

# A Transformerless Boost Converters with High Voltage Gain and Reduced Voltage Stresses on the Active Switches

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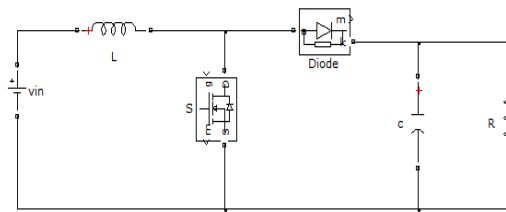
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**Abstract-** Usually basic dc-dc boost converters are unable to provide high step up voltage gain due to the effect of power switches, rectifier diodes and equivalent series resistance of inductors and capacitors and the voltage stresses on the power switches are high. This paper proposes a simple transformerless dc-dc converters to achieve high step up voltage gain without an extremely high duty ratio. The structure of the proposed converters is very simple. This paper proposes three transformerless Dc-Dc converters with switched inductor technique, the duty ratio and the voltage stresses in the active switches of the proposed converters is compared with basic boost converter. The experimental results confirm that the voltage stresses in the active switches is reduced without an extremely high duty ratio in the proposed converters. Finally a prototype circuit is simulated to verify the performance.

## I. INTRODUCTION

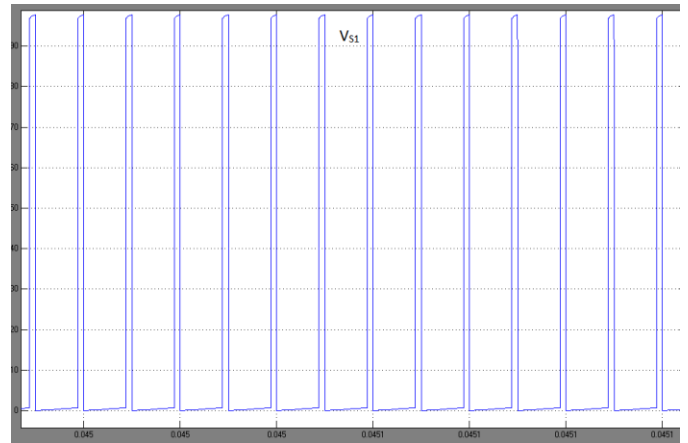
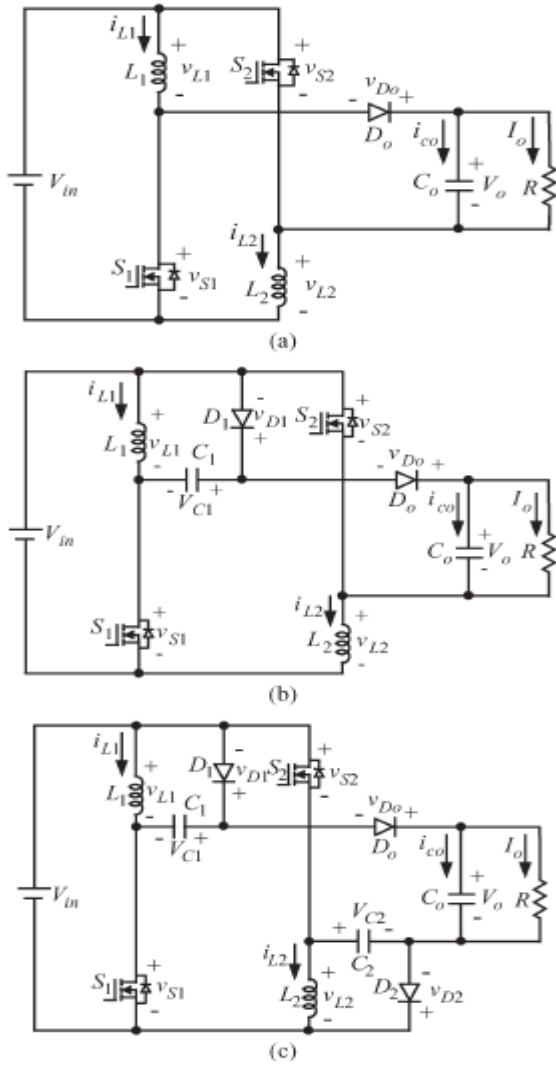
High step up dc-dc converters are used in many applications, such as renewable energy conversion, uninterruptible power supplies(UPS) and high intensity discharge lamp for automobile headlamps.

