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A high step-up and low switches voltage stress boost converter

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Abstract: To increase the output voltage range efficiently in distributed generation system, a novel high step-up and low switches voltage stress boost converter with charge pump capacitor is proposed in this paper. The structure and basic operating principles analysis are provided, but also the results of the analysis are verified by simulation and experiment.

Keywords: high step-up, low switches voltage stress, pump capacitor

Classification: Electron devices, circuits, and systems

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1 Introduction

In recent years, due to the shortage of traditional fossil energy, research of photovoltaic power generation system and fuel cell power generation system become more and more deeply. However, output voltage of photovoltaic panels, battery and fuel cell monomer is low. It is significant to add a step-up dc-dc converter in the front-end of photovoltaic generation system increasing output voltage of new energy efficiently [1].

Traditional boost converter is widely used in practice because of its simple structure and low cost. However, the input current ripple is big, the conduction duty of switch is larger, and the voltage stress of switch is equal to the output voltage [2]. In order to reduce the input current ripple, two-phase parallel interleaving boost structure is proposed [3]. However, the voltage gain is the same as

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that of traditional boost converter, and the voltage stress of switch is equal to the output voltage. In order to realize high voltage gain under low duty ratio, cascade boost topology is proposed [4]. But voltage stress of back-stage switch increases, circuit structure is complicated, and the control method is difficult.

In this paper, a novel high step-up and low switches voltage stress boost converter with charge pump capacitor is proposed. Compared with the conventional boost converter, the converter proposed not only has higher voltage step-up ratio, but the voltages across switches are lower than that in conventional converter.

2 Operating principles

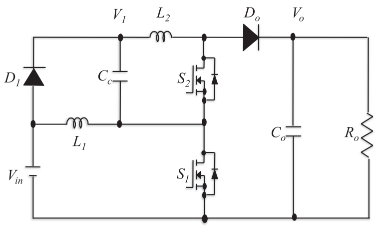

Fig. 1. Proposed boost converter

Block diagram of the proposed high step-up boost converter are shown in Fig. 1, respectively. For the proposed converter, L_1 and L_2 are equal in size. Furthermore, S_1 and S_2 are driven by the same gate driving signal obtained from the controller.

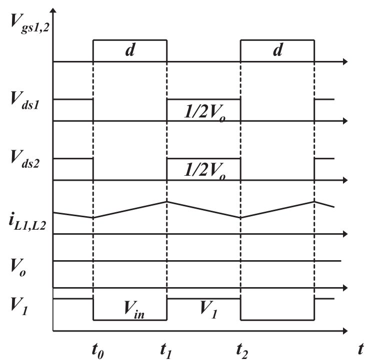

Fig. 2. Key waveforms of proposed converter

The key waveforms of proposed converter are shown in Fig. 2. For understanding proposed converter in detail, two states divided according to the state of two switches will be used to analyze the operation process.

1) State 1 ($t_0{\sim}t_1$): As shown in Fig. 3, S_1 and S_2 are on-state; D_1 is forward biased, while D_o is reverse biased. L_1, L_2 and C_c charge in parallel by three independent circuits. Due to the value of L_1 and L_2 is equal, the change rate of current i_{L1} and i_{L2} are the same. So at the time $t = t_1$, $i_{L1} = i_{L2}$.

Then, the equations of state 1 can be expressed as:

$$\begin{cases} L_1\dfrac{di_{L1}}{dt} = V_{in} & L_2\dfrac{di_{L2}}{dt} = V_{in} \\ V_{CC} = V_{in} & V_1 = V_{in} \end{cases} \tag{1}$$

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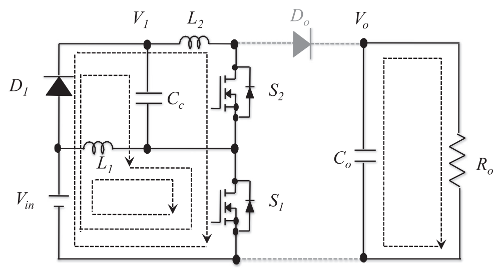

Fig. 3. Power flow in state 1

2) State 2 ($t_1 \sim t_2$): As shown in Fig. 3, S_1 and S_2 are off-state, D_1 is reverse biased, D_o is forward biased. L_1, L_2 and C_c discharge with input voltage in series.

