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Research Articles

Analysis of power losses of different Buck converters for LED application

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Abstract

A buck converter efficiently step-downs the voltage level. Financial power transformation expands the robustness of battery, loss of heat energy is lowered and aides in building smaller devices. This can be used in household and industrial areas. The activity of numerous converters relies upon the switching properties of the power elements. Many buck converters utilize the second MOSFET instead of a diode. When the diode turns ON in buck converter, losses occur in the diode, which are called conduction losses, which keep increasing when the ON time of diode increases. Hence, the efficiency of the converter decreases due to these conduction losses. Hence, the synchronous buck converter is proposed, which increases the efficiency reducing the conduction losses. Further improvement in the efficiency can be achieved using an interleaved synchronous buck converter. The main objective of this paper is designing the different buck converters for LED applications.

Keywords: Buck converter, conduction loss, interleaved, synchronous

I. Introduction

LEDs are potential successors of glowing lights with high iridescent adequacy and long lifetime. The existence time of LEDs is in excess of multiple times that of minimal fluorescent light (CFL). Additionally, the yield light productivity of LEDs has expanded around 100 lumens/watt. Additionally, LED lights do not have any destructive emanations, for example, Ultra-Violet (UV) or Infra-Red (IR) yield. They can be diminished easily from full yield to off. Driven lights have a particular development and do not have an outer reflector. A precise DC supply is required for the task of light emanating diode. This paper shows an alternate sort of buck converter for driving LED load. According to the required application, buck converter viably lessens the dimension of voltage. Higher conduction losses when ON time increment is brought about by the diode and it reduces the effectiveness. Along these lines, a synchronous buck converter is proposed to accomplish high efficiency. In this converter, another switch is utilized rather than a diode.

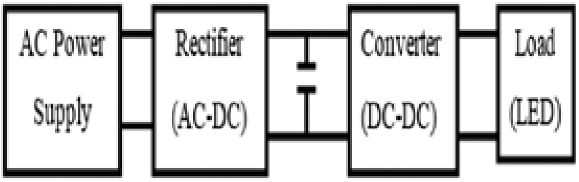

Figure1: General block diagram of the LED driver circuit

Further decrease in the switching loss can be accomplished utilizing an interleaved synchronous buck converter. An essential block diagram of the LED driver circuit has appeared in Fig 1. In this paper, we use MOSFET to design the distinctive buck converters. Utilizing basic rectifier circuit accessible AC supply is changed over to DC. Through a DC interface, the yield is then given to the DC-DC converter. DC interface keeps up consistent DC voltage at the contribution of the converter. This converter drives the LED load. Results were acquired utilizing MATLAB/SIMULINK.

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II. Buck Converter

Buck converter, transforms the input voltage to a voltage of lower value at the output side; a resistive load, a constant input voltage, a switch, a diode, an inductor and a capacitor. The average output voltage is a function of duty ratio. Output voltage varies as the duty cycle is varied. It is observed that output and input hold a linear relationship.

Vin - Source voltage
Is - Source current
L - Inductor
C - Capacitor
D - Duty ratio
V0 - Load voltage
I0 - Load current

When switch S is ON, diode D is OFF

$$V_L = V_{in} - V_o$$

$$L\frac{di_L}{dt} = V_{in} - V_o$$

$$\Delta i_{L(closed)} = \frac{(V_{in} - V_O)DT_s}{L}$$

When switch S OFF, diode D is ON

$$V_L = -V_o$$

$$L\frac{di_L}{dt} = -V_o$$

$$\Delta i_{L(opened)} = \frac{-V_o(1-D)T_s}{L}$$

To find the output voltage

$$\Delta i_{L(Closed)} + \Delta i_{L(opened)} = 0$$

$$V_o = V_{in}D$$

In a buck converter, since the inductor is connected to the output side, the inductor current becomes equal to the output current.

$$I_L = I_o$$

To calculate inductor current,

$$L = \frac{V_o(1-D)T_s}{(\frac{\Delta i_L}{I_L})} = \frac{(V_{in} - V_O)DT_s}{(\frac{\Delta i_L}{I_L})}$$

