A Single-Phase Cascaded H-bridge Quasi Switched Boost Inverter for Renewable Energy Sources Applications

Van-Thuan Tran, Minh-Khai Nguyen, Pan-Gum Jung, Youn-Ok Choi, and Geum-Bae Cho

***Abstract*—Recently, multilevel inverters have become more attractive for researchers due to low total harmonic distortion (THD) in the output voltage and low electromagnetic interference (EMI). This paper proposes a single-phase cascaded H-bridge quasi switched boost inverter (CHB-qSBI) for renewable energy sources applications. The proposed inverter has the advantage over the cascaded H-bridge quasi-Z-source inverter (CHB-qZSI) in reducing two capacitors and two inductors. As a result, cost, weight and size are reduced. Furthermore, the dc-link voltage of each module is controlled by individual shoot-through duty cycle to get the same values. Therefore, the proposed inverter solves the imbalance problem of dc-link voltage in traditional CHB inverter. This paper shows the operating principles and analysis of the single-phase cascaded H-bridge quasi switched boost inverter. Also, A control strategy for the proposed inverter is shown. Experimental and Simulation results are shown to verify the operating principle of the proposed inverter.**

***Index Terms*—Renewable energy sources, cascaded H-bridge inverter, quasi switched boost inverter, quasi Z-source inverer, shoot-through state, multilevel inverter.**

I. Introduction

Despite to fact that the matter of energy crisis does not catch a headline as frequently as other issues of society. It does not mean that it is not serious. Therefore, the use of renewable energy sources is good solutions. Renewable energy has some advantages i.e. its pollution free and cheaper. In recent years, multilevel inverters using renewable energy sources is getting more and more attention because of the large power-scale demands. The advantages of the multilevel inverters are as follows: improved output waveforms with lower THD, smaller filter size and lower EMI [1]-[3]. Three general multilevel inverter topologies are: 1) neutral point clamped (NPC) [4]; 2) flying capacitors [5]; and 3) cascaded H-bridge inverter [6]-[8]. Among these topologies, the cascaded H-bridge (CHB) inverter has unique advantages in higher output voltage and power levels. Moreover, it can reach a higher reliability because of its modular topology.

Fig. 1 shows the conventional five-level CHB inverter. Each inverter uses a dc-link voltage to generate a modulated voltage at the output terminals. The total output voltage is obtained by the sum of each individual output voltage. Each inverter is able to produce three output voltage levels, namely, $-V_{dc}$, 0, and $+V_{dc}$. This cascaded topology has some advantages in using the independent sources and cascading more H-bridge modules. In addition, the output voltage of the CHB inverter reaches medium voltage and has a high number of levels, which results in reducing the size of the output filter and removing the boost transformer. However, the traditional CHB inverter [6]-[8] is a buck DC-AC power conversion, where the total DC source voltages are lower than the peak AC output voltage. In addition, both power switches in a leg in the H-bridge cannot be turned on at the same time because it causes a short circuit DC source.

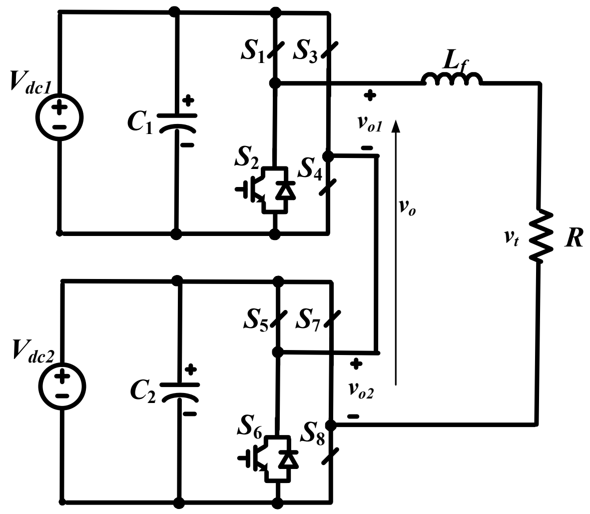

Fig. 1. Construction of traditional CHB topology.