A basic boost converters can achieve high step up voltage gain with an extremely high duty ratio[1]-[2],but extremely high duty ratio results in a serious reverse recovery problem. A dc-dc flyback converters [3] is a very simple structure with a high step up voltage gain, but the active switch of this converter will suffer a high voltage stress due to the leakage inductance of the transformer. A dc-dc flyback converter is a very simple structure with a high step-up voltage gain and an electrical isolation, but the active switch of this converter will suffer a high voltage stress due to the leakage inductance of the transformer. Literature includes some research of the transformerless dc-dc converters, which include the cascade boost type, the quadratic boost, [4]-[5], however these types are all complex. This paper proposes a transformerless dc-dc converter the high step up voltage gain can be achieved by switched inductor technique without an extremely high duty ratio and with reduced voltage stresses in the active switches. The boost converter is shown in fig.1. the voltage stress in the active switch S is equal to the output voltage and the duty ratio is high. The structure of this converter is very simple.

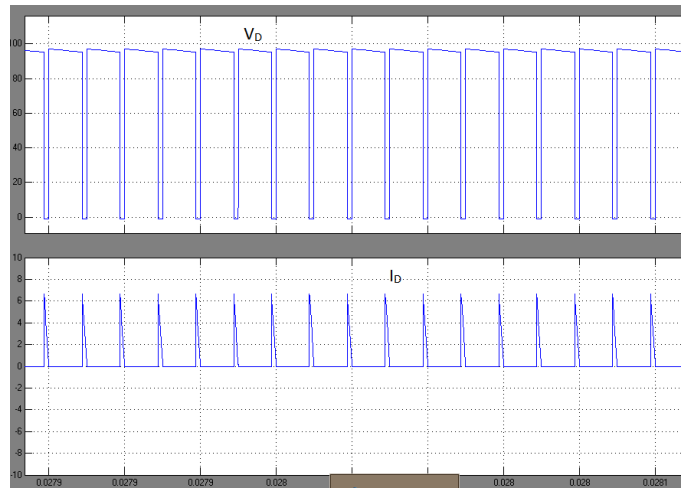


**Fig 1. Basic Boost Converter.**

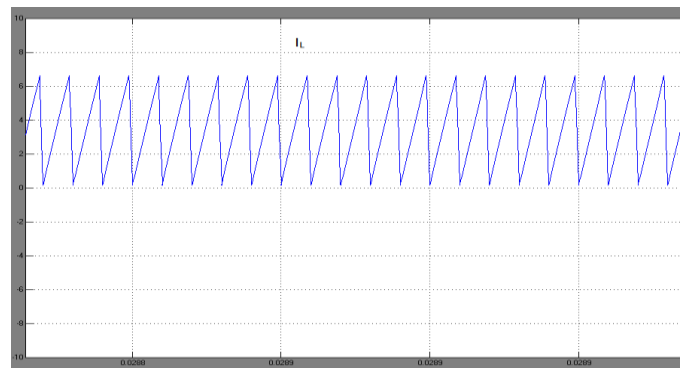
A transformerless dc-dc converters with reduced voltage stresses and high step up voltage gain is proposed in this paper, as shown in fig. 2(a,b,c). This is compared with the converter shown in fig.1, the proposed converters has the following merits. The voltage stresses on the active switches are less than the output voltage. Under the same operating conditions, including input voltage, output voltage, and output power, the current stress on the active switch during the switch-on period is equal to the half of the current stress on the active switch of the converter in fig.1. The three proposed dc-dc converters utilize the switched inductor technique, in which two inductors with same level of inductance are charged in parallel during the switch-on period and are discharged in series during the switch-off period, to achieve high step-up voltage gain without the extremely high duty ratio. The operating principles and steady-state analysis are discussed in the following sections. To analyze the steady state characteristics of the proposed converters, some conditions are assumed as follows: 1) All components are ideal—the ON-state resistance  $R_{DS(ON)}$  of the active switches, the forward voltage drop of the diodes, and the ESRs of the inductors and capacitors are ignored—and 2) all capacitors are sufficiently large and the voltage across the capacitors are treated as constant.



