

A Utility Model Relates to a Multi-Input Port High-Gain DC-DC Converter for Photovoltaic Power Generation System

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Abstract: Aiming at the problem of large number of photovoltaic modules and low output voltage in photovoltaic power generation system, a multi-input high-gain DC-DC converter is proposed. The converter has multiple input-single outputs, and has the advantages of low stress of the switching device, simple control, high output voltage gain, and the number of input ports are not limited by the switching tube duty ratio. Finally, an experimental prototype with a rated power of 100W was built to verify the feasibility of the theory.

1. Introduction

With the continuous advancement of society, the world's demand for energy is growing, and traditional fossil energy reserves are limited. Therefore, the research on renewable energy has become a very important direction. Among them, photovoltaic power generation has attracted widespread attention as a new energy source with wide distribution and no pollution.

The output voltage of commonly used photovoltaic panels generally ranges from 30 V to 60 V, while the input voltage of the DC bus during grid connection is generally 360 V to 400 V. Therefore, DC-DC converters with high boost capability are required to be lower. The photovoltaic cell output voltage rises to the input voltage of the DC bus. The traditional Boost converter can theoretically achieve an infinite output voltage gain by changing the duty cycle. However, due to the influence of parasitic parameters, it is difficult to achieve an infinite gain of the theoretical output voltage when the duty ratio is close to 1. [3-4]. In addition, the conventional photovoltaic power generation system generally adopts a photovoltaic panel with a converter, which causes problems such as low system power utilization efficiency and high design cost. Therefore, multi-input high-gain DC-DC converters have become a research hotspot in recent years [5-7].

By cascading multiple Boost converters, the problem that the single Boost converter has too large duty ratio during high boost can be solved, but the structure of the converter is complicated and the reliability is low [7]. In [6], a multi-input high-boost Boost converter is proposed, which can increase the output voltage gain by means of capacitor voltage double. However, since the

switching transistors are turned on and off alternately, when there are many input ports, the control method will become more complicated, except that the number of input ports is limited by the duty cycle of the switch. In [10-11], an isolated DC-DC converter is proposed, which can achieve high output voltage gain by adjusting the turns ratio of the transformer in the circuit. However, due to the high-frequency transformer, the structure is complex and bulky. And the power density is low, so it is not suitable for a wide range of applications. Literature [12] proposed a DC-DC converter based on switch.

Aiming at the large number of photovoltaic panels in photovoltaic power generation system and the need for high boost conversion, this paper proposes a multi-input high-gain DC-DC converter with simple control strategy, low voltage stress of switching devices, and no input port number. Subject to the main switch duty cycle limit.

2. Working principle

Figure 1 shows the topology of the multi-input high-gain DC-DC converter proposed in this paper. Taking two inputs as an example, in order to simplify the analysis process, the following assumptions are made:

- ① All components in the circuit are ideal devices, regardless of their parasitic parameters.
- ② Capacitance is infinite, and the voltage across the capacitor is considered constant.
- ④ The parameters of all the inductors in the circuit are identical. The switch tubes S_{11} , S_{12} , S_{21} , and S_{22} are turned on and off synchronously. The main waveform of the converter in one duty cycle TS is shown in Figure 2.

