Simulation of A Step-Up Converters Based Bootstrap Capacitors and Boost Inductors for Industrial Applications

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***Abstract*— This paper deals with a novel high voltage boosting converter. This high voltage boosting converter is constructed by using bootstrap capacitors and boost inductors. The technique used to improve voltage conversion ratio is pulse width modulation(PWM).In addition to bootstrap capacitors, boost inductors and pulse-width-modulation technique, connection position of the diode also plays a key role in boosting the input voltage. Two boost inductors connected non parallel helps facilitate the high output voltage for the given input, there by increasing the gain of the converter. These two inductors with different values of inductances, connected non parallel during demagnetizing period ,allows boost converters to work effectively. Each converter consists of three switches .But in this proposed converter model only one half bridge gate driver and one low side gate driver would be needed. There is no use of isolated gate driver in the proposed model. Such converters exhibits good performance. Some experimental results are provided to demonstrate the effectiveness of the proposed converters. Simulation of the proposed converters is carried out by using MATLAB-SIMULINK software.**

Keywords-Boosting converter, voltage conversion ratio, bootstrap capacitor, boost inductor, pulse width modulation(PWM).

I INTRODUCTION

Boost converters are also called as step-up converters. High step-up converters have been widely used in many industrial applications such as in UPS, solar cell system and high intensity discharge lamp driver etc. The traditional boost converter possess a simple structure but does not provide high voltage conversion ratio[1]. Many high voltage-boosting converters are proposed earlier and their method of improving the voltage conversion ratio is based on the fact that, as the number of inductors with different values of inductances is increased and these inductors are connected in non parallel during the demagnetizing period, helps to obtain the high voltage conversion ratio. During demagnetizing period, the current in each inductor acts as a current source as a result inductors with different values ,connected in non parallel, results in current sources with different values connected in series thereby violating the Kirchhoff's current law(KCL) and failing such a circuit. Later, voltage conversion ratio is increased by the usage of coupling inductors[1]. However, voltage spikes occurring due to leakage inductances and the complexity in analyzing such circuits with coupling inductors are unavoidable, thereby hinder analyses and applications. Hence, a simple boost converter is proposed with simple operation principles but the voltage conversion ratios are too low[2]. However, the voltage conversion ratio can be increased by increasing the number of voltage-boosting cells, additional components or floating active switches are required.

For the reasons stated above, two high voltage-boosting converters ,based on two bootstrap capacitors and two inductors are proposed here[3]. Although, two inductors connected in non parallel with different respective values of inductances during the demagnetizing period helps the proposed converters to work appropriately. In addition, based on the different switch turn-on times and different diode connections ,two voltage-boosting converters with different values of voltage conversion ratios are generated under the same circuit structure[4]. Under the same condition, with two inductors and two capacitors except the input capacitor, the voltage conversion ratios of the proposed converters are higher than all the voltage conversion ratios in the KY boost converter[5], in the self-circuit and re-lift circuit and in the positive output self-lift Luo converter, positive output super lift converter and positive output re-lift Luo converter. On the other hand, where the same components are used, the proposed converter possess higher voltage conversion ratios compared to existing models[6]. In addition, for each converter in the proposed model only one half-bridge gate driver and only one low-side gate driver would be needed. A brief illustration of the operation of these two converters is given with some experimental results to verify the effectiveness of the proposed converters.

II OPERATING PRINCIPLES

PROPOSED CONVERTER TOPOLOGIES

In this paper, the proposed two high voltage-boosting converters have individual voltage-conversion ratios. Hence, the type1 figure is described in Fig.2(a) and type2 figure is described in Fig.2(b).The difference in Fig. 2(a) and Fig. 2(b) is the connection of the anode of diode D_1.Each proposed converters consists of three MOSFET switches S_1,S_2 and S_3,two bootstrap capacitors C_b and C_c, three bootstrap diodes D_1,D_2 and D_b,one output diode D_0,two inductors L_1 and L_2,one output capacitor C_0,and one output resistor R_L. The input voltage is represented by V_1 and the output voltage is represented by V_2,the voltages across C_b,C_c,D_1 and D_2 are denoted by V_{cb},V_{cc},v_{D1} and v_{D2},respectively, and the current flowing through L_1,L_2 and D_0 are represented by i_{L1},i_{L2},and i_{D0},respectively.

