IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 11, Issue 6 Ver. I (Nov. – Dec. 2016), PP 70-78
www.iosrjournals.org

A Novel PFC Converter for LED Driver Application

Mr. Rajesh A V[1], Mr. Jijo Balakrishnan[2], Mrs.Saritha M[3]
[1]*(Dept.of EEE,College of Engineering,Perumon / CUSAT, India)*
[2]*(Dept.of EEE,College of Engineering,Perumon / CUSAT, India)*
[3]*(Dept.of EEE,College of Engineering,Perumon / CUSAT, India)*

Abstract: *This paper proposes a switched capacitor based driver circuit for high power light emitting diodes with a front end rectifier. LEDs are low-voltage light sources, requiring a constant DC voltage or current to operate optimally. LEDs, therefore, require a device that can convert incoming AC power to the proper DC voltage, and regulate the current flowing through the LED during operation. Proposed topology has a front end converter. It is a ac-dc rectifier that works on bridgeless boost topology which shape the input current waveform. The front end converter is followed by a dc-dc converter which provides a constant dc voltage across the LEDs. A 12v ac input is given to the input of frontend converter which rectifies and boost the voltage to 24v dc and gives it to the dc-dc converter. The dc-dc converter convert the 24v dc to 13v dc and regulate this constant dc voltage across the LED.*
Keywords: *Power factor correction (PFC), Bridgless rectifier, Total harmonic distortion (THD), SC converter, LED, DC/DC Convert.*

I. Introduction

The Nowadays there have been a fast growing requirement for street lighting and all such equipments are directly connected to the line supply,this may results in harmonics or peaky currents that causes poor powerfactor.This is because, due to the non linear characteristics of the load the Current drawn will be non sinusoidal. This input current characteristic results in current and possibly voltage distortions that can create problems with other equipment connected to the power line and degrade the capability of the mains. These problems have led to the creation of design standards for the purpose of limiting the allowable harmonic distortion on the power line. Fortunately, solutions are available for meeting these standards.

These solutions are referred to as Power Factor Correction (PFC) techniques. Conventional PFC scheme has lower efficiency due to significant losses in the diode bridge.Most of the PFC rectifiers utilize a boost converter at their front end. However, a conventional PFC scheme has lower efficiency due to significant losses in the diode bridge,which causes a significant conduction loss, caused by the forward voltage drop across the bridge diode.This would degrade the converter's efficiency, especially at a low line input voltage.Bridgeless PFC circuit allows the current to flow through the minimum number of switching devices. Previous PFC converters have drawbacks such as high component count,components are not fully utilized over whole ac line cycle,complex control,dc output voltage is always higher than peak input voltage, lack of galvanic isolation and, due to floating ground, some topologies require additional diodes and/or capacitors to minimize EMI. Inorder to overcome these problems proposed topology has front end converter with two semiconductor devices in current conduction path during each ac line cycle.It has low component count, single control signal and non floating output.

Since there is a fast growing demand for electricity inefficient incandescent lights are replaced with LED lights. The front end converter is followed by a LED driver which is a switched capacitor based dc-dc converter.The driver works on 24 V dc. LEDs have high luminous efficacy compared with incandescent lights that makes them competitive. Therefore solid state lighting based on LEDs has become quite attractive. Switched capacitors have light weight, small size and high power density. It uses a small inductor to improve the switching behavior and it does not affect the power transfer to the relay.In conventional LED drivers the average converter is directly proportional to the difference between supply voltage and the LED forward voltage. The LED forward voltage may vary that affects the LED array. This problem is rectified in the proposed converter by adding a magnetic component; ie. An inductor. SC converters works for low power applications. The converter is implemented in open loop configurations. Proposed topology operates in discontinuous conduction mode(DCM).

II. Proposed Converter

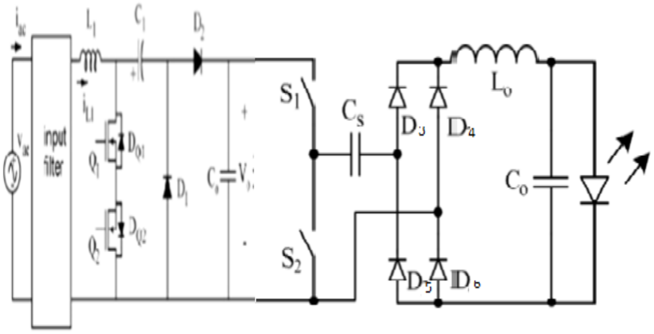

Fig 2.1. Proposed Converter

The proposed converter consist of a front end ac-dc converter and a dc-dc converter.The converter is designed for operating under discontinuous-conduction mode(DCM).As a result the switch current stress is similar to conventional discontinuous conduction mode PFC converters,while the switch voltage stress is higher.Moreover,the two power switches Q1 and Q2 can be driven by the same control signal,which significantly simplifies the control circuitry.But for each power switches isolated driver circuit is provided.The proposed converter works under 4 modes of operation.