The function of the capacitor here is to act as a filter and to filter out the ripples. So, for the design of the capacitor,

$$\Delta Q = C\Delta V_O$$

$$\frac{(1-D)T_S V_O}{2L} * \frac{T_s}{4} = C\Delta V_O$$

$$C = \frac{(1-D)V_O {T_s}^2}{8L(\Delta V_O/V_O)}$$

For lower values of the duty cycle, the diode conducts more duration than the switch does, over a period. This creates a problem because a drop across the diode becomes more. This problem can be rectified by replacing the diode with a MOSFET (forward voltage drop of MOSFET is lower than that of a diode) and in turn makes the converter circuit into a synchronous buck.

III. Synchronous Buck Converter

Most of the buck converters employ diodes. In synchronous converters, we replace the diode with a second MOSFET. This is essentially important in low voltage high current applications. An inductor and an output capacitor are the main components of this type of converter. They are used as switching devices.

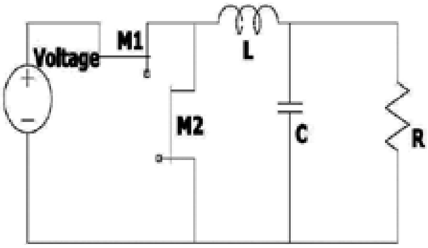

Figure 2: Synchronous buck circuit diagram

The MOSFET allows the inductor current to go negative. The converter designed should be necessarily operated in continuous current mode. The current flowing through the inductor should always flow in continuous conduction mode. Switch M1 is ON and M2 is OFF in the first mode of operation. The inductor gets charged due to the current that flows through it. Switch M1 is in the OFF condition in the second mode. The inductor gets discharged. M2 starts its conduction when the polarities of the inductor reverse. The efficiency of the system increases in the synchronous buck converter because we are using MOSFET. The MOSFET reduces the drop in the circuit.

IV. Interleaved Synchronous Buck Converter

An interleaved method is used to improve power converter execution regarding efficiency, transient response, size and electromagnetic emission. There are many benefits of using an interleaved method. The benefits include high power capability, modularity, and improvement in reliability. However, an interleaved topology contributes to cost as we use additional inductors, output rectifiers and power switching devices.

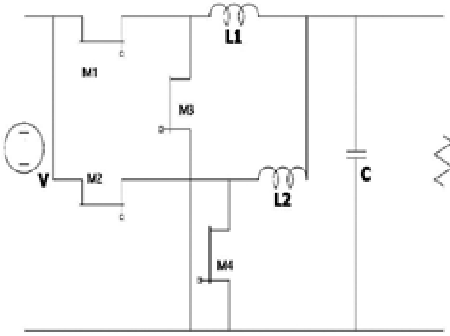

Figure 3: Circuit diagram of the interleaved synchronous buck converter

Interleaved buck converters consist of a parallel combination of multiple converters. Controlling signals to each of these converters are given with a phase shift from one another and all of the control inputs will be having the same frequency. Interleaved buck converter can be obtained by using two boost converters which are operating 180 degrees out of phase. The sum of the two inductors' current will give us the output current. Because inductor ripple currents are out of phase, they cancel out with each other and the output-ripple current produced by inductors of the buck converter reduces. The ON time for each converter is the same, but the time period has been reduced to half. So, the effective duty cycle for the total inductor current is half of that of the existing normal buck converter and switching frequency f is also increased to 2f.

V. Closed-Loop Analysis Of Synchronous Buck Converter

In order to maintain the output voltage or current in the required range for variation in the designed values, closed-loop is preferred. Voltage is sensed and is compared with a reference voltage. The error is then fed to an analog PI controller. This controlled output cannot be used to drive switches because the inductor current wave shape will change if the duty cycle is greater than 0.5. So, slope compensation is required. For this, add the PI controller output to an invented sawtooth waveform. This is then compared with the reference inductor current. The output of this drives an SR flip flop. The flip flop toggles the switches based on the input.

