Transformer less Dc – Dc Converter with high Step up Voltage gain Method

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ABSTRACT

A new circuit is proposed for a steep step-up of the line voltage. It integrates a switched-capacitor (SC) circuit with in a boost converter. An SC circuit can achieve any voltage ratio, allowing for a boost of the input voltage to high values. It is un regulated to allow for a very high efficiency. The boost stage has a regulation purpose. It can operate at a relatively low duty cycle, thus avoiding diode-reverse recovery problems. The new circuit is not cascade interconnection of the two power stages; their operation is integrated. The simplicity and robustness of the solution, the possibility of getting higher voltage ratios than cascading boost converters, without using transformers with all their problems, and the good overall efficiency are the benefits of the proposed converter.

Keywords – SC, voltage ratio, converters, transformers.

I. INTRODUCTION

The Recent emerging technology requires dc-to-dc converters with a steep voltage ratio. For example, high-intensity discharge lamps (HID) for automobile headlamps require stepping up the typical 12-V battery voltage to about 100-V output voltage, at 35-W power [1]. The telecommunication industry needs to interact with the computer industry in its desire to use the telecom infrastructure to provide Internet services. The telecom equipment uses a -V bus distributed power system, backed by a 48-V dc battery plant. The information industry uses uninterruptible power supplies, but the backup time provided by them is not enough; a better choice for providing longer reverse time is to use the -V telecom power supply and to boost it to the necessary 380-V intermediate dc bus. This application requires no isolation in the dc-to-dc step-up front-end, since the isolation is provided by the following stages, which transform the 380-V bus to the voltages required by the Servers for data processing. The DC-DC fly back converter is a very simple structure with high step-up voltage gain and electrical isolation, but the active switch of this converter will suffer high voltage stress due to the leakage inductance of the transformer. For recycling the energy of the leakage inductance and minimizing the voltage stress on the active switch, some energy-regeneration techniques have proposed to clamp the voltage stress on the active switch and to recycle the Leakage-inductance energy. The coupled inductor techniques provide solutions to achieve high voltage gain, low voltage stress on the active switch, and high efficiency without the penalty of high duty ratio. Some literatures research the transformer less DC-DC converters, which include the cascade boost type, the quadratic boost type, the voltage-lift type, the capacitor-diode voltage multiplier type and the boost type integrating with switched-capacitor technique. However, these types are all complex and higher cost. The modified boost type with switched-inductor technique is shown in Fig. 1 The structure of this converter is very simple. Only one power stage is used in this converter. However, this converter has two issues: (i) Three power devices exist in the current-flow path during the switch-on period, and two power devices exist in the current-flow path during the switch-off period. (ii) The voltage stress on the active switch equals the output voltage. A transformer less DC-DC high step-up converter is proposed in this paper, as shown in Fig. 2(a). Compared with the converter in, proposed converter I has the following merits: (i) Two power devices exist in the current-flow path during the switch-on period, and one power device exists in the current-flow path during the switch-off period. (ii) The voltage stresses on the active switches are less than the output voltage. (iii) 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 equals a half of the current stress on the active switch of the converter in. For getting higher step-up voltage gain, the other DCDC converters are also presented in this paper, as shown in Figs. 2(b) and 2(c). These three proposed DC-DC converters utilize the switched-inductor technique, 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: (1) All components are ideal. The on-state resistance RDS (ON) of the active switches, the forward voltage drop of the diodes, and the ESRs of the inductors and capacitors are ignored. (2) All capacitors are sufficiently large, and the voltages across the capacitors can be treated as constant.

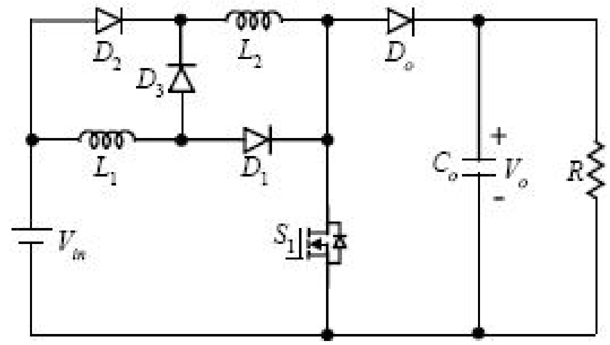


Fig. 1. Transformer less DC-DC high step-up converter

II. PROPOSED CONVERTER I

Fig. 2(a) shows the circuit configuration of proposed converter I, which consists of two active switches (S_1 and S_2), two inductors (L_1 and L_2) that have the same level of inductance, one output diode Do, and one output capacitor Co. Switches S_1 and S_2 are controlled simultaneously by using one control signal. Fig. 3 shows some typical waveforms obtained during continuous conduction mode (CCM) and discontinuous conduction mode (DCM). The operating principles and steady-state analysis of CCM and DCM are presented in detail as follows.