**Voltage across the switch S,  $V_{S1}$  : 100A/div**



**Voltage and current in the diode.  $V_D$  : 100A/div,  $I_D$  : 7A/div.**



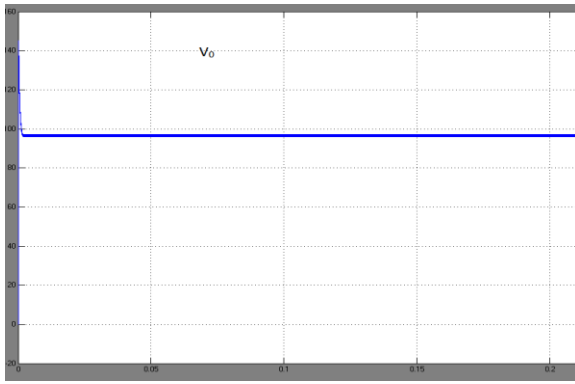
**Inductor current  $I_L$  : 7A/div.**

**Fig 2 . The proposed dc-dc converters. (a) Converter 1. (b) Converter II. (c) Converter III.**

**II. BASIC BOOST CONVERTER**

The fig.1 shows the circuit configuration of the basic boost converter.

The simulation results is given as follows.



Output voltage  $V_o : 100V/div.$

The simulation results confirm that the voltage across the switch is equal to the output voltage.

$$V_s = V_o$$

### III. PROPOSED CONVERTER I

The fig. 3 shows the circuit configuration of the proposed converter 1, which consists of two active switches  $S_1$  and  $S_2$ , two inductors  $L_1$  and  $L_2$ , output diode and a output capacitor. Switches  $S_1$  and  $S_2$  are controlled simultaneously by using one control signal.

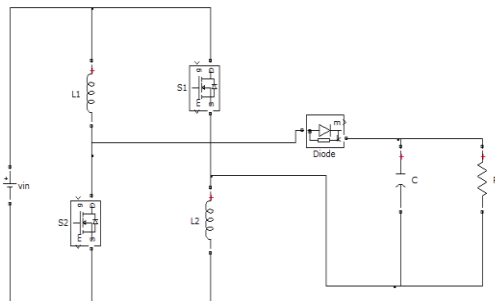


Fig.3

The operating principles and the steady state analysis of continuous conduction mode (CCM) are presented in detail as follows.

The operating modes can be divided into two modes as mode 1 and mode 2.

1) Mode 1-. During this time interval, switches  $S_1$  and  $S_2$  are turned on. The equivalent circuit is shown in Fig. 4(a). Inductors  $L_1$  and  $L_2$  are charged in parallel from the dc source, and the energy stored in the output capacitor  $C$  is released to the load. Thus, the voltages across  $L_1$  and  $L_2$  are given as,

$$V_{L1} = V_{L2} = V_{in} \quad (1)$$

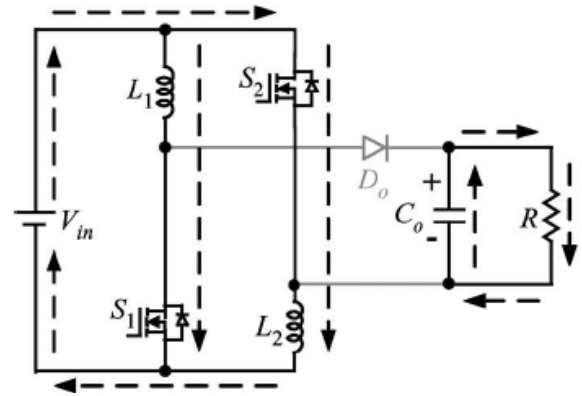


FIG: 4(a).

2) Mode 2 - During this time interval,  $S_1$  and  $S_2$  are turned off. The equivalent circuit is shown in Fig. 4(b). The dc source,  $L_1$ , and  $L_2$  are series connected to transfer the energies to  $C$  and the load. Thus, the voltages across  $L_1$  and  $L_2$  are derived as,

$$V_{L1} = V_{L2} = V_{in} - V_o/2 \quad (2)$$

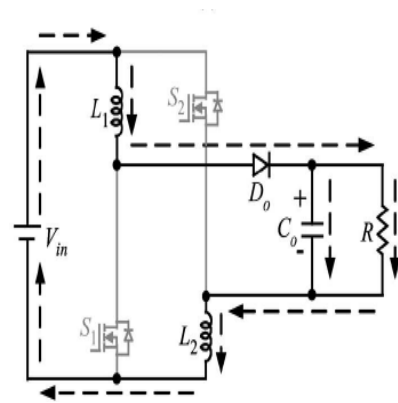


Fig:4(b).

