# Design a Single Stage AC to DC Converter for LED Driver With Power Factor Improvement

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*Abstract— This paper shows the design of a single switch LED driver circuit which is based on the operation of boost converter and flyback converter with power factor correction. In the proposed driver circuit, the boost converter is made to operate in DCM mode for achieving a high power factor and the flyback converter is used for isolating the input-output in order to provide safety. In addition to this, a snubber circuit is also designed for clamping the peak voltage of the main switch into low voltage and also to recycle the leakage inductor energy. A capacitor of low-voltage rating is made to function as the DC bus capacitor due to reason that some amount of the input power is conducted directly towards the output side; the amount of power remaining is then stored in the DC bus capacitor. In this way, the proposed LED driver circuit provides a power factor of greater value, i.e., above 0.95 PF and also a high value of power conversion efficiency, i.e., above 90%.*

*Keywords: AC to DC Converter, Power Factor correction (PFC), Light Emitting Diode (LED), Flyback Converter, Snubber Circuit, DC Bus Capacitor.*

## I. INTRODUCTION

The effect due to the presence of greenhouse gases and the petroleum crisis across the world has made the humans to emphasis more and more on efficient energy utilization. One the most common and convenient energy resources known to mankind is electricity. The electrical energy is easily accessible to the users through solar cells, wall plugs, batteries, etc. Electrical applications in today's worlds are basically omnipresent, for example lightning and motor applications. The total power consumption of these applications account for over more than 16% of the overall electrical energy consumption, which was to equivalent to approximately 587 billion kWh in the year 2001 [1]. Recently, the awareness towards the sustainability problems of the world has forced the governments and committees across the globe to begin the search for ways of promoting sustainability.

By increasing the efficiency of the lightning applications, a sufficient amount of electrical energy could be saved. The efficiency of an electrical appliance not only depends on the lightning sources (materials) but also takes into consideration the driving circuits of the system. In comparision to other lightning sources such as high intensity discharge lamps, fluorescent lamps and cold cathode fluorescent lamps, the LED has tremendous advantages of being devices which are mercury free, ultra long lifetime(above 55000h) and low voltage driving [2]-[4]. It has also been reported that the LED can also be applied to general lightning solutions [5]-[10], while successfully replacing halogen lamps and incandescent lamps.

Generally, the design of the driving circuit of LED affects its energy efficiency as significant to the lightning sources and is used to increase its efficiency through proper driving circuits. In order to drive LEDs a DC voltage is required, so conversion of AC voltage to DC voltage is required. Traditional AC to DC switching converters were basically composed of a bulk capacitor, a bridge diode rectifier and a DC to DC switching converter; this design had various drawbacks such as poor performance in power factor(PF) and harmonic distortion [6]. Initial LED drivers had two control circuits and two switches which are present in each stage, making it less efficient and more expensive. In order to overcome the problems of the initial driving circuits of complying with the regulations on harmonics present in the current and increasing the power factor, an additional PFC stage is cascaded in front of the initial converter. Boost PFC circuits are being used most commonly due to the fact that they can provide power factor of high value by using just a simple control circuitry and simple structure. In order to increase the efficiency and reducing the cost, single stage converter circuits are being developed over the past few years [11]-[26]. Despite of the various advantages, the efficiency of these single staged converters are not high enough (70%). However, when applying isolated transformers, the efficiency of the system is highly encumbered with the leakage inductance.

In an effort of solving these drawbacks, a single-stage AC-DC LED driver which is designed on the basis of a boost-flyback PFC converter with a lossless snubber as shown in figure 1 has been proposed in this paper. As the

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proposed LED driving circuit is based on the boost-flyback structure, a power factor of higher value is obtained based on the boost PFC, which continuously operates in the discontinuous conduction mode. As the energy required to fulfill the load is comparatively low enough because of the light loads, we prefer DCM for light loads.

