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Simulation of Open Loop and Closed Loop Synchronous Buck Converter for LED Applications

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Abstract: The demand of energy efficient lighting system is very essential in today's scenario. This is because the amount of energy consumption by lighting sources is approximately 20% of total electrical energy consumed in the world. In the recent years, LED lighting has emerged as a better energy efficient and eco-friendly solution for the residential and commercial lighting requirement. LED works on DC power and therefore it requires a device that can convert available AC power to DC power and regulate the current flowing through the LED during its operation. Thus to protect LED from line voltage fluctuations, a proper driver circuit is needed. In this paper the design of driver circuit for LED bulb with a synchronous buck converter is described. The simulation of driver circuit for both open loop and closed loop are done in MATLAB/SIMULINK software.

Keywords:LED, Synchronous buck converter, LED driver circuit, Open loop and Closed loop system.

I. INTRODUCTION

In the recent past, LED lighting has emerged as a better energy efficient and environment friendly solution for the general lighting purpose.TheLED technology so attractive because of its compact size, high reliability, chromatic variety, improved efficiency, good colour rendering index and low maintenance requirement [1].

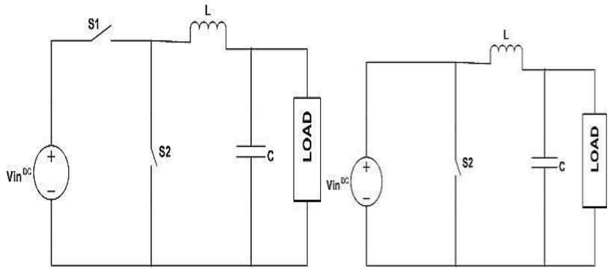
In general LED requires an accurate DC power for its operation[2].This paper presents a design of driver circuit for LED bulb with a synchronous buck converter. Buck converter is a step-down DC-DC converter which effectively reduces the level of voltage as per the required application. But recent years for low voltage applications synchronous rectification and synchronous buck converters have been of great concern in power electronics due to increased efficiency. In synchronous buck converters the diode in the buck converter is replaced with another MOSFET. The introduction of MOSFET over a diode typically decreases the drop from 0.5V to 1V of diode to a value of 0.3V or less [3]. This increases the efficiency of the converter by 5% or high. Thus efficiency of synchronous buck converter is higher than that for classical buck converter [10].

Synchronous buck converter uses two N-channel power MOSFETs, PWM control, synchronous MOSFET driver, power inductor and output capacitor. Incoming AC power is converted to DC power with the help of simple rectifier circuit. The rectified output is then given to the DC-DC converter through a DC link. To maintain constant DC voltage at the input of synchronous buck converter a DC link voltage is used. Incoming DC supply is reduced to lower level as required by the load through a synchronous buck converter.

This paper presents the application of synchronous buck converter to drive LED loads. The simulation of synchronous buck converter for both open and closed loop operation werealso discussed.

II. SYNCHRONOUS BUCK CONVERTER

The main goal of synchronous buck converter is to efficiently step down DC voltage to a lower level with minimum ripple. It mainly consist of two N-channel power MOSFETs, PWM control, synchronous MOSFET driver, power inductor and output capacitor as shown in Fig.1(a).



(a)

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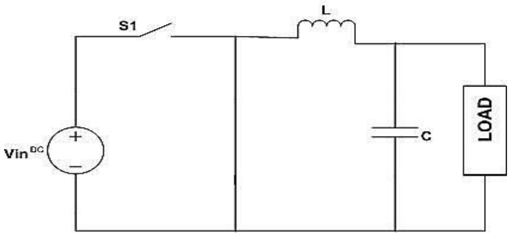

(b)

Figure 1(a) Buck dc-dc converter (b) Equivalent circuit for the switch closed (c) Equivalent circuit for the switch open

Synchronous MOSFET driver is used to control both power MOSFETs. When high side MOSFET (S_1) is ON, low side MOSFET (S_2) is OFF; when low side MOSFET is ON, high side MOSFET is OFF. If both power MOSFETs are ON then high shoot through current can occur [3]. In order to avoid this effect delay times are usually used. The inductor is used to store energy when the high-side MOSFET is turned on; this energy is then used to supply current for the load when the high-side MOSFET is turned off. A low-side MOSFET across the load and inductor circuit provides a return path for the current during the off period of high –side MOSFET. A simple schematic is shown in Fig 2(a). The input to the filter is 'V_s' when the switch S_1 is ON and is zero when the switch S_1 is off, provided that the inductor current remains positive, keeping the switch S_2 is ON. If the switch is closed periodically at a duty ratio 'D', the average voltage at the input of the filter is 'V_sD'. This analysis assumes that the low-side MOSFET remains ON for the entire time when the high-side MOSFET off, implying that the inductor current remains positive leading to continuous current mode.

