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Integrated Double Buck–Boost Converter as a High-Power-Factor Driver for Power-LED Lamps

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Abstract: ***The IDBB converter features just one controlled switch and two inductors and is able to supply a solid-state lamp from the mains providing high power factor and good efficiency. And with a careful design of the converter the filter capacitances can be made small enough so that film capacitors may be used. Thus the converter mean time between failures can be made as high as that of the solid-state lamp. The integrated double buck–boost (IDBB) converter will power-LED lamps from the ac mains providing high power factor, low LED current ripple and high efficiency. The operation of the converter is equivalent to two buck–boost converters in cascade, in which the controlled switch is shared by the two stages.***

Keywords: LED lamps, high reliability, double buck-boost converter

1. Introduction

Light Emitting Diode lamps are popular due to its efficiency and many believe it is a new technology. The LED is a light source which uses semiconductors and electroluminescence to create light. The LED as we know it has been around for over fifty years. The resent development of white LED is what has brought it into the public eyes as a replacement for other white light sources. It has longer lifetime and has no poison mercury content compared with the conventional fluorescent lamps. However, powers LEDs are still far from being a panacea since they suffer from several drawbacks. First, due to their nearly constant-voltage behavior, they cannot be supplied from the dc or ac input voltage directly. Therefore, some kind of current-limiting device must be used, similarly to the ballast used to limit the current through a discharge lamp. On the other hand, the high efficiency of power LEDs is only maintained under strict operating conditions, which include low direct current and low junction temperature [6].

In Section II, the IDBB converter is presented. In Section III, analysis of IDBB converter is done. In section IV, design and simulation of IDBB converter is done. In section V simulation results of IDBB converter are given.

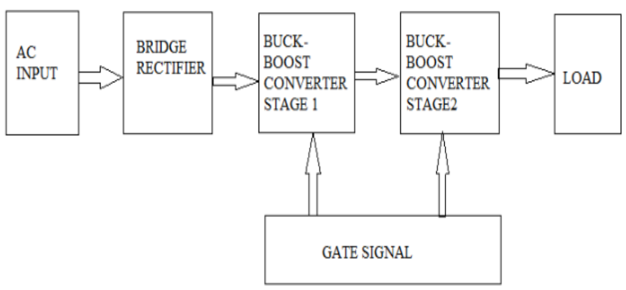

Figure 1: Block diagram of IDBB Converter

2. IDBB Converter

Fig. 1 shows the block diagram of an integrated double buck–boost (IDBB) converter. The IDBB converter is proposed to supply power-LED lamps from the ac mains, providing high power factor (PF), low LED current ripple, and high efficiency. The operation of the converter is equivalent to two buck–boost converters in cascade, in which the controlled switch is shared by the two stages. Thus the proposed converter includes two inductors, two capacitors, three diodes, and one ground-referenced controlled switch, featuring affordable low cost and good reliability for this kind of applications.

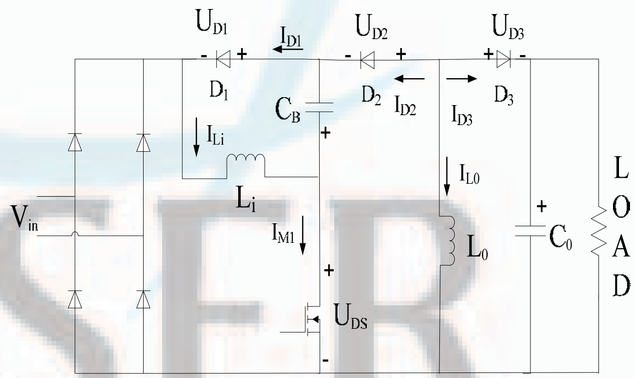

Figure 2: Electric diagram of the IDBB converter

Fig.2 shows the circuit diagram of an IDBB converter. As explained in the introduction, the converter behaves as two buck–boost converters in cascade. The input buck–boost converter is made up by L_i, D_1, C_B, and M_1, and the output buck–boost converter comprises L_O, D_2, D_3, C_O, and M_1. The reversing polarity produced by the first converter in the capacitor C_B is corrected by the second converter, given a positive output voltage with respect to ground. This simplifies the measurement of the load current for closed-loop operation, thus reducing sensing circuitry and cost.

