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Boost Converter with Improved Voltage Conversion Ratio Using Bootstrap Capacitors and Boost Inductors

[1]Vinny Babu, [2]Prof. Bindu Elias and [3]Dr. Bose Mathew Jose
[1]PG Scholar, *Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala*
[2,3]Professor, *Department of Electrical and Electronics Engineering, Mar Athanasius College of Engineering, Kothamangalam, Kerala*

ABSTRACT
In this paper, a high voltage boosting converter based on bootstrap capacitor and boost inductor is designed for improving the voltage conversion ratio. This is based on the fact that the number of inductors and capacitors are increased, and these inductors and capacitors are connected in series during the demagnetizing period, thereby pumping the energy created by the input voltage and the energy stored in the inductors into the output terminal. By changing the connection position of the anode of the diode and by using different pulse-width-modulation control strategies, different voltage conversion ratios can be obtained. The boost converter is controlled by PID controller. This makes a very high voltage conversion ratio than existing methods. Simulation study has been carried out in MATLAB/Simulink.
Keywords: *Boost converter, bootstrap capacitor, improved high voltage boosting converter, voltage conversion ratio*

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I. INTRODUCTION

As generally recognized, step-up converters have been widely used in many applications, such as battery powering device, uninterruptible power supply (UPS), photovoltaic (PV) system, etc. requiring some circuits transferring low voltages to high voltages used as input voltages for dc to ac converters. For the applications of the power supply using the low voltage battery, analog circuits, such as RF amplifier, audio amplifier[2], etc., often need high voltage to obtain enough output power and voltage amplitude. This is achieved by boosting the low voltage to the required high voltage. Therefore, in many 3C (consumer, communications, computer) electronics, some converters are needed to supply one boosted voltage or more under a given low voltage, especially for portable communications systems, such as MPEG-3 (MP3) players, Bluetooth devices, personal digital assistant, etc.

A voltage-boosting converter, named as KY converter, provides low output voltage ripple and is very suitable for supplying power to devices that must operate under low-ripple conditions [5]. In order to enlarge the output voltages, additional components are added to KY converter. KY converter always operates in continuous conduction mode (CCM). However, its ratio of the output voltage to the input voltage is one plus D, where D is the duty cycle of the main switch. In certain converter topologies, a method of improving the voltage conversion ratio is based on the fact that number of inductors is increased, and these inductors are connected in series during the demagnetizing period, thereby pumping the energy created by the input voltage and the energy stored in the inductors into the output terminal to obtain the high voltage conversion ratio [6].

II. IMPROVED HIGH VOLTAGE BOOSTING CONVERTER

A high voltage DC-DC boosting converters based on bootstrap capacitors and boost inductors with high voltage conversion ratio. The converter based on the charge pump of the KY converter and the series boost converter.

