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A SINGLE-STAGE INTERLEAVED BUCK-BOOST CIRCUIT AND LLC RESONANT CONVERTER FOR STREET LIGHTING APPLICATIONS

P.Mohanapriya[1] [2] Dr.I.Gnanambal[2]
[1]PG Scholar, [2]Associate Professor
Electrical and Electronics Engineering,
Government College of Engineering,
Salem, Tamil Nadu, India.

ABSTRACT

In this paper, a single-stage interleaved Buck-boost circuit and LLC resonant converter for the street lighting applications. The Buck-boost circuit and LLC resonant converter are integrated by sharing switches, which can decrease the system cost and improve system efficiency. The input voltage of the buck-boost circuit is half of the rectified voltage, and two buck-boost circuits are formed with the two half-bridge switches and corresponding diodes. The two buck-boost circuit's work in interleaved mode and the inductor current is in discontinuous conduction mode. The half-bridge LLC resonant converter is adopted here, and the soft switching characteristics of the LLC resonant converter is not changed by the switch integration. The primary-side switches still work in zero voltage switching (ZVS) mode, and the secondary diodes still work in zero current switching (ZCS) mode, which both reduce the switching losses and improves the efficiency of the system. The detailed design process of LED street lighting prototype is proposed with an efficiency of 94.8% at full load.

IndexTerms–*single-stage,Interleaved,LLC,buck-boost*

I. INTRODUCTION

LEDs are wide employed in many lighting systems such as street lighting, automobile headlights, and backlit screens as a result of their high efficiency, long lifespan, and good color rending properties. Moreover, with the event of LED packing and coating technology, the price of LEDs has been decreasing. Within the future, LEDs will gradually become a replacement light, replacement gas discharge lamps.

For achieving constant current driving, the standard semiconductor diode driver contains the power-factor correction (PFC) stage, DC/DC device stage, and constant-current stage. This three-stage structure will alter the planning method and facilitate obtaining a high power issue (PF) and low total harmonic distortion (THD). However, the three-stage drive has low efficiency and poor responsible, in conjunction with slow output dynamics. To solve this the traditional driver and to minimize system price, several types of research conducted studies on a single-stage crystal rectifier driver, which might help to minimize prices and size, whereas making certain high potency, high reliability, and quick output dynamics.

Single-stage AC/DC converters have their own disadvantages. First, the bus voltage is high for light-weight load and the high input voltage state. Second, although the integration decreases the elements of the converter, it adds further current or voltage stress to the switches. However, though the PF for the two-stage converters is often terribly high and also the THD can be terribly low, they have their own issues. For example, the cost is high, and also, the reliability is low. Therefore, insensible use, we have a tendency to should balance the price and performance of the converter, and then create an acceptable selection between the Single-Stage and two-stage converters.

Nowadays, most single-stage converters supported the integration of the flyback circuit and different discontinuous conduction mode (DCM) DC/DC converters, which square measure wide used thanks to their low price and quick dynamics. Reference [4] projected a single-stage converter supported buck and flyback circuits. However, for this converter, when the input voltage was under the output voltage, the input current was zero, the crystal rectifier to a low PF and high THD. Reference [5] projected a single-stage crystal rectifier driver supported buck-boost and flyback circuits, and though the PF and THD were higher and lower, severally, compared to PF and THD in [4], the efficiency remained low. Further, [6] proposed a single-stage crystal rectifier driver supported buck-boost and flyback circuits, and whereas the system PF was improved and transformer leakage inductance energy was fed back, the system switch losses remained high and also the efficiency was low thanks to switches still being in a very hard-switching mode. Reference [7] projected a single-stage AC/DC converter primarily based on a single-ended primary inductor converter and flyback circuits. As a result, of the flyback circuit worked in a very quasi-resonance stage, the switching losses decreased; but, the switch still didn’t add a true zero-voltage-switching (ZVS) stage, and also the switch losses remained high at a light-load state. Though several single-stage topologies primarily based on the flyback circuit are projected, no technique has been devised to more decrease the switch losses and improve system efficiency [8] -[10].

