# 단일 스위치와 전압 체배 회로를 이용하는 고변압비와 낮은 전압 스트레스를 가진 새로운 비절연형 DC-DC 컨버터 토폴로지

# Novel Non-Isolated DC-DC Converter Topology with High Step-Up Voltage Gain and Low Voltage Stress Characteristics Using Single Switch and Voltage Multipliers

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## ABSTRACT

The use of high voltage gain converters is essential for the distributed power generation systems with renewable energy sources such as the fuel cells and solar cells due to their low voltage characteristics. In this paper, a high voltage gain topology combining cascode Inverting Buck-Boost converter and voltage multiplier structure is introduced. In proposed converter, the input voltage is connected in series at the output, the portion of input power is directly delivered to the load which results in continuous input current. In addition, the voltage multiplier stage stacked in proper manner is not only enhance high step-up voltage gain ratio but also significantly reduce the voltage stress across all semiconductor devices and capacitors. As a result, the high current-low voltage switches can be employed for higher efficiency and lower cost. In order to show the feasibility of the proposed topology, the operation principle is presented and the steady-state characteristic is analyzed in detail. A 380W-40/380V prototype converter was built to validate the effectiveness of proposed converter.

*Index Terms* –High voltage gain, High efficiency, Inverting buck-boost (IBB) converter, low voltage stress, voltage multipliers (VM).

## 1. INTRODUCTION

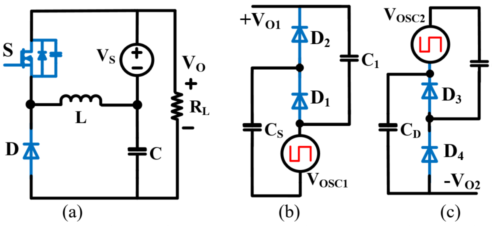
Due to the energy crisis and the global warming the renewable energy based on distributed power generation systems are drawing more and more attention. Since the outputs of the renewable energy sources such as fuel cells and solar cells are DCs and low in voltage, typically two stage power conversion is required to generate the AC output with a suitable voltage level. Therefore the use of a high voltage gain dc-dc converter to step up the low voltage of the renewable source is essential to provide a suitable DC link voltage for the rear-end DC-AC inverter. For example, in a small single-phase power system with a two-stage structure, the DC link voltage required for the grid-connected inverter is as high as 380V DC if the line voltage is 220V AC. However, the output voltage of a photo voltaic module or a fuel cell stack with a small power rating(less than 300W) ranges from 25 to 45 V typically, which requires at least 1:10 voltage conversion ratio. One simply way to cope with this issue can be the use of an isolated dc-dc converter topology but it would not be a good option for the small power system of which volume and cost are critical factors.

As well known, the classical non-isolated dc–dc converter is often used for voltage step-up applications. However, as the voltage gain is increased, the duty cycle approaches to unity. Hence, the current ripple of the inductor and the turn-off current of the power device become large, which result in large conduction losses and switching losses leading to a lower efficiency. In order to solve this problem the coupled inductor (CI) is employed to provide a high voltage gain by selecting an appropriate turns-ratio. However, the additional snubber circuit is needed to absorb the energy stored in the leakage inductor which makes the circuit complex and expensive [1]. Other methods to get the high voltage gain with no magnetic coupling include the converters utilizing the switched-capacitors (SCs) and the voltage multipliers (VMs). However, those technique has its own advantages and drawbacks. The Switched-capacitor can achieve high gain but has pulsating input current and poor regulation capability. To overcome above problems, many non-isolated high boost topologies have been studying by combining SC or VM structure with switching-mode converters. The high voltage gain and voltage regulation characteristics are dramatically improved [2]-[6]. Nevertheless, the voltage gain ratio, efficiency, structure simplicity, components stresses and discontinuous current need the further improvements.