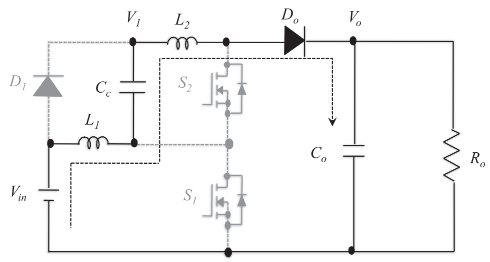

Fig. 4. Power flow in state 2

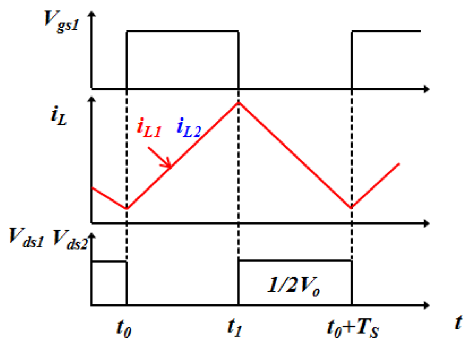

Fig. 5. Current of inductances

The equations of state 2 can be described as:

$$\begin{cases} L_1 \dfrac{di_{L1}}{dt} = \dfrac{L_1}{L_1 + L_2}(2V_{in} - V_o) \\ L_2 \dfrac{di_{L2}}{dt} = \dfrac{L_2}{L_1 + L_2}(2V_{in} - V_o) \end{cases} \tag{2}$$

Applying the volt-second balance to these states, the relationship between input and output voltage can be obtained:

$$V_o = \frac{2}{1-d} V_{in} \tag{3}$$

Then, the step-up ratio of proposed converter is

$$r_{pro} = \frac{V_o}{V_{in}} = \frac{2}{1-d} \tag{4}$$

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Where d is the duty cycle of the pulse width modulation (PWM) control signal for S_1 and S_2.

The voltages across S_1 and S_2 can be expressed as follows:

$$V_{ds1} = V_{ds2} = \frac{1}{2} V_o \tag{5}$$

The waveforms of currents through L_1 and L_2 and voltages across S_1, S_2 are shown in Fig. 5.

In the same case, the step-up ratio of conventional converter and the voltage across S are:

$$r_{con} = \frac{V_o}{V_{in}} = \frac{1}{1-d} \tag{6}$$

$$V_{ds} = V_o \tag{7}$$

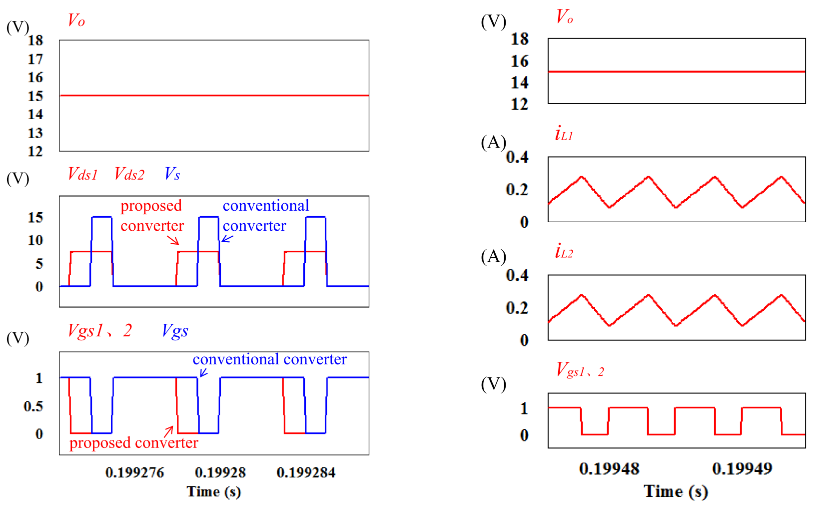
According to the analysis above, it is obvious that the step-up ratio of proposed converter increases to the twice of that of conventional. Meanwhile, the voltage stresses of switches reduce to the half of that of conventional.

