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Engineering

A DUAL INPUT DC-DC BOOST CONVERTER WITH HIGH VOLTAGE GAIN

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ABSTRACT A high gain dc-dc boost converter with two input stages is proposed here. The development of modern industrial technology and massive consumption of electrical energy results in rapid increase of distributed generation. PV cells and Fuel cells, the most important among DG technologies requires dc-dc converters. Also high step up dc-dc converters play a critical role in the industrial applications such as Uninterrupted Power Supplies (UPS), electric traction etc. The proposed converter has four voltage multiplier cells to achieve the high voltage gain. This converter offers continuous input current, which makes it more promising for the integration of renewable sources like solar panels to a dc bus. The converter design and comparison with conventional boost converter have been discussed in detail with supporting simulations using MATLAB/SIMULINK.

KEYWORDS : high voltage gain, DC-DC converter, voltage multiplier

INTRODUCTION

In recent years, the use of electrical energy is found to be tremendous and hence it demands to increase the power generation in an efficient way. Renewable energy utilization is found to be the most promising technique. Renewable power system requires DC-DC boost converters to step up low voltages from energy sources like PV arrays and fuel cells to high voltages for the grid-connected inverters. The need for such a converter can also be found in the back-up energy conversion for UPS, high-intensity discharge lamps, the front-end stage for the communication system etc. In those applications, highly efficient and high step-up DC-DC converters are required to maintain high output voltage gain. The conventional boost converters can provide large voltage gain with an extreme duty cycle. However, practical converters are affected by the parasitic parameters and have serious power loss. Besides, the modern power electronics cannot still provide efficient and economic high-voltage stress withstanding diodes and switch for the converters. Practical electronic converters use switching techniques.

Switched-mode power electronic converters convert one dc voltage to another level, which may be either higher or lower, by storing the input energy and then releasing that energy to the output at a different level. The energy can be stored in either magnetic components such as inductors, transformers or electric field storage components like capacitors. The higher efficiency of a switched-mode converter reduces the heat sinking required and increases battery life of equipments.

Voltage multiplier technique can be incorporated to the conventional non-isolated dc converters to obtain high step-up gain, decrement of the maximum switch voltage, turn on at zero current switching [2]. The reverse recovery problem of diodes is reduced and the voltage multiplier operates as a regenerative circuit, reducing the problem of EMI generation. These features allows the operation with high gain and high efficiency, making possible to implement a compact circuit for applications where the isolation is not required. This multiplier circuits can also be used in high frequency isolated dc converters, to obtain high output voltage in the range of KV applications [3].

A typical voltage range for solar panels is between 20 to 40V. Several panels are connected in series when connecting the PV array to the dc bus. Stepping up the array voltages to high voltage using conventional boost or buck–boost converters requires high duty ratios, which results in high component stress and lower efficiency [2]. Therefore, a typical choice would be connecting high voltage gain converters to each individual solar panel, which results in inefficient operation, reduced reliability, increased size, and stability problems.

In this paper, a two input stage boost converter is proposed. It can be used to absorb power from two independent dc sources just as a multiport converter. They draw continuous current from both the sources with comparitively low current ripple which is required in many practical applications. Several diode-capacitor stages can be cascaded together to step up the voltage which eventually limits the voltage stresses on the components. These advantages make the converters as good solution to integrate solar panels into a dc micro grid. Since it is a multi- input converter with a high voltage gain, different independent sources can be connected and various MPPT algorithms can be implemented separately at each input.

PROPOSED TOPOLOGY

The proposed two input converter with four voltage multiplier stages is shown in Fig1.Voltage multiplier stages are composed of capacitor and diode combination. Voltage multiplier (VM) stages are incorporated with two boost stages at the input. The VM stages help the boost stage to achieve a higher overall voltage gain. The voltage conversion ratio depends on the number of capacitor diode stages and the duty ratios of switches in the input boost stages. The converter can be expanded with *N* voltage multiplier stages.

For normal working of the converter, it needs some overlapping time when both the switches are ON and also one of the switches should be ON at any given time. Therefore, the converter has three modes of operation. The converter can operate when the switch duty ratios are small and there is no overlap time between the conduction of the switches. But, this mode of operation is not of consideration as it leads to relatively smaller voltage gains.

