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Advanced High Voltage Boosting Converters Based on Bootstrap Capacitors

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ABSTRACT: In this project, two high voltage-boosting converters are presented. 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. These converters are constructed based on bootstrap capacitors and boost inductors. Above all, two boost inductors with different values, connected in series, can still make the proposed converters work appropriately. The proposed converter gives high efficiency, low output ripple and low cost. The proposed converter gives the output power 200 V DC from 24 V DC at power 100 W. The proposed converter gives a high efficiency and transformation ratio by reducing the conduction losses and switching losses. Simulation was done in MATLAB/Simulink and results were verified for open loop and closed loop of converter.

KEYWORDS: Bootstrap Capacitors, Boost Inductors,Voltage-Boosting Converter, Voltage Conversion Ratio

I.INTRODUCTION

To design, develop and validate a high voltage boosting converter. The project work consists of a review of some of the important power electronic converters which are already used for power conversion. This work proposing a new DC-DC converter with high step up ratio. Scope of this thesis is limited to the steady state analysis and characteristics of the proposed converter under continuous conduction mode.

Major contributions of the project are:

1. Proposing two new DC-DC converters giving high step-up ratio and conversion efficiency.
2. The converters consist of bootstrap capacitors and boost inductors, in order to obtain high voltage conversion ratio.

The background and motivation for this work is the emerging need for high power converters to boost voltage levels from low voltage electrical power sources to higher voltages required by the load. Fig.1.1, presents the typical power architecture of these systems.Many conventional DC-DC converters are present, in which isolated converters are preferred because the non-isolated converters do not satisfy the requirements of galvanic isolation standards. In many DC-DC applications, multiple outputs are required and output isolation may need to be implemented depending on the application. In addition, input to output isolation may be required to meet safety specifications.

An isolated DC-DC converter boosts the unregulated low voltage supply to a much higher DC voltage, typically 400 V for single phase and 7-800 V for three phase utility grid interface. Wide input voltage range, typically in the range of 30-60 V, is normally required. Subsequently, a DC-AC inverter will typically convert high voltage DC output into single- or three phase ac voltage for interface to the utility grid or control ofelectrical motors etc.

II.HIGH VOLTAGE BOOSTING CONVERTERS BASED ON BOOTSTRAP CAPACITORS

This chapter gives a review of a high voltage DC-DC boosting converters based on bootstrap capacitors circuit with high voltage conversion ratio. These converters are constructed based on bootstrap capacitors and boost inductors. Above all, two boost inductors with different values, connected in series, can still make the high voltage converters work appropriately.

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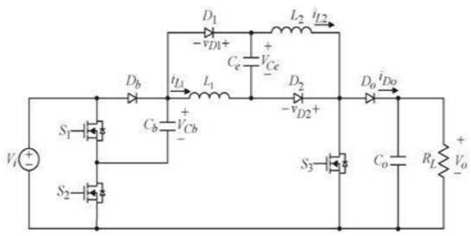

Figure (a) High Voltage Type 1 Boosting Converter

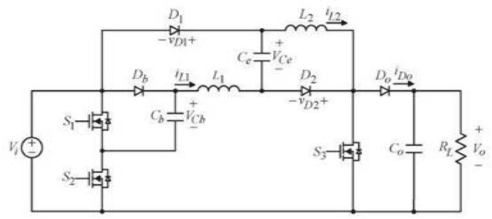

Fig.1 (b) High Voltage Type 2 Boosting Converter

. Each 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 output resistor R_L. In addition, the input voltage is signified by V_i, the output voltage is represented by V_o, the voltages across C_b, C_e, D_1, and D_2 are shown by V_{Cb}, V_{Ce}, v_{D1}, and v_{D2}, respectively, and the currents flowing through L_1, L_2 and D_o are denoted by i_{L1}, i_{L2}, and i_{Do}, respectively.It is noted that the proposed converters are based on the charge pump of the KY converter and the series boost converter. D_b, the conversion voltage ratio in continuous conduction mode (CCM) is $(3 + D)/(1 - D)$, where D is the duty cycle of the PWM control signal created from the controller, Therefore, the proposed converters can be used according to industrial applications.For these two converters to be considered, the PWM turn on types for three switches and the voltages on the bootstrap capacitors are tabulated in Table I. Above all, the converters operated in the CCM and in the discontinuous conduction mode (DCM) are to be analysed in the following, under the condition that L_1 is equal to L_2.

