

High Voltage-Boosting Converter with Improved Transfer Ratio

Rahul V. A. *, Denita D'Souza, Subramanya K.

Department of E & E, St Joseph Engineering College, Mangalore, India

Abstract In this paper, a novel high voltage-boosting converter is presented. This converter is constructed based on parallel and series combination of bootstrap capacitors and boost inductors during charging and discharging respectively. The proposed converter gives the output voltage 160 V DC from 24 V DC at duty cycle of 65%. The proposed converter gives a high efficiency, low output ripple and high transformation ratio by reducing the conduction losses and switching losses. Simulation of the circuit is obtained in MATLAB/Simulink.

Keywords Voltage-Boosting Converter, Voltage Conversion Ratio, Bootstrap Capacitors, Boost Inductors

1. Introduction

Boost converter are widely used in industry for the following applications such as discharge lamp driver, UPS, Motor drivers, and PV system [1, 2]. The boost converter or step up converters is simple in structure, but the voltage conversion ratio is less, whereas the fly-back converter possesses a high voltage conversion ratio but the corresponding leakage reactance is large. The voltage conversion ratio can be improved when the number of inductor in the circuit is increased, and these inductors are connected in series during their demagnetizing period [3, 4].

Normally isolated boost converters boosts the voltage to much higher voltages with wide input ranges typically in the range of 30-60V. Since the DC-AC converter operates at high voltage and is widely used in high power applications such as in UPSs, motor drives, solar converters etc., it is required to have low voltage to high voltage DC-DC converter with high efficiency.

High boosted output voltage is obtained by discharging the energy stored in the inductor and capacitor along with input voltage into the output terminals. In this paper, a brief illustration of the operation of high voltage boosting converter is given along with some simulation results provided to demonstrate the effectiveness of such converters. In [5-8], high voltage conversion ratios are achieved by coupling inductors, but the voltage spikes due to the accompanying leakage inductances and the complexity in the corresponding circuit analysis are unavoidable.

2. Proposed Converter Topology

In this paper a new high voltage boosting converter is proposed. The circuit is shown in figure 1.

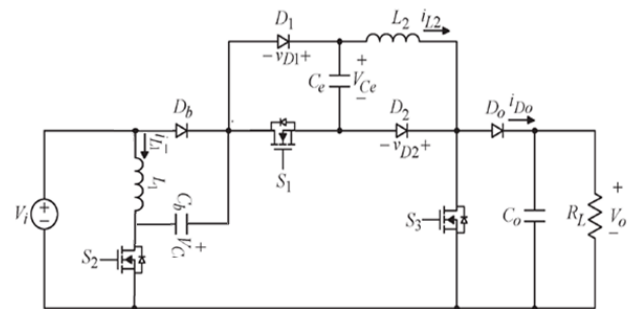


Figure 1. Proposed High voltage boosting converter

The converter contains three MOSFET switches S_1 , S_2 , and S_3 , two bootstrap capacitors C_b and C_e , three bootstrap diodes D_b , D_1 , and D_2 , one output diode D_o , two inductors L_1 and L_2 , one output capacitor C_o , and one load resistor R_L . In addition, the input voltage is signified by V_i , the output voltage is represented by V_o .

3. Basic Operating Principles

3.1. Continuous Current Mode Operation

Figure 2 shows the illustrated necessary waveforms of v_{gs1} , v_{gs2} , v_{gs3} , v_{L1} , v_{L2} , i_{L1} , and i_{L2} for the proposed circuit operated in CCM with L_1 equal to L_2 .

3.1.1 Mode 1 [$t_0 - t_1$]: The current flow in the proposed circuit during mode 1 in CCM is shown in figure 3. As in the

* Corresponding author:

rahulva11@gmail.com (Rahul V. A.)