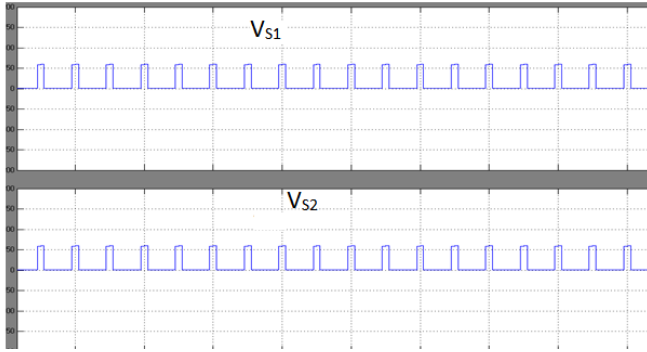
By using the volt-second balance principle on  $L_1$  and  $L_2$ , the following equation can be obtained:

$$\int_0^{DT_s} V_{in} dt + \int_{DT_s}^{T_s} \frac{V_{in} - V_o}{2} dt = 0 \quad (3)$$

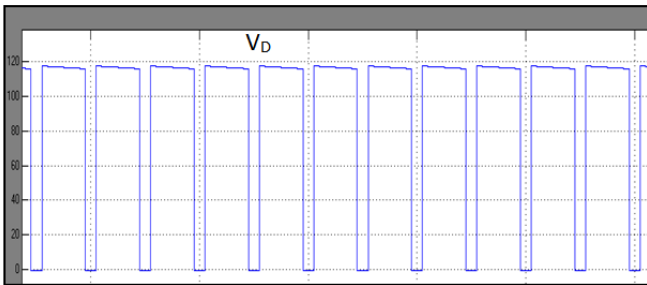
By simplifying (3), the voltage gain is given by

$$M_{CCM} = \frac{V_o}{V_{in}} = \frac{1 + D}{1 - D}$$

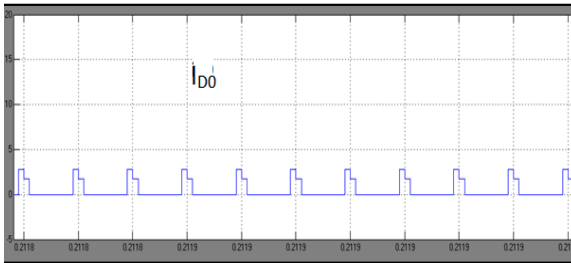
The simulation results of the proposed converter I is given as follows:



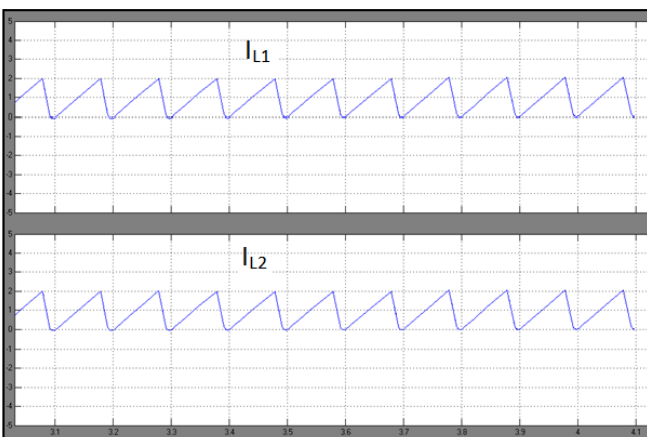
**Voltages across the switches S1 and S2.  $V_{S1}$ : 60V/div.  $V_{S2}$ : 60V/div.**