To decrease the switch losses of LED drivers, increasing varieties of researchers have centered on LLC resonant converter with a soft-switching property. The system efficiency increased significantly with the employment of LLC resonant converter [11] -[13]. However, the normal crystal rectifier driver primarily based on an LLC resonant converter is priced as a result of an addition PFC circuit is needed. Reference [13] planned a single stage AC/DC device supported a DCM boost circuit and a half-bridge LLC circuit. The soft-switching characteristics of the LLC electric circuit weren’t tormented by the integration of the switches for the single stage AC/DC device is 0.5, the bus voltage should be over double the peak input voltage; therefore, the device isn't appropriate for high-input voltage conditions. Reference [14] optimized the parameter style of the device planned in [13] to decrease the bus voltage; but, the device still didn't perform well beneath a high input voltage. Additionally, for the standard AC/DC device given in [2]-[14], the integrated switch was subjected to high voltage or current stress, that raised the power losses and reduced the reliableness of the system. Reference [15] planned a single-stage AC/DC device based mostly on the associate interleaved boost circuit and a half-bridge LLC resonant converter. The input voltage was divided into two elements in which two DCM boost circuits were formed; high PF and low THD were achieved. However, the topology contained two inductors that raised the entire value of the system. Moreover, the two inductors ought to have a constant price to obtain a high PF and low THD. Insensible applications, the inductor sometimes contains a deviation, considering the value and production technology.Though a very high PF and low THD can be obtained by the model developed in the laboratory, obtaining a high PF and low THD in observing is troublesome. Also, since the topology planned in [15] had an interchangeable structure and, therefore, the input voltage was divided into two elements, the two switches may share the voltage and current stress resulting from switch integration, which is incredibly advantageous. However, insensible use, deviations from the values inevitably occur as a result of one boost circuit needs one individual inductor. Therefore, the two boost circuits cannot equally share the input power.

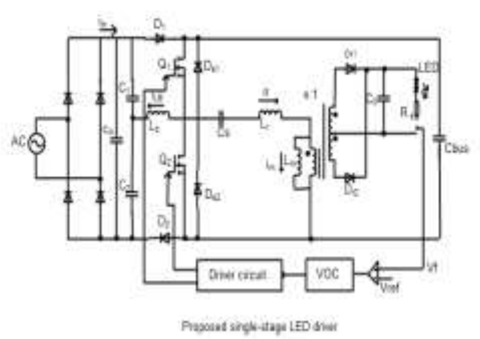


Fig. 1 Proposed single-stage LED driver

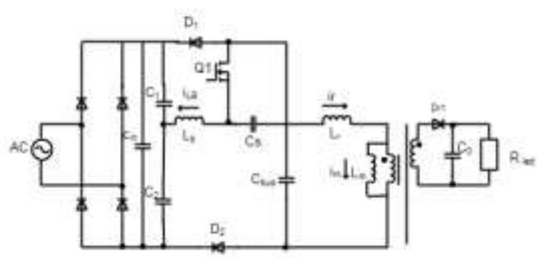
In this paper, a single-stage AC/DC device supported the boundary conduction mode (BCM) boost circuit and LLC resonant device is projected, associated it's applied to a light-emitting diode street lighting system. Within the projected single-stage AC/DC converter, two BCM boost circuits square measure obtained by desegregation the switches of the half-bridge LLC resonant device, which realizes a PFC operate. As a result, of the input voltage is split by two capacitors, the bus voltage is significantly reduced approximately to the worth of just about the peak input voltage, rendering the projected single-stage driver to approximately work under high input voltage conditions. The soft-switching characteristics of the half-bridge LLC resonant converter area unit not affected. Compared with the traditional single-stage AC/DC converter projected in [2]-[14], two integrated switches are a unit obtainable, and also the AC/DC converter options a symmetrical structure. Therefore, the integrated switches equally share the current and voltage stresses of the system caused by the switch integration, which improves the dependableness of the system. Additionally, compared to the converter projected in [15], the two switches will equally share the current and voltage stresses as a result of the two boost circuits continually work under a constant condition as they share one electrical device, which makes the novel converter applicable for sensible use.