(A) CCM Operation

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

(I) Mode 1 [t_0, t_1]: During this time interval, switches S1 and S2 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 output capacitor Co is released to the load. Thus, the voltages across L_1 and L_2 are given as

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

(II) Mode 2 [t_1, t_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 Co and the load. Thus, the voltages across L_1 and L_2 are derived as

$$V_{L1} = V_{L2} = \frac{V_{in} - V_o}{2}. \qquad (2)$$

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

(3)

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

Simplifying (3), the voltage gain is given by
(4)

$$\text{Mocm} = \frac{V_o}{V_{in}} = \frac{1+D}{1-D}.$$

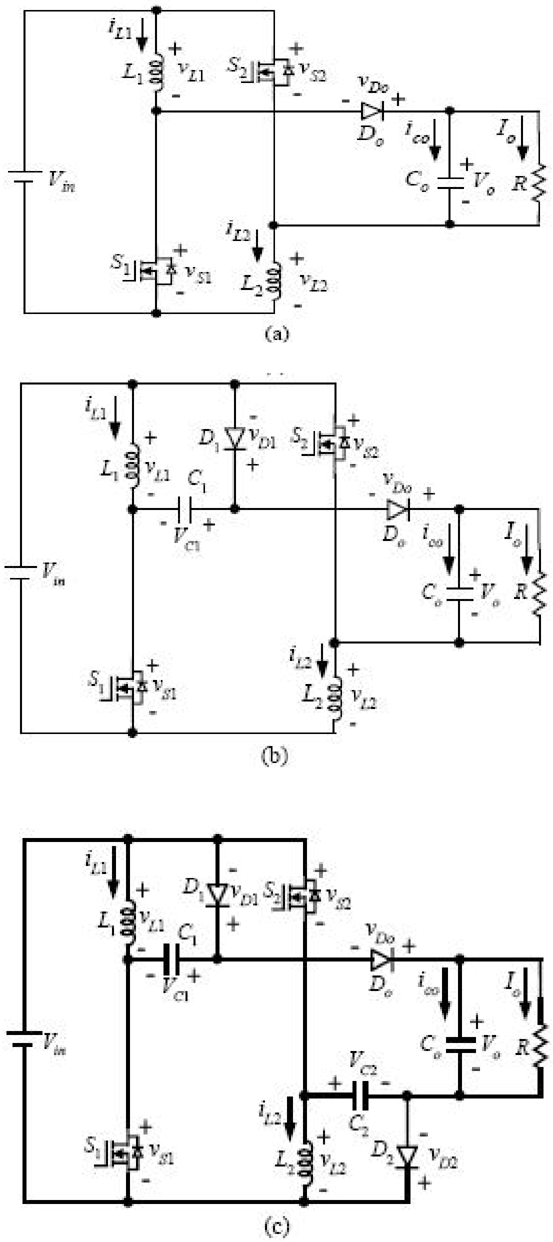


Fig. 2. Proposed high step-up DC-DC converters, (a) converter I, (b) converter II, and (c) converter III.

From Fig. 3(a), the voltage stresses on S_1, S_2 and Do are derived as

$$V_{s1} = V_{s2} = \frac{V_o + V_{in}}{2}$$

$$V_{Do} = V_o + V_{in}$$
(5)

(B) DCM Operation

The operating modes can be divided into three modes, defined as modes 1, 2, and 3.

(I) Mode 1 [t_0, t_1]: The operating principle is same as that for mode 1 of CCM operation. The two peak currents of L_1 and L_2 can be found as
(6)

$$I_{L1p} = I_{L2p} = \frac{Vin}{L} DT_s,$$

where L is the inductance of L_1 and L_2.

(II) Mode 2 [t_1, t_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 Co and the load. Inductor currents i_{L1} and i_{L2} are decreased to zero at $t = t_1$. Another expression of I_{L1P} and I_{L2P} is given as

$$I_{L1p} = I_{L2p} = \frac{Vo - Vin}{2L} D2T_s.$$
(7)

(III) Mode 3 [t_2, t_3]: During this time interval, S_1 and S_2 are still turned off. The equivalent circuit is shown in Fig. 4(c)

The energies stored in L_1 and L_2 are zero. Thus, only the energy stored in Co is discharged to the load.