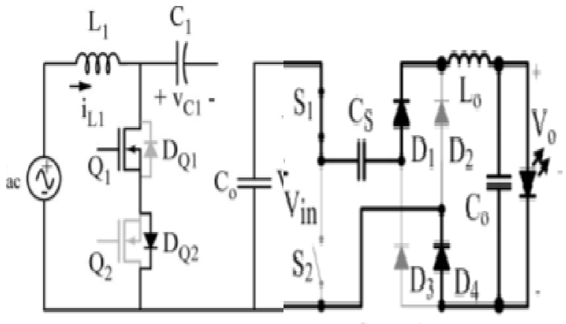

Fig 2.2(a)

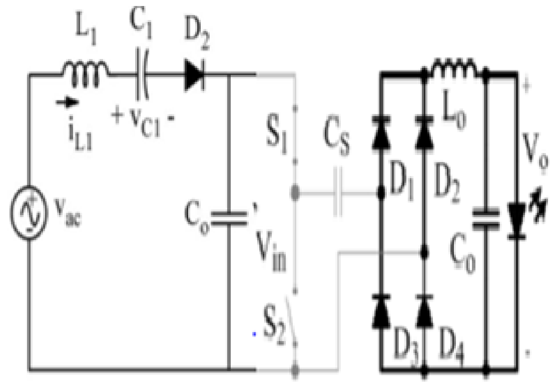

Fig 2.2(b)

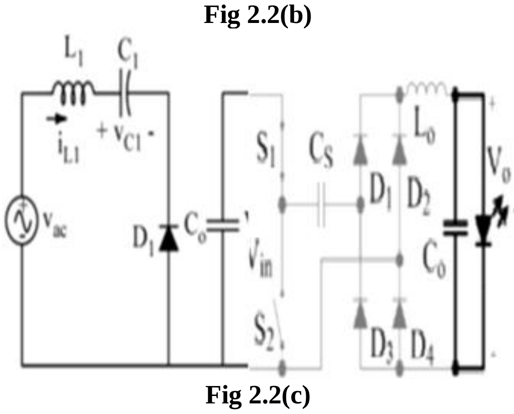

Fig 2.2(c)

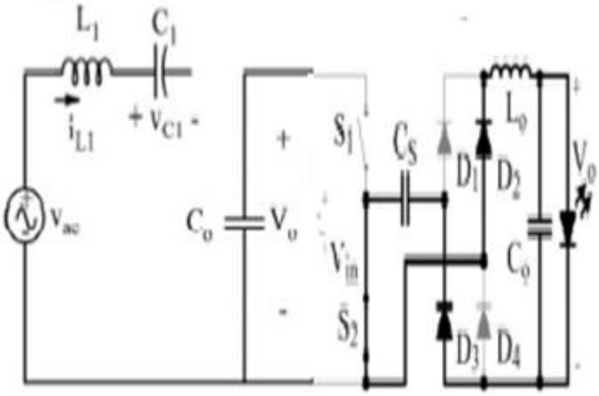

Fig 2.2(d)

Fig 2.2: Modes of operations (Stage 1-Stage 4)

Mode1: This stage starts when the switch Q1 is turned on. The body of Diode Q2 is forward biased by the inductor current iL1. Diode D1 is reverse biased by the voltage across C1, while D2 is reverse biased by the voltages Vo. In this stage, the current through inductor L1 increases linearly. At this instant, the voltage across Cs capacitor is null. Besides, switch S2 is turned off and switch S1 is turned on. The voltage across Cs increases until it reaches the input voltage (VIN). At instant t=t2, the current through capacitor Cs becomes zero. At t1, the peak current flows through capacitor Cs.

