Design and Implementation of a Single Switch Flyback converter for supplying LED Driver with PFC correction and Automation System

B. Dinesh kumar[1], S. Siva[2], U. Suresh[3], R. Rajasekar[4], G. Vasanth[5]
[1]Teaching Fellow, [2345]UG Student
Department of Electrical & Electronics Engineering,
University College of Engineering Arni
Email id- [1]dineshkumar.ucea@gmail.com, [2]siva.ucea.eee@gmail.com.

***Abstract*— A single switch led driver based on the boost converter and flyback converter with the power factor correction and automation system is proposed. In this proposed driver, the boost converter is operated in DCM mode to achieve high power factor and flyback converter is used to isolate the input-output to provide safety. Additionally snubber is also designed to clamp the peak voltage of the main switch into the low voltage and also recycles the leakage inductor energy. Additionally, a low-voltage-rating capacitor can be used as the DC-bus capacitor because some of the input power is directly conducted to the output; the remaining power is stored in the DC-bus capacitor. An automation system is designed to makes the circuit into emergency lamp during power failure. Therefore the proposed LED driver can provide a higher power factor and a higher power conversion efficiency. These results are verified for an output of 48[V] and 2[A] for the experimental prototype.**

***Keywords*— Boost-flyback converter, LED driver, power factor correction (PFC), lossless snubber, automation system.**

I. INTRODUCTION

Recently, with the advances in light-emitting-diode (LED) technology, LEDs have drawn much interest in a wide range of lighting applications. Compared to conventional lighting device such as fluorescent lamps, LEDs have many advantages: lower power consumption, longer lifetimes (typically 80,000h), higher optical efficiency, higher contrast ratios and superior environmental safety. Therefore, many studies of LED drivers (to replace conventional fluorescent lamp systems) have been produced. To operate LEDs, AC-DC or DC-DC converters are used in LED drivers to satisfy the demand for high efficiency, low cost, and low size. Specially, For an AC input voltage, the active power factor correction (PFC) circuit must produce little harmonic pollution and a high power factor. To achieve electrical isolation to improve safety, the conventional flyback converter is widely used in LED drivers. However, an additional RCD snubber is needed because of high voltage spikes from the main switch because the leakage inductance resonates with the parasitic output capacitance of the
MOSFETs. The flyback LED driver in was proposed to reduce switching losses and recycle the leakage inductor energy.

LED drivers have two switches and two control circuits in each stage; therefore, they are usually large size, have a large components, are more expensive and are less energy efficient. To overcome these problems, the two-stage LED driver is modified to become a single-stage LED driver by sharing a switch with both stages. Boost and a buck-boost PFC circuits are widely used because they can provide a high power factors using a simple structure and a simple control circuit.

In this paper, a single-stage AC-DC LED driver based on a boost-flyback PFC converter with a lossless snubber is proposed. Because the proposed LED driver is based on the boost-flyback structure, it achieves a high power factor based on the boost PFC, which is operated in the discontinuous-conduction mode (DCM). Because of light loads, the energy required to fulfill the load is small enough. So we only prefer DCM for light loads. Additionally, the proposed LED driver provides electrical isolation due to the DC-DC flyback module. And, because the lossless snubber circuit is used, the leakage inductor energy is recycled into the DC-DC flyback circuit and the peak voltage spike in the main switch is clamped to a low voltage. Moreover, the DC-bus capacitor is divided into two capacitors, i.e., the snubber capacitor and another DC-bus capacitor.Additionally, some of the input power is directly delivered to the output; the remaining power is stored through the snubber diode. Hence, the energy conversion efficiency is improved and a voltage of DC-bus capacitor is also reduced. In conclusion, the proposed LED driver can provide a high power factor and achieve a high power conversion efficiency.