**Voltage across the diode.  $V_D$  : 110V/div.  
 $V_D = V_0 + V_{in}$ .**



**Output diode current.  $I_{D0}$  : 3A/div.**



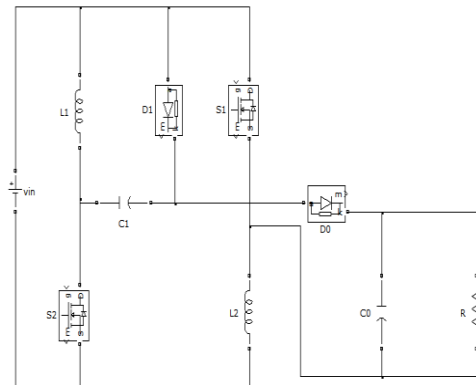
**Inductor currents.  $I_{L1}$  : 3A/div,  $I_{L2}$  : 3A/div.**

The simulation results confirm that the voltage stresses across the switches S1, S2 is greatly reduced as compared to the basic boost converter.

$$V_{S1} = V_{S2} = \frac{V_0 + V_{in}}{2}$$

#### IV. PROPOSED CONVERTER II.

The fig 5. Shows the circuit configuration of proposed converter II, which is the proposed converter I with one level voltage lift circuit. Thus the inductors L1 and L2 with the same level of inductance are also adopted in this converter. Switches S1 and S2 are controlled simultaneously by one control signal.



**Fig: 5**

The operating principles and the steady state analysis of continuous conduction mode (CCM) are presented in detail as follows.

The operating modes can be divided into two modes as mode 1 and mode 2.

##### Mode 1.

During this interval S1 and S2 are turned on. The equivalent circuit is shown in fig .6(a). L1 and L2 are charged in parallel from the dc source and the energy stored in C<sub>0</sub> is released to the load. Moreover, capacitor C1 is charged from the dc source. Thus the voltages across L1, L2 and C1 are given as,

$$V_{L1} = V_{L2} = V_{C1} = V_{in} \quad (4)$$

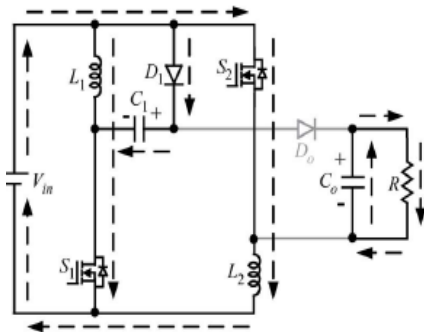
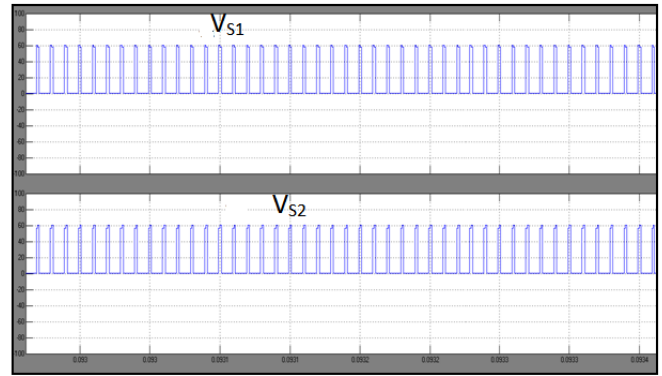


Fig :6(a).



Voltages across the switches S1 and S2..  $V_{S1}$ : 50V/div.  
 $V_{S2}$ : 50v/div.

**Mode 2.**

During this interval S1 and S2 are turned off. The equivalent circuit is shown in fig 6(b). The dc source  $L_1, C_1$ , and  $L_2$  are series connected to transfer the energies to  $C_0$  and the load. Thus the voltages across  $L_1$  and  $L_2$  are derived as,

$$v_{L1} = v_{L2} = \frac{V_{in} + V_{c1} - V_o}{2} = \frac{2V_{in} - V_o}{2} \quad (5)$$