Published online at <http://journal.sapub.org/eee>

Copyright © 2017 Scientific & Academic Publishing. All Rights Reserved

figure in mode 1, S_2 and S_3 are turned on, but S_1 is turned off. Diode D_o is reverse biased, but D_b , D_1 and D_2 are forward biased. The capacitor C_b and the inductor L_1 charges through switch S_2 . And the capacitor C_e and the inductor L_2 charges through switch S_3 . The capacitor voltages abruptly reach to its peak value V_i . At the same time, the voltages across L_1 and L_2 both are V_i , thereby causing L_1 and L_2 to be magnetized. Also, C_o releases energy to the output.

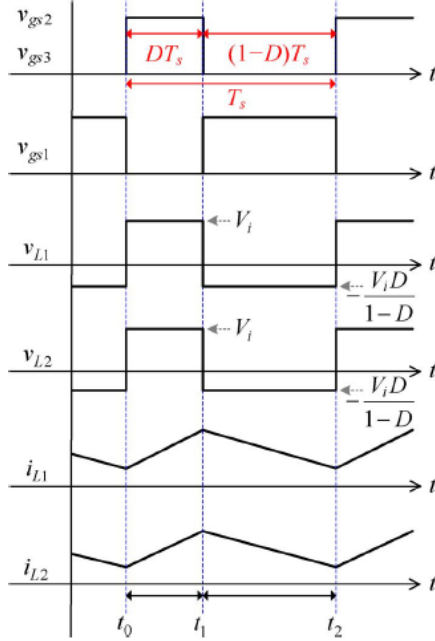


Figure 2. Waveforms of CCM operation

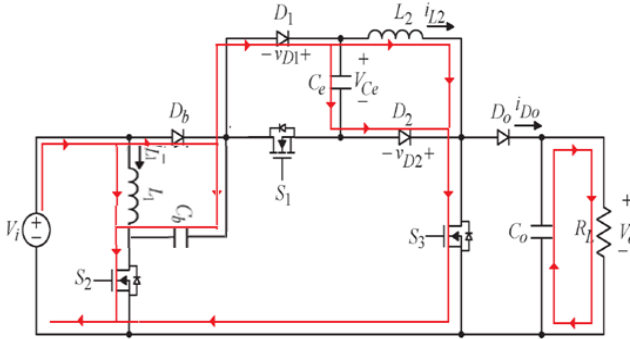


Figure 3. Operation of the proposed circuit in mode 1

In this mode, the voltages across L_1 and L_2 , v_{L1-ON} and v_{L2-ON} , can be written as

$$V_{L1\ on} = V_i \quad (1)$$

$$V_{L2\ on} = V_i \quad (2)$$

3.1.2 Mode 2 [t_1 - t_2]: Mode 2 operation is shown in figure 4. The switches S_2 and S_3 are turned off, but S_1 is turned on. At the same time, the input voltage plus the energy stored in C_b and C_e plus the energy stored in L_1 and L_2 supplies the load, thereby causing C_o to be charged, C_b and C_e to be discharged, and L_1 and L_2 to be demagnetized. By doing so, the output voltage is boosted up, and is higher than the input

voltage. According to the voltage-second balance, the voltages v_{L1-OFF} , v_{L2-OFF} , and V_o can be expressed as

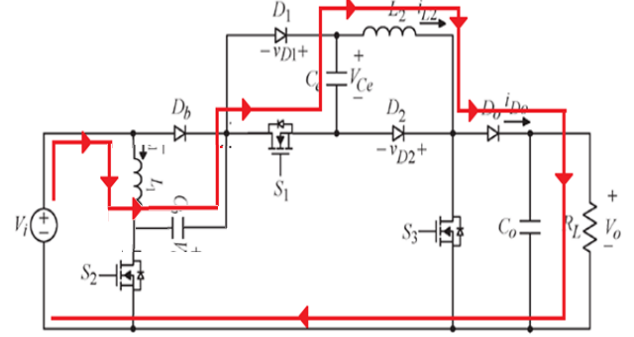


Figure 4. Operation of the proposed circuit in mode 2

$$V_{L1\ off} = \frac{-D}{1-D} V_{L1\ on} \quad (3)$$

$$V_{L2\ off} = \frac{-D}{1-D} V_{L2\ on} \quad (4)$$

$$V_o = -V_{L1\ off} - V_{L2\ off} + V_i + V_{Ce} + V_{Cb} \quad (5)$$

Since $V_{Ce} = V_{Cb} = V_i$, and from equation (1)-(4), Equation (5) can be written as