II. WORKING PRINCIPLE OF THE PROPOSED CONVERTER

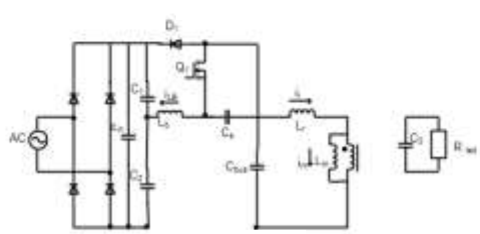
Fig.1 shows the proposed single-stage AC/DC converter. The input voltage is split by C_1 and C_2, C_{bus} is that the bulk capacitor of the boost circuit, C_{bus}, D_1, L_b, Q_1 and D_{s2} constitute one of the two boost circuits, that is said as boost1 circuit, whereas C_{bus}, D_2, L_b, Q_2, and D_{s1} represents the opposite boost circuit, said as boost2 circuit. L_b is shared by the two boost circuits. As a result, of the summation of the input power for the two boost circuits is capable the entire input power of the LED system, the current stress of the integrated switch is decreased by half compared in addition to that within the single-stage AC/DC converter planned in [13] and [14]. The DC/DC cell is a half-bridge LLC resonant converter, where L_r is that the leakage inductor of the transformer, L_m is that the magnetizing electrical device and R_{led} is that the equivalent impedance of the LED loads. Compared with the Converter proposed in [13], only D_1, C_1, and C_2 are added. Further, compared with the classical two-stage interleaved solution, two MOSFET and one electrical device square measure reduced, and two extra ultrafast diodes square measures are added. Since the price of the ability switch is that the main a part of the entire cost for a crystal rectifier driver, it's a low-cost solution.

This circuit has six operating modes in working period, as shown in Fig. 2. Fig. 3 shows the most voltage and current waveforms.

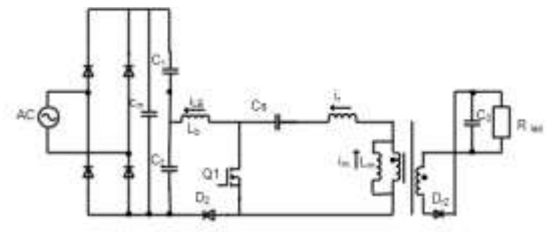
discharges to the output capacitance of Q_2. The voltage between the drain and source



Mode 1



Mode 3



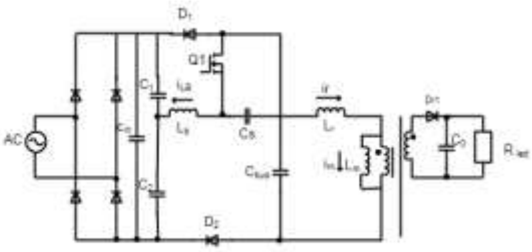
Mode 5

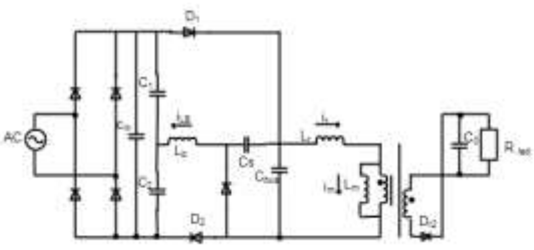
Fig. 2 Six working modes of the proposed AC/DC converter

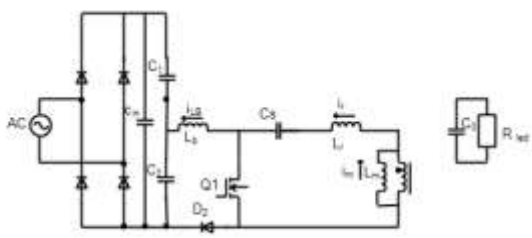
Mode 1 (t_0-t_1): At time t_0, Q_2 is turned off, Q_1 is not yet turned on, and L_b begins to discharge via D_{s1}, C_{bus1}, D_2, and C_2. During this point, the resonant current i_r discharges to the output capacitance of Q_1. The voltage between the drain and source poles of Q_1 decreases till it becomes zero. The body diode D_{s1} is turned on. On the secondary side, D_{r1} is turned on, the voltage of L_m is clamped by the output voltage, L_r, and C_s along type a resonant tank, and, therefore, the magnetizing current linearly will increase.

