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Experimental Study on High Voltage Gain DC-to-DC Boost Type Converter EmployingSwitched-Inductor

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Abstract : The high boost dc-dc scheme is one most of the topic that attracted the attention of researchers because they have some merits over the conventional boost converter. Recently, a high gain DC-to-DC boost type converter has been introduced by employing switched-inductor. The high gain DC-to-DC boost type converter topology is suitable for high gain conversion applications where a varying low dc input voltage is converted to a high stabilized dc output voltage. In the paper, the experimental results of the novel high gain DC-to-DC boost type converter employing switched-inductor are illustrated. Furthermore, an extended high gain DC-to-DC boost type converter is also proposed. Circuit analysis, operating theories of the extended high gain DC-to-DC boost type converter are presented. Finally, the experimental results of the high gain DC-to-DC boost type converter are also presented to validate the performance of the high gain DC-to-DC boost type converter for the practical implementation.

Keyword : step-up converter, PWM control strategy, high voltage gain, Switched-inductor, power conversion.

1. Introduction

In recent years, the power demand is significantly rising due to population increase and the significant industrialization. Therefore, the green energy has attracted more and more attention of the researcher. Renewable energy sources have many advantages, i.e. its clean and cheap. So, using the green energy sources is an effective approach. However, the output voltage of green energy sources is relatively low and instability. The power conversion system is inserted into between input DC source such as FC, PV, or battery and residential loads such as load DC, DC-AC inverter to achieve higher DC voltage. Traditional DC-DC boost converter [1] was used to boost low input DC sourced to higher voltage. Nevertheless, for high step-up conversion applications, the conventional boost converter is not suitable. Besides that, a large inductance that is required to guarantee operating in continuous conduction mode and high voltage stress across power semiconductor are limitations of conventional DC-DC boost converter. By applying transformer to the boost converter as discussed in [2]-[5], to voltage again was improved and voltage stress across the component was reduced. But with using Transformer leads to cost and size of system. The high gain transformerless converters [6]-[10] were introduced. It is a combination of two-level dc/dc converters. As a result, a large number of components was used and it results in an increase in expense. In order to improve high voltage gain, switched capacitor techniques and switched inductor techniques were also discussed [11]-[13]. But the demerit was that the high charging current will flow through power semiconductor. As a result, the conduction losses increased significantly. The high gain DC-to-DC boost type converter employing switched-inductor was proposed in [14]. The introduced inverter was applicable to photovoltaic or fuel cells

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applications that need a high voltage gain ratio.

In the study, the experimental results of the novel high gain DC-to-DC boost type converter employing switched-inductor is presented to validate the performance of the high gain DC-to-DC boost type converter for the practical implementation. Furthermore, an extended high gain DC-to-DC boost type converter is also proposed. Circuit analysis, operating theories of the extended high gain DC-to-DC boost type converter are presented. In section 2, Extended High Gain DC-to-DC Boost Type Converter and principles of converter operation are presented. Experimental verifications are shown in section 3. The conclusion is presented in section 4.

2. Extended High Gain Dc-To-Dc Boost Type Converter

Fig. 1 shows the high gain DC-to-DC boost type converter topology [14]. From [14], the capacitor C1 voltage and the inductor currents are:

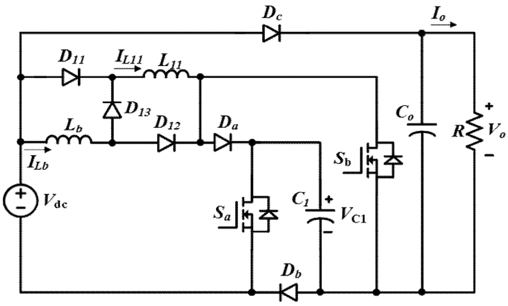

Figure 1. High Gain DC-to-DC Boost Type Converter.