In order to overcome the limitation of the traditional CHB voltage-source inverters, CHB-qZSI with single-stage power conversion were proposed in [9]-[11]. However, each quasi Z-source network module uses two inductors and two capacitors in increasing the size and cost of the power system. Thus, the CHB-qZSI may not be suitable for low-power applications such as the microinverters that are applied to the microgrid-connected photovoltaic (PV) power generation, where weight, size, and cost are the main considerations. A class of quasi-switched boost inverter (qSBI) was presented in [12]. A fully comparison between single-phase qSBI and single-phase qZSI is presented in [13]. The advantages of the qSBI over the qZSI are as follows [13]: uses one less inductor with a higher inductance and one less capacitor with a lower capacitance; higher boost factor with the same parasitic effect; lower current rating on both diodes and switches; and higher efficiency.

Because the qSBI has many advantages over the qZSI, a new CHB inverter topology based on the qSBI is implemented. This paper presents a new cascaded H-bridge

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inverter topology based on the quasi switched boost inverter. The operating principles and analysis of the single-phase cascaded H-bridge quasi switched boost inverter is presented. By control the shoot-through duty cycle, each module in the single-phase cascaded H-bridge quasi switched boost inverter can produce the dc-link voltage. Also, a control strategy for the proposed inverter is shown. Simulation results are shown to verify the operating principle of the proposed inverter.

II. Single-Phase Cascaded H-Bridge QSBI

The configuration of the proposed inverter based on cascaded qSBI is illustrated in Fig. 2. The proposed inverter consists of two separate DC sources, two qSBI modules, and an inductor filter connected to the load. Each DC source is connected to qSBI module. Comparing to the conventional H-bridge module, a qSB network including one inductor, one capacitor, one active switch and two diodes is added. The output voltage of the cascaded qSBI is the sum of two-module output voltages with five levels. In comparison with the CHB-qZSI [10], the proposed CHB-qSBI uses two less inductors, two less capacitors, two more diodes and two more switches. On the other hand, the proposed inverter reduces the size and cost significantly in comparison to the CHB-qZSI topology as shown in Fig. 3 when the number of the output voltage levels is increased.

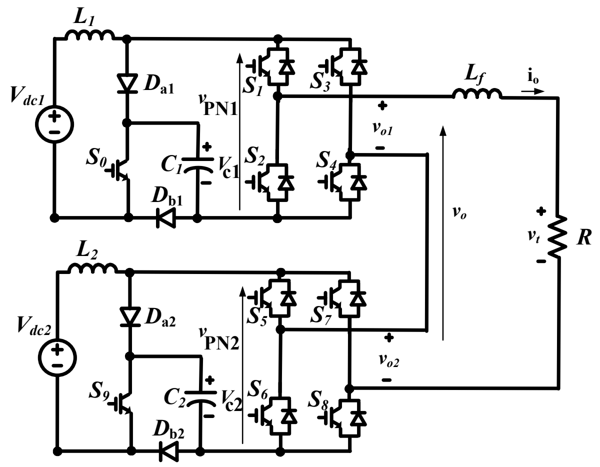


Fig. 2. Construction of proposed inverter topology.

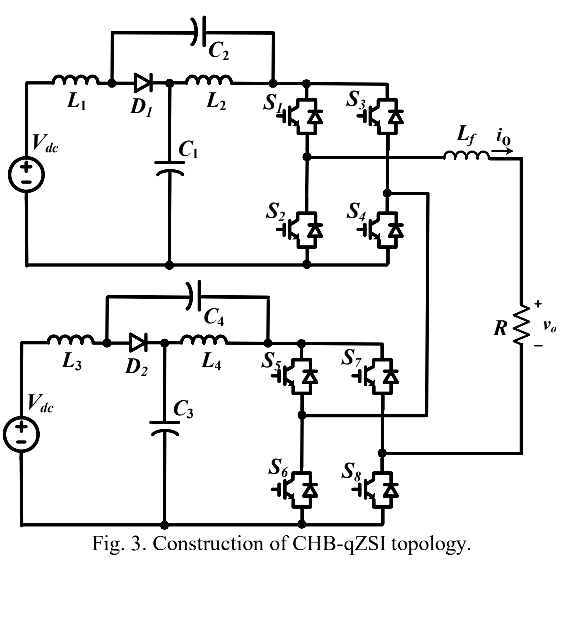


Fig. 3. Construction of CHB-qZSI topology.