Due to the presence of snubber circuit which has no losses, the leakage energy of the inductor present is being recycled into the DC-DC flyback circuit and the peak voltage spike in the main switch has been clamped to a low voltage value.
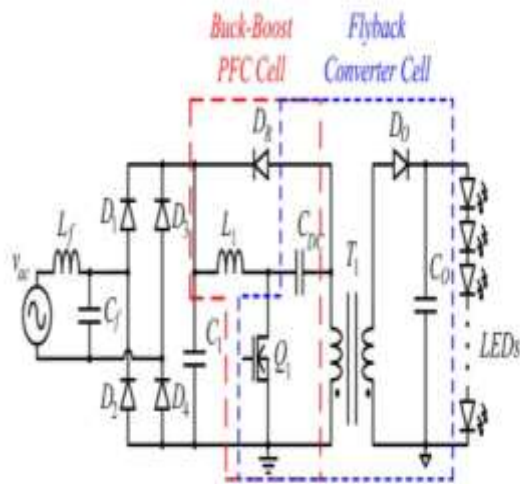


**Fig.1. Basic Circuit Diagram**

The DC bus capacitor has been divided into two capacitors, the first one being the snubber capacitor and the other one being DC bus capacitor.. Therefore, the energy conversion efficiency has been removed in addition to a reduction in voltage of DC bus capacitor. The LED driver circuit proposed in this paper provides a high power factor in order to achieve a high power conversion efficiency.

## II. PROPOSED SYSTEM

In the driver circuit proposed, the system consists of Lf and Cf as shown in figure 2. The boost PFC converter comprises of the main switch S1, the boost conductor Lb and the reverse blocking diode Db. The reverse blocking diode restricts the flow of reverse current through the boost inductor for Direct Conduction Mode operation. The flyback converter present in the system consists of the DC bus capacitor Cdc, the coupled inductor T1, the shared switch S1, the output capacitor C0 and the output diode D0. The lossless snubber circuit is comprised of C1,L1 and D1.



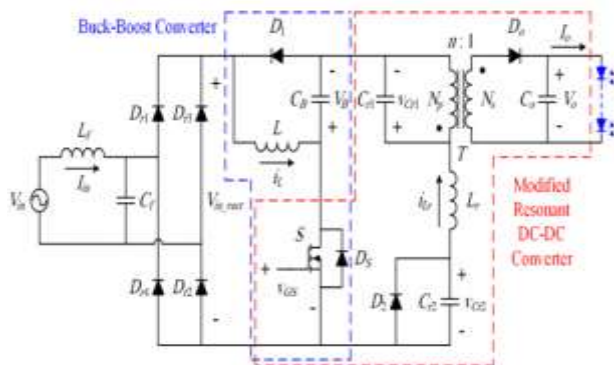**Fig.2. Proposed Driving Circuit**

The capacitor CS1 is used as the parasitic output capacitance of S1. The coupled inductor T1 contains a magnetizing inductor Lm and a leakage inductor Lk having a turn ratio of n:1(n=Np/Ns).. In accordance to the volt-second balance law, as the average voltage across the inductor at the steady state should be equal to zero, the voltage present across the C1 and Cdc sholud be automatically equal to Vdc. The capacitances of C1, Cdc and C0 have a large value such that their voltages are considered constant.

Whenever a power failure occurs across the system, the power is automatically delivered to the load by the help of a battery. The PNP transistor starts to act as a switch. When the mains power is ON, the positive part of the supply is kept at the base of the transistor, keeping the transistor in OFF condition.

## III. MODES OF OPERATION

Before mode 1, all the seminconductor devices are assumed to be off. The resonant capacitors $C_{r1}$ and $C_{r2}$ have voltages equal to $-V_1$ and $V_2$ respectively.
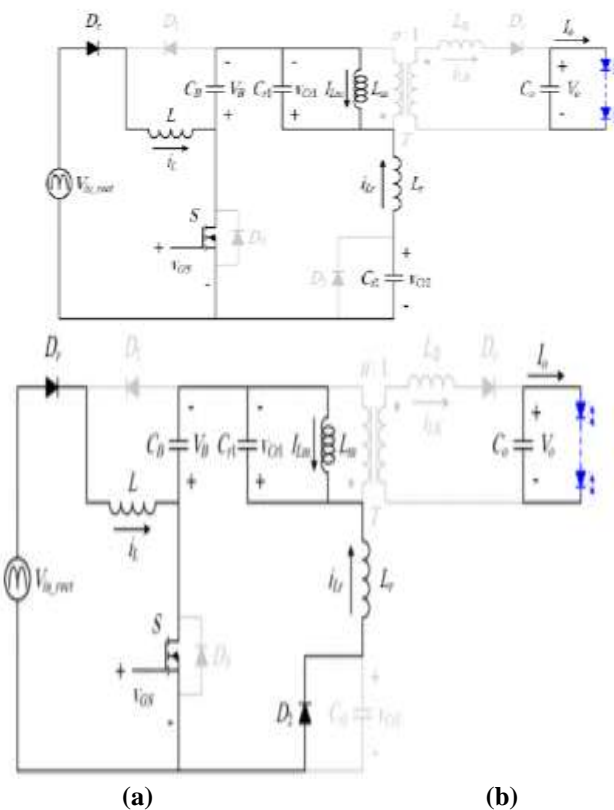