The input inductor Li is operated in discontinuous conduction mode (DCM), the average current through the line will be proportional to the line voltage, therefore providing a near unity PF. On the other hand, the output inductance L_O can be operated either in continuous conduction mode (CCM) or DCM. The operation in DCM has the advantage of providing a bus voltage across C_B independent of the duty cycle and output power. However, it presents the disadvantage of requiring a higher value of the output capacitance to achieve low current ripple through the load.

The output inductor is operated in CCM in order to have a reduced value for the output capacitance, because the current ripple is lower in this operation mode. In addition, the operation of the second stage in CCM with a duty cycle lower than 0.5 reduces the low-frequency ripple voltage since it is multiplied by the buck–boost converter voltage ratio. In this way, it will be possible to use a film capacitor to implement the output capacitance, thus having a higher life rating and better efficiency than using electrolytic capacitors.

3. Analysis of IDBB Converter

In this section the analysis of IDBB converter is done. Equivalent circuits for the operation of IDBB converter within a switching period are shown. There are three operating periods.

3.1 Interval I [$0<t< DT_s$]

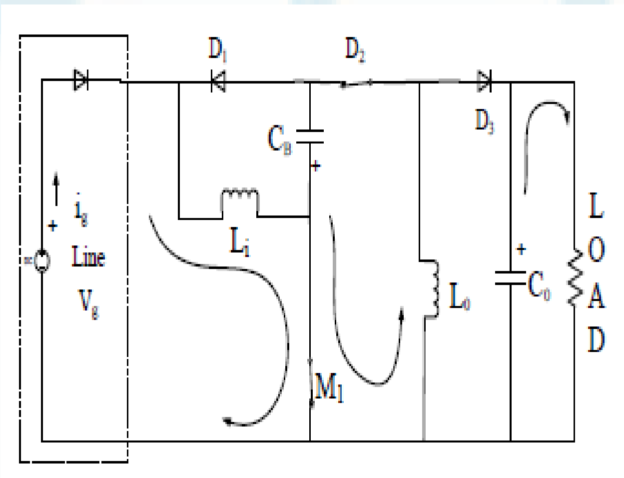

Figure 3: Equivalent circuit for interval I

In this interval, switch is ON, the input inductor L_i is charged to V_{Li}, such that $V_{Li} = V_g$. At that time the capacitor C_B is discharged through L_0 and D_2 , such that $V_{L0} = V_{CB}$. And output voltage V_0 is supplied by the output capacitor C_0

3.2 Interval II

In interval II [$DT_s<t<DT_s+t_1$], the switch is turned OFF the input inductor L_i discharges to C_B through D_1. The charge stored in the output inductor L_0 is given to output capacitor C_0 and load through diode D_3.

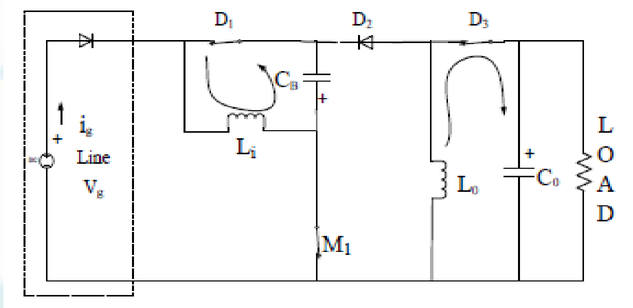

Figure 4: Equivalent circuit for interval II

3.3 Interval III

In the third interval [$DT_s+t_1<t<T_s$], the switch remain OFF. The input inductor completely discharges. And input inductor current becomes zero. The diode is turned OFF. The charge stored in the output inductor is given to the output capacitor and load through the diode.