Proposed converters are based on the charge pump of the KY converter and the series boost converter, so that conversion ratios can be upgraded further. If the anode of diode D_1 is connected to the cathode of diode D_b, the voltage conversion ratio in continuous conduction mode (CCM) is given by (3+D)/(1-D),where D is the duty cycle of the PWM control signal generated from the controller. Similarly, if the anode of diode D_1 is connected to the anode of diode D_b with switch turn-on types different from those of the former, the voltage conversion ratio in CCM is given by (3-D)/(1-D).Hence, the proposed converters can be used for industrial applications.

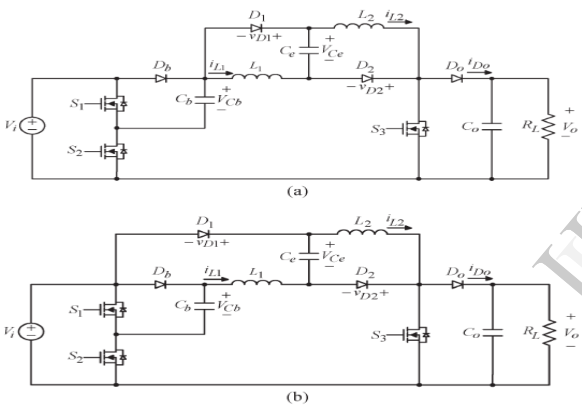

Fig.2:Proposed voltage-boosting converters: a)Type 1;b)Type 2

III BASIC OPERATING PRINCIPLES

For the two converters to be considered, the converters operated in CCM and DCM mode, are to be analyzed under the condition L_1 is equal to L_2.However,L_1 is different from L_2.However, for analysis convenience,types1 and types2,operated only in continuous conduction mode (CCM) under the condition that L_1 is larger than L_2 or L_1 is smaller is than L_2,are considered.

TYPE 1 WITH L1 GREATER THAN L2:

CCM OPERATION: Fig.3.1,shows the illustrated key waveform for type1 operated in CCM with L1 not equal to L2,where Ts denotes the switching period and are the gate driving signals for S1,S2 and S3.

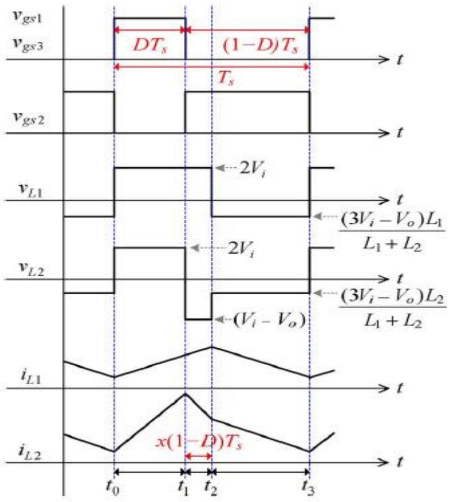

Fig.3.1: Illustrated key waveforms for type 1 operated in CCM with L1 larger than L2.

A)MODE 1 [T0 ~ T1]:

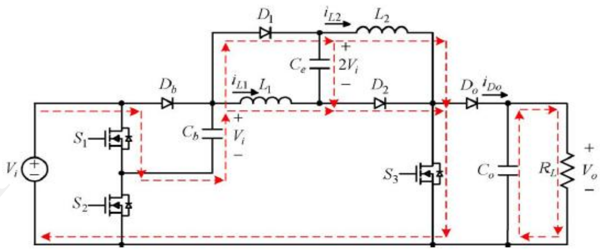

Fig-3.2:Power flow of type 1 operated in CCM with $L1$ larger than $L2$ in mode 1.