Mode2: During this stage, capacitor C1 is charged until it reaches a peak value and diode D2 is turned ON simultaneously providing a path for the inductor currents iL1. The remaining energy stored in Lo flows through the diodes and such current decreases linearly to zero at t=t3.Since the diodes are considered as ideal, all four devices remain turned on.

Mode3: During this stage diode D1 is forward biased to provide a path for the capacitor discharge until it reaches a voltage vac. Capacitor Co provides energy to the LED. At t=t3, half the energy provided by the input source is transferred to the load represented by the LED

Mode4: During this stage all switches in the front end converters are in their off stage.The inductor current reaches zero but the voltage across the capacitor Co remains constant.At this time the the switch M2 of the dc-dc converter turns on.The switches capacitor starts charges to the input voltage and diode D4 and D5 turns on.

III. Design Procedures

The front end rectifier is designed for Vac=13V, V0=24V, Pout=115W and fs=50kHz. The equations are derived from the base quantities such as Base voltage=Output voltage,Vo

Base impedence=Z0= $\sqrt{\frac{L_1}{C_1}}$ (1)

Base current= $\frac{V_0}{Z_0}$ (2)

Base frequency, Fr= $\frac{\omega_r}{2\pi} = \frac{1}{2\pi\sqrt{L_1 C_1}}$ (3)

The circuit components are designed by assuming the efficiency as 100%.

1. The voltage conversion ratio,

$$M = \frac{Vo}{V_m} = \frac{d_1}{\sqrt{2K}} = \sqrt{\frac{RL}{2R_e}} \quad (4)$$

Since, $R_e = \frac{2L_1}{d_1^2 T_s}$ (5)

The value of M is obtained by

$$M = \frac{Vo}{V_m} = \frac{24}{\sqrt{2} \times 13} = 1.305 \quad (6)$$

2. For ensuring the DCM operation,the normalised switching frequency must be less than one. So for that F is chosen as 0.8
3. The diamensionless conduction parameter ,

$$K=\frac{2L_1}{R_L T_s} \qquad (7)$$

$$k<\frac{1}{2}\times(\frac{f}{\pi})^2 == \text{Kcr} \qquad (8)$$

4. From these the value of critical inductance required to maintain DCM operation is

$$L1 \le \frac{R_L T_s}{4}\times(\frac{f}{\pi})^2 \qquad (9)$$

$$C_1= \frac{1}{L_1(2\pi fr)^2} = 65nF \qquad (10)$$

The switch duty cycle,

d_1=M √(2K)=0.4 (11)

5. Input power factor

$$PF=\frac{(P_{in(t)})_{TL}}{V_{ac,\,rms} I_{ac,\,RMS}}. \qquad (12)$$

6. The line current distortion is represented by the factor total harmonic distortion (THD).THD is the ratio of harmonic contents to the fundamental contents. It can be calculated by using the relation

$$THD=\frac{\sqrt{\sum_{n=2}^{\infty} I\wedge 2_{ac,\,rms(n)}}}{I_{ac,\,rms(1)}} \qquad (13)$$

The total harmonic distortion and power factor can be related as

$$THD=\sqrt{\left(\frac{\cos(\theta_1)}{PF}\right)^2-1} \qquad (14)$$

Table 3.1. Design parameters of front end rectifier

Parameters	Values
Tank Inductor,L1	100uH
Tank Capacitor,C1	65nF
Filter Inductor,LF	1mH
Filter capacitor,CF	1uF
Output Filter,C0	470uF

The dc-dc converter is regulated by an input source voltage of 24V.The switching function is provided by IRF540 MOSFET(M1&M2) It has easy paralleling, fast switching and simple drive requirements. The driver TLP 250 is used for driving the MOSFET, which also provides a switching frequency of 130kHz. To minimize the frequency variation with temperature the polyester capacitor C3 is used.
Three white LEDs(Luxeon III Emitter LXHL-PW09) are used as load.The intrinsic resistance (RLED=0.9Ω)and the LED forward voltage (VLED=3.15V) can be determined from the voltage versus current characteristics.

1. LED output voltage

V_o=n (V_{LED}+$R_{LED\ x}$ I_{AVG}) (15)

If n= and rated current is 0.9A ,the output voltage of LED array is

V_O=3× (3.15+0.6×0.9) =11.88 V (16)

2. Filter capacitor Co is calculated by considering 10% ripple current(□ILED%)

$$C_0=\frac{2}{3\times\Delta I_{LED\%}(2\pi f_S)(n\times R_{LED})}=3.03\mu F \qquad (17)$$

Here polypropylene capacitor CO is chosen with a commercial value of 4.7uF ,because of its low resistance and long useful time.