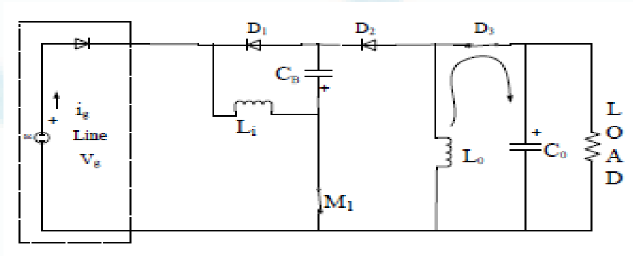

Figure 5: Equivalent circuit for interval III

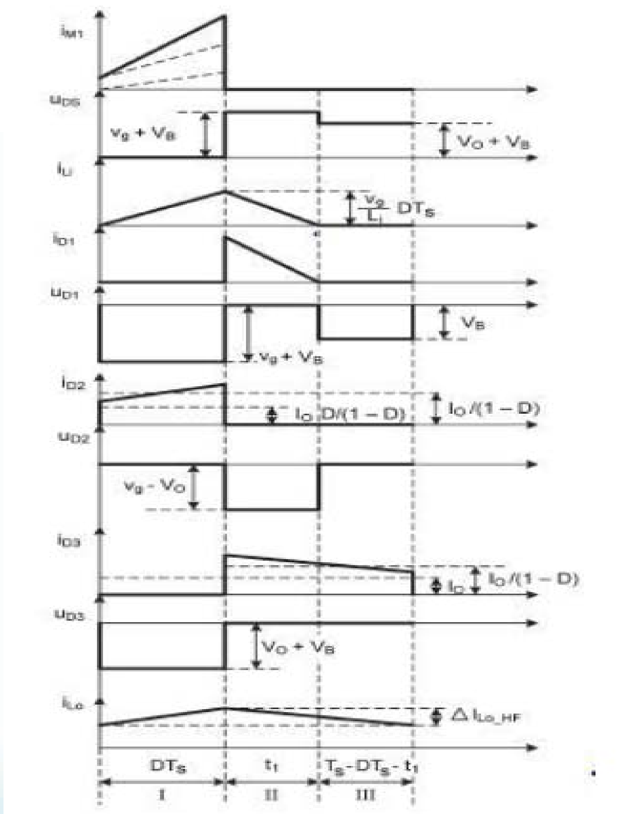

Figure 6: Main waveforms of the IDBB converter within a high frequency switching period

4. Design

The design of the converter is as shown in the following sections.

4.1 Output and Bus Voltages

The output voltage is obtained as follows

$$V_o = \frac{DV_g}{2\sqrt{K}} \quad (1)$$

When k is a factor given by

$$K = \frac{f_s \times L_i}{R} \quad (2)$$

Since the output stage corresponds to a buck–boost converter operating in CCM, bus voltage V_B can be calculated by using the voltage conversion ratio for this converter

$$V_B = \frac{1-D}{D} V_0 = \frac{(1-D)V_g}{2\sqrt{K}} \quad (3)$$

It must be noted that the input stage must be operated in DCM under any load and input voltage conditions to assure high input PF. The limit duty cycle D_{limit} can be obtained from the voltage conversion ratio in the DCM–CCM boundary

$$D_{limit} = \frac{1}{1 + V_g / V_B} \quad (4)$$

Substituting equation (4) in equation (3) we get the bus voltage =255V and substituting this value in equation (4) we get duty cycle as 0.43 and we select D=0.4.

The non dimensional factor K is obtained by substituting the value of D in equation (2), and we get K=0.1058. Substituting the value of K in equation (1), we get the value of output voltage 200V.

4.2 Reactive Component

The input inductance Li can be calculated for a given output power using (3.2) and assuming 100% efficiency.

$$L_i = \frac{D^2 V_g^2}{4P_o f_s} \quad (5)$$

We get input inductor 1.2mH and we select 0.4mH. The necessary bus capacitance for a given peak-to-peak ripple in the bus voltage is then calculated from as follows.

$$C_B = \frac{D^2 V_g^2}{8\pi\pi \times L_i \Delta V_{B\text{-}LF} f_s f_L} \quad (6)$$

From the above relation, bus capacitance is obtained as 80mF.