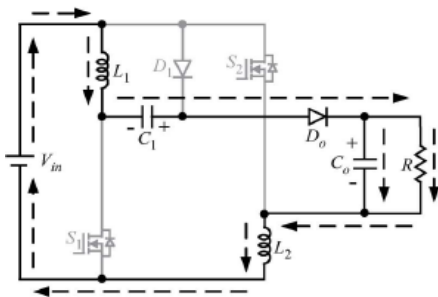
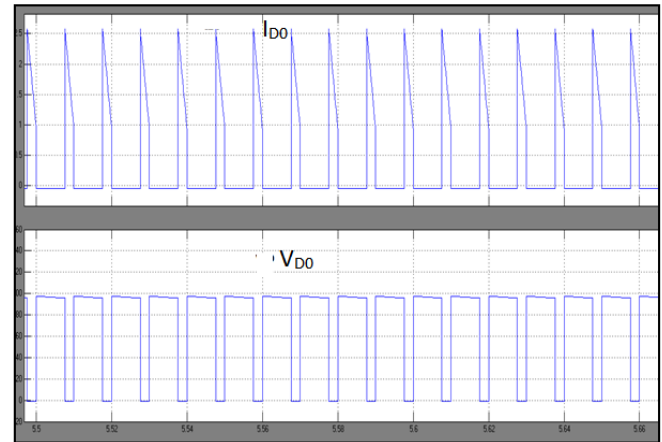


Fig : 6(b)



Voltage and current in output diode.  $V_{D0}$ : 100V/div.  
 $I_{D0}$ : 2.5A/div.

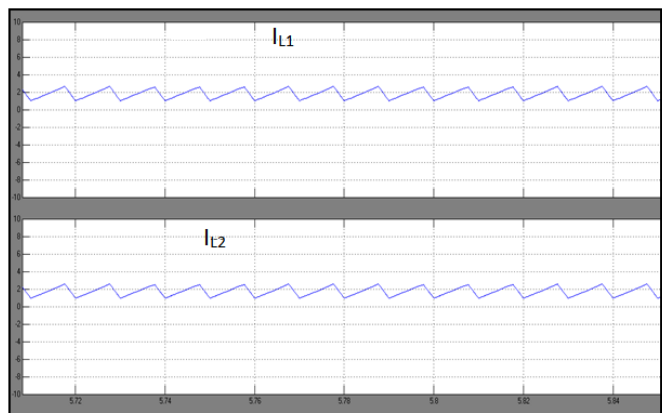
By using volt-second balance principle on  $L_1$  and  $L_2$ , the following can be obtained:

$$\int_0^{DT_s} V_{in} dt + \int_{DT_s}^{T_s} \frac{2V_{in} - V_o}{2} dt = 0. \quad (6)$$

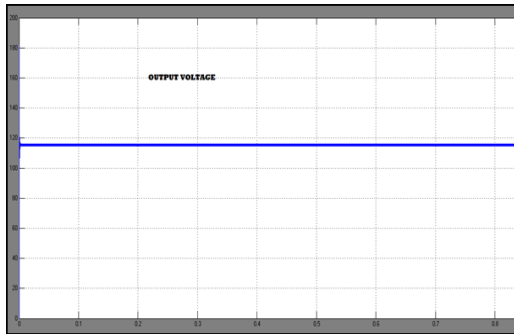
By simplifying (6), the voltage gain is given by,

$$M_{CCM} = \frac{V_o}{V_{in}} = \frac{2}{1-D}$$

The simulation results of the proposed converter II is given as follows:



Inductor currents.  $I_{L1}$ : 2.5A/div.  $I_{L2}$ : 2.5A/div.



Output voltage.  $V_o : 100V/div.$

The simulation results confirm that the voltage stresses across the switches S1 and S2 is greatly reduced as compared to the proposed converter I and the basic boost converter.

$$V_{S1} = V_{S2} = V_{D1} = \frac{V_o}{2}$$

$$V_{D_o} = V_o.$$

### V. PROPOSED CONVERTER III.

The fig.7 shows the circuit configuration of proposed converter III, which is the proposed converter I with two voltage-lift circuits. Thus, two inductors (L1 and L2) with the same level of inductance are also adapted in this converter. Switches S1 and S2 are controlled simultaneously by one control signal.

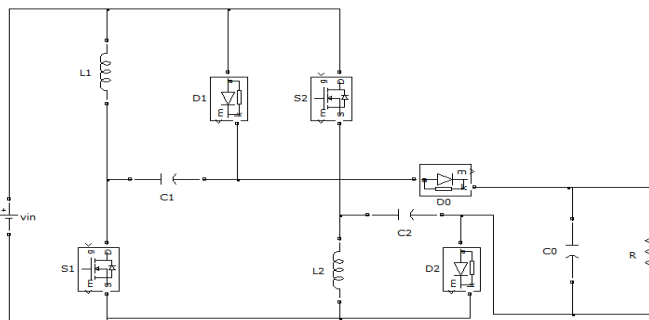


Fig :7

The operating principles and the steady state analysis of continuous conduction mode(CCM) are presented in detail as follows.