3 Simulation and experiment results

Table I. Circuit parameters

parameter	value
input voltage V_{in}/V	3
inductor L_1/µH	46
inductor L_2/µH	46
capacitor C_c/µF	330
resistor R/Ω	200
filter capacitor Co/µF	47
switch frequency f/kHz	200

To verify the validity of theoretical analysis, simulation models for conventional boost converter and proposed converter have been carried out in PSIM. The main parameters for proposed converter are displayed in Table I.



(a) (b)

Fig. 6. Simulation waveforms of proposed and conventional converter

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The input voltage and the output voltage of the proposed and conventional converter are set as 3 V and 15 V, respectively. Fig. 6(a) shows the output voltage, switch voltage stresses and switching signals waveforms of the conventional and proposed converter. It can be found that to guarantee the same output voltage of two converters, the duty cycle of proposed converter is smaller than the duty cycle of conventional converter. The duty cycle of the proposed converter is 0.6, in contrast, that of the conventional is 0.8. In addition, the switch voltage stresses of the proposed converter are half of that of conventional which equals to the output voltage. The currents flow through the inductor L_1 and L_2 of proposed converter, which are equal in size, are displayed in Fig. 6(b).

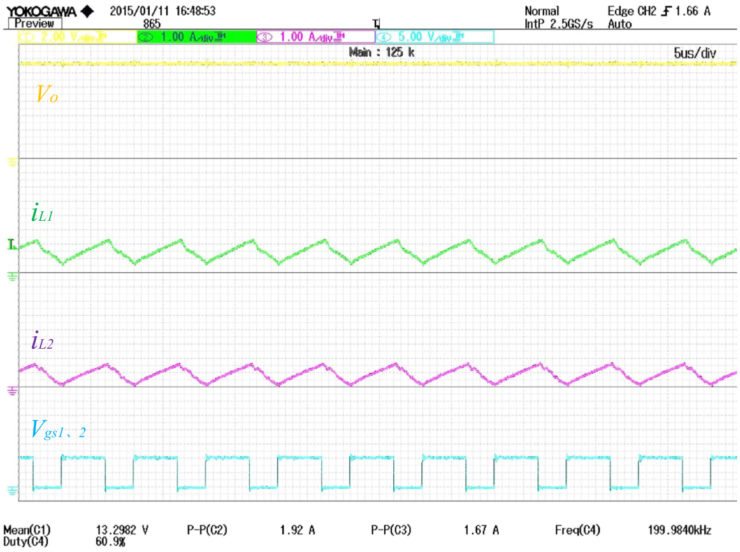

Fig. 7. Experiment waveforms of proposed converter

An experiment model is implemented to prove the feasibility of the proposed converter. Experiment parameters are consistent with the simulation parameters displayed in Table I. Moreover, the duty cycle of experiment is set as 0.6. Experiment results are shown as Fig. 7. Due to the existence of the parasitic resistances, the value of experiment output voltage is smaller than the simulation result. However, it is acceptable. The currents flow through the inductor L_1 and L_2 roughly have the same waveform, which absolutely matches the theoretical analysis and simulation result.

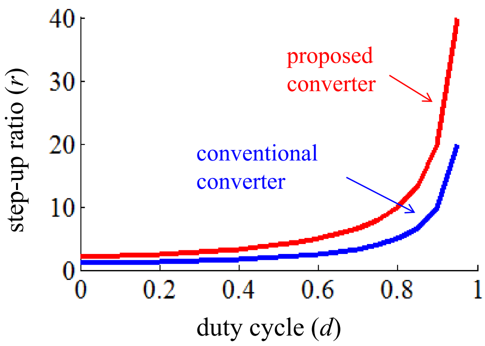

Fig. 8. Step-up ratio comparison of proposed and conventional boost converter

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4 Conclusion

Summing up the above analysis, the proposed converter has several advantages as follows:

(a) The proposed converter can obtain high voltage gain compared with that of conventional converter. A step-up ratio comparison result of proposed and conventional boost converter is shown in Fig. 8.

(b) The voltage across S_1 and S_2 is half of the output voltage in proposed converter, which is lower than that in the conventional converter.

Finally, feasibility and superiority of proposed converter is verified by simulation and experiment results. In addition, it should point out that in the case that the inductances of L_1 and L_2 are different will be discussed in the future.

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