$$V_{c1} = \frac{1+2D}{1-2D} V_{dc} \quad (1)$$

$$I_{Lb} = I_{L11} = \frac{1}{1-2D} I_o$$

The output voltage, V_o of the high gain DC-to-DC boost type converter topology is calculated as follows:

$$V_o = V_{dc} + V_{c1} = \frac{2}{1-2D} V_{dc} \quad (2)$$

where T and D are the switching period and the duty cycle of Sa, respectively

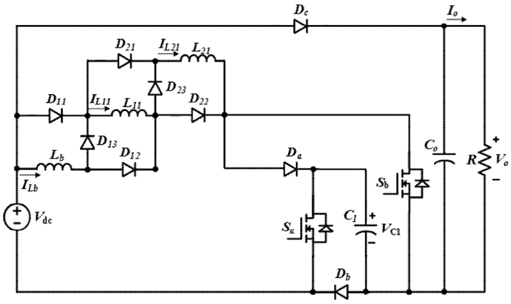

Figure 2. Proposed High Gain DC-to-DC Boost Type Converter employing 2 switched-inductor cell.

Fig. 2 presents the proposed high gain DC-to-DC boost type converter employing 2 switched-inductor cells. As shown in Fig. 2, The proposed topology consists of two active-switches (S_a and S_b), three inductors (L_b, L_{11}, and L_{21}), nine diodes, aboost capacitor (C_1), one input voltage source and a capacitor (C_o) directly connecting in parallel with a resistive load(R) in parallel. The PWM strategy for two active-switches of the high gain DC-to-DC boost type converter topology is applying The proposed topology. In this paper, to simplify the circuit analysis, the components in proposed converter were assumed to be ideal, and the proposed converter is operating in continuous conduction mode. Similar to the high gain DC-to-DC boost type converter topology, the proposed topology also has three operating states in CCM as shown in Fig. 3.

In the state 1, three inductors and capacitor C_o are charged while capacitor C_1 is discharged as shown in Fig. 3(a). We have:

$$L_b \frac{di_{Lb}}{dt} = L_{11} \frac{di_{L11}}{dt} = L_{21} \frac{di_{L21}}{dt} = V_{dt} \quad (3)$$

$$V_o = V_{c1} + V_{dc}$$

$$C_1 \frac{dv_{c1}}{dt} = I_{Lb} + I_{L11} + I_{L21} - i_{\in *}$$

$$C_o \frac{dv_{co}}{dt} = i_{\in *} - I_{Lb} - I_{L11} - I_{L21} - I_o$$

Where i_{in^*} is the input dc current during state 1 when Switch S_a is switched on.

In the state 2, Capacitor C_o is discharged while three inductors are charged as shown in Fig. 3(b). Capacitor C_1 is disconnected from the main circuit. We have:

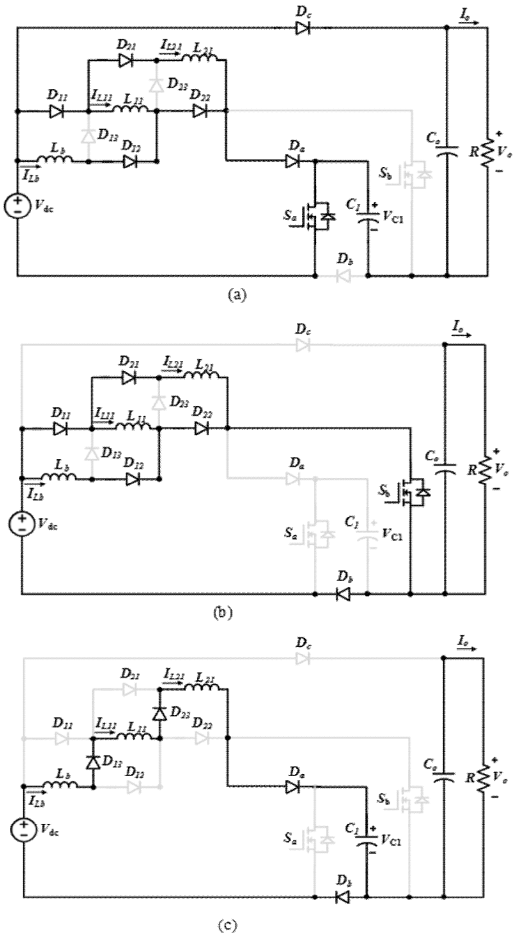

Figure 3. Operating states of the proposed converter: (a) state 1, (b) state 2, and c) state 3.