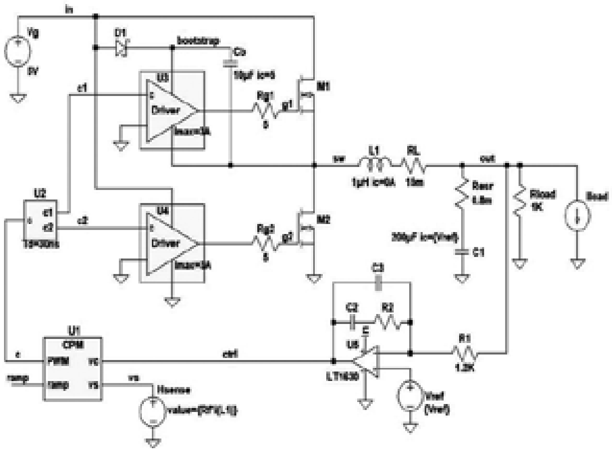

Figure 4: Closed-loop synchronous buck converter

In order to drive the switches, gate driver circuits are required, because the pulses from the controller cannot operate the switches. The switches used in the circuit require 5 voltages across the gate and source. The gate driver circuit makes sure that the pulses at the gates are having the amplitude of 5V. A certain time delay is maintained between the two switches to prevent the switches from being in ON state simultaneously.

VI. Results and Discussion

The brightness of the LED is proportional to the current flowing through it. For a 6 W LED load, 6 no. of 1W LEDs are connected in series and parallel. For this, 1W LED and the Edison C series cool white LEDs are selected.

The forward voltage of each LED is 3.4V. Thus, the output voltage is 10.2V; output current across the load is 350mA. Since the load is LED, switching frequency should be greater than 100Hz, so that the human eye does not perceive flicker. Hence switching frequency is fixed at 25kHz. Output voltage ripple is considered as 10%. Designed parameters are calculated and tabulated below.

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Parameters	Buck converter & Synchronous buck converter	Interleaved synchronous buck converter
Input voltage(Vin)	15V	15V
Duty cycle(D)	0.68	0.34
Switching frequency(fs)	25kHz	50kHz
Self-inductor(L)	112μH	65μH
Output capacitor(Co)	6μF	6μF
Output resistor(R)	30Ω	30Ω

MATLAB simulation of the conventional buck converter is as shown in Fig 5.

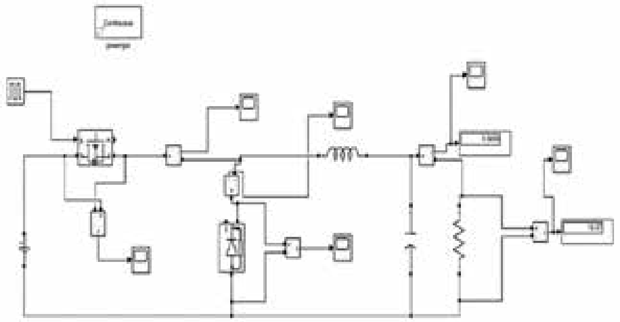


Figure 5: Simulation circuit of the conventional buck converter

The loss across the diode can be analysed using corresponding voltage and current waveform. Conduction loss is high if a diode is on for a long time. Corresponding voltage and current waveform across diode have been shown in Fig 6.

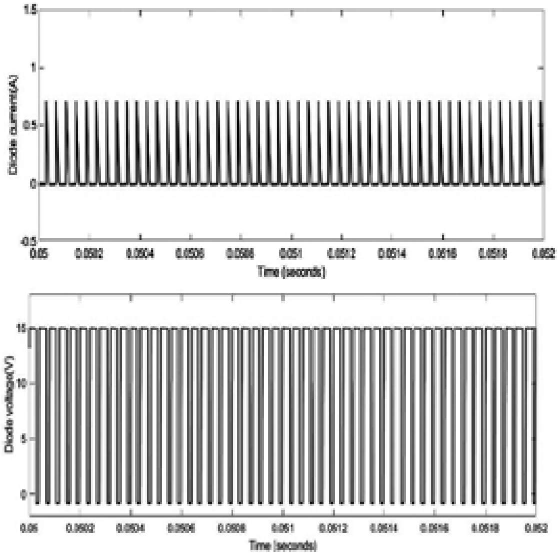


Figure 6: Voltage and current waveform across the diode

The voltage waveform across the load LED is about 10.2V and the corresponding current is about 350mA is presented in Fig 7.