Mode 2 (t_1-t_2): At time t_1, the discharge current of L_b is equal to zero, i.e., $i_{Lb} = 0$. Throughout this point, the drive signal of Q_1 has already arrived, and Q_1 is turned on within the ZVS state. C_1 charges to L_b via Q_1 and D_1. The magnetizing current still linearly increases, and, therefore, the resonant current will increase and flows with a sinusoidal form through Q_1. Once the resonant current is equal to the magnetizing current, this mode ends.

Mode 3 (t_2-t_3): This mode begins at time t_2. L_b continues to be charged till i_{Lb} reaches its peak value when Q_1 is turned off. D_{r1} is turned off within the zero-current-switching (ZCS) state, and the secondary-side


Mode 2


Mode 4


Mode 6

one electrical device L_b; thus, the charging method of the boost2 circuit is interrupted from the Primary-Side circuit. At this moment, the voltage of the magnetizing inductor is now not clamped by the output voltage, and L_m is concerned in the resonant tank. Once the turn-off signal of Q_1 arrives, this mode ends.

Mode 4 (t_3-t_4): At time t_3, Q_1 is turned off, Q_2 is not yet turned on, and L_b continues to discharge via D_{s2}, C_{bus}, D_1, and C_1. Throughout now, resonant current i_r poles of Q_2 decreases till it becomes zero. The body diode D_{s2} is turned on. On the secondary side, D_{r2} is turned on, the voltage of L_m is clamped by the output voltage, L_r, and C_s along type a resonant tank, and, therefore, the magnetizing current linearly will increase.

Mode 5 (t_4-t_5): At time t_4, the discharge current of L_b is equal to zero, i.e., $i_{Lb} = 0$. By now, the drive signal of Q_2 has already arrived, and Q_2 is turned on within the ZVS state. C_2 charges to L_b via Q_2 and D_2. The magnetizing current continues to increase linearly, and therefore, the resonant current will increase and flows with a sinusoidal form through Q_2. Once the resonant current is capable the magnetizing current, this mode ends.

Mode 6 (t_5-t_6): This mode begins at time t_5. L_b continues to be charged till i_{Lb} reaches its peak value when Q_2 is turned off. D_{r2} is turned off within the ZCS state, and, therefore, the secondary-side circuit is bringing to an end from the Primary-Side circuit. At this moment, the voltage of the magnetizing inductance are not any longer clamped by the output voltage, and L_m is concerned into the resonant tank. When the turn-off signal of Q_2 arrives, this mode ends.

Fig. 3 shows that the two boost circuits alternately work in one high-frequency period. Here, the two boost circuits share

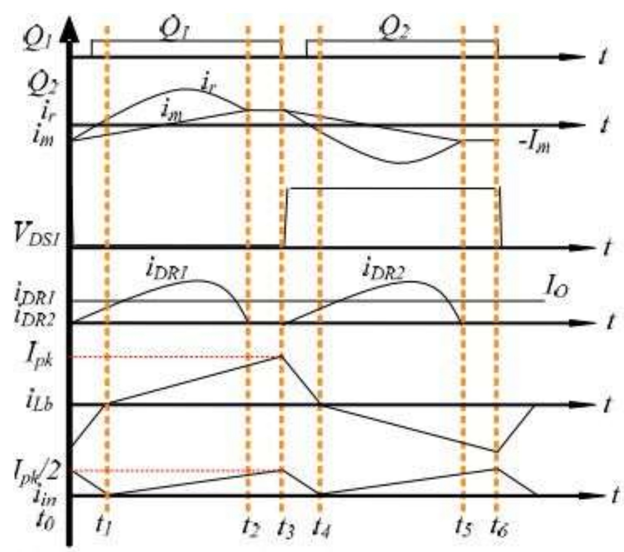


Fig. 3 Voltage and current waveforms of the main components of the proposed AC/DC converter

circuit can begin only the discharging method of the boost1 circuit is complete. Within the same manner, the charging method of the boost1 circuit will begin one time the discharging method of the boost2 circuit is complete. Thus, the present waveform of L_b naturally stays within the BCM state.