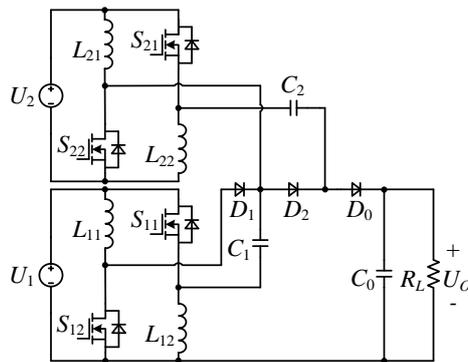


Fig. 1 High gain DC-DC converter with two-input ports

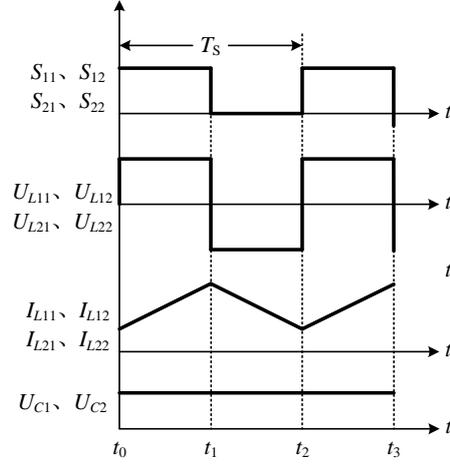


Fig. 2 Main waveforms in a working period T_s

Mode 1[t_1 - t_2]: The equivalent circuit is shown in Figure 3(a). S_{11} , S_{12} , S_{21} , and S_{22} are simultaneously turned on. U_1 charges L_{11} and L_{12} , and U_2 charges L_{21} and L_{22} . The voltages across inductors L_{11} and L_{21} are:

$$U_{L11} = U_{L12} = U_1 \quad (1)$$

Where: U_1 is the input voltage of port 1.

The voltages across the inductors L_{21} and L_{22} are:

$$U_{L21} = U_{L22} = U_2 \quad (2)$$

Where: U_2 is the input voltage of port 2.

During this phase, the current flowing through the inductors L_{11} , L_{12} , L_{21} , L_{22} increases linearly.

At the same time, U_1 , C_1 , U_2 , C_2 are connected in series to C_0 and the load, and diodes D_1 and D_2 are reversed. At this time:

$$I_{D1} = I_{D2} = 0 \quad (3)$$

Where: I_{D1} , I_{D2} are the currents flowing through diodes D_1 , D_2 , respectively.

$$U_o = U_1 + U_{C1} + U_2 + U_{C2} \quad (4)$$

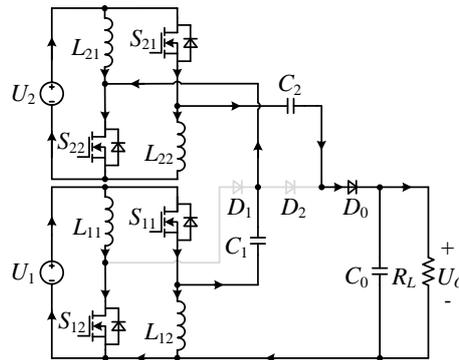
Where: U_o is the output voltage of the converter, U_{C1} and U_{C2} are the voltages across the capacitors C_1 and C_2 respectively.

Mode 2[t_1 - t_2]: The equivalent circuit is shown in Figure 3(b). S_{11} , S_{12} , S_{21} , and S_{22} are

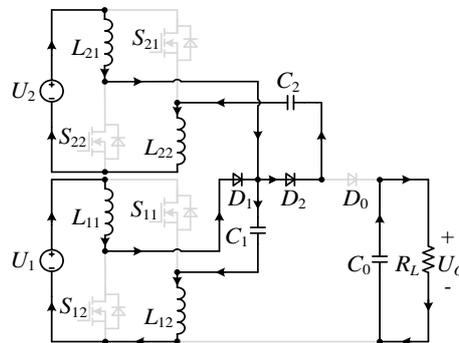
tur-ned off at the same time. U_1 , L_{11} , and L_{12} are connected in series to charge capacitor C_1 , and U_2 , L_{12} , and L_{22} are connected in series. Capacitor C_2 is charged and capacitor C_0 supplies power to the load. The current flowing through the inductors L_{11} , L_{12} , L_{21} , and L_{22} decreases .And at this time:

$$U_1 + U_{L11} + U_{L12} = U_{C1} \quad (5)$$

$$U_2 + U_{L21} + U_{L22} = U_{C2} \quad (6)$$



(a) Mode 1



(b) Mode 2

Fig. 3 The equivalent circuit of each mode

3 Performance analysis

The two input topologies are extended to a multi-input high-gain DC-DC converter as shown in Fig.4, and the input/output voltage gain and the switching tube voltage stress of the converter are analyzed. Let the converter have a total of n input ports, taking the i-th input port as an example.