II. OPERATING PRINCIPLE

A. Circuit Description

A circuit diagram of the proposed LED driver is shown in Fig. 1. The input line filter consists of L_f and C_f. The boost PFC circuit is composed of the boost inductor L_b, the main switch S_1, and the reverse-blocking diode D_b (which blocks reverse current through the boost inductor for DCM operation). The DC-DC flyback circuit includes the coupled inductor T_1, the shared (common) switch S_1, the DC-bus capacitor C_{dc}, the output diode D_o, the output capacitor C_o, and the lossless snubber circuit composed of L_1, C_1, and D_1.

In order to describe to parasitic component of circuit parts for theoretical analysis, An equivalent circuit diagram of the proposed LED driver is shown in Fig. 2 (the input line filters and the bridge diode are not included). The input voltage is expressed as the rectified line voltage Vin; it is considered to be constant value during a switching period.

The capacitor CS1 is the parasitic output capacitance of S1. The coupled inductor T1 has a magnetizing inductor Lm and a leakage inductor Lk with a turn ratio of n:1 (n=Np/Ns). Lk is assumed to be much smaller than the Lm. According to the volt-second balance law, since the average inductor voltage should be zero at the steady state, the voltage across the C1 and Cdc should be equal to Vdc.The capacitances of C1, Cdc and C0 are large enough their voltages are considered to be constant.

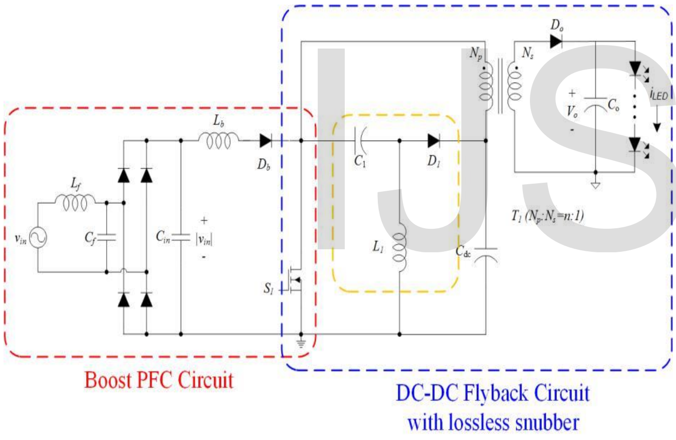

Fig. 1. Circuit diagram of the proposed LED driver

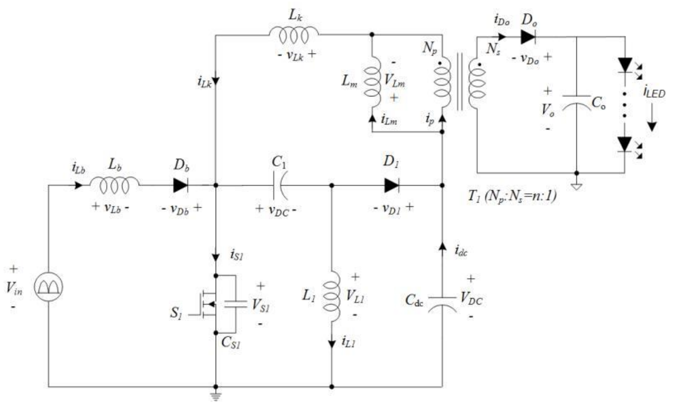

Fig. 2. Equivalent circuit diagram of the proposed LED driver

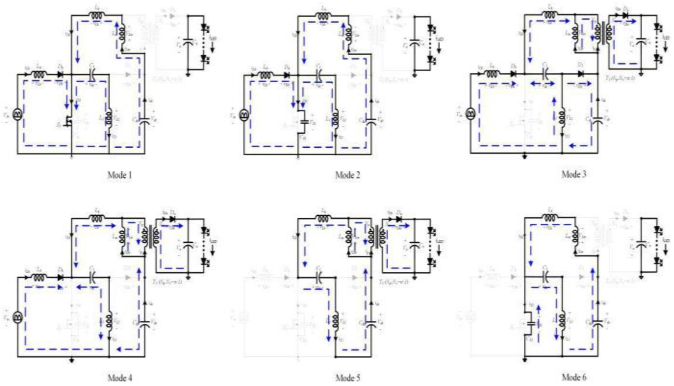

Fig. 3. Operating Modes

Before t_0, the main switch S_1 and the output diode D_o are turned off. The parasitic output capacitance of S_1 is discharged because of the drain-source voltage oscillation between $(L_m+L_k)//L_1$ and C_{S1}. The magnetizing inductor current i_{Lm} and the snubber inductor current i_{L1} are the same as the freewheeling current i_{fw} (which is a constant).