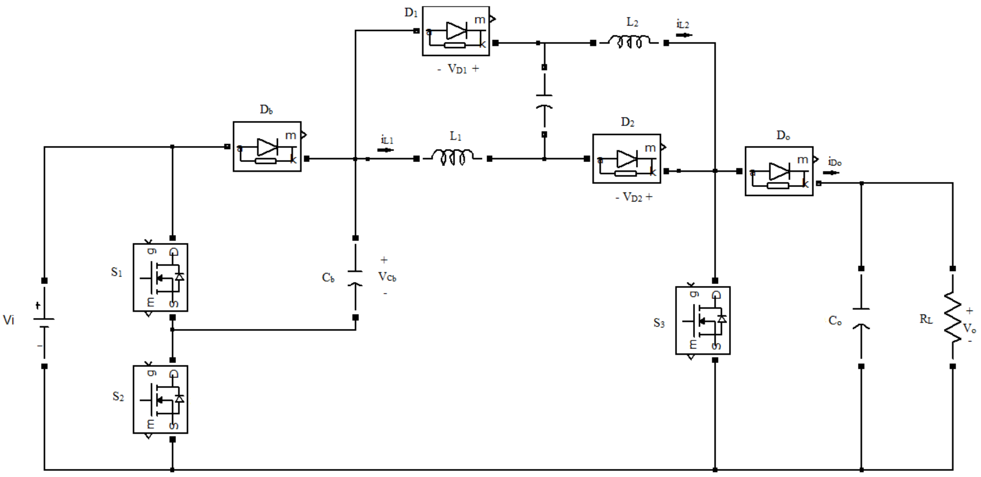

Fig.1. High Voltage Boosting Converter

Fig. 1.shows the high voltage boosting converter. In this circuit, diode D_1 is connected to the cathode of diode D_b. The conversion ratio in CCM is (3+D)/(1-D). This converter contains three MOSFET switches S_1, S_2, S_3, two bootstrap capacitors C_b and C_e, three bootstrap diodes D_b, D_1, D_2, One output diode D_o, two inductors L_1 and L_2, one output capacitor C_o, and one output resistor R_L. Fig. 2. shows the improved high voltage boosting converter. But in the case of improved high voltage boost converter contains five MOSFET switches S_1, S_2, S_3, S_4 and S_5, three bootstrap capacitors C_{b1}, C_{b2} and C_e, four bootstrap diodes D_{b1}, D_{b2}, D_1 and D_2. The input and output voltage is signified by V_i and V_o respectively. The voltage across C_{b1}, C_{b2}, C_e, D_1 and D_2 are shown by V_{cb1}, V_{cb2}, V_{ce}, V_{D1}, and V_{D2}, respectively. The currents flowing through L_1, L_2 and D_o are denoted by i_{L1}, i_{L2} and i_{Do} respectively.

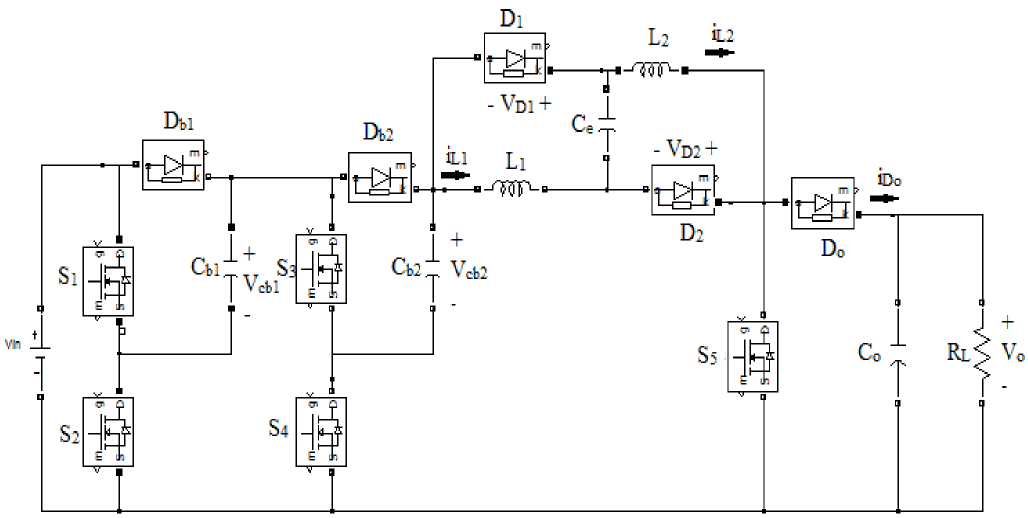

Fig. 2. Improved High Voltage Boosting Converter

2.1. Basic Operating Principle

Mode 1 [t_0-t_1]: As shown in Fig.3. the switches S_1, S_3 and S_5 are turned on, but S_2 and S_4 are turned off. D_o is reverse biased due to S_5 being turned on but D_1 and D_2 are forward biased, thereby causing C_e to be abruptly charged to V_i plus $2V_{cb}$. Due to S_1 being turned on, D_{b1} is reverse biased, thereby causing C_{b1} to be discharged. D_{b2} is reverse biased due to S_3 being turned on, thereby causing C_{b2} to be discharged. The voltages across L_1 and L_2 are V_i plus V_{cb}, thereby causing L_1,and L_2 to be magnetized and C_o releases energy to the output.