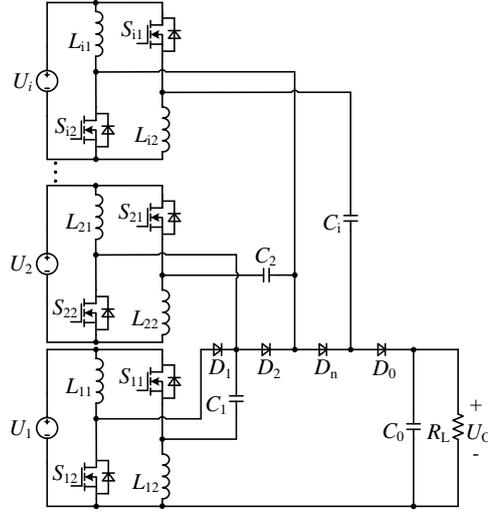


Fig. 4 High gain DC-DC converter with multiple-input ports

3.1 Input and output voltage gain

According to the volt-second balance of the inductors L_{i1} and L_{i2} :

$$DU_i = (1-D) \cdot \frac{U_{Ci} - U_i}{2} \quad (7)$$

Where: U_i is the input voltage of the i -th port of the converter, and U_{ci} is the voltage across the capacitor C_i .

According to equation (7), we know :

$$U_{Ci} = \frac{1+D}{1-D} \cdot U_i \quad (8)$$

According to KVL and equation (8), when the i -th power supply is separately input, the output voltage of the converter is:

$$U_{Oi} = \frac{2}{1-D} \cdot U_i \quad (9)$$

According to the superposition theorem, when n power supplies are simultaneously input, the output voltage of the converter is:

$$U_O = \sum_{i=1}^n U_{Oi} = \frac{2}{1-D} \cdot \sum_{i=1}^n U_i \quad (10)$$

If $U_1=U_2=\dots=U_i=\dots=U_n=U$, the single output voltage gain of the converter is:

$$M_1 = M_2 = \dots = M_i = \dots = M_n = \frac{2}{1-D} \quad (11)$$

In the formula: $M_1, M_2, \dots, M_i, \dots, M_n$ is the output voltage gain of the converter when the i -th power supply acts alone.

It can be found that the converter can increase the voltage of the multi-port input separately,

superimpose and finally output, and achieve higher output voltage gain when the duty ratio is not too large.

3.2 Switching device voltage stress

The switching tubes S_{i1} and S_{i2} are provided; the voltage stress of the diode D is U_{si1} , U_{si2} , and U_{Di} , respectively. According to KVL, we know:

$$U_{Si1} = U_{Ci} - U_{Li1} \quad (12)$$

$$U_{Si2} = U_{Ci} - U_{Li2} \quad (13)$$

$$U_{Di} = U_i + U_{Ci} \quad (14)$$

Associative (5), (6), (8), (12), (13)

$$U_{Si1} = U_{Si2} = \frac{1}{1-D} \cdot U_i \quad (15)$$

The simultaneous (8) and (14) can be known:

$$U_{Di} = \frac{2}{1-D} \cdot U_i \quad (16)$$

If $U_1=U_2=\dots=U_i=\dots=U_n=U$, then:

$$U_o = \frac{2}{1-D} \cdot \sum_{i=1}^n U_i = \frac{2n}{1-D} \cdot U \quad (17)$$

Then:

$$U_{Si1} = U_{Si2} = \frac{U_o}{2n} \quad (18)$$

$$U_{Di} = \frac{U_o}{n} \quad (19)$$

From the above theoretical analysis, it can be concluded that compared with the conventional Boost converter, the voltage stress of the switching device is significantly reduced under the same output voltage gain.