III. MODES OF OPERATIONS FOR TYPE 1 WITH L_1=L_2

A. Mode 1 [t_0-t_1]: As shown in Fig below, $S_1$and S_3 are turned on, but S_2 is turned off. Due to S_3 being turned on, D_o is reverse biased, but D_1 and D_2 are forward biased, thereby causing C to be abruptly charged to V_i plus V_{Cb}, whereas due to S_1 being turned on, D_b is reverse biased, thereby causing C_b to be discharged. At the same time, the voltages across L_1 and L_2 are V_i plus V_{Cb}, thereby causing L_1 and L_2 to be magnetized. Also, 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

$$vL1{-}ON = Vi + VCb \qquad (3.1)$$

$$vL2{-}ON = Vi + VCb \qquad (3.2)$$

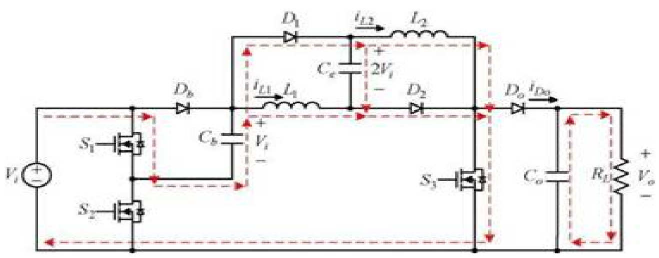

Fig.2 Mode 1

B. Mode 2 [t_1-t_2]: As shown in Fig below, $S_1$and S_3 are turned off, but S_2 is turned on. Due to S_2 being turned on, D_b is forward biased, thereby causing C_b to be abruptly charged to V_i. At the same time, the input voltage plus the energy stored in C_e plus the energy stored in L_1 and L_2 supplies the load, thereby causing C_o to be energized, 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 much higher than the input voltage. According to thevoltage-second balance, the voltages v_{L1-OFF}, v_{L2-OFF}, and V_o in this mode can be expressed to be