$$L_b\frac{di_{Lb}}{dt}= L_{11}\frac{di_{L11}}{dt}= L_{21}\frac{di_{L21}}{dt}= V_{dc} \quad (4)$$
$$C_1\frac{dv_{c1}}{dt}=0$$
$$C_o\frac{dv_{co}}{dt}=-I_o$$

In the state 3, the capacitor C_1 is charged while three inductors and capacitor C_o are discharged as shown in Fig. 3(c). We have:

$$L_b\frac{di_{Lb}}{dt}+L_{11}\frac{di_{L11}}{dt}+L_{21}\frac{di_{L21}}{dt} = V_{dc}- V_{c1} \quad (5)$$
$$C1\frac{dv_{c1}}{dt}= I_{Lb} = I_{L11} = I_{L21}$$
$$C_o\frac{dv_{co}}{dt}=-I_o$$

From (3), (4) and (5), we have

$$V_{c1} = \frac{1+4D}{1-2D}V_{dc} \quad (6)$$
$$I_{L1} = I_{L2} = \frac{1}{1-2D}I_o$$

The output voltage, V_o of the proposed converter topology is

$$V_o = V_{dc}+V_{c1} = \frac{2-2D}{1-2D}V_{dc} \quad (7)$$

The proposed converter topology can be extended by adding more switched-inductor cells into the main circuit. The structure of a switched-inductor cell is shown in Fig. 4. Fig. 5 shows the proposed high gain DCo-DCoost type converter employing n-switched-inductor cells.

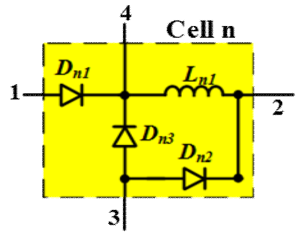

Figure 4. The structure of a switched-inductor cell.

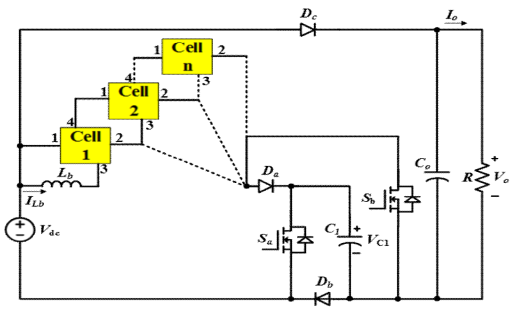

Figure 5. Proposed Converter employing Multi switched-inductor cells

The capacitor C_1 voltage of the proposed converter topology employing n-switched-inductor cells can be derived as

$$V_{c1} = \frac{1+2nD}{1-2D} V_{dc} \tag{8}$$

The output voltage, V_o of the proposed converter topology employing n-switched-inductor cells is

$$V_o = \frac{2+2(n-1)D}{1-2D} V_{dc} \tag{9}$$

The voltage gain, G of the proposed converter topology employing n-switched-inductor cells is

$$G = \frac{V_o}{V_{dc}} = \frac{2+2(n-1)D}{1-2D} \tag{10}$$

Fig. 6 shows voltage gain comparison with employing n-switched-inductor cells. For the same duty cycle, voltage gain can be risen by increasing the number of switched-inductor cells as shown in Fig. 6.

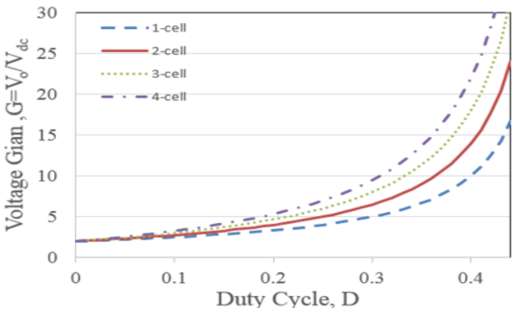

Figure 6. Comparative plots of voltage gain and duty cycle with employing n-switched-inductor cells.