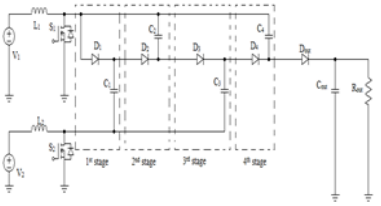

Figure 1: Proposed converter

MODES OF OPERATION

***Mode* 1:** In this mode of operation, both switches S_1 and S_2 are tuned ON. The inductor L_1 is charged from the input source V1 and similarly L2.The current in both the inductors increases linearly. The diodes in all voltage multiplier stages are reverse biased and hence do not conduct. The output diode D_{out} is reverse biased. The VM capacitor voltages remain unchanged and thus the load is supplied by the output capacitor C_{out}.

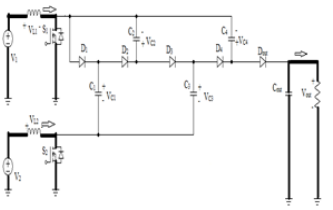

Fig 2: Mode 1 of operation

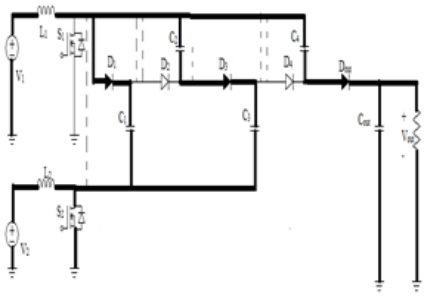

Figure 3: Mode 2 of operation

***Mode* 2 :** In this mode, switch S_1 is OFF and S_2 is ON (shown in Fig.3). All the odd numbered diodes D_1, D_3 are forward biased. The current through inductor L_1 charges the odd numbered capacitors, (C_1, C_3) and discharges the even numbered capacitors (C_2, C_4).. Since, the number of VM stages is four, the output diode is forward biased charging the output capacitor C_{out} and supplying the load. If the number of VM stages is odd, then the output diode D_{out} is reverse biased and the load is supplied by the output capacitor.

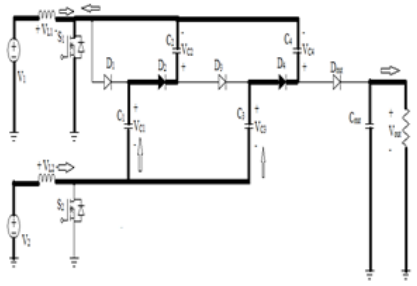

Fig 4: Mode 3 of operation

***Mode* 3**: Switch S_1 is ON and S_2 is OFF (shown in Fig.4) in this mode of operation. Now the even numbered diodes like D_2, D_4 are forward biased .The current through inductor L_2 charges the even numbered VM capacitors C_2, C_4 and discharges the odd numbered capacitors C_1, C_3. If the number of VM stages is odd, then the output diode D_{out} is forward biased charging the output capacitor and supplying the load. Since the number of VM stages is four in the proposed converter, the output diode is reverse biased and the load is supplied by the output capacitor C_{out}.

STEADY STATE ANALYSIS OF THE CONVERTER

For the proposed converter with four stages of VM (shown in Fig. 1), the voltage gain can be derived from the volt-second balance equation of the boost inductors. From Fig. 3, it can be observed that the capacitor voltages can be expressed in terms of upper boost switching node voltage as

$$V_{C1} = V_{C3} - V_{C2} = V_{out} - V_{C4} = \frac{V_1}{(1-d_1)} \quad (1)$$

where *d*1 is the duty ratio for S_1.

Similarly, from Fig.4 capcitor voltages can be written in terms of lower boost switching node voltage as

$$V_{C2} - V_{C1} = V_{C4} - V_{C3} = \frac{V_2}{(1-d_2)} \quad (2)$$

Where d_2 is the duty ratio for S2.

From (1) and (2), the capacitor voltages for the proposed converter can be derived as

$$V_{C1} = \frac{V_1}{(1-d_1)} \quad (3)$$

$$V_{C2} = \frac{V_1}{(1-d_1)} + \frac{V_2}{(1-d_2)} \quad (4)$$

$$V_{C3} = \frac{2V_1}{(1-d_1)} + \frac{V_2}{(1-d_2)} \quad (5)$$

$$V_{C4} = \frac{2V_1}{(1-d_1)} + \frac{2V_2}{(1-d_2)} \quad (6)$$

The output voltage V_{out} can be derived from (1) as

$$V_{out} = \frac{3V_1}{(1-d_1)} + \frac{2V_2}{(1-d_2)} \quad (7)$$

The output voltage V_{out} of the converter with *N* number of multiplier stages depends on whether *N* is odd or even and is given by