$$V_o = \frac{D}{1-D} V_i + \frac{D}{1-D} V_i + 3V_i \quad (6)$$

CCM voltage conversion ratio is then given by:

$$V_o = \frac{3-D}{1-D} V_i \quad (7)$$

3.2. Discontinuous Conduction Mode Operation

Figure 5 shows the illustrated key waveforms v_{gs1} , v_{gs2} , v_{gs3} , v_{L1} , v_{L2} , i_{L1} , and i_{L2} for the circuit operated in DCM with L_1 equal to L_2 .

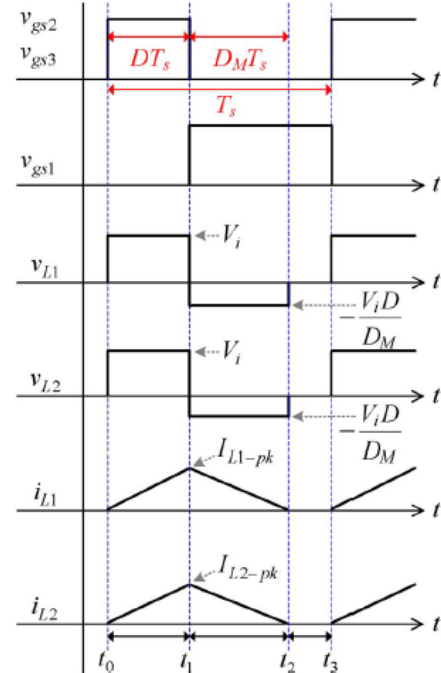


Figure 5. Waveforms during DCM mode operation

3.2.1 Mode 1 [t_0 - t_1]: In this mode, the operating principle is the same as that of circuit operated in CCM in mode 1. Hence, the associated equations can be written as

$$V_{L1\ on} = V_i$$

$$V_{L2\ on} = V_i$$

$$I_{L1\ peak} = \frac{V_i}{L_1} DT_s \quad (8)$$

$$I_{L2\ peak} = \frac{V_i}{L_2} DT_s \quad (9)$$

Since L_1 is equal to L_2 and set to L ,

$$I_{peak} = I_{L1\ peak} = I_{L2\ peak} = \frac{V_i}{L}DT_s \quad (10)$$

3.2.2 Mode 2 [t_1 - t_2]: In this mode, the circuit operates same as CCM in mode 2. Therefore, the related equations can be written as

$$V_{L1\ off} = \frac{-D}{D_M} V_{L1\ on} = \frac{-D}{D_M} V_i \quad (11)$$

$$V_{L2\ off} = \frac{-D}{D_M} V_{L2\ on} = \frac{-D}{D_M} V_i \quad (12)$$

3.2.3 Mode 3 [$t_2 - t_3$]: In this mode, all the switches and diodes are turned off, and the currents in two inductors are zero. Hence, the energy needed by the load is supplied from Co . The output voltage is expressed as

$$V_o = -V_{L1\ off} - V_{L2\ off} + V_i + V_{Ce} + V_{Cb} \quad (13)$$

Since $V_{Ce} = V_{Cb} = V_i$, and from equation (11) (12)

$$V_o = \frac{D}{D_M} V_i + \frac{D}{D_M} V_i + 3V_i \quad (14)$$

Simplifying the above equation results

$$V_o = \left(\frac{2D}{D_M} + 3\right) V_i \quad (15)$$

4. Simulation Results

The circuit simulated in SIMULINK/MATLAB in open loop. The various parameters given according to design as explained earlier are shown in Table 1.