As an example, the qSBI module 1 in the proposed inverter is used to analyze the operating principle. The operating states of the qSBI are simplified into the shoot-through, and the non-shoot-through states as shown in Fig. 4.

In the shoot-through state, as shown in Fig. 4(a), the inverter side is shorted by both the upper and lower switching devices of any phase leg. The time interval in this state is $D_1.T$. During the shoot-through state, S_0 is turned on, while D_{a1} and D_{b1} are turned off. The capacitor is discharged, while inductor stores energy. We obtain:

$$L_1\frac{di_{L1}}{dt}=V_{dc1}+V_{c1}. \tag{1}$$

In the non-shoot-through state, as shown in Fig. 4(b), the inverter has two active states and two zero states of the inverter main circuit for single-phase topology. The time interval in this state is $(1-D_1).T$. During the non-shoot-through state, D_{a1} and D_{b1} are turned on, while S_0 is turned off. The capacitor is charged from V_{dc1}, while the inductor transfers energy from the DC voltage source to the main circuit. We obtain:

$$L_1\frac{di_{L1}}{dt}=V_{dc1}-V_{c1} \tag{2}$$

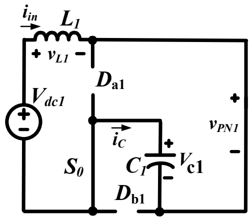
Applying the volt-second balance principle to L in steady state, (1) and (2) yield:

$$V_{c1}=\frac{1}{1-2D_1}V_{dc1} \tag{3}$$

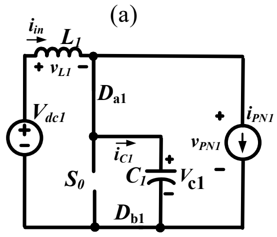
The peak DC-link voltage that crosses the inverter of module 1 is expressed in the nan-shoot-through state as:

$$V_{PN1}=V_{c1}=\frac{1}{1-2D_1}V_{dc1} \tag{4}$$

Fig. 5 shows an improved phase shifted sinusoidal pulse width modulation strategy for the proposed cascaded inverter. With the modulation in Fig. 5, the output voltage of each H-bridge module has three levels. For module 1, two control waveforms, $V_{control}$ and $-V_{control}$ are compared to a high frequency triangle waveform, V_{tri}, to generate control signals for H-bridge switches. A constant voltage V_{SH1} is compared to another triangle waveform (dashed line) with double frequency and half of the amplitude of that of V_{tri} to generate a control signal for the S_0 switch. The S_0 control signal is then inserted into the control signals of switches S_1 to S_4 through OR logic gates to generate the shoot-through states in the inverter bridge. The output voltage v_{o1} of H-bridge module 1 is a 3-level: $-V_{PN1}$, 0 and V_{PN1}. The high frequency triangle waveform of second H-bridge module is shifted in 90° to produce the output voltage v_{o2} of H-bridge module 2. The output voltage of the proposed CHB-qSBI is total v_{o1} and v_{o2}. As a result, the 5-level output voltage of the proposed inverter is produced.



(a)



(b)

Fig. 4. Operating states of qSBI module 1; (a) shoot-through and (b) non-shoot-through.

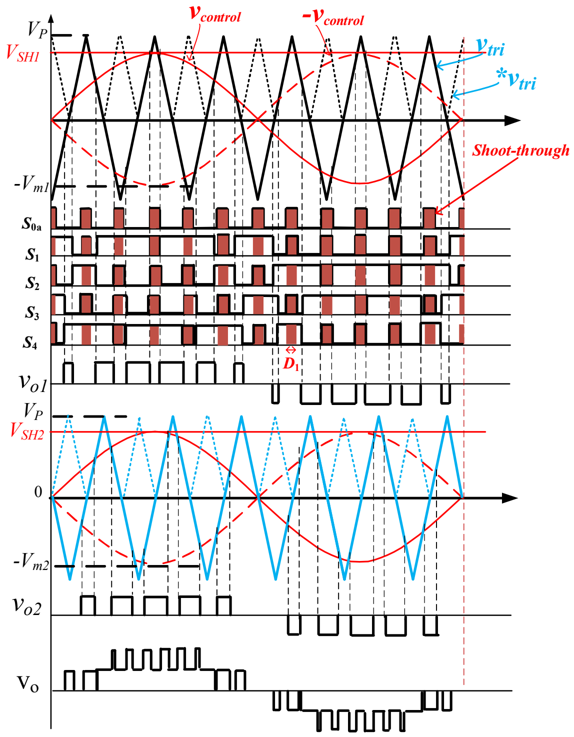


Fig. 5. PWM strategy for the proposed CHB-qSBI.