3. The output power,

Pout =IAVG ×Vo =0.9×11.88 = 10.69 W (18)

For an input voltage of 24 V ,a 270 Ω resistor is used to limit the current through the IC IR2153.At low power ,the power consumption is a function of overall losses.The resistor R2 and capacitorC3 are responsible for switching frequency.The output rectifier section consist of four Schottky diodes(MBR 1100) ,which is suitable for high frequency operation.

The SC Capacitance,

$$C_s = \frac{I_{AVG} \times V_0}{f_s \times \eta \times V_{in}^{\;2}} = \frac{0.9 \times 11.88}{130 \times 10^3 \times 0.95 \times 24^2} = 150.3nF \quad (19)$$

Here 150 nF is used for switched capacitor .The dead time of IC IR2153 is 1.2 us.

$$L_0 = \frac{\left(\frac{1}{2 \times 130 \times 10^6} - 1.2 \times 10^{-6}\right)^2}{1.25 \times 150 \times 10^{-9}\left[ar\cos\left(\frac{11.88}{11.88 - 24}\right)\right]^2} \cong 4.5\mu H \quad (20)$$

Core CNF are used for the physical implementation of inductor, which does not need a reel,which reduce final cost of magnetic component

Table 3. 2. Design consideration and parameters of dc-dc converter

Parameter	Value
Switching Frequency(f_s)	130kHz
Switched Capacitor(C_s)	150nF
Inductance(L_0)	4.5uH
Output Filter Capacitance(C_0)	4.7uF
Ripple Current through the LED(ΔI_{LED})	10%
Output Power(P_{OUT})	10.69W