As shown in the Fig.3.2,S1 and S3 are on, but S2 is off. Since S3 being turned on, D0 is reverse biased, and D1 and D2 are forward biased, thereby causes Ce to charge to Vi plus Vcb suddenly. On the other hand,S1 is also in on condition, causing Db to be reverse biased, thereby causing Cb to be discharged. At the same time, the voltages across L1 and L2 are Vi plus Vcb, there by causing L1 and L2 to be magnetized. Also, Co releases energy to the output. In addition, iL1 is smaller than iL2 since L1 is larger than L2.In this mode, the voltages across L1 and L2, are vL1-on and vL2-on respectively, and these voltages can be represented mathematically as

$$v_{L1-ON} = v_{L2-ON} = 2V_i \qquad (1)$$

B) MODE 2 [T1 ~T2]:

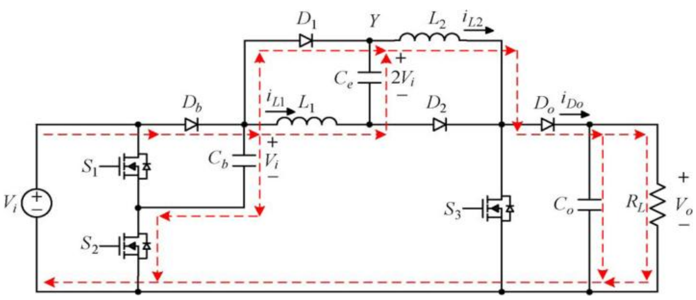

Fig-3.3: Power flow of type 1 operated in CCM $L1$ larger than $L2$ in mode 2.

As shown in Fig.3.3, S1 and S3 are turned off, and S2 is turned on. In this mode,iL1 is smaller than iL2,as a result D1 is in forward bias condition. Hence, the voltage across L1 is 2Vi and L1 is said to be magnetized, where as the voltage across L2 is Vi minus V0,therefore L2 is said to be demagnetised. At the same time, Ce starts discharging. No sooner the iL1 is equal to iL2,than the operation goes to mode 3.Therefore,the related equations can be expressed as

$$v_{L1-OFF} = 2V_i \quad (2)$$

$$v_{L2-OFF} = V_i - V_0 \quad (3)$$

C)MODE 3[T2~T3]:

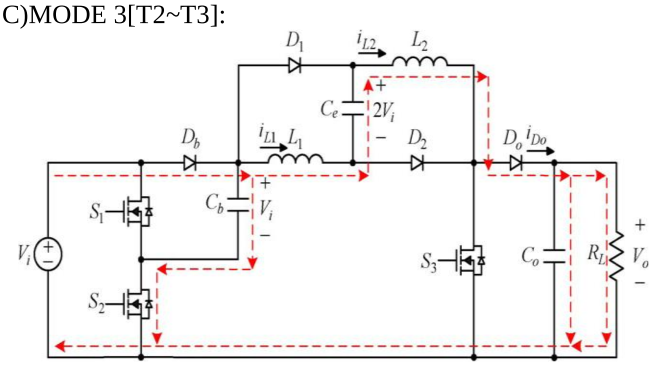

Fig.3.4-Power flow of type 1 operated in CCM with L1 larger than L2 in mode 3.

As shown in Fig.3.4., S1 and S3 are off, and s2 is turned on. Since S2 turned on, Db is forward biased, as a result Cb abruptly charges to Vi. At the same time, the input voltage, the energy stored in Ce, the energy stored in L1 and the energy stored in L2 supplies the load, and L1 and L2 are said to be demagnetized. In this manner, the output voltage is boosted up, and is much higher than the input voltage. Thus the relevant equations for voltages across L1 and L2 can be written as

$$v_{L1-OFF} = (3V_i - V_0)\frac{L_1}{L_1 + L_2} \quad (4)$$

$$v_{L2-OFF} = (3V_i - V_0)\frac{L_2}{L_1 + L_2} \quad (5)$$

TYPE2 OPERATED IN CCM WITH L1 LARGER THAN L2:

CCM WAVEFORM:

Fig.3.5.,shows the key waveforms for type2 operated in CCM with L1 not equal to L2,where Ts denotes the switching period and are the gate driving signals for S1,S2 and S3.