TABLE I: PARAMETERS OF THE PROPOSED INVERTER

Parameter	Value
Output voltage	110 Vrms
Output frequency	50 Hz
Inductors (L_1, L_2)	1 mH
Capacitors (C_1, C_2)	1000 uF
Filter inductor (L_f)	3 mH
Resistive load (R)	60 Ω
Switching frequency	10KHz

III. EXPERIMENTAL AND SIMULATION RESULTS

A. Simulation Results

In order to verify the operating principle of the CHB-qSBI as shown in Fig. 2, PSIM simulation is used. Table I provides a list of the simulation parameters for the CHB-qSBI.

First, we set $V_{dc1} = V_{dc2} = 50V$ to test properties of proposed inverter. Fig. 6 and Fig. 7 illustrate the simulation results for the CHB-qSBI when two modules are balanced. By control shoot-through duty cycle, the dc-link voltage of two modules is the same. As shown in Fig. 6, we can see that the output voltage is 110Vrms with 5-level. The THD of load voltage is 2.5 %. From Fig. 7, we can see that both capacitor voltages are boosted to 130 V in the steady state, the dc-link voltage of two modules are boosted to 130 V.

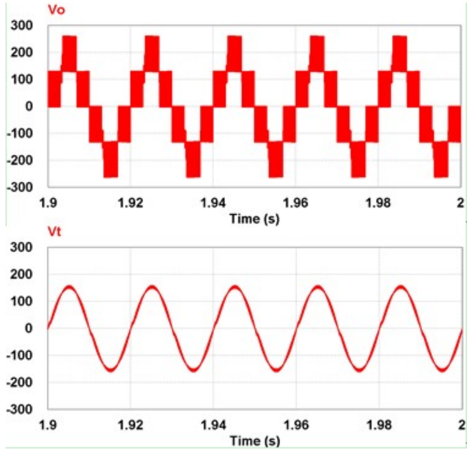


Fig. 6. Simulation results for the proposed CHB-qSBI under the same source voltage condition. Top waveform: five-level output voltage, and bottom waveform: load voltage.

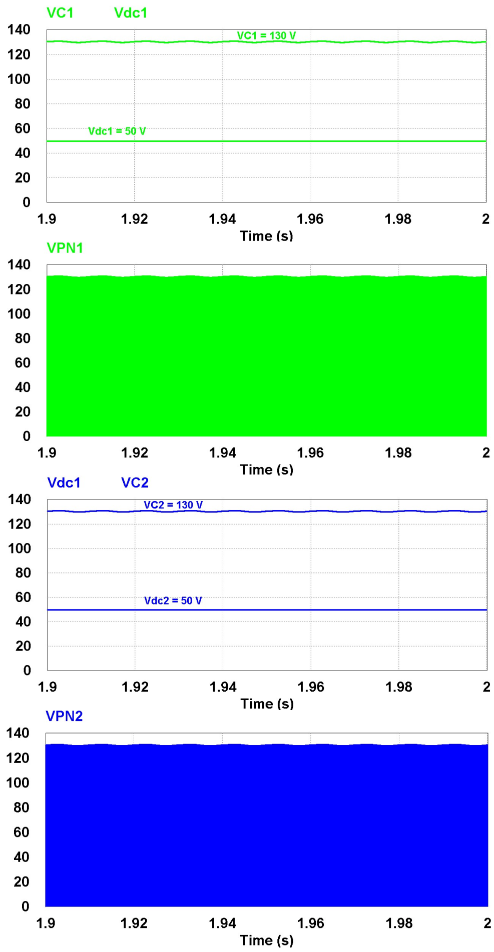


Fig. 7. Simulation results for capacitor voltages and dc-link voltage under the same source voltage condition. From top to bottom: capacitor voltage of module 1, input voltage of module 1, dc-link voltage of module 1, capacitor voltage of module 2 and input voltage of module, and dc-link voltage of module 2.