When the high-side MOSFET switch is closed in the synchronous buck converter circuit of Fig 1(a), the low side MOSFET is open and fig 1(b) is an equivalent circuit. The voltage across the inductor is,

$$V_L = V_S - V_0 = L\frac{di}{dt} \qquad (1)$$

When the switch S_1 is open, the switch S_2 gets closed to carry inductor current and the equivalent circuit of fig 1(c) applies. The voltage across the inductor when the high-side MOSFET is open is,

$$V_L = -V_0 = -L\,{}^{di_L}/_{dt}$$

III.LED DRIVER CIRCUIT

LEDs are current driven source. Their brightness depends on current flowing through it. Let us consider a load of 9W LED.The LED selected is Edison C series 1W cool white LED. To get 9W power nine such 1W LEDs are arranged in series parallel connection such that three 1W LEDs are connected in series and three such branches are connected in parallel.

Each LED having forward voltage of 3.4V. Thus here the output voltage is 10.2V, since we used buck converter input voltage selected is 15V.

The characteristics of Edison LED obtained from datasheet are shown in Table I.

TABLE I LED PARAMETERS FROM EDISON C SERIES DATASHEET

Parameter	Value
DC Forward Current	350mA
Reverse Voltage	5V
Forward voltage	3.4V
Drive Voltage	5V
Viewing Angle	130º
Thermal resistance	10ºC/W
Max. Luminous Flux @ 350mA	130 lm
Colour	Cool white
LED Junction Temperature	125ºC
CRI	68

Input voltage, $V_{in} = 15V$

Output voltage across the string of LEDs = 3*3.2=10.2V

Output current across the string of LEDs = 3*350mA =1050mA

Output voltage ripple, $\frac{\Delta V_0}{V_0} = 10\%$

Switching frequency, $f_s = 25kHz$

Since the load is LED, the switching frequency should be greater than 100Hz so the human eye does not perceive flicker. Hence the value of switching frequency is fixed at 25 kHz.

Period, $T = \frac{1}{f_s} = 40\mu S$

Duty cycle, $D = 0.68$

Inductor current at boundary condition, $I_{LB} = I_{OB} = \frac{P_0}{V_0} = 0.882A$

$$\text{Inductance, L} \geq \frac{DT\,(V_s - V_0)}{2I_{OB}}$$

$$\geq \frac{0.68*40*10^{-6}*(15-10.2)}{2*0.882}$$

$$\geq 74.013*10^{-6} \geq 74\mu H$$

$$\text{Capacitance, } C \leq \frac{T^2(1-D)}{8L\frac{\Delta V_0}{V_0}} \leq \frac{(40*10^{-6})^2(1-0.68)}{8*112*10^{-6}*0.1}$$

$$\leq 8.647*10^{-6} \approx 9\mu F$$

IV.SIMULATION RESULTS

TABLE II SYSTEM PARAMETERS

Parameter	Value
Input Voltage(V_{in})	15V
Output Voltage(V_0)	10.2V
Inductor(L)	74µH
Capacitor(C)	9µF

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Case-1: Open loop Synchronous Buck converter

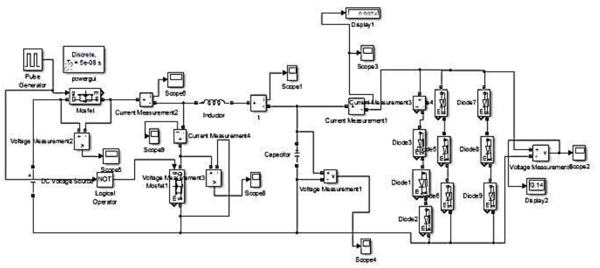

Fig.2Simulation model of Open loop Synchronous Buck converter

The simulation model of open loop synchronous buck converter is shown in Fig.2. Here the model is simulated with 15V supply voltage andthe output waveform is observed. The simulation model wasmade asper the system parameters given in Table II. In this model the diode in ordinary buck converter is replaced with a MOSFET.