In this paper a novel high step up converter with single switch and single inductor is proposed as shown in Fig.2. This converter can be derived by stacking the positive and negative voltage multiplier structures into a proposed cascoded (Inverting Buck-Boost) IBB converter as shown in Fig. 1. Hence, the output voltage of the proposed converter is connected in series with the voltage across capacitors, thereby achieving a higher voltage gain. Furthermore, the voltage stresses on all semiconductor devices and capacitor is significantly reduced. It is also advantageous in that its power conversion efficiency is good since a portion of the power is deliver directly to the load and hence a continuous input current can be achieved. In order to achieve the even higher voltage gain, the proposed converter can be easily expanded when an enormous voltage gain is required by integrating more VMs.

## 2. OPERATION PRINCIPLE

### A. *Proposed Topology.*



(a) (b) (c)

*Fig 1. (a) Proposed cascode IBB converter, (b) Positive voltage multiplier. (c) Negative voltage multiplier.*

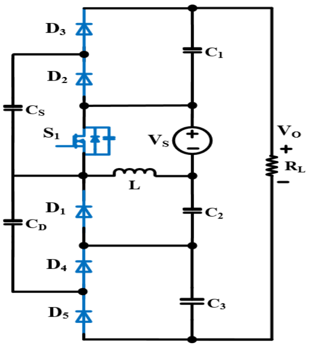
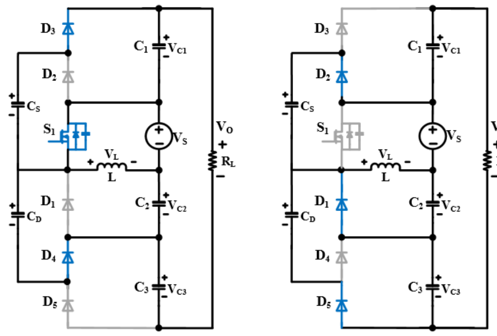


*Fig 2. Proposed high-boost converter*



(a) (b)

*Fig 3. Two stage expansion of the Proposed Non-isolated Buck-Boost converter*

The proposed topology is presented in Fig.2, Which consist two sets of VM stacking into a modified NBB converter as described in Fig.1. In the proposed structure, it includes a single switch, five diodes, a single inductor and five capacitors. This structure can be further expanded by adding more VMs.

### B. Operating principle in CCM mode

In this section, the operation principle of the proposed converter is described in the continuous conduction mode (CCM). As shown in Fig. 3 one switching cycle is divided into two states based on the status of the main switches. In order to describe the operation principle of the proposed converter, following assumptions need to be made.

- The circuit is operating in the steady state and the inductor currents are continuous.
- All the components are ideal and the parasitic components are neglected.
- All the capacitors are large enough to maintain their voltages constant during a switch-off period.
- A switching period is *Ts*; the switches are closed for time *DTs* and open for time *(1-D)Ts*.

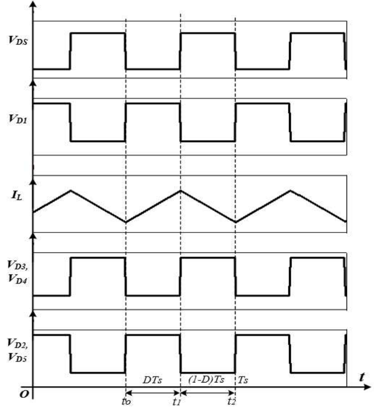


*Fig 4. Key waveforms of proposed converter for CCM operation With D = 0.5*

1. *Main Switch On State (Fig. 4: $t_0$=0, $t_1$ = DTs)*

The circuit operational mode is presented as shown in Fig 3. (a). During switch ON state, the input voltage source is applied to the inductor L. Hence, the inductor L is charged and the current $I_L$ is linearly increased. The diodes D3 and D4 are forward-biased while D2, D1 and D5 is stop conducting. Assuming that all capacitors get fully charged at steady state and diode voltage drop are neglected. The following equations can be obtained:

$$\begin{aligned} V_L &= V_S \\ V_{Cs} &= V_{C1} \\ V_L &= V_{CD} - V_{C2} \end{aligned} \tag{1}$$