Next, we keep $V_{dc2} = 50$ V and decrease V_{dc1} to 40 V for unbalanced test. Fig. 8 and Fig. 9 show the simulation results for the CHB-qSBI when two modules are unbalanced in the input voltage. By control shoot-through duty cycle, the dc-link voltage of two modules is the same. From Fig. 8, we can see that the output voltage is 110Vrms with 5-level. The THD of load voltage is 2.56%. As shown in Fig. 9, we can see that both capacitor voltage are also boosted to 130 V in the steady state with a small insignificant disturbance, the dc-link voltage of two modules are boosted to 130 V. Therefore, the proposed inverter solves the imbalanced problems in the conventional CHB.

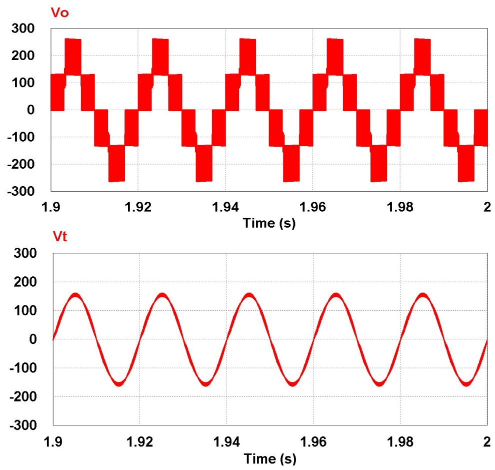


Fig. 8. Simulation results for the proposed CHB-qSBI under condition of unbalance source DC voltage between two modules. Top waveform: five-level output voltage, and bottom waveform: load voltage

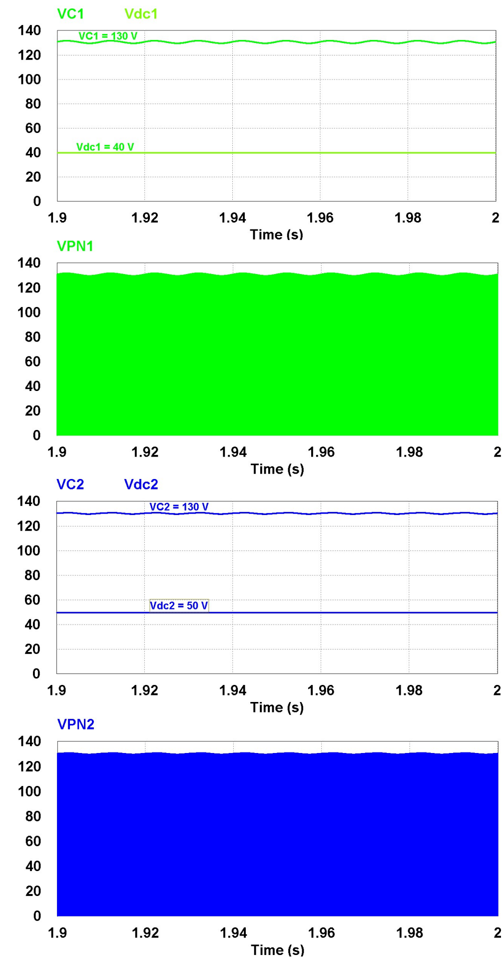
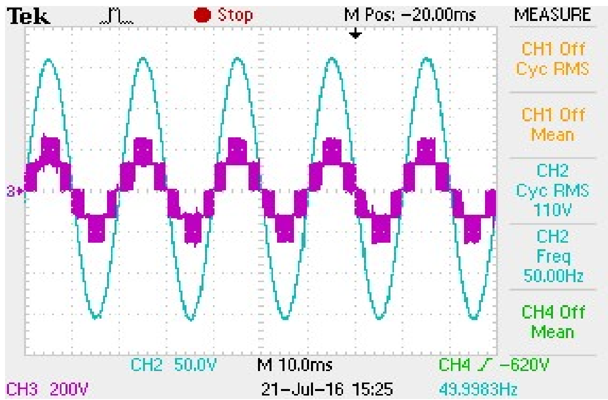


Fig. 9. Simulation results for capacitor voltages and dc-link voltages under condition of unbalance source DC voltage between two modules. From top to bottom: capacitor voltage of module 1, input voltage of module 1, dc-link voltage of module 1, capacitor voltage of module 2, input voltage of module 2, dc-link voltage of module 2.