From (6) and (7), D2 is derived as follows:

$$D_2 = \frac{2DV_{in}}{V_0 - V_{in}}.$$
(8)

From Fig. 3(b), the average value of output-capacitor current during each switching period is given by
(9)

$$I_{co} = \frac{\frac{1}{2} D_2 T_s I_{L1p} - I_o T_s}{T_s} = \frac{1}{2} D_2 I_{L1p} - I_o.$$

Substituting (6) and (8) into (9), Ico is derived as

$$I_{co} = \frac{D^2 V_{in}^2 T_s}{L(V_0 - V_{in})} - \frac{V_o}{R}.$$

(10)

Since Ico equals zero under steady state, equation (10) can be re-written as follows:

$$\frac{D^2 V_{in}^2 T_s}{L(V_0 - V_{in})} - \frac{V_o}{R}. \qquad (11)$$

Then, the normalized inductor time constant is defined as

$$T_L \equiv \frac{L f_s}{R},$$

(12)

where fs is the switching frequency (fs=1/Ts). Substituting (12) into (11), the voltage gain is given by

(13)

$$M_{DCM} = \frac{V_0}{V_{in}} = \frac{1}{2} + \sqrt{\frac{1}{4} + \frac{D^2}{T_L}}.$$

III. PROPOSED CONVERTER II

Fig. 2(b) shows the circuit configuration of proposed converter II, which is proposed converter I with one voltage lift circuit . Thus, two 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. 6 shows some typical waveforms of CCM and DCM. Also, the operating principles and steady-state analysis of CCM and DCM are presented as follows.

(A) CCM Operation

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

(I) Mode 1 [t_0, t_1]: During this time interval, S1 and S2 are turned on. The equivalent circuit is shown in Fig. 7(a). L1 and L2 are charged in parallel from the DC source, and the energy stored in Co is released to the load. Also, capacitor C1 is charged from the DC source. Thus, the voltages across L1, L2, and C1 are given as

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

(14)

(II) Mode 2 [t_1, t_2]: During this time interval, S1 and S2 are turned off. The equivalent circuit is shown in ig. 7(b). The DC source, L1, C1, and L2 are series-connected to transfer the energies to Co and the load. Thus, the voltages across L1 and L2 are derived as

(15)

$$V_{L1} = V_{L2} = \frac{V_{in} + V_{c1} - V_o}{2} = \frac{2V_{in} - V_o}{2}.$$

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

(16)

$$\int_0^{DT_s} V_{in}\,dt + \int_{DT_s}^{T1} \frac{2V_{in} - V_0}{2}\,dt = 0.$$

Simplifying (17), the voltage gain is given by

$$M_{CCM} = \frac{V_0}{V_{in}} = \frac{2}{1-D}.$$

(17)

From Fig. 6(a), the voltage stresses on S1, S2, D1, and Do are derived as

$$\begin{cases} V_{S1} + V_{S2} + V_{D1} = \dfrac{V_0}{2}. \\ V_{D0} = V_0 \end{cases}$$

(18)

(B) DCM Operation

The operating modes can be divided into three modes, defined as modes 1, 2, and 3.

(I) Mode 1 [t_0, t_1]: The operating principle is the same as that for mode 1 of CCM operation. The two peak currents of L1 and L2 can be found as

$$V_{L1P} = V_{L2P} = \frac{V_{in}}{L} DT_S.$$

(19)

(II) Mode 2 [t_1, t_2]: During this time interval, S1 and S2 are turned off. The equivalent circuit is shown in Fig. 7(b). The

DC source, L1, C1, and L2 are series-connected to transfer the energies to Co and the load. The values for iL1 and iL2 are decreased to zero at t = t_2. Another expression of IL1p and IL2p is given as

(20)

$$V_{L1p}=V_{L2p}=\frac{V_0+V_{in}-V_{c1}}{2L}D_2T_s=\frac{V_0-V_{in}}{2L}D_2T$$

(III) Mode 3 [t_2, t_3]: During this time interval, S1 and S2 are still turned off. The equivalent circuit is shown in Fig. 7(c). The energies stored in L1 and L2 are zero. Thus, only the energy stored in Co is discharged to the load.