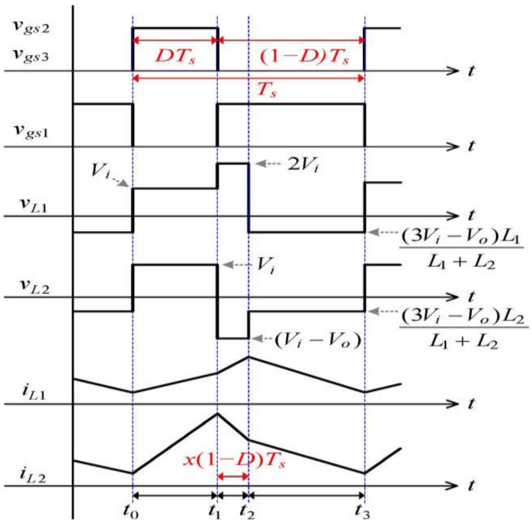

Fig-3.5: Illustrated key waveforms operated in CCM with L1 larger than L2 for type 2.

A)MODE 1 [T0 ~ T1]:

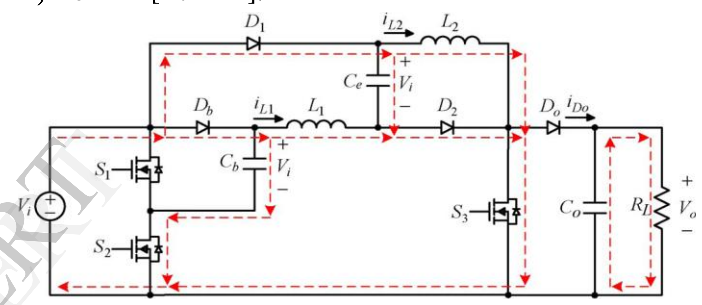

Fig.3.6:Power flow in CCM with L1 larger than L2 in mode 1 operated for type 2.

As shown in Fig.3.6,S2 and S3 are turned on and S1 is turned off. Since S3 is turned on,D0 is reverse biased and D1 and D2 are forward biased, therefore Ce abruptly charges to Vi. Since S2 is turned on ,Db is forward biased, therefore Cb abruptly charges to Vi. At the same time, the voltages across L1 and L2 both are Vi and Vi respectively, thereby causing L1 and L2 to be magnetised.C0 releases energy to the output. In addition,iL1 is smaller than iL2 due to L1 larger than L2.In this mode, the voltages across L1 and L2,vL1-on and vL2-on,can be written as

$$v_{L1-ON} = v_{L2-ON} = V_i \quad (6)$$

B) MODE 2 [T1 ~ T2]:

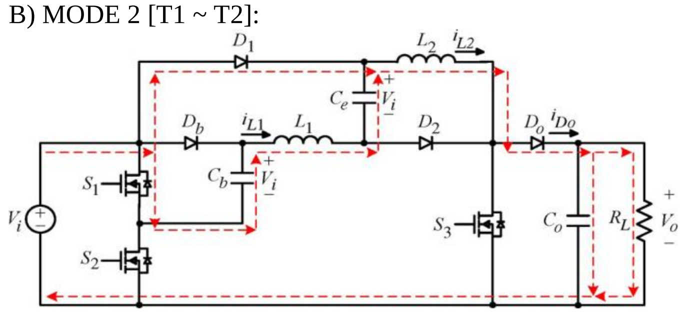

Fig.3.7-Power flow in CCM with L1 larger than L2 in mode 2 for type 2.