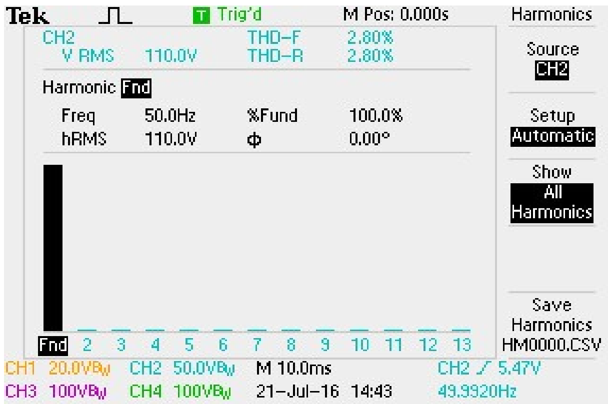
B. Experimental Results

To verify the properties of the proposed inverter, a 200 W laboratory prototype was constructed based on DSP TMS320F28335. The same parameters as in the simulation were used.

Fig. 10 illustrates the experimental results for the CHB-qSBI when the input voltage in each module is the same at 50 V. As shown in Fig. 10(a), we can see that the output voltage is 110Vrms with 5-level. The THD of load voltage is 2.8% as shown in Fig. 10(b).



(a)



(b)

Fig. 10. Experimental results for the proposed CHB-qSBI under the same source voltage condition, $V_{dc1} = V_{dc2} = 50$ V. (a) Top waveform: five-level output voltage, and bottom waveform: load voltage; (b) THD of load voltage.

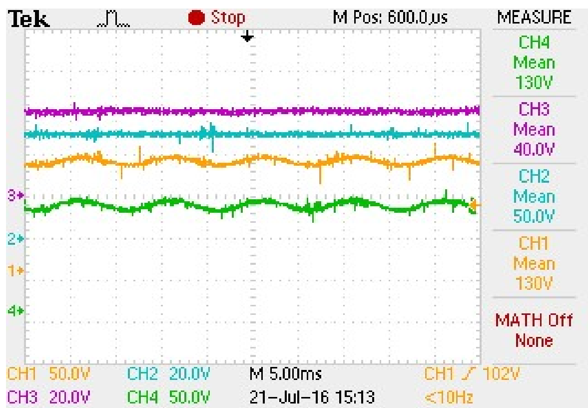


Fig. 11. Experimental results for capacitor voltages under condition of unbalance source DC voltage between two modules: $V_{dc1} = 40$V, $V_{dc2} = 50$V. From top to bottom: input voltages and capacitor voltage of module 1 and 2.

We keep V_{dc2} = 50 V and decrease V_{dc1} to 40 V for unbalanced test. Fig. 11 shows the experimental results for the capacitor voltages when two modules are unbalanced in the input voltage. By control shoot-through duty cycle, the dc-link voltage of two modules is the same. As shown in Fig. 11, we can see that both capacitor voltage are also boosted to 130 V in the steady state with a small insignificant disturbance. Therefore, the proposed inverter solves the imbalanced problems in the conventional CHB.

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IV. Conclusion

This paper presents the operating principles and analysis of the single-phase cascaded H-bridge quasi switched boost inverter. The proposed inverter operates well not merely when the input voltage between modules is balance but also when the input voltage between modules is unbalance. Furthermore, ac output voltage of the proposed inverter is higher than source DC input voltage. Therefore, the proposed inverter suits fuel-cell and PV applications where a low input voltage must be inverted to a high ac output voltage for the microgrid-connected PV power generation. Also, a low THD of the output voltage can achieve with a small inductive filter. Experimental and Simulation results prove the validity of the proposed PWM technique for controlling the single-phase cascaded H-bridge quasi switched boost inverter.

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