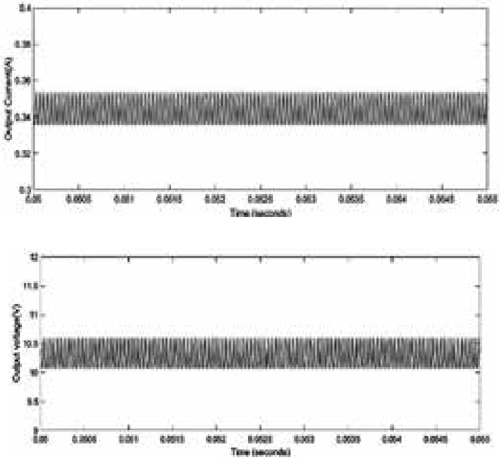


Figure 7: Output voltage and current waveform

MATLAB simulation of the synchronous buck converter is as shown in Fig 8.

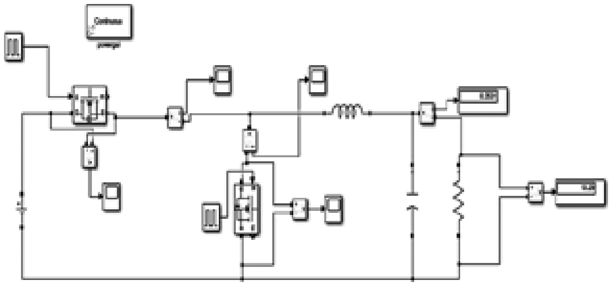


Figure 8: Simulation circuit of the synchronous buck converter

The loss across the diode is minimized by means of a switch. Corresponding voltage and current waveform across the switch has been shown in Fig 9.

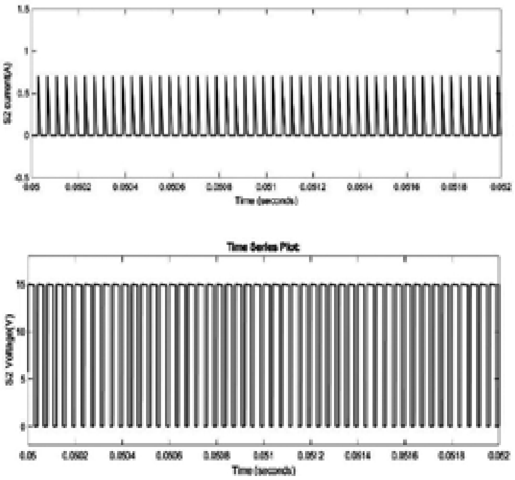


Figure 9: Voltage and current waveform across the switch

The voltage waveform across the load LED is about 10.2V and the corresponding current is about 350mA is presented in Fig 10. Reduction in ripple content in the current, as well as voltage, is also observed.

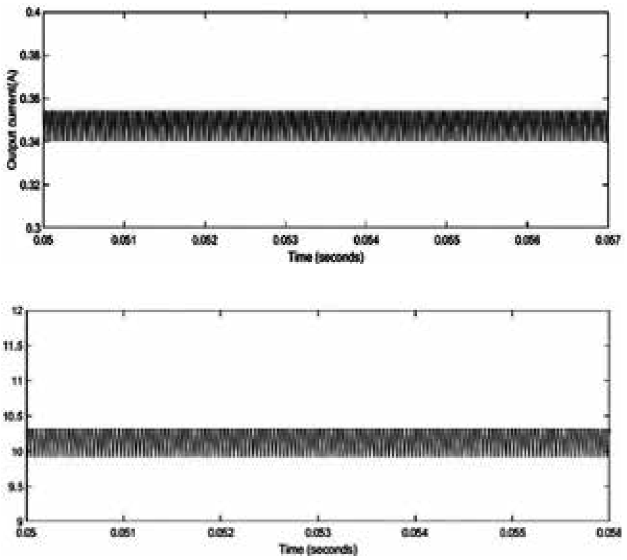


Figure 10: Output voltage and current waveform

MATLAB simulation of the interleaved synchronous buck converter is as shown in Fig 11.