Table 1. Simulation Parameters

Parameters	Value
Input Voltage	24V
Output Voltage	161V
Switching Frequency	200KHz
Inductors (L1=L2)	0.170mH
Bootstrap Capacitors	300μF
Load resistance	400Ω
Output Capacitor	1000μF
Capacitor C2	300μF

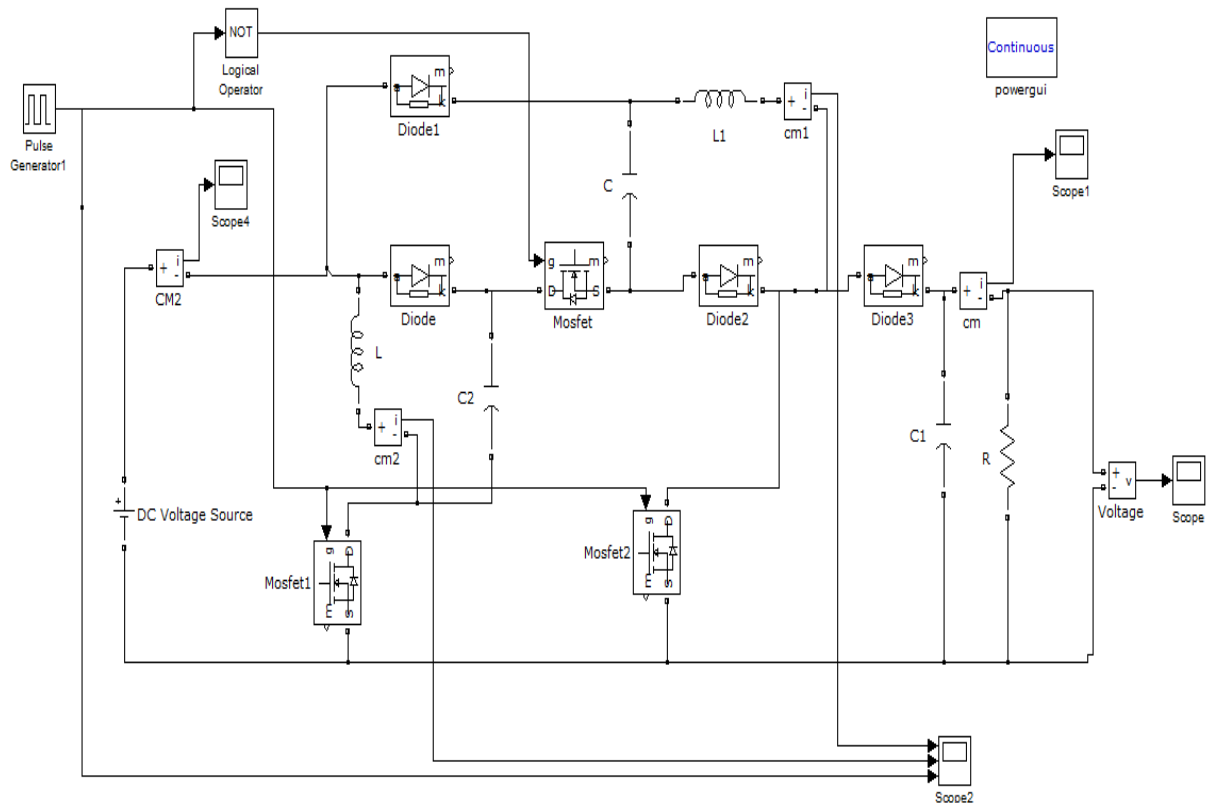


Figure 6. MATLAB simulation of proposed topology

The simulated circuit in MATLAB/SIMULINK is shown in Fig.6. The input DC voltage is given using DC voltage supply block. There are three switching MOSFETs in the circuit. Gating pulses are given to the switches using pulse generator. The signals so formed are given to a scope to be verified. The input voltage, output currents, current through the inductors, voltage across the output load is analyzed.

4.1. Input Voltage

DC voltage of 24V is given to the converter input terminals.