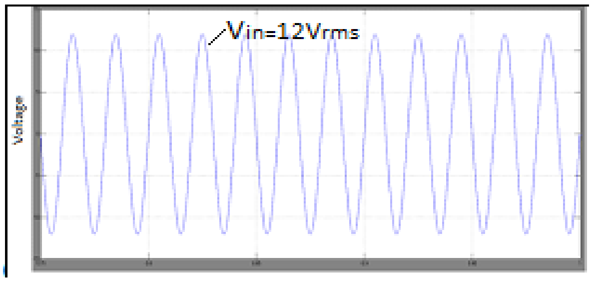

Fig 3.1 a

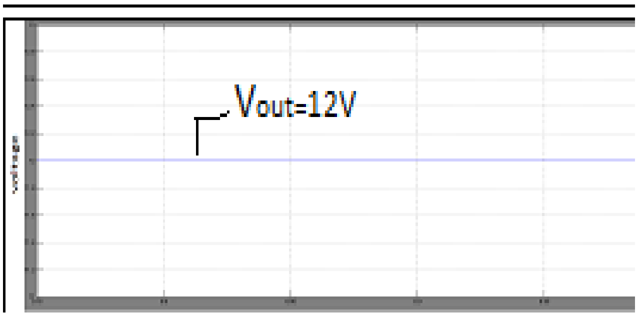

Fig 3.1 b

Fig 3.1 c

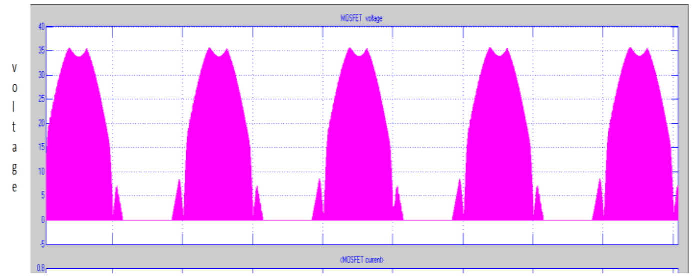

Fig 3.1 d

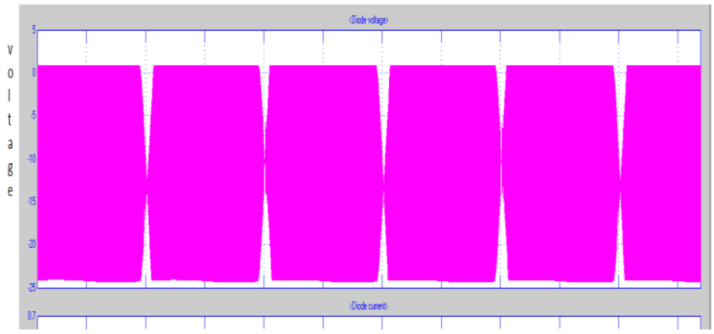

Fig 3.1e

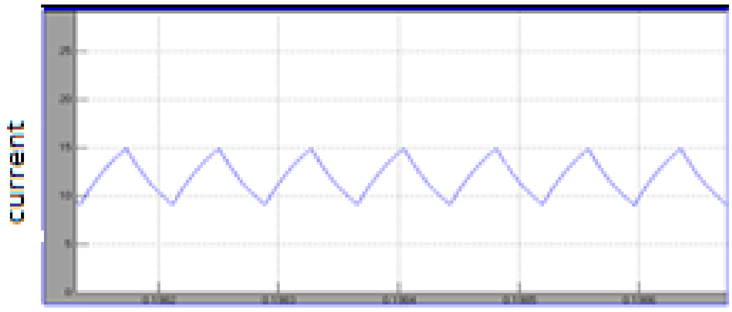

Fig 3.1 f

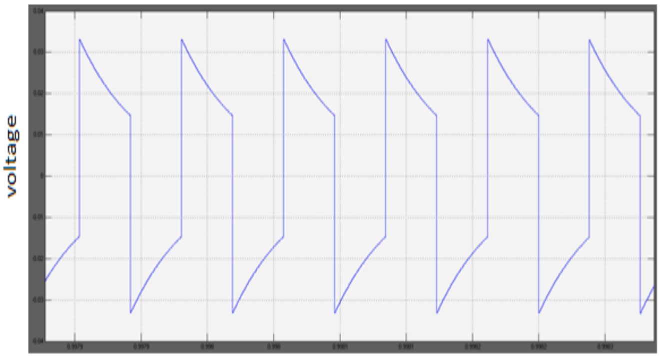

Fig 3.1g

Fig 3.1 Simulated wave forms of the converter

Fig shows the simulated wave forms of the proposed converter.The input voltage of is shown by the fig (a) and the output voltage of the converter is shown in the fig (b).The voltage across the mosfet switches Q1 and Q2 are shown in the fig. (C) and (d).From fig. (c) and(d) it is clear that only one switch will turn on at a time.That is switches are operates in a complimentary manner.Fig (e) shows the voltage across the diode.It is clear that the diodes are turn OFF under zero current condition.The current through and the voltage across the switched capacitor is given by the fig (f) and (g).

The experimental waveforms of the converter at full load are depicted in fig. The input voltage, and the output voltage waveforms are shown in Fig(a) and (b). 4 .The input ac is given to the front end rectifier through a transformer.A constant dc voltage is obtained at the output of the dc-dc converter.Fig.(c) shoes the voltage across the MOSFET switch.The voltage waveform across the diode is given by the fig (d).It is evident that both diodes D1 and D2 are turned OFF under zero current conditions. The high frequency ringing in the Q1 current at turn-off and in the diode D2 current at turn-on appears as a consequence of resonances between converter inductances and device parasitic capacitances.The switch Q1 turns ON under zero current condition. The voltage across diode D1of pseudo boost rectifier is shown in fig (d). It is clear that both diodes D1 and D2 are turned OFF under zero current conditions.The voltage across mosfet M1 is given by the Fig.(e).The current peaks occur due to discharge of intrinsic capacitances of MOSFETs. When the switch is turned on under zero current, the drain-to-source voltage is not null and the energy stored in the intrinsic capacitance is dissipated in the semiconductor increasing switching losses. The losses due the MOSFET capacitances can be determined.The current and voltage through the switched capacitor is given by the Fig (f) and (g).The charging and discharging of this switched capacitor helps to drive led modules.

It can be seen that varying the input voltage affects the current through the LED. If the input voltage is reduced e.g. due to the discharging of a battery, the LED brightness will be reduced. Therefore the input voltage of the converter must remain constant for open loop operation. Otherwise, by using a microcontroller to generate the drive signals of the switches, it is possible to adjust the switching frequency to keep the current through the LED array constant when the input voltage varies.The charge and the discharge of the SC is evidenced, as presented in the theoretical analysis.