If N is odd

$$V_{out} = \frac{V_2}{(1-d_2)} + V_{CN}$$

$$= \left(\frac{N+1}{2}\right)\frac{V_1}{(1-d_1)} + \left(\frac{N+1}{2}\right)\frac{V_2}{(1-d_2)} \quad (8)$$

If N is even

$$V_{out} = \frac{V_1}{(1-d_1)} + V_{CN}$$

$$= \left(\frac{N+2}{2}\right)\frac{V_1}{(1-d_1)} + \left(\frac{N}{2}\right)\frac{V_2}{(1-d_2)} \quad (9)$$

When the converter operates in an interleaved manner with single input source, if d_1 and d_2 are also chosen to be identical, i.e., $d_1 = d_2 = d$, then the output voltage is given by

$$V_{out} = \frac{V_{in}}{(1-d)}(N+1) \quad (10)$$

DESIGN AND SIMULATION RESULTS

For better understanding, the converter is simulated in an interleaved manner with input voltage V_1=V_2 = 20 V and output voltage of 400 V, 400W. The switching frequency of the converter is selected as 100 kHz. Duty ratio of the switches S_1 and S_2 is found to be 0.75 from (10). The component selection is critical as it determines the output voltage regulation and the efficiency of the converter. The design of inductors is similar to that of a normal boost converter. The inductor value is selected such that both the converter operates in continuous conduction mode (CCM). The critical value of inductor for the CCM operation of both the boost stages is given by

For N is odd

$$L_{1crit} = \frac{V_1\, d_1(1-d_1)}{(N+1)I_{out}f_{sw}} \quad (11)$$

$$L_{2crit} = \frac{V_2\, d_2(1-d_2)}{(N+1)I_{out}f_{sw}} \quad (12)$$

For N is even

$$L_{1crit} = \frac{V_1\, d_1(1-d_1)}{(N+2)I_{out}f_{sw}} \quad (13)$$

$$L_{2crit} = \frac{V_2\, d_2(1-d_2)}{NI_{out}f_{sw}} \quad (14)$$

The inductor values selected for the assumed ripple current ΔI_L (10% of input current)is

$$L_1 = L_2 = \frac{V_{in}(V_{out}-V_{in})}{\Delta I_L f_{sw} V_{out}} \cong 100\mu H \quad (15)$$

The ripple voltage in output capacitor is assumed to be very small , ΔV=0.02875% of output voltage, then value of output capacitor is

$$C_{out} = \frac{I_o(1-d)}{\Delta V_o f_{sw}} \cong 22\mu F \quad (16)$$

All the VM stage capacitors are chosen to have same value. For a ripple voltage ΔV=0.02875% of output voltage, the value of VM stage capacitors C_1,C_2,C_3,C_4 (generalized as C_n) is

$$C_n = \frac{I_o(1-d)}{\Delta V f_{sw}} \cong 20\mu F \quad (17)$$

TABLE – 1 SIMULATION PARAMETERS

Parameters	Value
Input voltage	20V
L_1,L_2	100µH
C_1,C_2,C_3,C_4	20µF
C_{out}	22µF
R_{out}	400Ω
Duty ratio	0.75

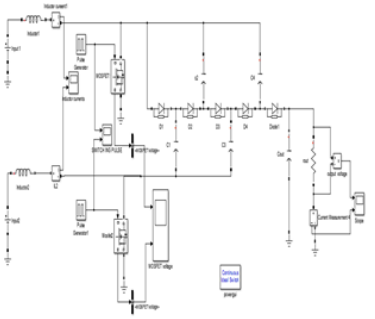

Fig 5: Simulink model of the proposed converter

The proposed converter is simulated in MATLAB 2014A Simulink platform. The current through inductors L_1 and L_2 in the two input stages is shown in fig 6.