From (20) and (21), D2 is derived as follows:

$$D_2=\frac{2DV_{in}}{V_0-2V_{in}}. \quad (21)$$

From Fig. 6(b), the average output-capacitor current during each switching period is given by

$$I_{CO}=\frac{\frac{1}{2}D_2T_sI_{L1p}-I_0T_s}{T_s}=\frac{1}{2}D_2I_{L1p}-I_0. \quad (22)$$

Substituting (20) and (22) into (23), Ico is derived as

$$I_{CO}=\frac{D^2V_{in}^2T_s}{L(V_0-2V_{in})}-\frac{V_0}{R}. \quad (23)$$

Since Ico equals zero under steady state, equation (24) can be re-written as follows:

$$\frac{D^2V_{in}^2T_s}{L(V_0-2V_{in})}-\frac{V_0}{R}. \quad (24)$$

Thus, the voltage gain is given by

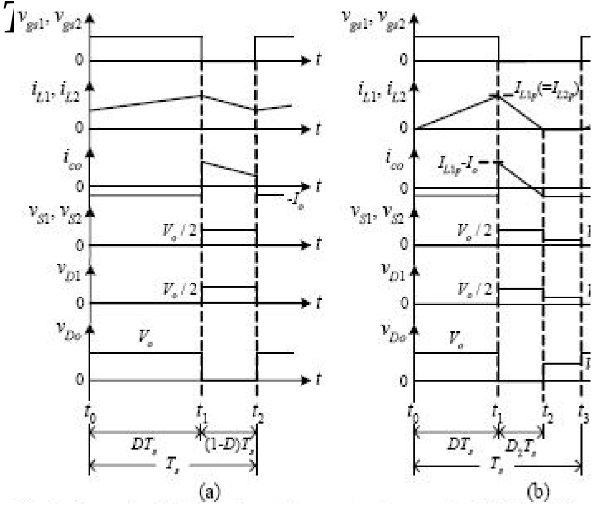
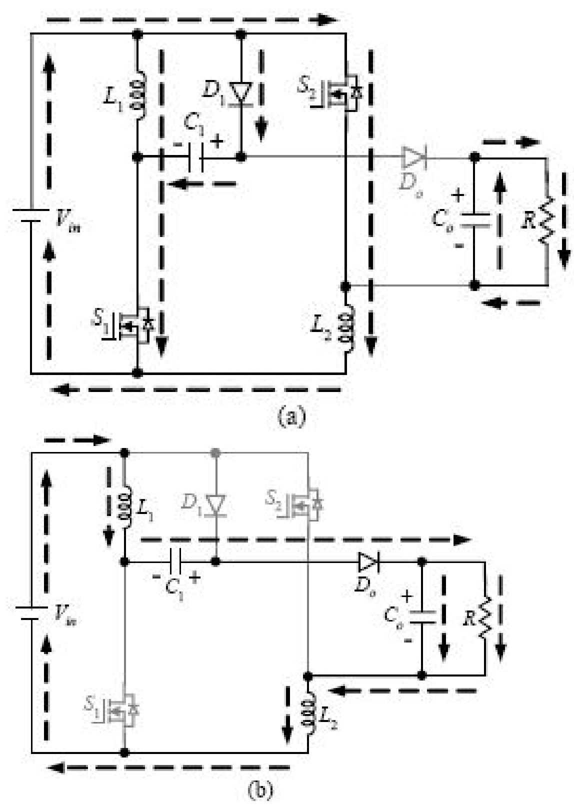


Fig. 6. Some typical waveforms for proposed converter II, (a) CCM operation, and (b) DCM operation.



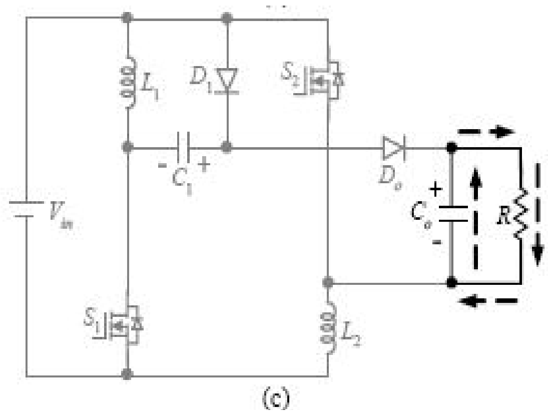


Fig. 7. Equivalent circuits of proposed converter II, (a) switches ON, (b) switches OFF, and (c) switches OFF in DCM operation.

IV. CONCLUSION

This paper has studied three novel transformers less DCDC 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 RDS(ON) can be selected. The steady-state analyses of voltage gain and boundary operating condition are discussed in detail. Finally, to illustrate the theoretical analysis, a 40 W prototype circuit of proposed converter I is built in the laboratory.

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