4.2. Output Voltage

The output voltage obtained is as shown in Fig.7. The output voltage of 155 V is obtained and the ripple content in the output voltage is very low. The model is simulated by setting duty ratio as 0.65 to achieve this boosting.

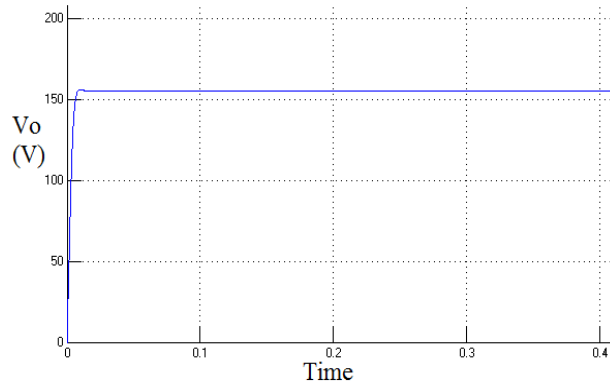


Figure 7. Output voltage waveform

4.3. Output Current

The output current obtained is as shown in Fig 8. The output current of 0.38A is obtained.

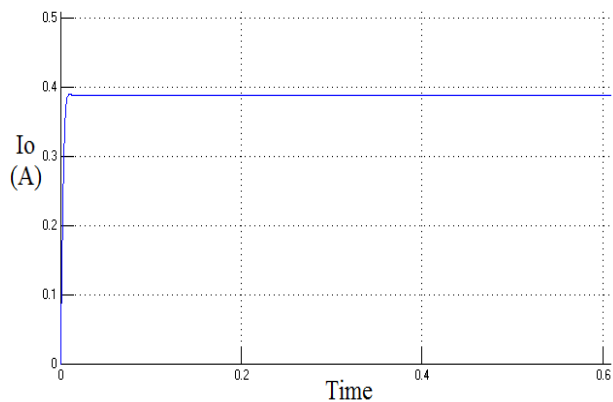


Figure 8. Output current waveform

4.4. Inductor Current and Gate Pulse

The inductor current and gate pulse waveform when $L1=L2$ is shown in Fig.9. Here the inductors are of same value. The inductor and current waveform when $L1>L2$ is shown in Fig.10.

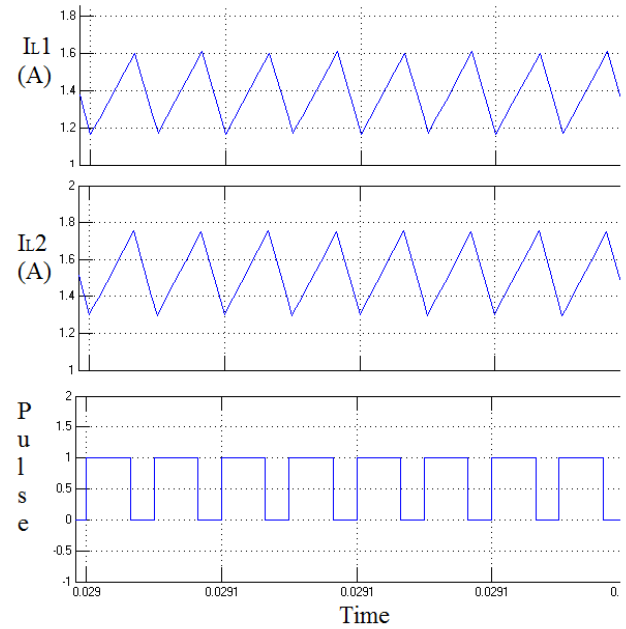


Figure 9. Inductor current and gate pulse ($L1=L2$)