|        (a)         |         (b)          |

**Fig.3. (a) Mode 1  (b) Mode 2**

In mode 1, fig 3 shows the switch S is turned on. The inductor L carries a voltage $V_{in\_rect}$, due to this $i_L$ increases from zero linearly. There is an occurrence of a resonance between $L_r$ ,$L_m$ ,$C_{r1}$ and $C_{r2}$. This resonance occurrence maakes $V_{Cr2}$ reduce to a value of zero. There is a smooth increase in the currents across the inductors which ensures the ZCS turn on condition of the switch S. If $L_m$ is considered to be a large value, the current across it will become much smaller than the resonant current $i_{Lr}$, this small value of

inductor current can be neglected. Hence, the resonant capacitors $C_{r1}$ and $C_{r2}$ are connected in a series connection. The effect of $L_m$ on the resonant currents and the voltages in the other operating modes are also ignored. In mode 1, $i_{Lr}$ and $V_{Cr2}$ can be written as

$$I_{Lr}(t)=V_1+V_2+V_s/0.707Z_{r1}*\sin(1.414W_{r1}(t-t_o))$$
(1)

$$V_{Cr2}(t)=V_2-V_1+V_2+V_s/2*[1-\cos(1.414W_{r1}(t-t_o))]$$
(2

If $V_2$ is considered to be equal to $V_1+V_B$, then according to (1) and (2) $i_{Lr}$ will reach to its peak at the same time when the voltage across $C_{r2}$ becomes zero

$$i_{Lr}(t)=1.414V_2/Z_{r1}*\sin(1.414W_{r1}(t-t_o))$$
(3)

$$v_{Cr1}(t)=V_2[1-\cos(1.414W_{r1}(t-t_o))]-V_1$$
(4)

$$v_{Cr2}(t)=V_2\cos(1.414W_{r1}(t-t_o))$$
(5)

Mode 1 ends when the voltage $V_{Cr2}$ reaches a value of zero. In mode 2, the diode $D_2$ is turned on under a zero voltage switching condition. Due to this $L_r$ and $C_{r1}$ continues to resonate and the value of $V_{Cr1}$ increases. When $V_{Cr1}$ obtains a value of $nV_o$, the output diode voltage reaches a value of zero and mode 2 ends

$$i_{Lr}(t)=1.414V_2/Z_{r1}*\cos(W_{r1}(t-t_1))$$
(6)

$$v_{Cr1}(t)=V_B+1.414V_2\sin(w_{r1}(t-t_1))$$
(7)

In mode 3, the output diode starts to conduct under the ZVZCS condition and the inductor $L_{lk}$ starts to resonance.
$$I_{Lr}(t)=(1-L_{eq}/L_r)i_{Lr}(t_2)-(nV_o-V_s)L_{eq}/W_{r3}L^2_r*\sin(W_{r3}(t-t_2)) + L_{eq}/$$

$$L_r * i_{Lr}(t_2)\cos(W_{r3}(t-t_2))+nV_o-V_s/L_r+n^2L_s(t-t_2)$$
(7)

$$v_{Cr1}(t)=V_B+Z_{r1}i_{Lr}(t_2)\sin(W_{r1}(t-t_2))+(nV_o-V_B)\cos(W_{r1}(t-t_2))$$
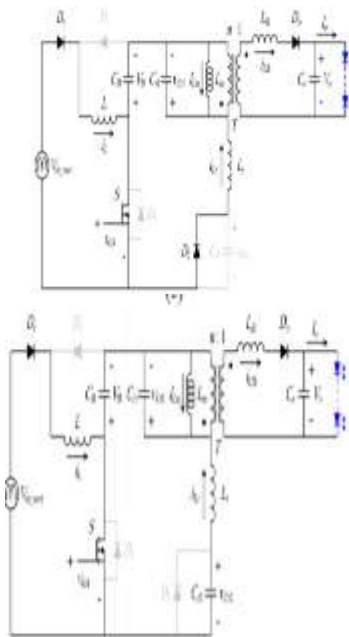(8)



(a)                              (b)
**Fig.4. (a) Mode 3  (b) Mode 4**

Mode 3 ends when the value of resonant current $i_{Lr}$ attains zero. In mode 4, the direction of the current $i_{Lr}$ is inversed and the diode $D_2$ is turned off under the ZVZCS condition. The capacitor $C_{r2}$ continues to resonate.