III. ANALYSIS AND DESIGN OF THE LED DRIVER

A. *BCM Boost Cell*

Figs. 2 and 3 show that at time t_3, the voltage of L_b reaches its peak value in one operational amount. Here, we tend to assume that the input voltage is constant in one operating period; then, the peak input current of L_b is calculated by (1). Here, V_{bus} is the bus voltage, V_{in} is the input voltage, and T_s is the working period.

$$I_{pk} = \frac{2V_{bus} - V_{in}}{8L_b V_{bus}} T_s V_{in} \qquad (1)$$

Fig. 3 shows that the peak input current in one operational period is half I_{pk}; then, the common input current in one high-frequency amount.

B. *LLC Resonant Converter*

Fig. 4 shows the equivalent circuit of the LLC half-bridge converter supported the elemental wave analysis technique. L_{sr} is that the discharge inductance of the secondary side and R_e is that the dynamic electrical resistance.

$$R_e = V_{eac}/I_{eac} = \frac{8n^2}{\pi^2} R_{led} \qquad (2)$$

Because the worth of the secondary discharge electrical device is incredibly low, we can omit it within the analysis as its influence would be negligible.

$$f_m = 1/2\pi\sqrt{L_r(L_r + L_m)} = \omega_m/2\pi$$
$$f_r = 1/2\pi\sqrt{C_r L_r} = \omega_r/2\pi \qquad (3)$$

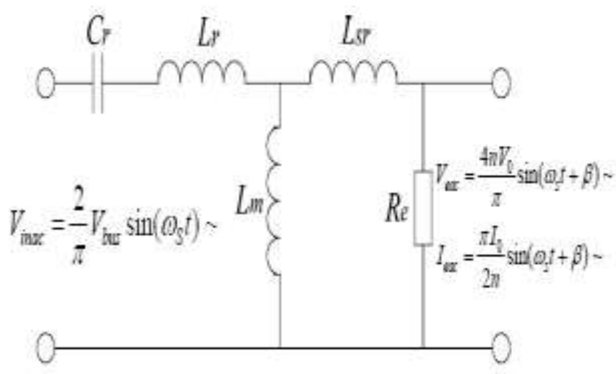


Fig. 4 Equivalent circuit of LLC resonant circuit

V_{inac} is the equivalent fundamental input voltage of the LLC resonant circuit, V_{eac} is the equivalent fundamental output voltage of the LLC resonant circuit, I_{eac} is the equivalent fundamental output current of the LLC resonant circuit, and β is the phase angle between the input and output. The equivalent load Impedance R_e can be calculated by the above equation, where R_{led} is the equivalent resistance of the LED load.

IV. SIMULATION OF THE PROPOSED CONVERTER

Fig. 5 shows the PSIM simulation circuit of the proposed converter operating under DCM conditions in open loop.

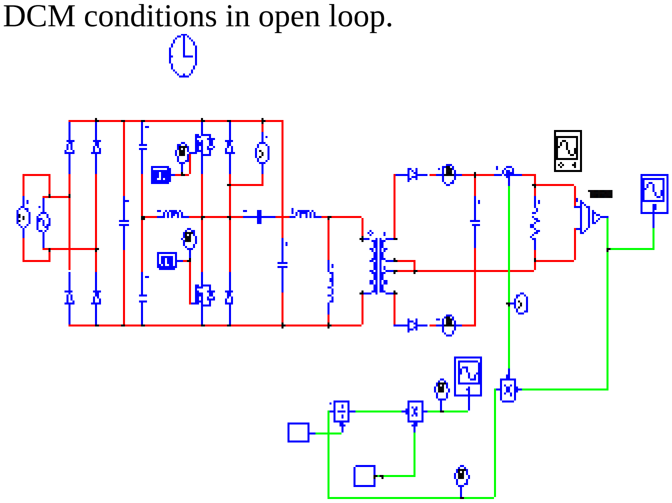


Fig. 5 Simulation circuit of proposed circuit under DCM (open loop)