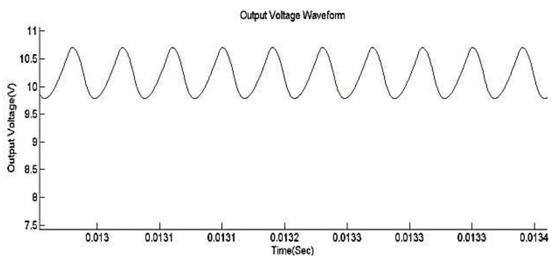

Fig.3 Simulation result of output voltage

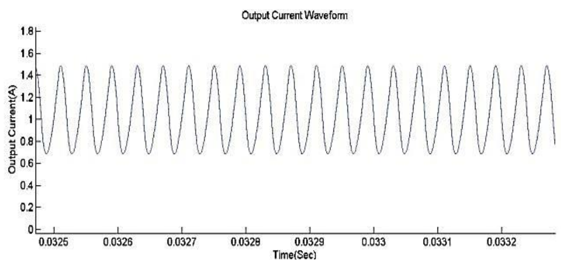

Fig.4Simulation result of output current

Fig.3 shows the simulation result of the voltage across the LED string which is about 10.2V. Fig.4 shows the simulation result of output current. Average output current of about 1050mA is observed.

The main disadvantages of open loop system are they are inaccurate and unreliable. They give inaccurate results because they cannot sense environmental changes and internal disturbances. To overcome these disadvantages, closed loop systems are used.

Case -2: Closed loop Synchronous Buck Converter

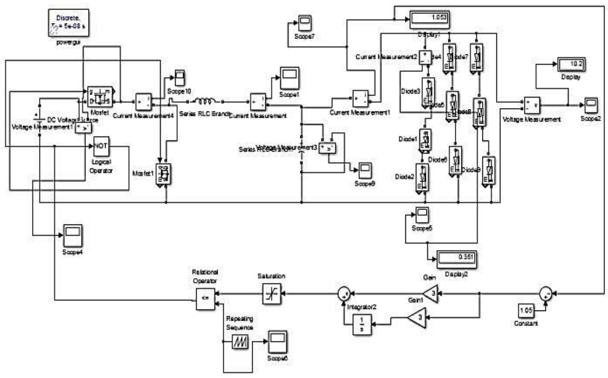

Fig.5 Simulation model of closed loop synchronous buck converter

Fig.5 shows the simulation model of closed loop synchronous buck converter. Here the model is simulated with 15V supply voltage and the output waveform is observed. The simulation model was made as per the system parameters given in Table II.

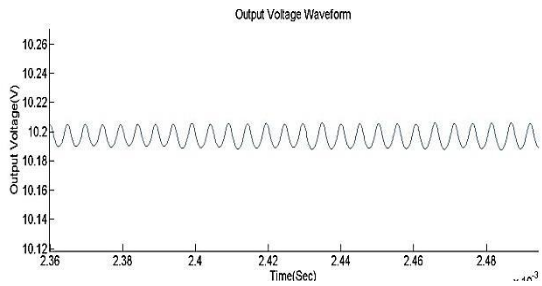

Fig.6 Simulation result of output voltage

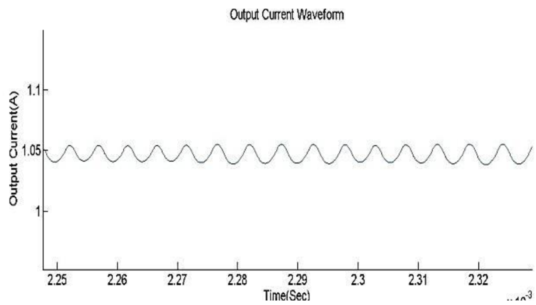

Fig.7 Simulation result of output current

Fig.6 shows the simulation result of the voltage across the LED string which is about 10.2V. Fig.7 shows the simulation result of output current. Average output current of about 1050mA is observed. Closed loop operation gives us much accurate result compare to the open loop operation.In closed loop systems controller modifies and manipulates the actuating signal such that error in the system will be zero. These system senses environmental changes, as well as internal disturbances. So accuracy of such system is always very high.

V. CONCLUSION

The design and analysis of synchronous buck converter for LED driver design is presented in this paper. The proposed converter can be used in low voltage high current applications. To increase efficiency synchronous buck converter is proposed. Modeling and simulation of proposed system is performed in MATLAB/SIMULINK environment.

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