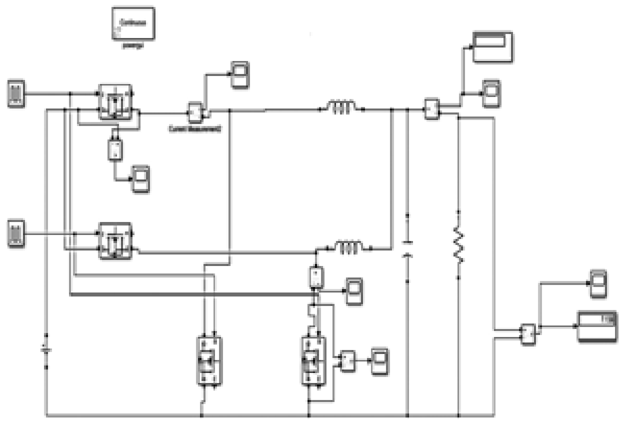
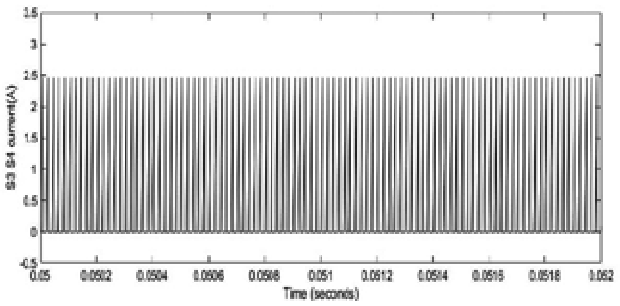


Figure 11: Simulation circuit of the interleaved synchronous buck converter



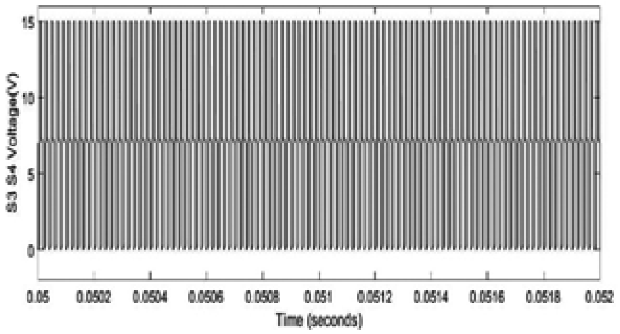


Figure 12: Voltage and current waveform across the switch

Switching frequency is doubled and the duty cycle becomes half compared to the synchronous buck because of the presence of the four switches. Further reduction in the loss across the switch can be observed as well as a reduction in the ripple content of output voltage and current. The corresponding waveform is as shown in Fig 12.

Devices	Power loss
Buck converter	11.77mW
Synchronous buck converter	1.14mW
Interleaved synchronous buck converter	0.4mW

Power losses across the diode and switch of different buck converters are as shown in the table. It is observed that power loss in the conventional buck converter is more because of the presence of the diode. Reduction in loss can be observed in synchronous buck converter and interleaved synchronous buck converter.

VII. Conclusion

The design and simulation of conventional buck, synchronous buck and interleaved synchronous buck DC-DC converter for the LED driver are designed in this paper. The major application of these converters is in land vehicles, landscape lighting and watercraft because of its low voltage level. The minimum amount of power loss is observed in the interleaved synchronous buck converter compared to the conventional and synchronous buck converter. Hence, the efficiency of the whole driver circuit is also improved.

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