The circuit is drawn by using PSIM

software components. Now assign the parameter values for each component in the circuit diagram. In order to measure voltage and current of power devices and load, voltage probe and current probes are used. Gating block is used to assign the duty period of the semiconductor switch. Digital values of voltage and current are displayed by selecting show probe value during simulation in each voltage and current probe block. Alternatively, these values are measured in the Simview screen. Finally, set the simulation control values and run the simulation. Simulation results are displayed in Simview.

The Fig.7 shows the waveforms of the output current and voltage for proposed converter circuit. The output voltage is 52V, and the output current is 2A.

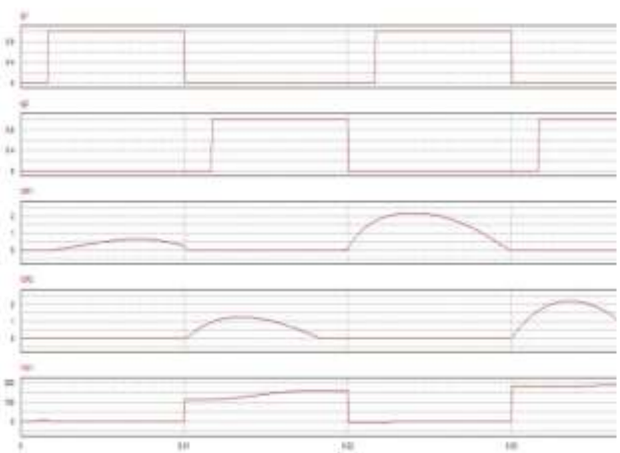


Fig. 6 Voltage and Current waveforms of the main components of the proposed converter

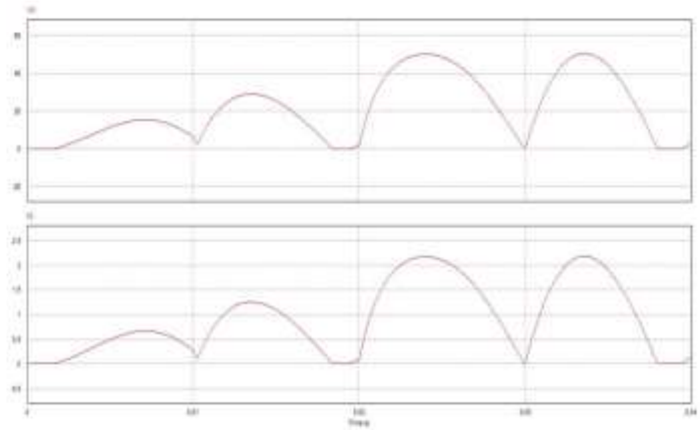


Fig. 7 Output voltage and current waveforms of the proposed converter(open loop)

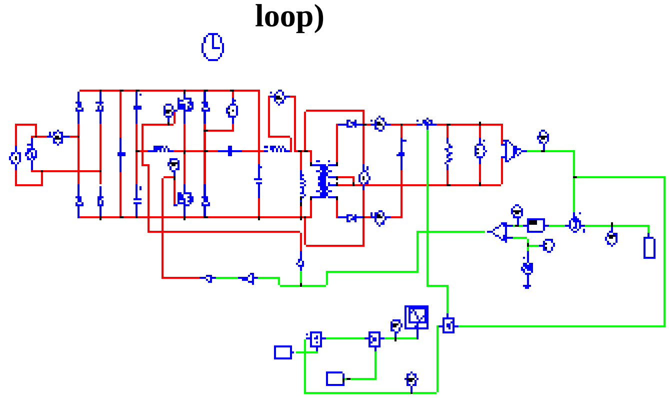


Fig. 8 Simulation circuit of proposed circuit under DCM (closed loop)

The parameters of the major components for the LED driver are listed in table.1.

