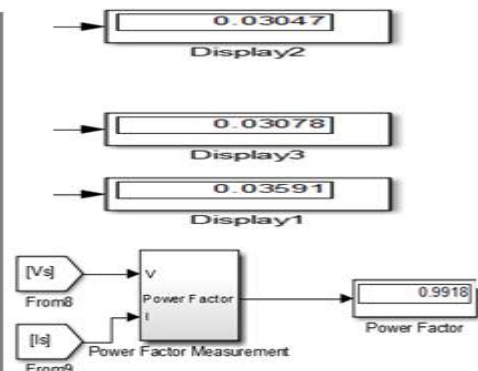
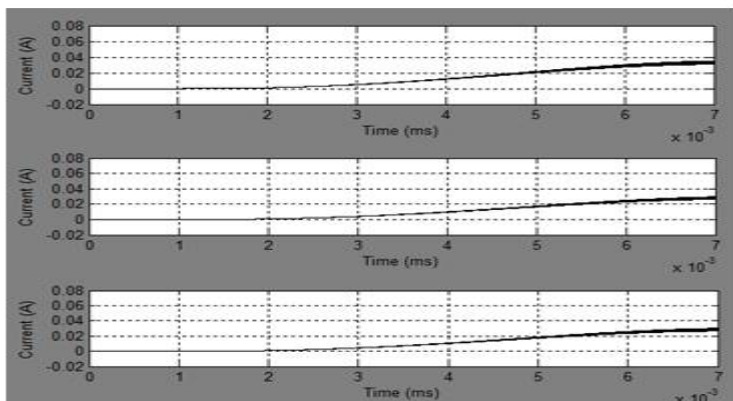


Figure shows the current through the three loads and is equally distributed as shown in fig 13. By using the capacitor clamped current sharing circuit the current gets equalized.

VI.HARDWARE IMPLEMENTATION

The picture of the experimental setup of the proposed LED driver for electronic ballast with capacitor clamped current sharing circuit is shown in Fig 14. Table 1 show the components used in hardware implementation.

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Table (1) Components Used

VOLTAGE REGULATOR	7812
DIODE	1N4740
MOSFET	IRFZ44N
INDUCTOR	1.3mH, 3Mh
CAPACITOR	2200 μ F, 100 μ F, 1 μ F, 1nF, 3Nf
MICROCONTROLLER	Atmega 328
IC	CD4071, ULN2003

The main power supply used is 23V. A decade counter CD 4071 is used to switch the higher loads (LED). It is a CMOS IC. It has a very small value of current and has a voltage of 5V. Instead of using three transistors for switching this is used in order to reduce the complexity of circuit.

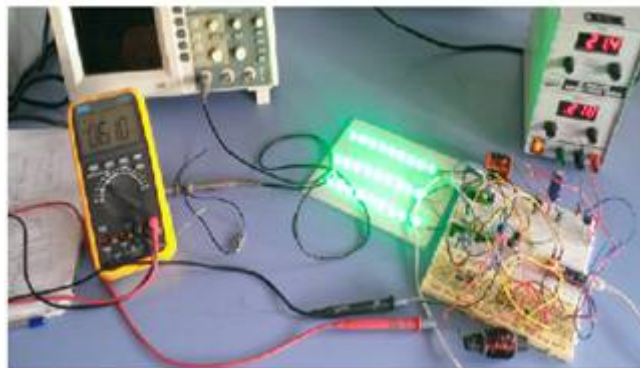


Fig (15)

The micro controller used is Atmega 382. The output waveforms of the experimental setup cannot be displayed on a DSO as it is in millivolt range, so the value is obtained using a mutlimeter.

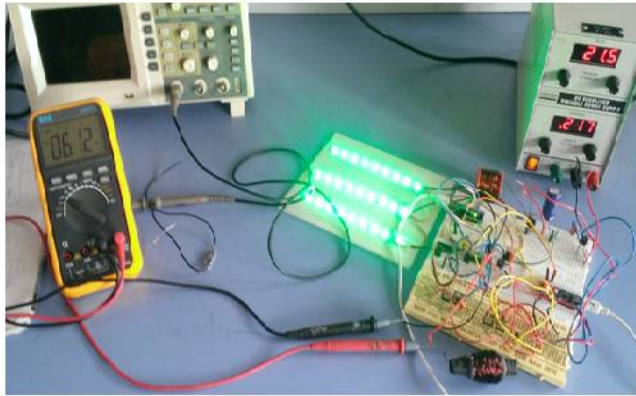


Fig (16)

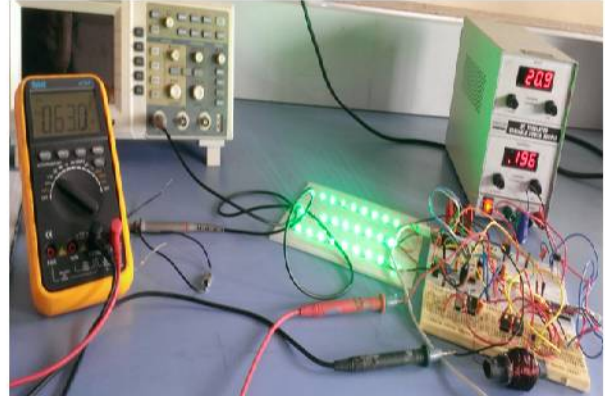


Fig (17)

The current is measured using a 1ohm resistor. Three 1ohm resistors are connected through the load and voltage across that is measured and current is obtained. Figure 15, 16 and 17 shows the results of the experimental set up. By using the capacitor clamped current sharing circuit the current through the strings are equally shared.

VI.CONCLUSION

A new design of LED driver for electronic ballast with capacitor clamped current sharing circuit is designed and analyzed. Using this technology the current imbalance problem caused by negative temperature coefficient of LED is overcome and the current through the loads are equally shared. Simulation of the circuit is carried out in MATLAB-SIMULINK for analyzing the performance of the LED driver for electronic ballast. From the analysis of the proposed topology and by comparing it with the previous topologies it is concluded that the power factor has been improved. The hardware of the same is implemented and the output of the hardware came close to that obtained in the simulation. Both simulation and hardware yielded satisfactory results. Power factor obtained is 0.9918.

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