Mode 1 [t_0, t_1]: At t_0, S_1 is turned on and D_o is reverse-biased. Therefore, the boost inductor voltage V_{Lb} is equal to V_{in}.The total voltage across both components L_m and L_k is V_{dc}. Therefore, the voltage V_{dc} is divided into V_{Lm} and V_{Lk}, which are given by $V_{dc}L_m/(L_m+ L_k)$ and $V_{dc}L_k/(L_m+ L_k)$, respectively.

Mode 2 [t_1, t_2]: At t_1, S_1 is turned off and the parasitic output capacitor C_{S1} begins to charge. Because C_{S1} is assumed to be very small, the interval between t_1 and t_2 is very short. i_{Lb}, i_{Lm}, and i_{L1} are considered to remain at constant values; ($i_{Lb(\max)}$, $i_{Lm(\max)}$, and $i_{L1(\min)}$, respectively). V_{Lb}, V_{Lm}, and V_{L1} are considered to linearly increase with very large slops.

Mode 3 [t_2, t_3]: At t_2, when C_{S1} charges up to $2V_{dc}$, the snubber diode D_1 is forward biased and begins to conduct. Therefore, the main switch voltage V_{S1} is clamped to $2V_{dc}$ by D_1. The current flowing into D_1 is determined by $i_{Lb}+i_{Lk}-i_{L1}$. In this mode, the current of leakage inductor is absorbed by the capacitors C_1 and C_{dc}. Since the L_k is assumed to be very small, the time interval between t_2 and t_3 is short.

Mode 4 [t_3, t_4]: When D_1 is turned off, this mode starts. Then, i_{Lb}, i_{L1}, and i_{Lm} flow through the coupled inductor T_1 to the secondary side. It shows that the boost inductor current i_{Lb} flows through the coupled inductor T_1 to the output diode D_o.

Therefore, some of the input power is directly delivered to the load.

Mode 5 [t_4, t_5]: At t_4, the boost inductor current i_{Lb} reaches zero. Therefore, the reverse-current-blocking diode D_b is turned off. Thus, the output diode current i_{Do} decreases linearly.

Mode 6 [t_5, t_6]: When the output diode current i_{Do} reaches zero, this mode starts. Therefore, the output diode D_o is turned off. In this mode, the freewheeling current I_{fw} flows through L_k, C_1, L_1, C_{dc}, and L_m. Then, V_{S1} nonlinearly decreases with the oscillation between C_{S1} and $L_1//(L_m + L_k)$.

III .AUTOMATION SYSTEM

Whenever the power failure occurs, battery is automatically delivers the power into the load. This makes the circuit as emergency lamp circuit. PNP Transistor is act as a switch, As long as the mains power is ON, the positive from the supply is maintained at the base of the transistor, keeping it switched OFF. This prevents the voltage from battery reaching LEDs. The moment, ac mains power is lost, the positive voltage at the transistor goes off, which makes the transistor biased though R1. The voltage from battery now passes through transistor lighting up the LEDs.

IV. EXPERIMENTAL RESULTS

To verify the steady-state performance and theoretical analysis of the proposed single-switch AC-DC LED driver based on the boost-flyback PFC converter with a lossless snubber, a laboratory prototype with the following specifications is implemented and tested:

Input line voltage range vin = 100 to 230[Vac];
Input line frequency fL = 50[Hz];
Output voltage Vo = 48[V];
Output current Io = 2[A];
Output current ripple ΔIo = 2[%];
Switching frequency fS = 50[kHz];
Measured THD 16.28[%] at 100[Vac], 24.62[%] at 230[Vac].