2. *Main Switch Off State (Fig. 4 :$t_1$ = DTs, $t_2$ =Ts)*

As shown in Fig. 3 (b), the switch S1 is turn OFF, the energy stored in L is discharged linearly. D2, D1 and D5 are conducted when the previous diodes becomes blocked. The following relationships can be withdrawn:

$$\begin{aligned} V_L &= -V_{C2} \\ V_L &= V_S - V_{Cs} \\ V_{CD} &= V_{C3} \\ V_O &= V_{C1} + V_{in} + V_{C2} + V_{C3} \end{aligned} \tag{2}$$

3. *Voltage gain Derivation*

In the steady state, according to the voltage-second relationships of inductor L, the average voltage across the inductor in a period switching is zero, the following equations can be obtained:

From Eqs (1) & (2):

$$\begin{aligned} \overline{V_L} &= DV_S - (1-D)V_{C2} = 0 \\ \overline{V_L} &= DV_S - (1-D)(V_S - V_{CS}) = 0 \\ \overline{V_L} &= D(V_{CD} - V_{C2}) - (1-D)V_{C2} = 0 \end{aligned} \tag{3}$$

By manipulating equations (1), (2) and (3), the voltage across the capacitor and voltage gain ratio of proposed converter are derived in following equations:

$$V_{C2} = DV_S/(1-D) \tag{4}$$
$$V_{C1} = V_{CS} = V_{CD} = V_{C3} = V_S/(1-D) \tag{5}$$
$$V_O/V_S = 3/(1-D) \tag{6}$$

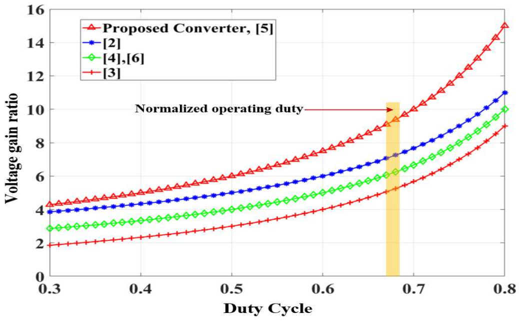


*Fig. 5. Voltage gain vs. duty cycle of the high voltage gain converters*

Fig. 5 shows the voltage gain vs. duty cycle plots of the various kinds of high voltage gain non-isolated dc-dc converters. It can be found that the voltage gain of the proposed converter is higher than that of others. The normalized operating duty is 0.685 when $V_S$ is 40V.

4. *Voltage stress on components*

In proposed converter, it should be noticed that the voltage across the switch and diodes are clamped by the voltage across the capacitors. Moreover, the capacitors are connected in series to deliver energy to the output. As a results, the low voltage stress for all semiconductor devices and passive components can be achieved. The voltage stress equations are withdrawn from Eqs (4), (5), and (6) as following equations.

$$V_{C1} = V_{CS} = V_{CD} = V_{C3} = V_O/3 \tag{7}$$
$$V_{C2} = DV_O/3 \tag{8}$$
$$V_{S1} = V_{D1} = V_{CD} = V_{C3} = V_O/3 \tag{9}$$

## 3. EXPERIMENT RESULTS.

To verify the operating principle and validate the performance of the proposed DC-DC converter, a prototype of high boost DC-DC converter for 360W photovoltaic power generation module is fabricated as shown in Fig with the specifications listed in Table I.

TABLE II
SPECIFICATION OF THE PROPOSED TWO STAGE DC-DC CONVERTER

| Parameter | Designator | Value |
|---|---|---|
| Input Voltage | $V_S$ | 36-45 $V$ |
| Output voltage | $V_O$ | 380 $V$ |
| Output power | $P_O$ | 360 $W$ |
| Switching frequency | $f_{SW}$ | 100 $KHz$ |
| Input inductor | $L$ | 280 $uH$ |
| Capacitors | $C_S$,$C_D$<br>$C_1$- $C_3$ | 47$uF$x3 |