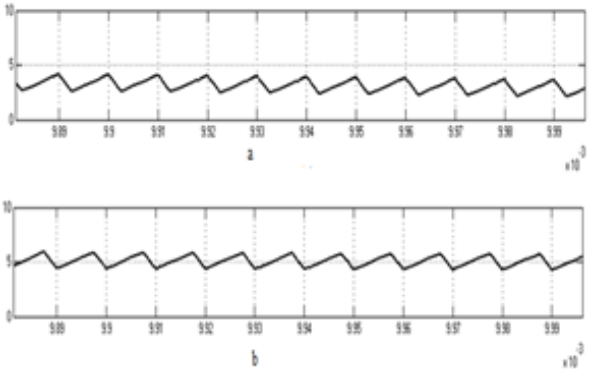

Fig 6: Current through inductors (a) L_1, (b) L_2

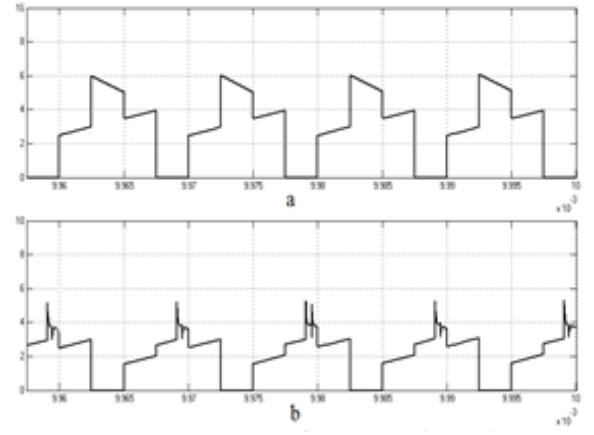

Fig 7: Current through switch (a) S_1 (b) S_2

It is found that there is a distortion and spike in the switch current waveforms (fig. 7). The spike in currents is due to the voltage imbalance between VM stage capacitors. The spike in current through S_2 appears during mode-II of operation of the converter (see Fig. 3). Initially diode D3 conducts the total inductor current I_{L1}, since V_{C3}-V_{C2} is less than V_{C1} and V_{out}-V_{e4}. When V_{C3}-V_{C2} and V_{out}-V_{e4} are balanced, then diodes D3 and Dout start conducting and share almost equal inductor current IL1/2. When V_{c1}, V_{C3}-V_{C2} , and \ V_{out}-V_{e4} are all balanced, Diode D1 starts conducting. The ratio between the currents is dependent on the values chosen for the VM stage capacitors. Current through switch S_2 during this period is the sum of IL2, ID1, and ID3 and hence there is spike and distortion in the switch currents. The currents exhibit characteristics similar to charging/discharging of an RC circuit.

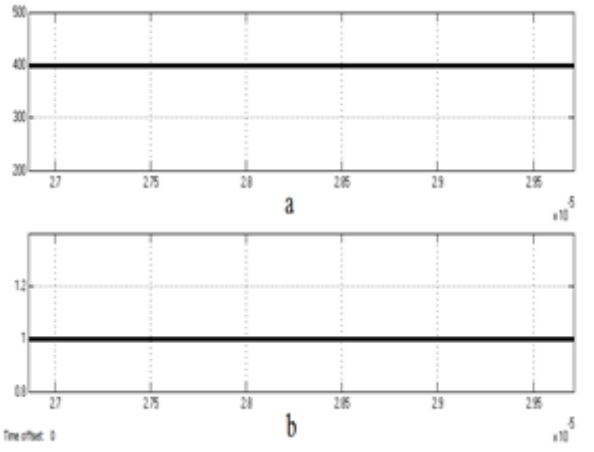

Fig 8: a). Output voltage b). Output current of the proposed converter

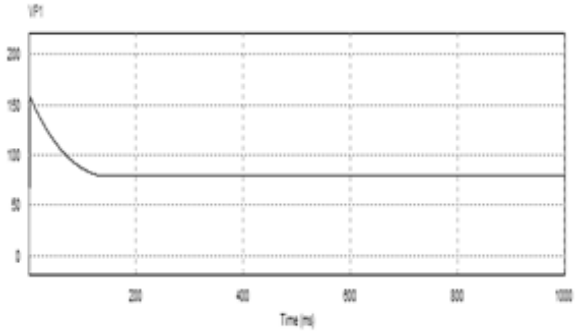

Fig 9: Output voltage of a conventional boost converter.

The proposed converter is compared with a conventional boost converter. For the same input voltage and duty ratio, normal boost converter can provide only 80V. Even though the proposed converter requires more components than the normal boost converter , it provides very high gain making it suitable for high voltage applications particularly grid integration of solar panels.

CONCLUSIONS

A high voltage gain dc-dc converter with two boost stages at the input has been proposed. This converter is based on four diode capacitor VM stages. It can draw power from two input sources like a two port converter or can operate in an interleaved manner. One of the main advantages of the proposed converter is that since it is a multi input port converter with high voltage gain, it has the ability to be connected to independent sources while allowing power sharing. MPPT algorithms can be implemented independently at each input port. This multiport converter can be used for solar applications where each panel can be individually linked to the 400-Vdc bus .

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