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

$$V_{L1-ON} = V_i + V_{Cb1} + V_{Cb2} \qquad (1)$$

$$V_{L2-ON} = V_i + V_{Cb1} + V_{Cb2} \qquad (2)$$

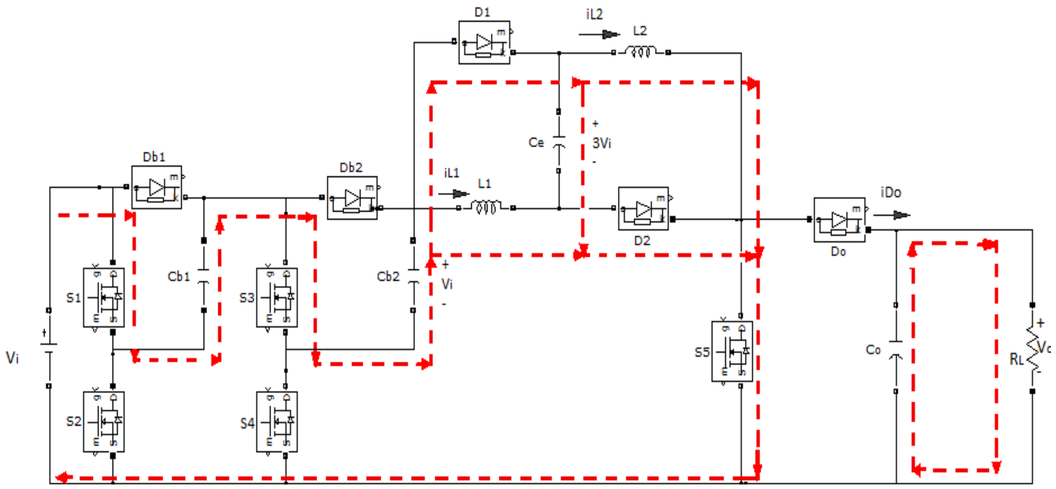

Fig. 3. Power flow of Improved High Voltage Boosting Converter operated in mode 1

Mode 2 [t_1-t_2]: As shown in fig.4.below, S_1, S_3 and S_5 are turned off, but S_2 and S_4 are turned on. Due to S_2 being turned on, D_{b1} is forward biased, thereby causing C_{b1} to be abruptly charged to V_i. Due to S_4 being turned on, D_{b2} is forward biased, thereby causing C_{b2} to be abruptly charged to V_i. At the same time, V_i plus the energy stored in C_e, plus the energy stored in L_1 and L_2 supplies the load. The output voltage is boosted up and is much higher than the input voltage.

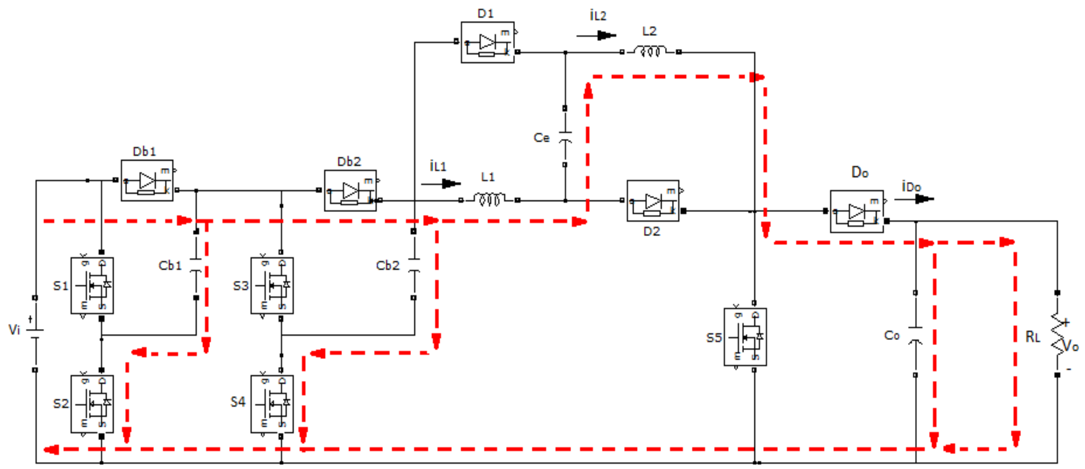

Fig. 4. Power flow of Improved High Voltage Boosting Converter operated in mode 2