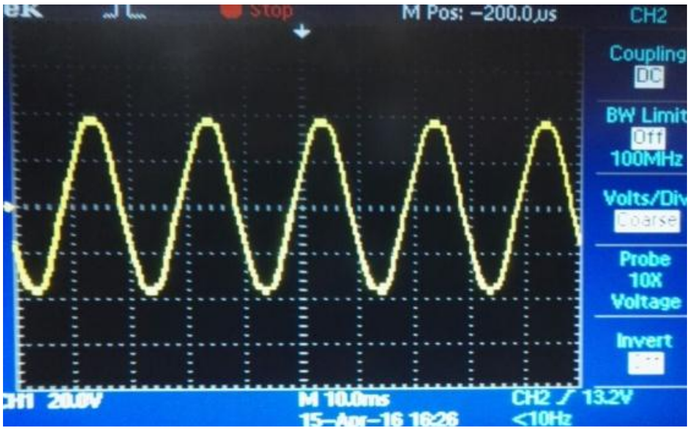

Fig 3.2 a

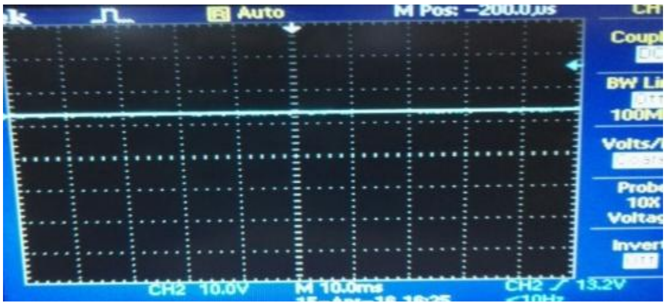

Fig 3.2 b

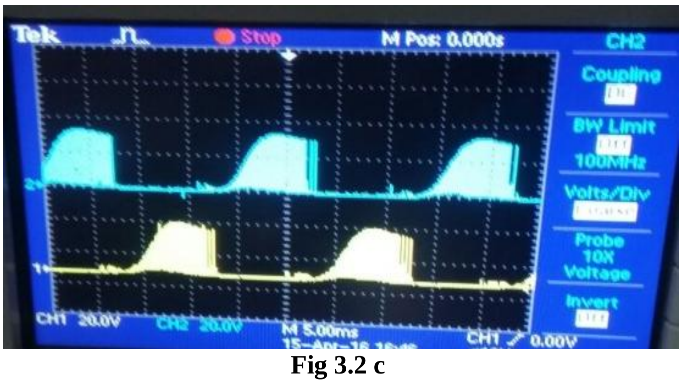

Fig 3.2 c

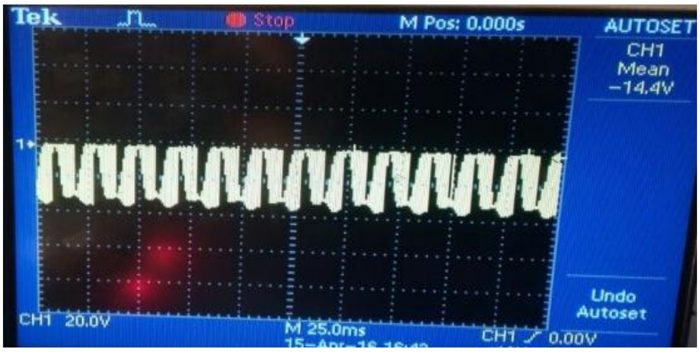

Fig 3.2 d

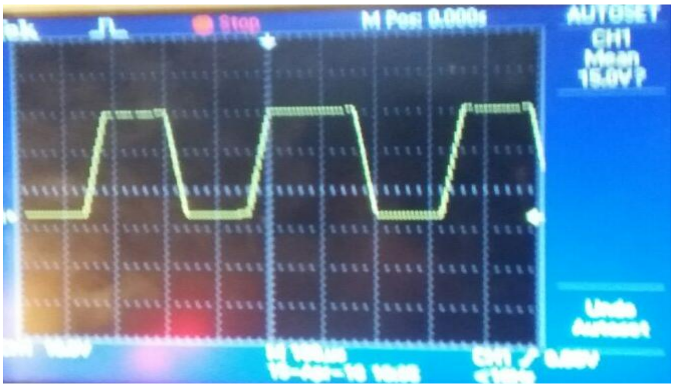

Fig 3.2 e

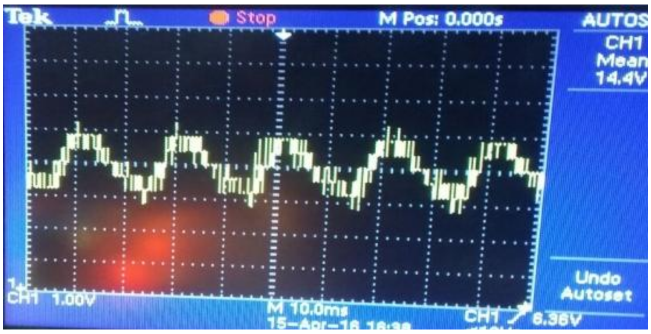

Fig 3.2 f

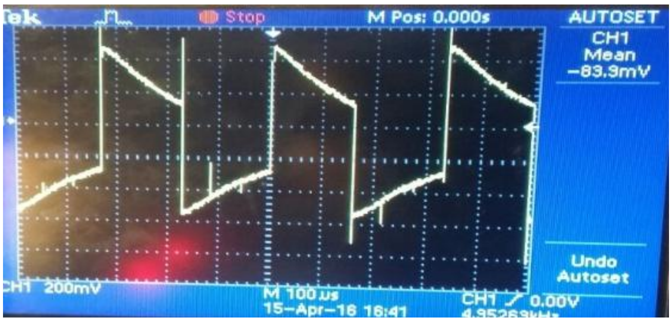

Fig 3.2 g

Fig 3.2 Experimental wave forms

IV. Conclusion

The non linearty of load leads to harmonics in the input current, which causes a distortion power factor.Several methods are available for power factor correction such as passive and active methods. Among them active power factor correction methods such as boost,buck,buck boost topologies are widely used. Boost has more advantages because of inductor is connected in series with line input terminal so that line input current ripple is reduced and also which offers a continuous input current with average current mode. From boost topology bridgeless topology improve the performance of the system by reducing the conduction loss because of less component count of semiconductor devices, higher power density, improved thermal management etc. Here load is used as LED, for optimal operation of LED constant DC voltage or current is required which is provided by a converter. Compared to conventional constant current dc drivers switched capacitor converter with magnetic component is used here. Which solve the problems of diode forward voltage drop, current sharing problem, power losses etc. Which also has additional advantages such as simpler implantation, reduced cost, and reduced dimensions.