As shown in Fig.3.7. S2 and S3 are turned off and S1 is turned on. In this mode,iL1 is smaller than iL2,making D1 to be forward biased. Hence, the voltage across L1 is 2Vi,and L1 is in magnetized state, whereas the voltage across L2 is Vi minus V0,making L2 to be demagnetized. At the same time, Ce starts discharging. No sooner iL1 is equal to iL2,than the operation goes to mode 3.In this mode, the voltages across L1 and L2,vL1-off and vL2-off,can be written as

$$v_{L1-OFF} = 2V_i \quad (7)$$

$$v_{L2-OFF} = V_i - V_0 \quad (8)$$

C) MODE 3 [T2 ~ T3]:

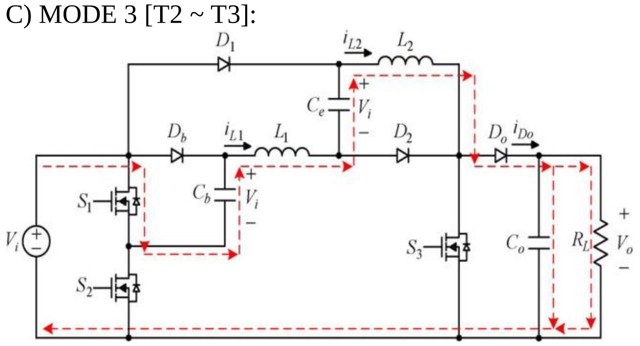

Fig-3.8: Power flow of type 2 operated in CCM with L1 larger than L2 in mode 3.

As shown in Fig.3.8. S2 and S3 are off. Since S1 is turned on, Db is forward biased, as a result Cb abruptly charges to Vi. At the same time, the input voltage, the energy stored in Ce, the energy stored in L1 and the energy stored in L2 supplies the load, and L1 and L2 are said to be demagnetized. In this manner, the output voltage is boosted up, and is much higher than the input voltage. Thus the relevant equations for voltages across L1 and L2 can be written as

$$v_{L1-OFF} = (3V_i - V_0)\frac{L_1}{L_1+L_2} \quad (9)$$

$$v_{L2-OFF} = (3V_i - V_0)\frac{L_2}{L_1+L_2} \quad (10)$$

IV RESULTS AND DISCUSSION

A.PROPOSED VOLTAGE BOOSTING CONVERTER

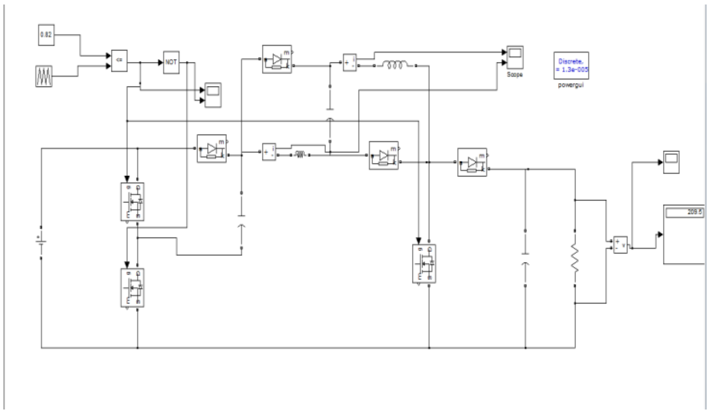

Fig.4.1 Simulation diagram of the proposed type 1 voltage boosting converter.

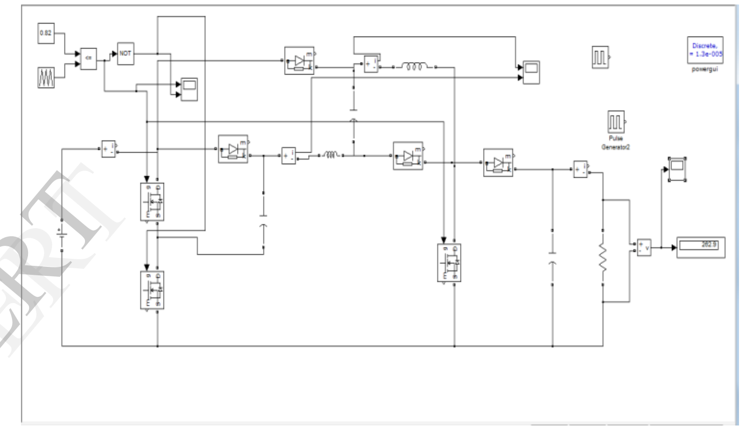

Fig.4.2 Simulation diagram of the proposed type 2 voltage boosting converter.