The selected parameters and components of the laboratory prototype, which are based on the above design specification, are listed in Table II.

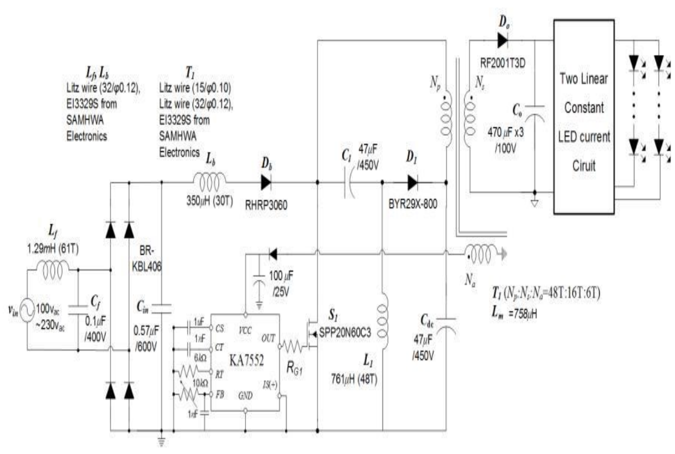

Fig.4. Laboratory prototype circuit diagram of the proposed LED driver

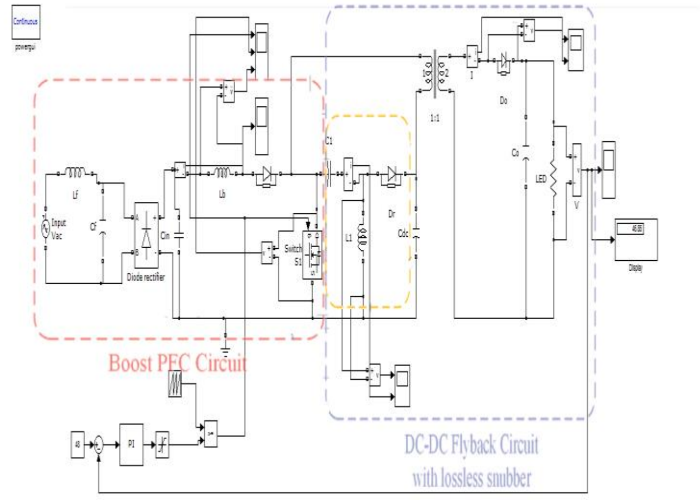

Fig. 5. Simulink diagram

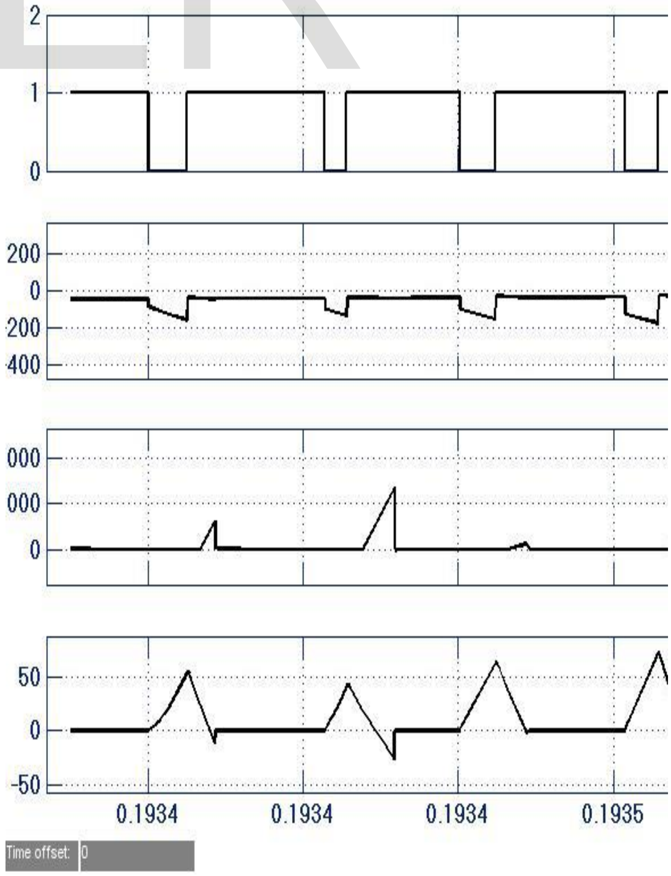

Fig. 6.Experimental waveforms of the proposed led driver

TABLE I. SELECTED PARAMETERS AND COMPONENTS OF THE LABORATORY PROTOTYPE

Component		Value	Description
Input filter	L_f	1mH	EI3329S, Li wire (32/φ0.12)
	C_f	0.47μF	630V
Input capacitor, C_{in}		1000μF	630V
Bridge diode, D_{bridge}		BR-W10406	600V/4A
Boost inductor, L_b		100μH	EI3329S,Li (32/φ0.12)
Revers-blocking diode, D_b		1N4007	600V/30A ultra-fast di
Main switch, S_1		4N60	650V/20.7A R_{ds_on}=0.19
Snubber circuit	D_1	1N4007	800V/8A ultra-fast di
	L_1	47μH	EI3329S, Li wire (32/φ0.12)
	C_1	1000μF	450V
DC-Bus capacitor, C_{dc}		1000μF	450V
Coupled inductor, T_1		L_m=758μH L_k=1μH N_p:N_s:N_a=48T:16T:6T	EI3329S, Li wire (15/φ0.10) (32/φ0.12)
Output diode, D_o		RF2001T3D	300V/20A ultra-fast di
Output capacitor, C_o		470μF x3	100V
Control IC		PIC16F877A	PWM contr
Two linear constant LED current circuit	S_{D1}, S_{D2}	IRF540	100V/28A, R_{ds_on}=0.077
	Op-Amp	LM2904	Dual Opera Amplifier
LED module		SBEME30	5W, White, CCT:5500