$$v_{L1-OFF} = [-D/(1-D)] * v_{L1-ON} \quad (3.3)$$

$$v_{L2-OFF} = [-D/(1-D)] * v_{L2-ON} \quad (3.4)$$

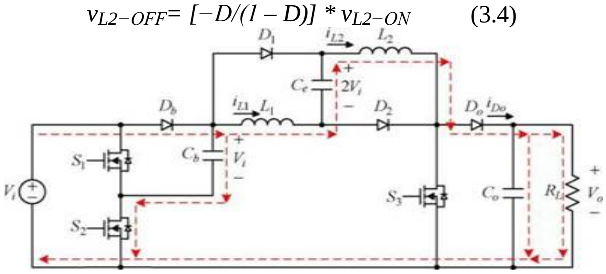

Fig.3 Mode 2

Waveform for Type 1 Converter with L_1=L_2

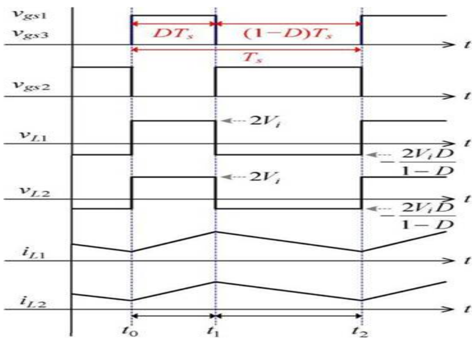

Fig.4 CCM Waveform for type 1 Converter with L_1=L_2

IV. MODES OF OPERATION FOR TYPE 2 WITH L_1=L_2

Mode 1 [t_0- t_1]: As shown in Fig. 3.8, $S_2$and S_3 are turned on, but S_1 is turned off. Due to S_3 being turned on, D_o is reverse biased, but D_1 and D_2 are forward biased, thereby causing C_e to be abruptly charged to V_i, whereas due to S_2being turned on, D_b is forward biased, thereby causing Cb to be abruptly charged to Vi. At the same time, the voltages across L1and L2 both are Vi, thereby causing L1 and L2 to be magnetized. Also, Co releases energy to the output. In this mode, the voltages across L1 and L2, vL1−ONand vL2−ON, can be written as,

$$vL1-ON=Vi \quad (3.8)$$

$$vL2-ON=Vi \quad (3.9$$

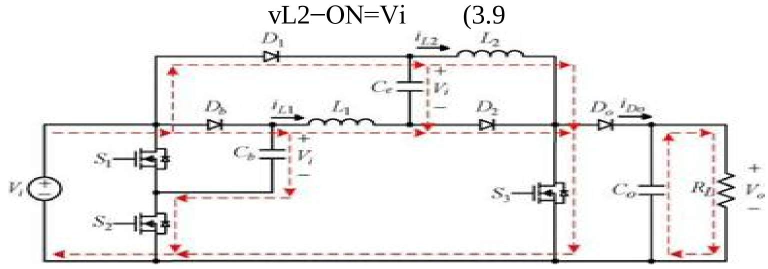

Fig.5 Type 2 mode 1 operation

Mode 2 [t_1-t_2]: As shown in Fig.3.9, $S_2$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 energized, 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

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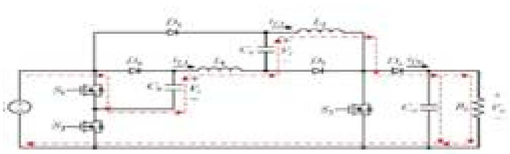
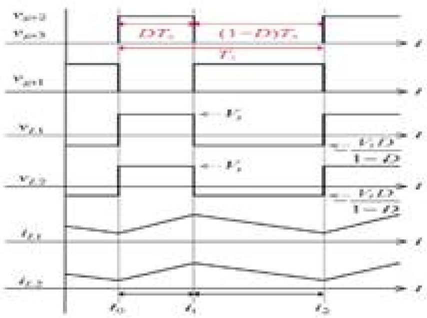
$$v_{L1-OFF} = [-D/(1-D)] * v_{L1-ON} \quad (3.10)$$

$$v_{L2-OFF} = [-D/(1-D)] * v_{L2-ON} \quad (3.11)$$





V SIMULATION AND RESULT ANALYSIS

Open Loop Simulation and Waveforms of High Voltage Boosting Converters

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

Parameters	Value
Power rating	100W
Input Voltage	24 V
Switching Frequency	195Khz
Output Voltage	200V
Inductors	170µH
Bootstrap Capacitor,C_1	100 µF
Output Capacitor,C_3	680µF
Load Resistance	400 Ω
Capacitor,C_2	220 µF

Open Loop Simulation of Type 1 Converter

The simulation circuit drawn in MATLAB/SIMULINK is shown in Fig 8.The input DC is given using DC voltage supply block. There are three switching MOSFETs in the circuit. Gating pulses are given to the switches using a subsystem.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 examined