In this mode $i_{Lr}$ has two frequency components.
$$i_{Lr}(t)=-v_{Cr1}(t_3)-V_B/1.414Z_{r1}*\sin(1.414W_{r1}(t-t_3))$$
(9)

$$v_{Cr1}(t)=V_B+v_{Cr1}(t_3)-V_B/2*[1+\cos(1.414W_{r1}(t-t_3))]$$
(10)

$$v_{Cr2}(t)=v_{Cr1}(t_3)-V_B/2*[1-\cos(1.414W_{r1}(t-t_3))]$$
(11)

$$i_{Llk}(t)=i_{Llk}(t_3)\cos(W_{r2}/1.414*(t-t_3))$$
(12)

There is a reduction in the current through the switch due to the negative current of $i_{Lr}$. Mode 4 ends when the value of $i_{Lr}$ is equal to the value of $i_L$, due to this the switch current attains a value of zero.
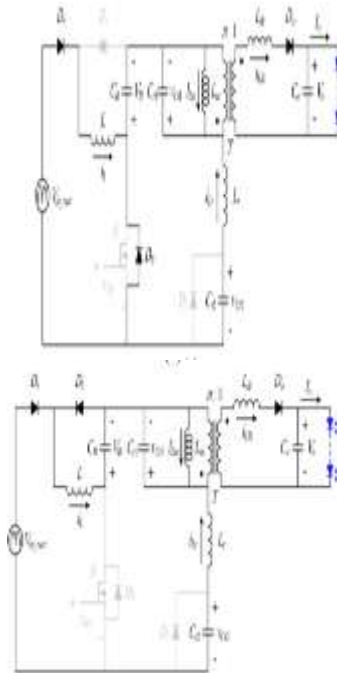


(a)                              (b)
**Fig.5. (a) Mode 5  (b) Mode 6**

In mode 5, the body diode of the switch $D_s$ is turned on,due to the value of current $i_{Lr}$ exceeding the value of $i_L$. The $L_r$,$C_{r1}$,$C_{r2}$ and $L_{lk}$ continues to resonate until the value of current $D_s$ reaches to zero. The switch S is turned off ny the ZVZCS condition.

he ZCS turn on condition of $D_1$ is provided due to the reduction of $i_{Lr}$ at a faster rate as compared to $i_L$. at the end of mode 6, the voltage $V_{Cr2}$ is increased to $V_2$ and the current $i_{Lr}$ approches zero.
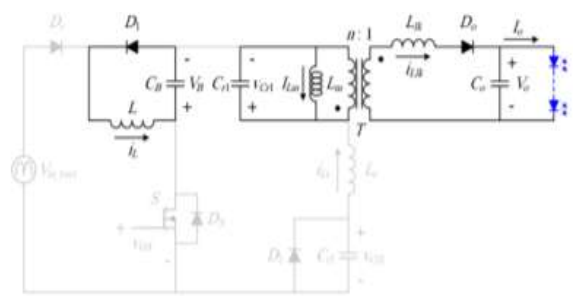
(a)                      (b)
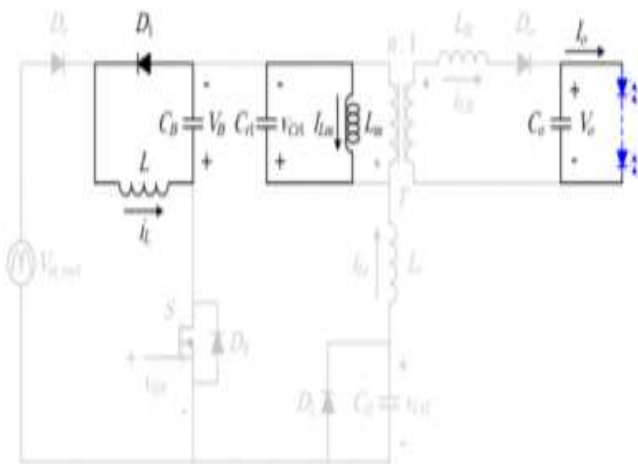
**Fig.6. (a) Mode 7  (b) Mode 8**