The operating modes can be divided into two modes as mode 1 and mode 2.

#### Mode 1.

During this interval, S1 and S2 are turned on. The equivalent circuit is shown in fig 8(a). L1 and L2 are charged in parallel from the dc source, and the energy stored in C0 is released to the load. Moreover capacitors C1 and C2 are charged from the dc source. Thus, the voltages across L1, L2, C1 and C2 are given as,

$$V_{L1} = V_{L2} = V_{C1} = V_{C2} = V_{in}.$$

(7)

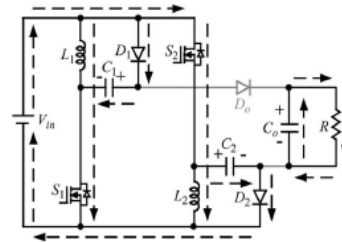


Fig :8(a)

#### Mode 2

During this time interval, S1 and S2 are turned off. The equivalent circuit is shown in fig.8(b). The dc source, L1, C1, C2, and L2 are series connected to transfer the energies to Co and the load. Thus the voltage across L1 and L2 are derived as follows,

$$V_{L1} = V_{L2} = \frac{V_{in} + V_{C1} + V_{C2} - V_o}{2} = \frac{3V_{in} - V_o}{2}.$$

(8)

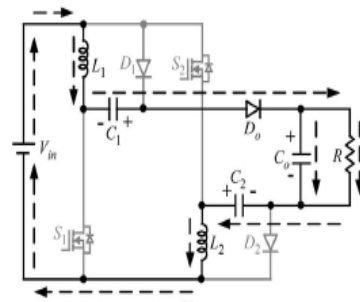


Fig :8(b).

By using the volt-second balance principle on L1 and L2, the following can be obtained:

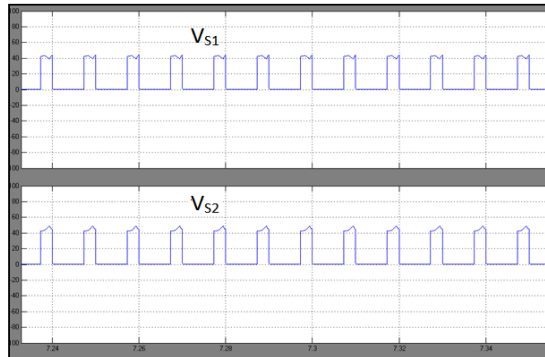
$$\int_0^{DT_s} V_{in} dt + \int_{DT_s}^{T_s} \frac{3V_{in} - V_o}{2} dt = 0.$$

(9)

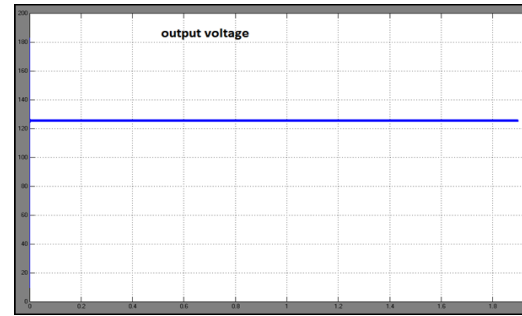
By simplifying (9), the voltage gain is given by:

$$M_{CCM} = \frac{V_o}{V_{in}} = \frac{3 - D}{1 - D}.$$

The simulation results of the proposed converter III is given as follows:



**Voltages across the switches S1 and S2.  $V_{S1}$  : 45v/div.  $V_{S2}$  : 45v/div.**

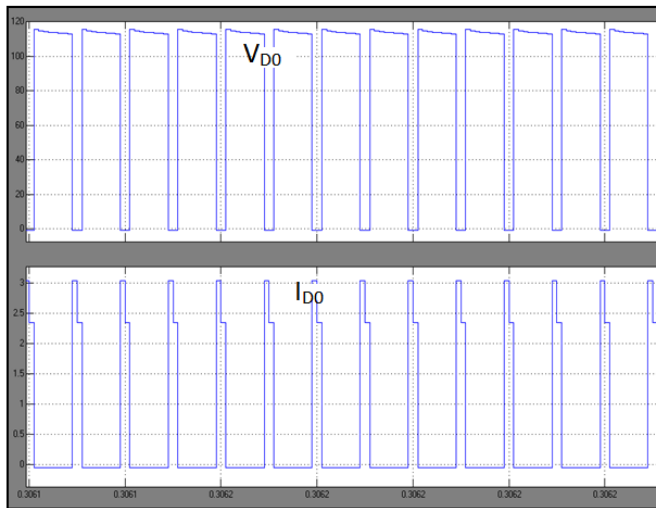


**Output voltage.  $V_o$  : 100V/div.**

The simulation results confirm that the voltage stresses across the switches S1 and S2 is greatly reduced as compared to the proposed converter I and proposed converter II and the basic boost converter.

$$V_{S1} = V_{S2} = V_{D1} = V_{D2} = \frac{V_o - V_{in}}{2}$$

$$V_{D_o} = V_o - V_{in}$$



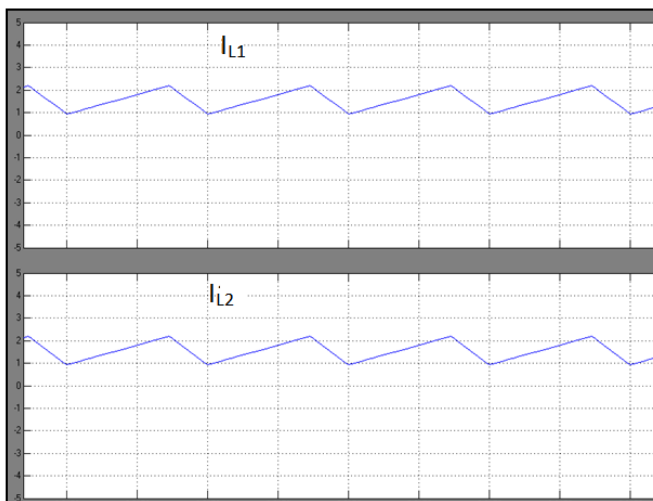
**Voltage and current in output diode.  $V_{D0}$  : 100V/div,  $I_{D0}$  : 2A/div.**

#### VI. COMPARISON OF PROPOSED CONVERTERS AND BOOST CONVERTER.

The voltage stresses on the active switch and the voltage gains of the boost converter and the proposed converters are summarized in Table I. The voltage stresses on the active switch of the three proposed converters are less than the voltage stress on the active switch of the boost converter, and thus, the active switches with low voltage ratings and low ON-state resistance levels  $R_{DS(ON)}$  can be selected.

**TABLE I  
 COMPARISON OF VOLTAGE GAIN AND VOLTAGE STRESS ON ACTIVE SWITCH FOR BOOST CONVERTER AND THREE PROPOSED CONVERTERS.**

	$M_{CCM}$	Voltage stress
Boost converter	$\frac{1}{1-D}$	$V_o$
Proposed converter I	$\frac{1+D}{1-D}$	$\frac{V_o + V_{in}}{2}$
Proposed converter II	$\frac{2}{1-D}$	$\frac{V_o}{2}$
Proposed converter III	$\frac{3-D}{1-D}$	$\frac{V_o - V_{in}}{2}$



**Inductor currents.  $I_{L1}$  : 2A/div.  $I_{L2}$  : 2A/div.**

## VII. EXPERIMENTAL RESULTS.

To verify the theoretical analyses of the proposed converter III a 40-W prototype is built in the laboratory for use in an automobile headlamp application.

Under the conditions  $V_{in}=12V$ ,  $V_o=100V$ , and  $P_o=40W$ , the simulation results are shown for all the three proposed converters. The results shows the voltage stresses on S1 and S2 is reduced. It is seen that the voltage gain and the efficiency of the proposed converters is greatly improved and higher than the boost converter.

## VIII. CONCLUSION

This paper has studied three transformerless dc-dc converters with high step-up voltage gain. The structures of the proposed converters are very simple. Since the voltage stresses on the active switches are low, active switches with low voltage ratings and low ON-state resistance levels  $R_{DS}(ON)$  can be selected. The steady-state analyses of the voltage gain are discussed in detail. Finally, to illustrate the theoretical analysis, a 40-W prototype circuit of the proposed converter III built in the laboratory. The experimental results confirm that high step-up voltage gain can be achieved.

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