According to the voltage-second balance, the voltages V_{L1-OFF} , V_{L2-OFF} , and V_o in this mode can be expressed to be

$$V_{L1-OFF} = \frac{-D}{1-D} V_{L1-ON} \qquad (3)$$

$$V_{L2-OFF} = \frac{-D}{1-D} V_{L2-ON} \qquad (4)$$

$$V_o = -V_{L1-OFF} - V_{L2-OFF} + V_i + V_{Ce} \qquad (5)$$

Since V_{Cb} and V_{Ce} are equal to V_i and $3V_i$, respectively, (1), (2), and (5) can be rewritten as

$$V_{L1-ON} = V_{L2-ON} = 3V_i \qquad (6)$$

$$V_o = -V_{L1-OFF} - V_{L2-OFF} + 4V_i \qquad (7)$$

By substituting (6) into (3) and (4), V_{L1-OFF} and V_{L2-OFF} can be rewritten to be

$$V_{L1-OFF} = V_{L2-OFF} = \frac{-D}{1-D} 3V_i \qquad (8)$$

Substituting (8) into (7) yields the following CCM voltage conversion ratio:

$$\frac{V_o}{V_i} = \frac{4+2D}{1-D} \qquad (9)$$

III. SIMULATION MODELS AND RESULTS

Table1. Simulation Parameter of Improved High Voltage Boosting Converter

Parameters	Values
Input Voltage	24 V
Switching Frequency	195 kHz
Inductors (L_1 & L_2)	170 µH
Bootstrap Capacitors (C_{b1} & C_{b2})	100 µF
Output Capacitor (C_o)	680 µF
Capacitor (C_e)	220 µF
Load Resistance (R_L)	400 Ω
Duty Ratio	0.6
Output Voltage	280 V

Fig.5. shows the simulation diagram of closed loop control of improved high voltage Boosting converter. in the case of improved high voltage boost converter contains five MOSFET switches S_1, S_2, S_3, S_4 and S_5, three bootstrap capacitors C_{b1}, C_{b2} and C_e, four bootstrap diodes D_{b1}, D_{b2}, D_1 and D_2. The input and output voltage is signified by V_i and V_o respectively. The voltage across C_{b1}, C_{b2}, C_e, D_1 and D_2 are shown by V_{cb1}, V_{cb2}, V_{ce}, V_{D1}, and V_{D2}, respectively. The currents flowing through L_1, L_2 and D_o are denoted by i_{L1}, i_{L2} and i_{Do} respectively. In this circuit, PID control method is applied to control the duty ratio of switches. The input to the converter is fed from 24 V DC supply. By using PID controller, output voltage is maintained at 280 V DC at duty ratio 0.6.