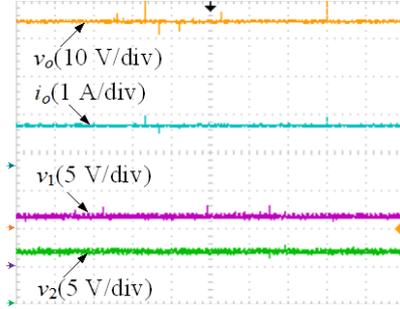
4. Experimental research and analysis

In order to verify the feasibility of the theory, an experimental prototype with a rated output of 60 W and two input ports was built. The input voltage $U_1=U_2=7V$, the duty cycle of the switching tube $D=0.5$, the rated output voltage $U_o=56 V$, and the switching frequency $f=33 \text{ kHz}$. The specific parameters of the selected components are shown in the following table:

Tab. 1 specific parameters of the experimental prototype

Components	Model or parameter
$S_{11}, S_{12}, S_{21}, S_{22}$	IRFB4110
D_0, D_1, D_2	MBR20100CT
$L_{11}, L_{12}, L_{21}, L_{22}$	1 mH
C_1, C_2	3300 μ F
C_0	10000 μ F

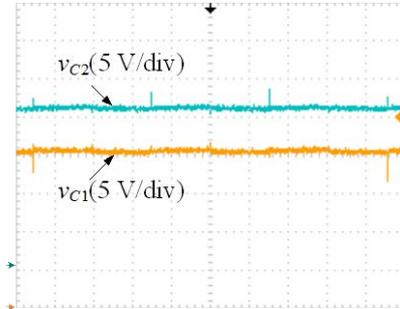
The main working waveform of the converter is shown in Figure 5. Figure 5 (a) is the converter input voltage and output voltage, current waveform; Figure 5 (b) is the capacitor C1, C2 voltage waveform; Figure 5 (c) is the switch tube S11, S12, S21, S22 voltage waveform; Figure 5 (d) is the voltage waveform of the diodes D1 and D2.



(10 μ s/div)

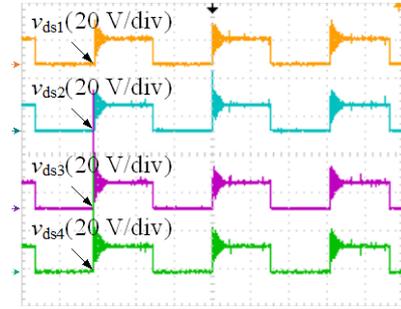
(a) Converter input voltage and output voltage,

c-current



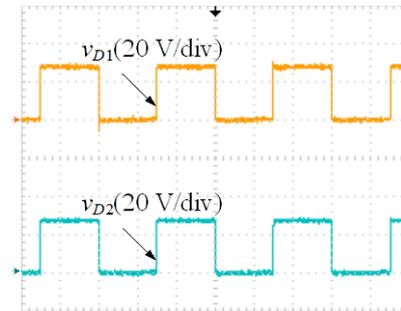
(10 μ s/div)

(b) Capacitor C₁, C₂ voltage



(10 μ s/div)

(c) Switching tubes S₁₁, S₁₂, S₂₁, S₂₂ voltage



(10 μ s/div)

(d) Diode D₁, D₂ voltage

Fig. 5 Main working waveforms of the converter

It can be found from the experimental data that when $U_1=U_2=7$ V and duty ratio $D=0.5$, the output voltage of the converter is 54V, which is close to the theoretical value of 56 V; the voltage stress of the switching tubes S11, S12, S21 and S22 is approximately 14 V, which is 0.25 times the output voltage U_0 ; the voltage stress of the diodes D1, D2, and D3 is approximately 28 V, which is 0.5 times the output voltage U_0 , which is in agreement with the theory.

5 Conclusion

This paper presents a multi-input high-gain DC-DC converter for photovoltaic power generation

systems. Through theoretical analysis and experimental verification, the results show that the converter has the following characteristics:

(1) The output voltage of the converter is equal to twice the serial output voltage of n conventional Boost converters, enabling higher output voltage gain.

(2) The converter has the advantage of low voltage stress of the switching device.

(3) The number of input ports of the converter is not limited by the switching tube duty ratio, so any number of input ports can be realized, which reduces the number of converters in the photovoltaic power generation system and reduces the design cost.

In summary, the converter is suitable for photovoltaic power generation systems with a large number of photovoltaic cells.

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