In mode 7, due to the resonance of the $C_{r1}$ and $L_{lk}$, the voltage $V_{Cr1}$ decreases. The resonance of the $C_{r1}$ and $L_{lk}$ continues till the output diode is turned off under ZCS condition and the current $i_{Llk}$ reaches zero.

$$i_{Llk}(t) = -n[nV_o - v_{Cr1}(t_6)]/Z_{r2} * \sin(W_{r2}(t-t_6)) + i_{Llk}(t_6)\cos(W_{r2}(t-t_6))$$

(13)

$$v_{Cr1} = nV_o - Z_{r2}i_{Llk}(t_6)/n * \sin(W_{r2}(t-t_6)) - [nV_o \ v_{Cr1}(t_6)]\cos(W_{r2}(t-t_6))$$
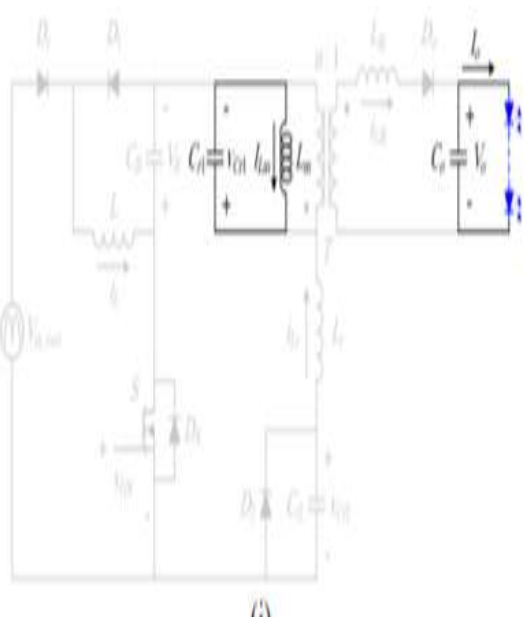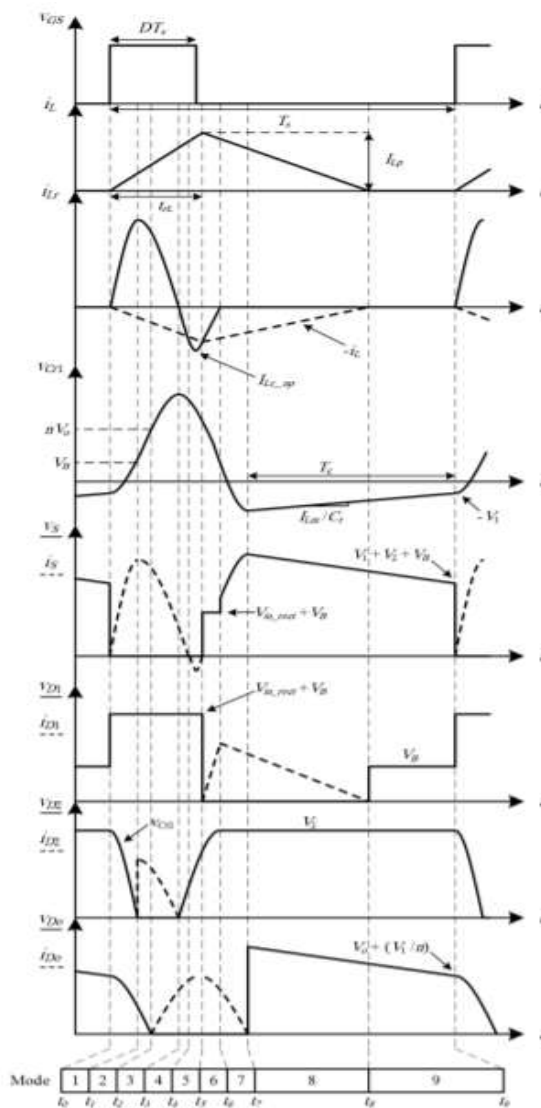
(14)



Fig.7. Mode 9



**Fig.8.  Modes of  operation**

In mode 8, the current $i_L$ starts to reduce in a linear way until the value reaches zero. Apart from this, $V_{Cr1}$ starts to rise in a linear way, due to the cahrging of $C_{r1}$ by the current of transformer magnetizing inductance. When $D_1$ is turned off under ZCS condition and the current $i_L$ reaches zero, then the mode 8 ends.