Power factor great role in residential, commercial industrial application because of the presence of non linearity of load .So that bridgeless power factor correction boost topology in DCM mode can be used in the application such as street lighting, Induction motor, Synchronous motor,BLDC Motor, switched mode power supply etc.

References

[1]. Abbas A. Fardoun, and Mustafa A. Al-Saffar, "A Bridgeless Resonant Pseudo boost PFC Rectifier," IEEE Trans. Power Electron., vol. 29, no. 11, November 2014.

[2]. L. Huber, Y. Jang, and M. Jovanovic, "Performance evaluation of bridgeless PFC boost rectifiers," IEEE Trans. Power Electron., vol. 23, no. 3, pp. 1381- 1390, May 2008.

[3]. M. Gopinath and D. Yogeetha " Efficiency Analysis of Bridgeless PFC Boost Converter with the Conventional Method," International Journal of Electronic Engineering Research, Volume 1, Number 3 (2009).

[4]. J. Zhamg, L. Xu, X. Wu, and Z. Qian, "A precise passive current balancing method for multioutput LED srivers", IEEE Transactions on Power Electronics, vol. 26, no. 8, pp. 2149–2159,Aug.2011

[5]. S.M.Baddela and D.S.Zinger, "Parallel connected LEDs operated at high to improve current sharing", in Proc. IEEE Industry Applications – IAS Annual Meeting, vol. 3, 2004, pp.1677–1681.,

[6]. J. Zhang J. Wang, and X. Wu, "A capacitor-isolated LED driver with inherent current balance capability", IEEE Transactions on Industrial Electronics, vol. 59, no. 4, pp. 1708–1716, Apr.2012.

[7]. Q. Hu and R. Zane, "LED driver circuit with series-input-connected converter cells operating in continuous conductionmode",IEEE Transactions on Power Electronics, vol. 25, no. 3, pp.574–582, Mar. 2010.

[8]. Pedro H. A. Miranda , Edilson M. Sá Jr, Fernando L. M. Antunes , Esio E. dos S. F, " A LED Driver with Switched Capacitor"IEEE Transactions on Industry Applications,vol.28,no.4,october 2014