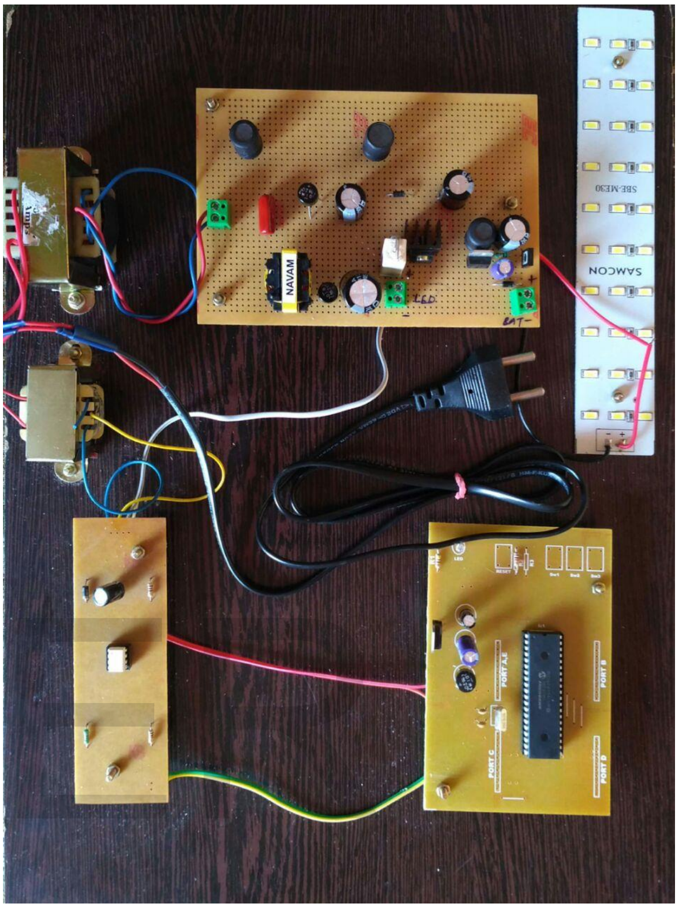

Fig. 7. The photograph of the prototype

V. CONCLUSIONS

A single-switch AC-DC LED driver based on a boost-flyback PFC converter with a lossless snubber has been proposed. Using the boost PFC circuit in DCM operation, a high power factor is achieved. In the DC-DC flyback circuit, Because of the lossless snubber circuit, the peak voltage stress of the switch is clamped and the leakage inductor energy is recycled. The DC-bus capacitor is split into two capacitors (because the snubber capacitor is used). Additionally, a low-voltage-rating capacitor can be used because some of the input power at the boost inductor is directly conducted to the output. Therefore, the total efficiency is improved. The performance of an LED driver prototype has been experimentally evaluated at an output current of 2[A] and an output voltage of 48[V].

ACKNOWLEDGMENT

This work was supported by the Human Resources Development of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant funded by the Korea government Ministry of Trade, Industry & Energy. (NO. 20154030200720).

REFERENCE

1. N. Chen and H. S.-H. Chung, “An LED lamp driver compatible with low-an high-frequency sources,” *IEEE Trans. Power Electron.*, vol. 28, no. 5, pp. 2551– 2568, May 2013.
2. J. Choi, H.-S. Han, and K. Lee, “A current-sourced LED driver compatible with fluorescent lamp ballasts,” *IEEE Trans. Power Electron.*, vol. 30, no. 8, pp. 4455– 4466, Aug. 2015.
3. C.-A. Cheng, H.-L. Cheng and T.-Y. Chung, “A novel single stage high power-factor LED street- lighting driver with coupled inductors,” *IEEE Trans. Ind Appl.*, vol. 50, no. 5, pp. 3037–3045, Sep./Oct. 2015.
4. P. S. Almeida, H. A. C. Braga, M. A. D. Costa, and J. M. Alonso, “Offline soft-switched LED driver based on an integrated bridgeless boost-asymmetrical half-bridge converter,” *IEEE Trans. Ind, Appl.*, vol. 51, no. 1, pp. 761–769, Jan./Feb. 2015.
5. Y.-C. Li and C.-L. Chen, “A novel single-stage high-power-factor AC-to-DC LED driving circuit with leakage inductance energy recycling,” *IEEE Trans. Ind. Electron.*, vol. 59, no. 2, pp. 793–802, Feb. 2012.
6. Y.-C. Li and C.-Lin Chen, “A novel primary-side regulation scheme for single-stage high-power- factor AC–DC LED driving circuit,” *IEEE Trans. Ind. Electron.*, vol. 60, no. 11, pp. 4978–4986, Nov. 2013.
7. Y. Hu, L. Huber, and M. M. Jovanovic, “Single-stage, universal-input AC/DC LED driver with current-controlled variable PFC boost inductor,” *IEEE Trans. Power Electron.*, vol. 27, no. 3, pp. 1579–1587, Mar. 2012.

BIOGRAPHIES

B. Dinesh Kumar[1] received the Bachelor degree in Electrical and Electronics Engineering at Sri Manakula Vinayagar Engineering College. He completed his Master degree in Pondicherry engineering college. He served as Assistant Professor in E.S. college of Engineering and Technology. Presently he is working as Teaching fellow in University College of Engineering Arni.

S.Siva[2] presently pursuing Bachelor degree in Electrical and Electronics Engineering at University College Engineering Arni.

U.Suresh[3] presently pursuing Bachelor degree in Electrical and Electronics Engineering at University College Engineering Arni.

R.Rajasekar[4] presently pursuing Bachelor degree in Electrical and Electronics Engineering at University College Engineering Arni.

G.Vasanth[5] presently pursuing Bachelor degree in Electrical and Electronics Engineering at University College Engineering Arni.