Finally, the output inductance and capacitance L_0 and C_0 are obtained using the well-known expressions for a buck–boost converter operating in CCM.

$$L_0 = \frac{DV_B}{0.5\Delta_{L_0\text{-HS}} f_s} \quad (7)$$

$$C_0 = \frac{DI_0}{\Delta V_{0\text{-HF}} f_s} \quad (8)$$

The output inductance is obtained as 7.0mH and output capacitance as 40 mF.

Table 1: Parameters of IDBB Converter

Input Voltage	230V
Input Inductance	80mH
Input Capacitance	0.4mF
Output Inductance	7.0mH
Output Capacitance	40mF
Resistance	577ohm

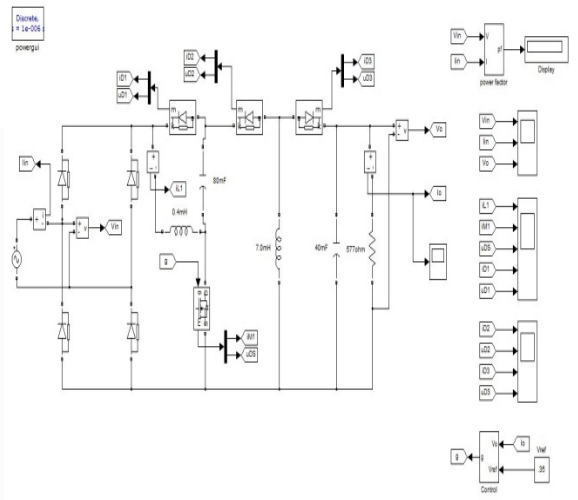

Figure 7: Simulation of IDBB converter

5. Simulation Results

The Integrated Double Buck-Boost Converter was simulated using MATLAB/SIMULINK and the resulting waveforms are as shown below.

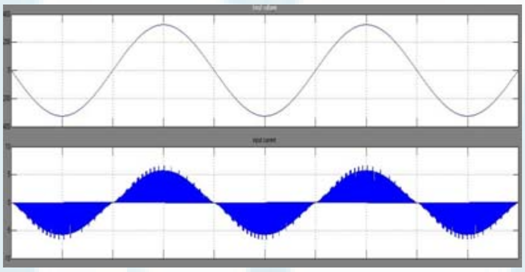

Figure 8: Input voltage and input current waveform.

The output voltage waveform is shown in Fig. 9. The output voltage is 200V.

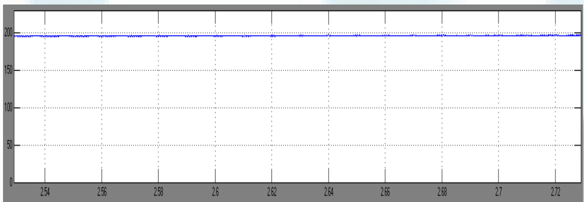

Figure 9: Output voltage waveform

The output current waveform is shown in Fig. 10. The output current is 0.35A.

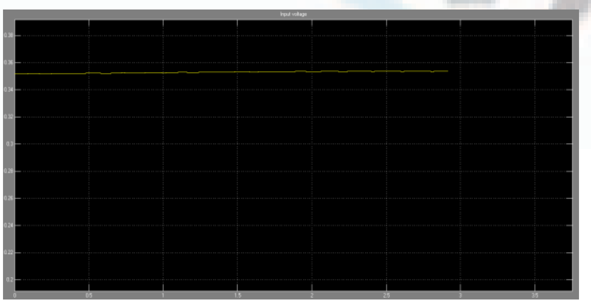

Figure 10: Output current waveform

6. Conclusion

An IDBB converter has been investigated to supply power for LED lighting applications. The two buck– boost converter is cascaded but using only one controlled switch. By operating the input converter in DCM, a high input PF can be obtained. On the other hand, the operation of the second stage in CCM assures a low-ripple current through LED load without using a very high output capacitance. In this way, the converter can be implemented using only film capacitors, avoiding the use of electrolytic capacitors and increasing the converter mean time between failures. Thus the proposed converter can provide high power factor and good efficiency.

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