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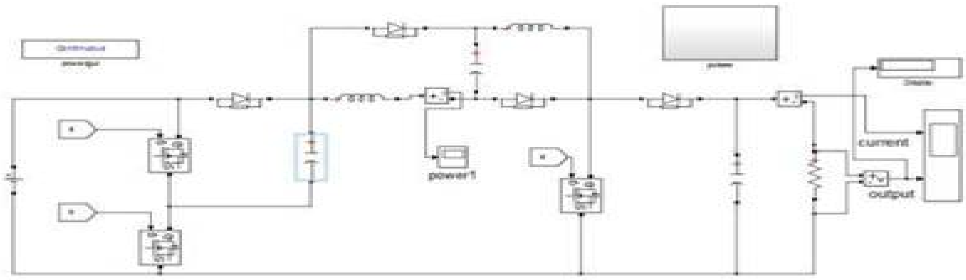


Fig.8 (a) Open loop Circuit for Type1 Converter

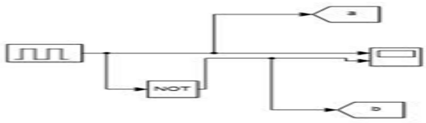
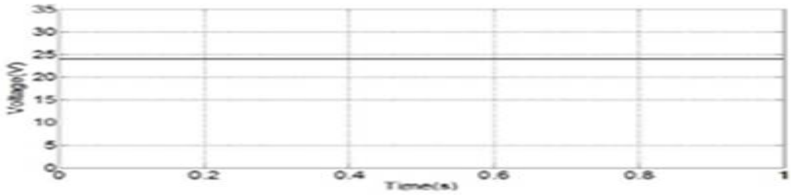


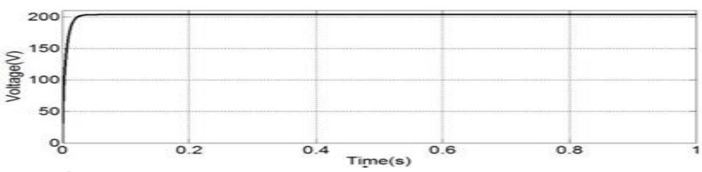
Fig.8 (b) Switching Control Module

- ***Open Loop Simulation Results***

A. Input Voltage:The input voltage waveform given as shown in Fig 9. In the design consideration, the input voltage was taken to be 24V.

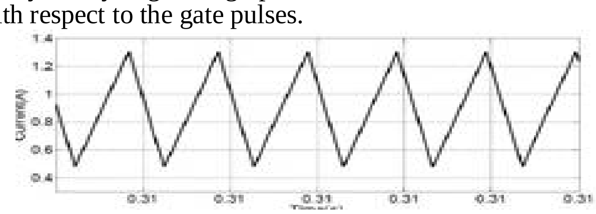


*B. Output Voltage:*The output voltage obtained is as shown below. The output voltage of 207V is obtained and the ripple content in the output voltage is very low. Project aim is fulfilled by achieving a high boosting voltage of 207 V from a 24 V input. The model is simulated by setting duty ratio as 0.65 to achieve this boosting.



C. Inductors Currents with Gate Pulse (L_1& L_2)

In the design consideration, both the inductors have equal parameters (i.e. L_1=L_2), Fig 4.4 shows the inductors' currents along with gate pulses.By analyzing the graphs, it is clear that both inductors are magnetizing and demagnetizing in same manner with respect to the gate pulses.



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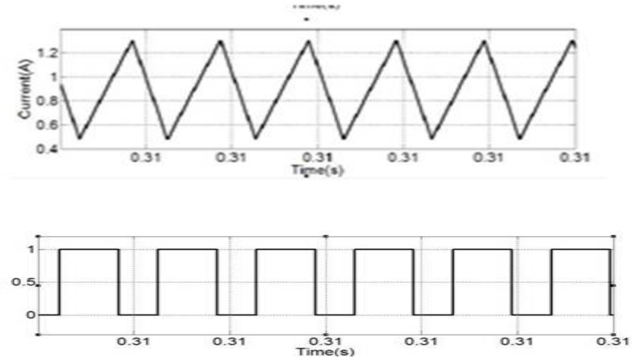