In mode 9, the voltage $V_{cr1}$ continues to rise until it reaches a value $-V_1$ and all the semiconductor devices are turned off in mode 9.

## IV. SIMULATION

The driver circuit proposed in this paper has been simulated by the help of  Matlab software. The input AC voltage at the source is given to be 100V with a frequency of 50Hz. An inductor with an inductance value of $1*10^{-3}$ H and a capacitor with capacitance of $1200*10^{-6}$ F have been connected across the input voltage source. A diode bridge rectifier is then connected to convert the AC input to DC.

The bridge rectifier consists of four diodes each having a resistance of $1*10^{-3}$ ohms with a forward voltage of 0.8V. The snubber resistance present in each of the diode is 500

ohms and the snubber capacitance value is $250*10^{-9}$ F. A boost converter is connected to the bridge rectifier with an inductor of inductance $1*10^{-6}$ H and a capacitor of capacitance $1200*10^{-6}$ F. The diode present in the boost converter has a resistance of $1*10^{-3}$ ohms with a forward voltage of 0.8V. This diode present in the boost converter also has a snubber resistance of 500 ohms and a snubber capacitance of $250*10^{-9}$ F. The pulse generator in the boost converter generates an amplitude of 1 metre with a time period of $2*10^{-5}$ seconds. The pulse width by the pulse generator is given to be 45 Hz with a zero phase delay. The MOSFET present in the boost converter has a FET resistance of 0.1 ohms and the internal diode resistance of 0.01 ohms. The snubber resistance value of the MOSFET is given to be $1*10^{-5}$ ohms.

The boost converter is then connected to a snubber circuit through an inductor of inductance $3*10^{-6}$ H and a capacitor of capacitance $12*10^{-6}$ F. The diode present in the snubber circuit has a resistance of $1*10^{-3}$ ohms with a forward voltage of 0.8 V. The diode has a snubber resistance of 500 ohms and a snubber capacitance of $250*10^{-9}$ F. The snubber circuit also has a capacitor with a capacitance of $1*10^{-6}$ F. The snubber circuit is then connected to the flyback circuit through a linear transformer.

The linear transformer has nominal power of 100 VA and frequency of 10000 Hz. The winding 1 has a voltage of 100 V and the winding 2 has a voltage of 400 V. The magnetizing resistance of the linear transformer is given to be $1.0805*10^{6}$ ohm and the magnetizing inductance is given to be 2866 H. The flyback circuit consists of a resistor of resistance 1000 ohms and a capacitor of capacitance $1200*10^{-6}$ F. The diode in the flyback circuit has a resistance of $1*10^{-3}$ ohms with a forward voltage of 0.8 V. The snubber resistance of the diode is 500 ohms while the snubber capacitance is $250*10^{-9}$ F. The LED driver circuit proposed in the paper has been simulated in the Matlab software using these values and the output was obtained as shown in figure 9.

## V. ANALYSIS OF THE CIRCUIT & RESULTS

In the section concerned, LED driver circuit has been analyzed . The sinusoidal waveform line voltage has an amplitude $V_m$ and angular frequency $w_l$.

Eliminating the high frequency harmonics of the PFC cell's input current with the help of input current, the line current $I_{in}$ mentioned above is the average of input current pulses over each switching period is given by,

$$I_{in}(t)=1/T_S*1/2*I_{Lp}(t)t_{Rl} \qquad (15)$$

$I_{Lp}$ =peak current of inductor L in every switching cycle
$t_{rL}$ =rise time of I that is time duration of modes 1 to 5.

$t_{Rl}$ is assumed equal to $DT_S$ where D is called the switch duty cycle. Hence using eqn.(15)

$$I_{in}(t)=D^2T_SV_m/2L*\sin(w_lt) \qquad . \qquad (16)$$



**Fig.9. Output Voltage wave form simulation**

By the help of eqn.(16),it can be considered that the line current is in phase with line voltage, provided switch duty cycle D is constant.