3. Experimental Verifications

As an example, the converter topology employing 1 switched-inductor cell as shown in Fig. 1 is used to validate the performance of the high gain DC-to-DC boost type converter for the practical implementation in this paper. The configurations of the converter topology employing 1 switched-inductor cell are as follow: $L_1 = L_2 = 700\mu H$, $C_1 = 68\mu F$, $C_o = 220\mu F$, and s$R = 200\Omega$. The switching frequency is 20 kHz. An output DC voltage of 400 V is produced from an input voltage of 50 V. Table 1 shows a list of parameters for experiment.

Table 1. List of parameters for experiment.

Parameter		Value
Input voltage		50V
Out voltage		400V
Output power		800W
Capacitor	C_1	68 μF
	C_2	220 μF
Inductors		700 μH
Resistor load		200 Ω
Switching Frequency		20 kHz

Fig.7 shows experimental results of the high gain DC-to-DC boost Type Converter employing 1-switched-inductor cell with $G=8$ and $V_{dc}=50V$. As shown in Fig.7, the output voltage is 400V with the low input voltage of 50V. The voltage of the C_1 and output current are 350V and 2A, respectively. Diode Da voltage waveform, Diode Db voltage waveform, and Diode Dc voltage waveform are the square waveform as shown in Fig. 5.26. The maximum voltage across the Diode D_a and Diode D_b are 150V meanwhile that of Diode Dc is 50V. The maximum voltage across the Diode D_3 is 350V. We can see that switch S_a voltage and switch S_b voltage are the square waveform and are 350V. The inductor L_1 current and inductor L_2 current are the same value and are 8A. The current ripple on inductor L_1 and inductor L_2 are 2.8A. The voltage across on the inductor L_1 and inductor L_2 are the same value. The current stress on Diodes D_a, D_b and D_c is equal to the inductor current and are 9A.

Fig. 8 shows the dynamic performance of the high gain DC-to-DC boost type converter when $G=8$. In this case, resistor load is 200Ω and input voltage changes from 0V to 50V. The output voltage reaches from 0V to 400V and the transient time is approximately 0.03sec.