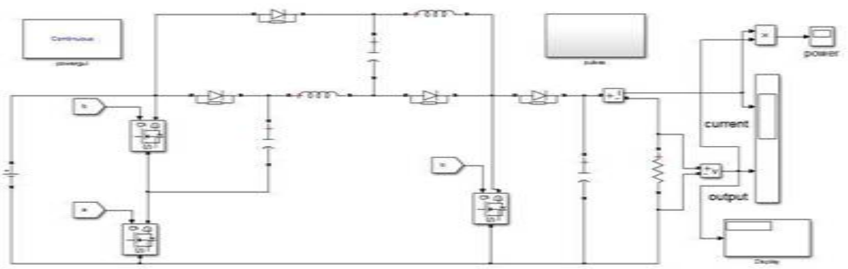
Fig.11 Inductor Currents (i_{L1}& i_{L2}) with Gate Pulse

- **Open Loop Simulation of Type 2 Converter**

The circuit simulated in SIMULINK/MATLAB in open loop. The various parameters given according to design as explained earlier in this chapter are shown in Table 4.3.

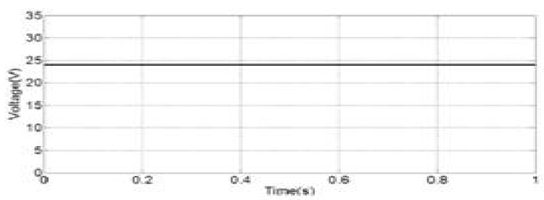
Parameters	Value
Power rating	100 W
Input Voltage	24 V
Switching Frequency	195 kHz
Output Voltage	145 V
Inductors	80 μH
Bootstrap Capacitor, C_1	330 μF
Output Capacitor, C_3	680 μF
Load Resistance	400 Ω
Capacitor, C_2	330 μF

The simulation circuit drawn in MATLAB/SIMULINK is shown in Fig 12



Simulation Results

A. Input Voltage:The input voltage waveform given as shown, In the design consideration, the input voltage was taken to be 24V.



Output Voltage: The output voltage obtained is as shown below. The output voltage of 166 V is obtained and the ripple content in the output voltage is very low. Project aim is fulfilled by achieving a high boosting voltage of 166 V from a

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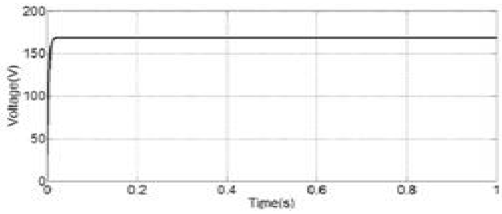
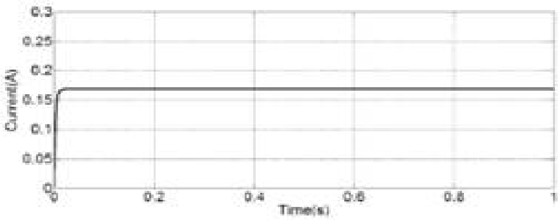
24 V input. The model is simulated by setting duty ratio as 0.65 to achieve this boosting.



Output Current: The output current obtained is as shown below. The output current of 1.8A is obtained.



- **Closed Loop Simulation**

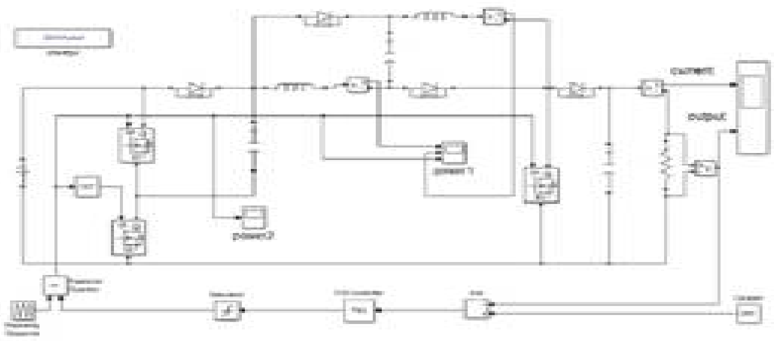


Fig.17 Closed loop simulation

➢ **Closed Loop Simulation Results**

A.Input Voltage:The input voltage waveform given as shown, In the design consideration, the input voltage was taken to be 24V.