TABLE I PARAMETERS OF THE PROPOSED AC/DC CONVERTER

Components	Symbol	Value	Part name
Boost inductor	L_b	200 μH	
Switches of half –bridge Converter	Q_1, Q_2		7N60B
Diodes for two boost Circuits	D_1, D_2		F8L60

Resonant capacitor	C_s	22 nF	
Leakage inductor of the transformer	L_r	11 5 µH	
Magnetizing inductor of the transformer	L_m	60 0 µH	
Turn ratio of the transformer	n	3. 5	
Input filter	C_{in}	1 µF	
Voltage dividers	C_1, C_2	330 nF	
Output diodes	*Dr1, Dr2*		B20100
Rectifier			D6KBA 80R
Bus capacitor	*Cbus*	33 0 µF	
Output capacitor	C_o	33 0 µF	

From the above circuit, the switching pulses for the MOSFETs are provided by the corresponding output voltage of the circuit. Fig. 8 shows the PSIM simulation circuit of proposed circuit operating under closed loop condition. In the closed loop configuration, it has additional feedback path to provide a constant output voltage for any input voltage variations. Here the carrier wave and reference DC wave from the sensor voltage output is compared and produces

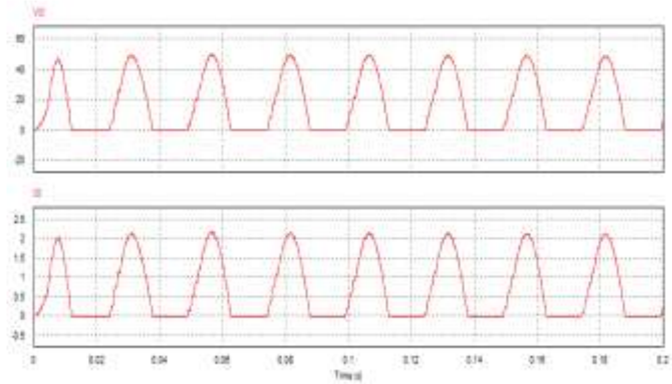


Fig. 9 Output voltage and current waveforms of the proposed converter (Closed loop)

PWM gate signals at the comparator output. Thus, the gate signal is applied to switches S1 and S2 via the on-off controller.

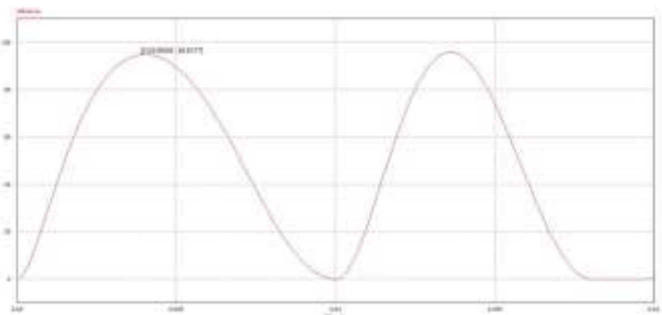


Fig. 10 Efficiency of the proposed converter circuit

Fig. 10 shows the waveforms of the efficiency of the proposed circuit. The system efficiency of 94.8%. The proposed converter is suitable for an LED street lighting system because of its low-cost and high-efficiency characteristics.

CONCLUSION

A single-stage interleaved buck-boost circuit and LLC resonant circuit for the street lighting system is proposed. In this proposed converter is used as an LED driver for a street lighting system. By using interleaved technology, the converter can work in high voltage input conditions. Also, the LLC circuit can make the system work in soft switching mode, which improves the system efficiency. A 100-W prototype is proposed in the paper, with a system and efficiency of 94.8% at full load. The proposed single-stage converter is suitable for an LED street lighting system because of its low cost and high- efficiency characteristics.

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