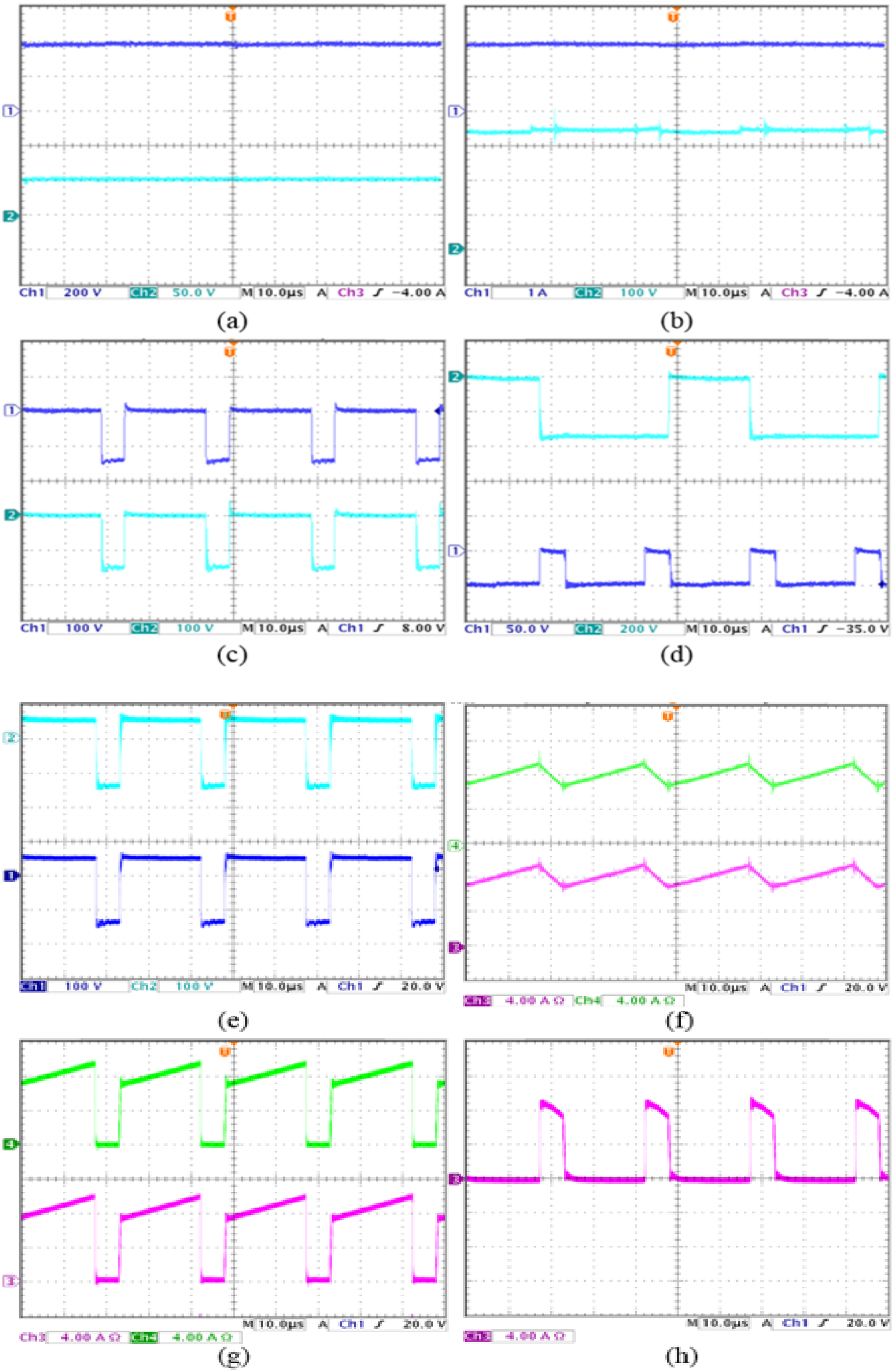

Figure 7. Experimental waveforms of the proposed converter when $V_g = 50\,V$. From top to bottom: (a) output voltage V_o and input voltage V_{dc}, (b) load current I_o and C_1 capacitor voltage; (c) diode D_a voltage, diode D_b voltage, (d) diode D_3 voltage and diode D_c voltage. (e) voltage across inductor L_1 (V_{L2}), and voltage across inductor L_2 (V_{L2}), (f) inductor L_1 current (i_{L2}), and inductor L_2 current (i_{L2}); (g)Diode D_a current (i_{Da}), and Diode D_b current (i_{Db}); (h)Diode D_c current (i_{Dc}).

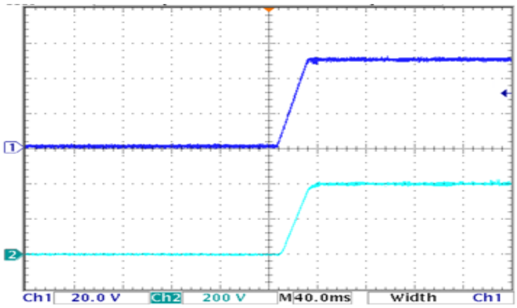

Figure 8. Dynamic performance of high gain DC-to-DC boost type converter employing 1 switched-inductor cell. From top to bottom: input voltage and output voltage.

4. Conclusions

The extended high gain DC-to-DC boost type converter employing n-switched-inductor cells is introduced in this paper. The major properties of proposed extended converter topology are continuous input current with low ripple and high voltage gain. The operating principles and circuit analysis of proposed extended converter topology are presented. The experimental results of the high gain DC-to-DC boost type converter are also presented to validate the performance of the high gain DC-to-DC boost type converter for the practical implementation.

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