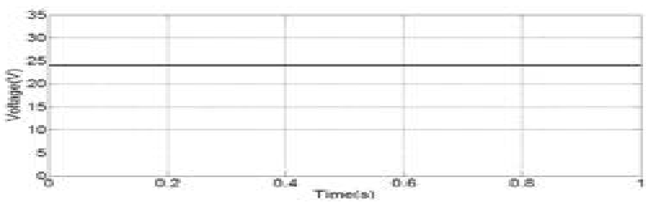


Fig.18 Input voltage

B. Output Voltage: The output voltage waveform was obtained as shown, for a 24V DC input voltage, converter output voltage of 200V is obtained and the ripple content in the output voltage is low.

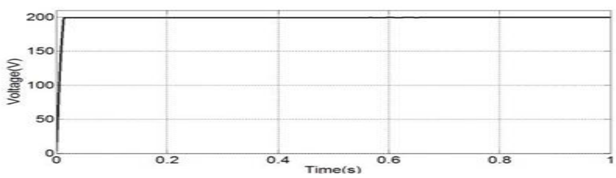
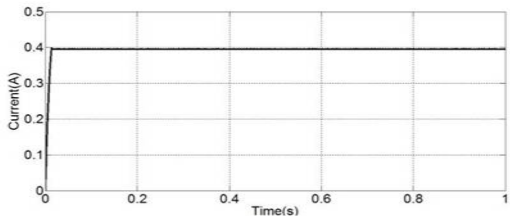


Fig.19 Output voltage

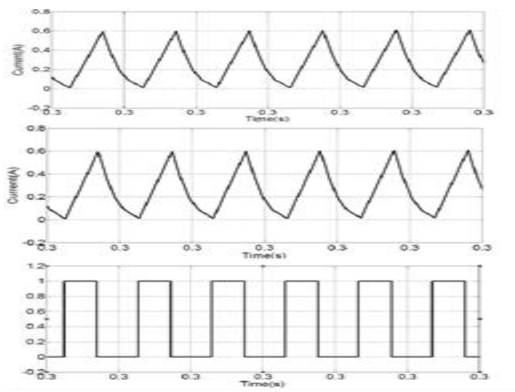
C.Output Current

The output current obtained is as shown below.The output current of 0.39A is obtained.



D. Inductors Currents with Gate Pulse (L_1& L_2)

In the design consideration, both the inductors have equal parameters (i.e. L_1=L_2), Fig 20 shows the inductors' currents along with gate pulses.By analyzing the graphs, it is clear that both inductors are magnetizing and demagnetizing in same manner with respect to the gate pulses. These graphical representations of the current waveforms describe the identical working of two boost inductors in continuous conduction mode



The simulation results meet all the needs of the proposed system. The open loop simulations for both the converters and closed loop simulation for Type 1 converter are done and waveforms are obtained. By comparing open loop simulations of the both converters, Type 1 converter has better voltage conversion ratio and better performance.

VI. CONCLUSION

In this project work, two high voltage boosting converters were employed. The proposed system was simulated, constructed and functionality of suggested control concept was proven advanced than the prevailing concept. From the detailed simulations an experimental analysis, it is clear that the presented converters have the following advantages.

conversion ratios with fewer losses.There are two types of high voltage-boosting converters, depending on the circuit connection and the PWM control strategy. Exhibit good performances even with different inductances, and hence are suitable for industrial applications. Proposed converters need lesser components making it less weight, low cost and compact.

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