Hence, input power $P_{in}$ can be calculated with the help of using line current equation.

The inductance value L is to be designed such that the input power required can be provided with the desired duty cycle and switching frequency.

Here the output power $P_O$ is equal to average input power. Hence value of L is given by,

$$L=D^2V^2_m/4P_Of_s \qquad (17)$$

During mode 5 the circuit is turned off. Hence the on time value of switch is expressed with the help of $T_{r1}$ of $L_r$ and $C_r$, where $T_{r1}$ is resonant period. Hence

$$DT_s=1/4*0.707*T_{r1}+1/4*T_{r1}+1/4T_{r1}*0.707 \qquad (18)$$

According to eqn.(18), $T_{r1}$ can be obtained with the help of $DT_s$. Now value of $I_{Lp}$ in accordance to above equation is $V_mDT_s/L$.

Value of $i_{Lr}$ negative peak is equal to,

$$|I_{Lr\_np}|=V_2/0.707Z_{r1} \qquad (19)$$

Hence by integrating $i_{Lr}$, $V_2$ is obtained as,

$$V_2=P_OT_S/0.707C_rV_B \qquad (20)$$

$I_{Lm}$ is obtained by considering average current of $C_{r1}$ equal to zero. Hence, by using eqn.(20), we get

$$I_{Lm}=(I_o/n)-(P_o/V_B) \qquad (21)$$

Now the magnetizing inductance of the transformer is parallel to the $C_{r1}$. Integrating $V_{Cr1}$ during mode 1 yields,

$$3.14(V_2-V_1)/2.82W_{r1}-V_2/1.41W_{r1} \qquad (22)$$

Integration of $V_{Cr1}$ gives,

$$nV_oT_{r2}/2$$

Now $T_C$ is the time duration of mode 8 and 9. Hence

$$T_C= T_s-T_{r1}/5.65-T_{r2}/2 \qquad . \qquad (23)$$

Using eqn.(23), appropriate value of $C_r$ is selected such that,

$$|I_{Lr\_np}|>V_mDT_s/L \qquad (24)$$

## VI. HARDWARE

The hardware consists of a combination of a transformer, rectifier and a filter as shown in figure 10. Here the transformer used is a step down transformer. Firstly, the step down voltage is used to convert the 230V AC into 12V AC. The stepped down voltage of 12V AC has an RMS value of 17V, but the voltage required by the circuit is only 5V. So

for this purpose, the 17V AC is firstly converted into DC and then it is stepped down to 5V DC voltage. AC voltage can be converted to DC with the help of rectifiers.The rectifier used here is a bridge rectifier due to its advantage over half wave and full wave rectifier.



**Fig.10. Hardware**

**Table – Hardware Components**

| Component | Rating |
|---|---|
| Linear Transformer | 230 V AC, 12 V DC, 1 A |
| Resistors | $1*10^{-3}$ ohms |
| Capacitors | $1200*10^{-6}$ F |
| Inductors | 2866 H |
| DSPIC Microcontroller | PIC32MX250F128B-50I/SP |
| Arduino UNO | R3    CH340G ATMEGA328P |
| LED Display | 16*2    Green    LED Blacklight |

Before the 15V DC is converted into 5V DC, it is necessary to obtain the pure DC voltage. The output of the bridge rectifier contains a considerable amount of ripples. These ripples can be eliminated with the help of capacitor filter.

Now, the input voltage is increased from zero to the peak value and the supply voltage reduces from peak value to zero. Due to the continuous charging and discharging of the capacitor, the DC output supply which contain ripples gets converted into pure DC supply.

## VII. CONCLUSION

In this paper, a single switch AC-DC LED driver circuit which is based on a boost converter and a flyback converter with a lossless snubber circuit has been proposed. A power factor of high value is achieved by the help of boost PFC converter operating in Direct Conduction Mode. In the flyback converter, the peak voltage stress of the switch gets clamped and there is a recycling of the leakage inductor energy. This takes place because of the presence of a lossless snubber circuit in the system. The DC capacitor gets spilt into two different capacitors. In addition to this, some amount of input power of the boost inductor gets directly conducted to the output due to the usage of a low voltage rating capacitor. Hence, the power factor is corrected and due to which the overall efficiency of the system is improved.

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