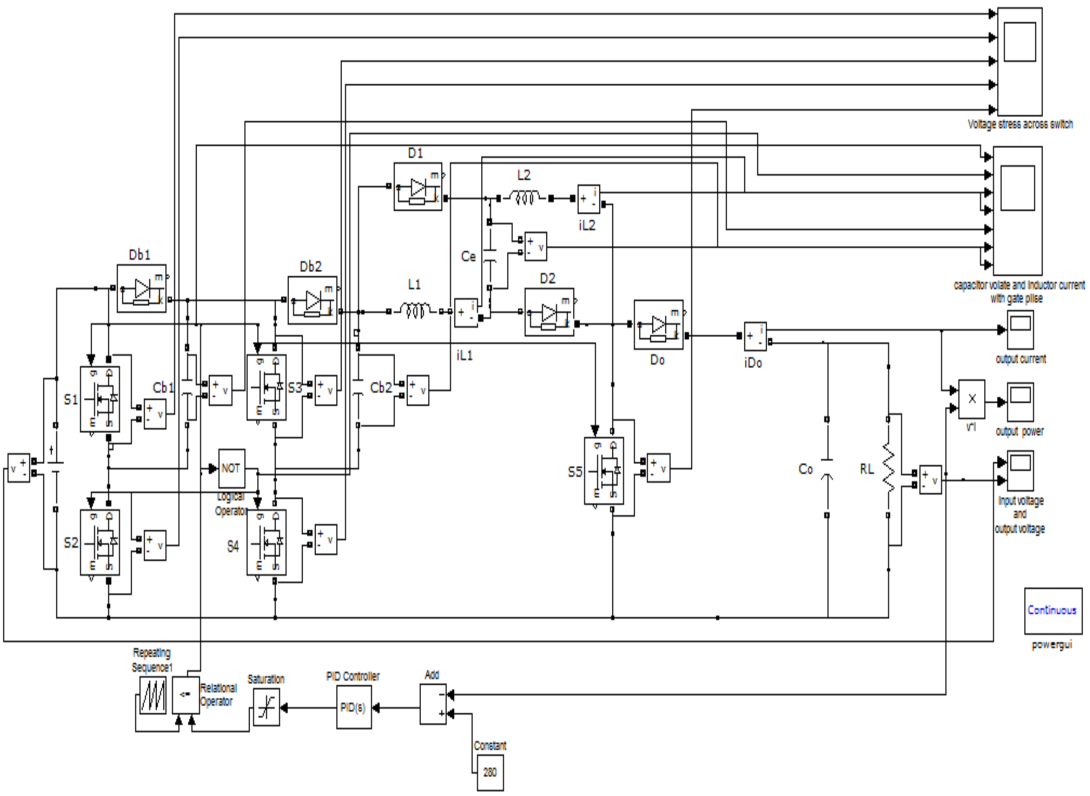

Fig. 5. Simulation Circuit of Improved High Voltage Boosting Converter

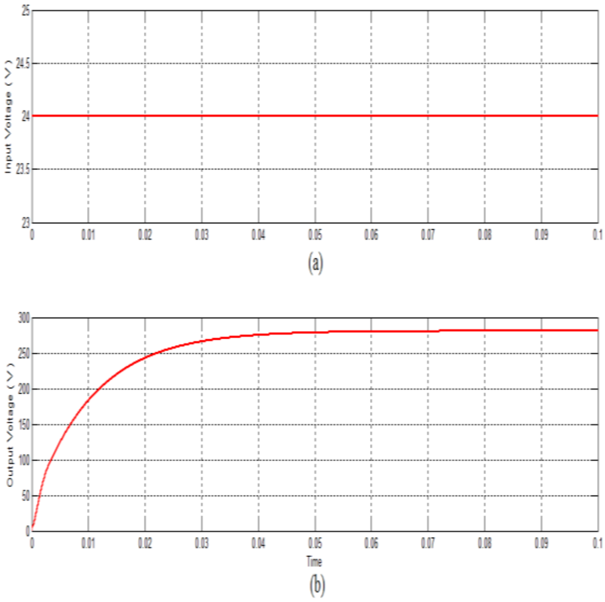

Fig.6. Input and Output Voltage waveform

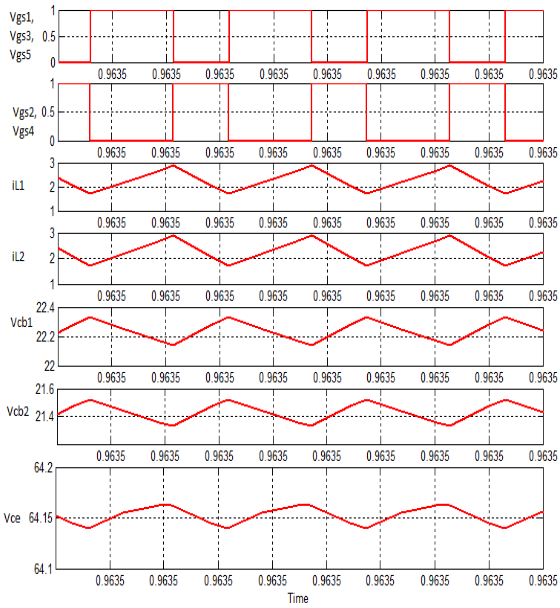

Fig.7. Inductor Current and Capacitor Voltage waveform

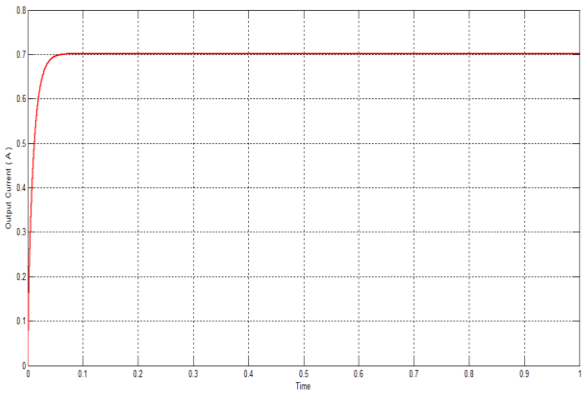

Fig.8. Output Current waveform

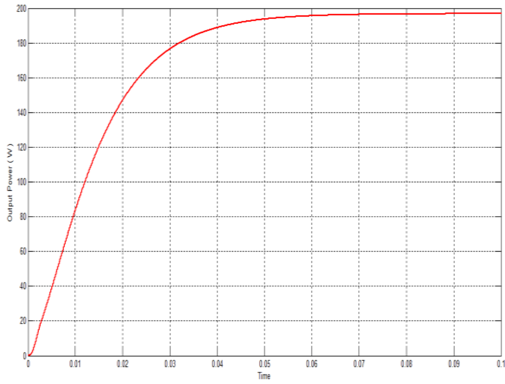

Fig.9. Output Power waveform

Fig.6. shows the input and output voltage waveforms. Input voltage applied to the converter is 24 V DC and the output voltage obtained is 280.6 V DC. Fig.6(b). also shows the obtained output voltage when 24 V DC is applied to the converter and it is clear that output voltage is exponentially increased up to 0.03 sec. After that output voltage reaches a steady state value of 280 V DC. Fig.8. shows the waveforms of inductor current and capacitor voltage with input gate pulse. V_{gs1},V_{gs2}, V_{gs3}, V_{gs4} and V_{gs5} are the gate driving signals for S_1, S_2, S_3, S_4 and S_5 respectively, i_{L1} and i_{L2} are the inductor current waveforms corresponding to inductors L_1 and L_2, V_{cb1}, V_{cb2} and V_{ce} are the capacitor voltage waveforms corresponding to bootstrap capacitors and energizing capacitor. Fig.8 shows the output current waveform. When switch is turned on, output current shoots the value, after that it reaches steady state value of 0.701 A. Fig.9. shows the output power waveform up to 0.03 sec, it follows a straight line path and approaches a constant value 196 W.

IV. CONCLUSIONS

The DC-DC boost converter has applications in the automotive, telecommunications, IT industries as well as in renewable energy generation via fuel cells, photovoltaic arrays and wind turbines. The step-up power conversion is continuously increasing its applications and power capability demands. In this paper, improved high voltage boosting converter is designed. The converter is based on inductors connected in series with bootstrap capacitors. The converter has high voltage conversion ratio than conventional boost converter. Two inductors are connected in series during demagnetizing period. 39.74 percentage of output voltage is improved by using modified circuit improved high voltage boosting converter. The conversion ratio is (4+2D)/(1-D). Closed loop control is done using PID controller in order to maintain output voltage constant at 280 V, such a converter is suitable for industrial application.

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