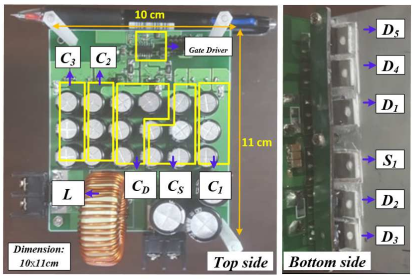
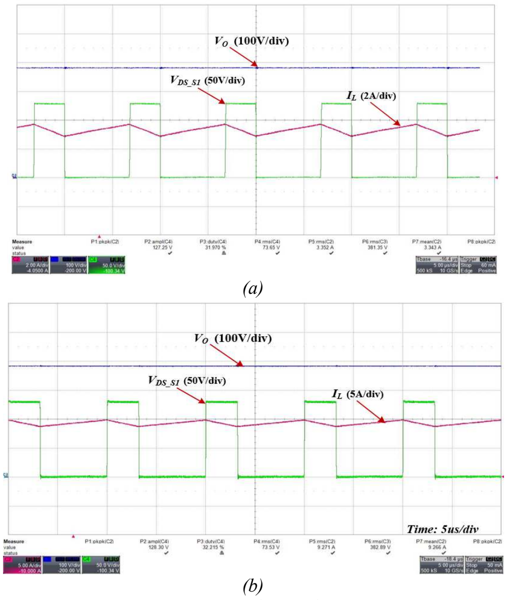


*Fig. 6. Prototype of the proposed converter.*

In the experiment, the gate signals is generated by DSP TMS320F28335, the electrolytic capacitor is used for all $C_S$, $C_D$, $C_1$, $C_2$, and $C_3$ which include multiple parallel capacitors to reduce ESR. The semiconductor devices are mounted with heat sink and located at the bottom of circuit board as shown in Fig.6.



*(a)*

*(b)*

*Fig. 7. Key experiment waveforms of proposed converter*
*(a) 20% load (b) 100% load*

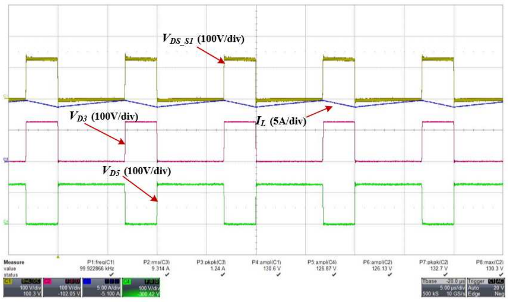


*Fig. 8. Voltage stress across the main switch and diodes at 100% load*

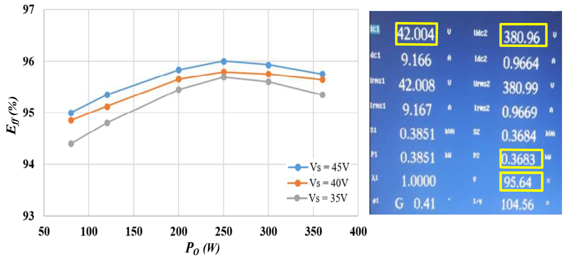


*Fig. 9. Measured efficiency of proposed converter*

The key experiment waveforms including the output voltage $V_O$, drain-source voltage of $S_1$, inductor current $I_L$ are given in Fig.7 under two different load conditions. As shown in Fig.7, the output voltage is boosted from 40V to 380V with a duty cycle of 0.685 and it can be seen that voltage stress across switch and diodes are equal $V_O/3$ which is matching with the above analysis. Fig.9 shows the measured efficiency plot of proposed converter proposed NBB converter when $V_S$ = 35-45V, $V_O$ = 380V and $f_{sw}$=100 kHz. It can be seen that the maximum efficiency of 96% is obtained at 250W and $V_S$ = 45V.

## 4. CONCLUSION

In this paper a novel non-isolated single-switch and single-inductor converter with high voltage gain and high efficiency characteristic is proposed and its validity and feasibility have been proved by the experiments. Since the proposed converter adopts a cascoded IBB structure stacking with voltage multipliers, its voltage gain and efficiency are relatively higher than those of other topologies. In addition, the low components stress can be achieved for both switches and capacitors compared with other high-boost single switch dc-dc converters. Moreover, the proposed technique allows extendable voltage gain and provides a continuous input current. Throughout the experiments it has been verified that the proposed converter can achieve the theoretical voltage gain and the maximum efficiency of 96% was obtained. It can be concluded that the proposed converter is suitable for distributed power generation systems with renewable energy sources.

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