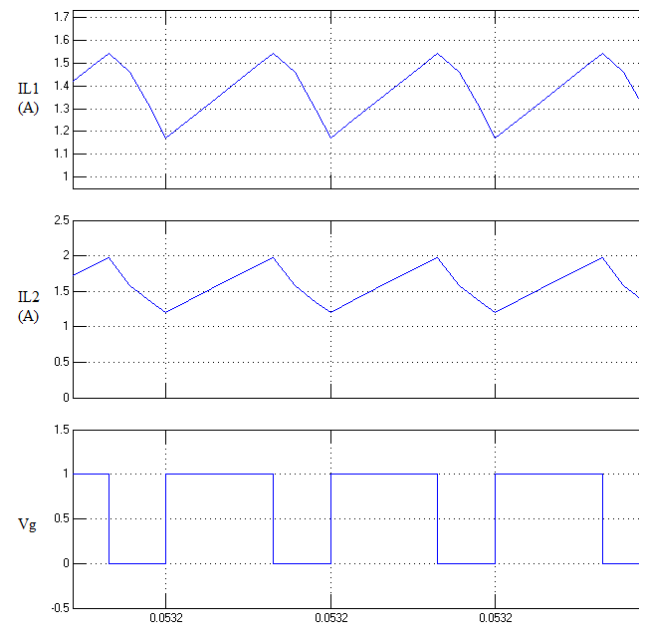


Figure 10. Inductor current and gate pulse ($L1>L2$)

5. Conclusions

A high voltage boosting converter based on inductors connected in series with bootstrap capacitors is proposed in this paper. From the experimental results, such converters exhibit good performances even with different inductances, and hence are suitable for industrial applications, such as the energy-recycling burn-in test of the buck-type converter, isolated or non-isolated. From the detailed simulations an experimental analysis, it is clear that the presented converters have the following advantages.

1. The proposed system is simple and easily constructed to achieve expected voltage conversion ratios with less loss.
2. For each converter, the power switches are easy to drive, as this converter only needs one PWM control signal to drive all three switches making its controlling simple.
3. From the simulation results, such converters exhibit good performances even with different inductances, and hence are suitable for industrial applications.
4. Proposed converters need lesser components making it less weight, low cost and compact.

REFERENCES

- [1] W. Li and X. He, "Review of no-isolated high step-up dc/dc converters in photovoltaic grid-connected applications," *IEEE Trans. Ind. Electron.*, vol. 58, no. 4, pp. 1239–1250, Apr. 2011.
- [2] H. Tao, J. L. Duarte, and M. A.M. Hendrix, "Line-interactive UPS using a fuel cell as the primary source," *IEEE Trans. Ind. Electron.*, vol. 55, no. 8, pp. 3012–3021, Aug. 2008.
- [3] D. Nicolae, C. Richards, and J. van Rensburg, "Boost converter with improved transfer ratio," in *Proc. IEEE IPEC*, 2010, pp. 76–81.
- [4] B. Axelrod, Y. Berkovich, and A. Ioinovici, "Switched-capacitor/ switched-inductor structures for getting transformerless hybrid dc-dc PWMconverters," *IEEE Trans. Circuits Syst. I, Reg. Papers*, vol. 55, no. 2, pp. 687–696, Mar. 2008.
- [5] K. I. Hwu and Y. T. Yau, "Voltage-boosting converter based on charge pump and coupling inductor with passive voltage clamping," *IEEE Trans. Ind. Electron.*, vol. 57, no. 5, pp. 1719–1727, May 2010.
- [6] K. C. Tseng and T. J. Liang, "Novel high-efficiency step-up converter," *Proc. Inst. Elect. Eng.—Elect. Power Appl.*, vol. 151, no. 2, pp. 182–190, Mar. 2004.
- [7] W. Li and X. He, "A family of isolated interleaved boost and buck converters with winding-cross-coupled inductors," *IEEE Trans. Power Electron.*, vol. 23, no. 6, pp. 3164–3173, Nov. 2008.
- [8] K. B. Park, H. W. Seong, H. S. Sim, G. W. Moon, and M. J. Youn, "Integrated boost-sepic converter for high step-up applications," in *Proc. IEEE PESC*, 2008, pp. 944–950.