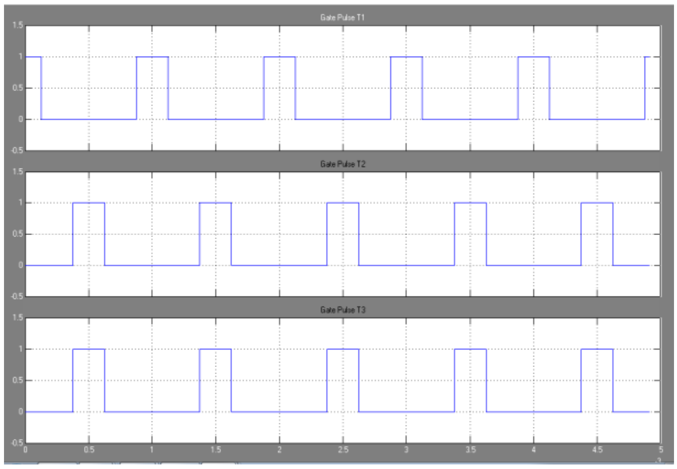

Fig.4.3:Gate pulse waveform for type 1 and type 2

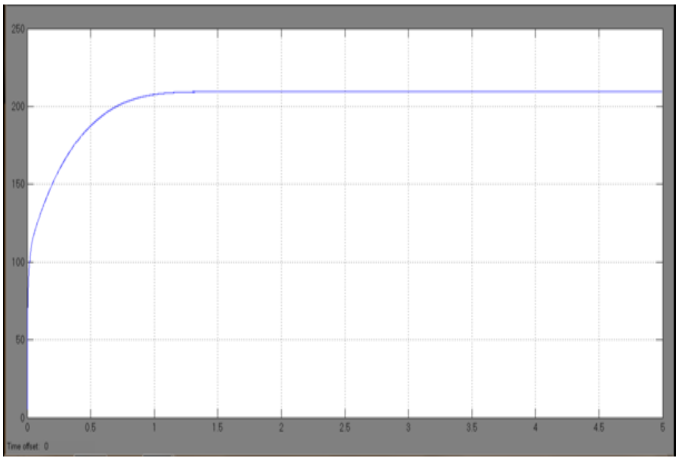

Fig.4.4:Output voltage waveform for type 1

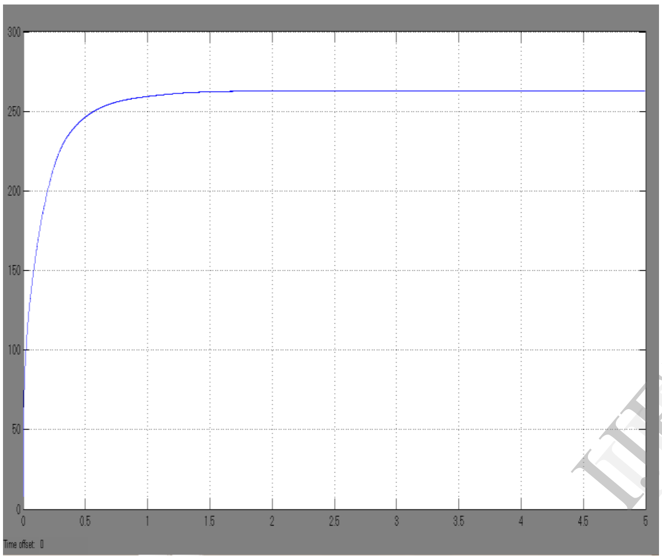

Fig.4.5. Output voltage waveform for type 2

V CONCLUSION

In this paper, high voltage- boosting converters are proposed with help of inductors connected in series with the bootstrap capacitors. There are two types of voltage converters based on the circuit connection. One half bridge driver and one low side gate driver would be needed to drive the power switches. From the experimental results, these type of converters exhibit good performance, even for different values of inductances and hence are very useful in industrial applications.

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