Cascaded Boost Multilevel Converter for Distributed Generation Systems

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Abstract

This paper presents a new cascaded boost multilevel converter topology for distributed generation (DG) systems. Most of DG systems, such as photovoltaic (PV), wind turbine and fuel cells, normally require the complex structure power converters, which makes the system expensive, complex and hard to control. However, the proposed converter topology can generate a much higher output voltage just by using the standard low-voltage switch devices and low voltage DC-sources in a simplified structure, also enhancing the reliability of the switch devices. Simulation and experimental results with a 1.2kW system are presented to validate the proposed topology and control method.

Keywords: cascaded NPC H-Bridge, distributed generation system, Z-Source, multilevel inverter, hybrid PWM

1. Introduction

In recent years, distributed generation (DG) systems based on renewable energy sources have significantly increased throughout the world. Especially, photovoltaic (PV), wind turbine and fuel cells have been considered dominant DG sources with a high potential [2]. However, their terminal voltages are usually low and vary widely, so they need the power converters for boosting their low voltage sources and converting them to a predefined ac grid voltage, which makes the system expensive, complex and difficult to control.

As an alternative for these DG power systems, in this paper, a new Cascaded Boost Multi-Level Inverter (CB-MLI) topology is proposed as shown in Fig. 1, which is based on combination of Cascaded H-Bridge (CHB), Neutral Point Clamped (NPC) multilevel converters [1], and the Z-Source [3]. The cascaded H-Bridge is based on the series connection of single-phase inverters with separate dc sources, which enables to reach a much higher output voltage as well as to have a high number of output voltage levels. The NPC topology enables the conventional inverter to generate a higher output voltage just by using standard low-voltage switch devices available in the market. In case the NPC is combined with the cascaded topology, it can contribute in reducing the number of cascaded power cells, which can result in the reduction of cost and complexity. For each power inverter cell connected in series, a Z-Source Inverter (ZSI) is used because it enables the existing two-stage inverter to be single-stage and can improve the reliability by allowing both switches of the same phase-leg to be turned ON simultaneously without damaging the switch devices.

Consequently, the proposed converter topology enables existing power systems to generate the much higher output voltage in an effective way using the standard low-voltage components and the low voltage DC-sources in a reduced number of power cells. Moreover, each inverter cell used for this topology can boost DC-source voltage in the cost effective single-stage, keeping exactly the equal DC-link voltage of each cell without the imbalance problem. It can also be more robust by preventing the switch devices from the shoot-through problem by EMI Noise's mis-gating-on that exists in the traditional VSI.

In controlling the proposed multilevel inverter, the new Hybrid Carrier PWM (HC-PWM) and the improved boost control schemes are proposed. Simulation and experimental results verify the proposed topology and the control schemes.

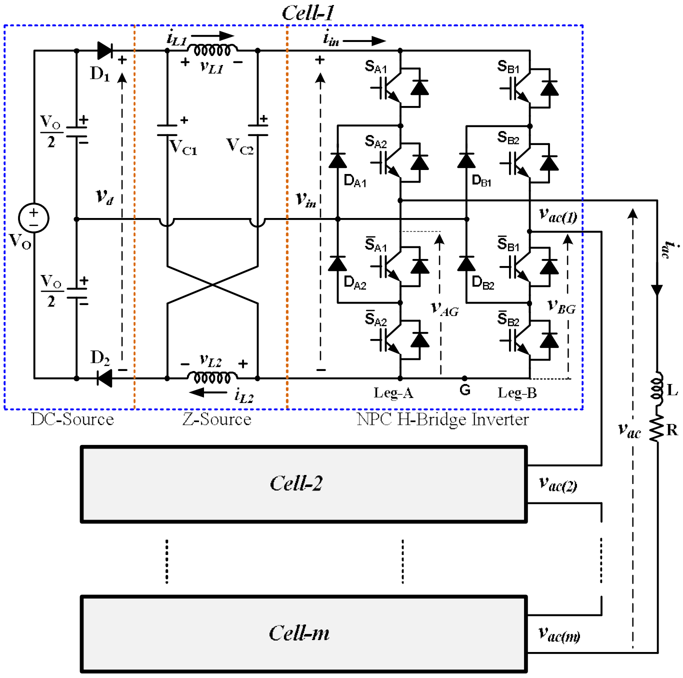


Fig. 1. The proposed Cascaded Boost Multilevel Converter.

2. The Cascaded Boost Multilevel Converter

A. Topology description

The main circuit configuration of the CB-MLI is shown in Fig. 1. The building block of the proposed topology consists of several identical CB-MLI cells. Each cell is composed of a single-phase three-level NPC H-Bridge inverter, a Z-Source and an isolated voltage source. Since all cells are connected in series, the total output voltage of cascaded B-MLI is equal to the sum of the individual cell voltages. The total inverter sinusoidal output voltages at fundamental frequency are given by

$$v_{ac} = \sum_{i=1}^{m} \hat{v}_{ac(i)} \left(= M \cdot B_{(i)} \cdot V_{o(i)}\right) \cdot \sin(\omega t) \qquad (1)$$

where $\hat{v}_{ac(i)}$ is the peak output voltage of each cell, M is the modulation index, $B_{(i)}$ and $V_{o(i)}$ are the boost factor and DC-source voltage of each cell respectively, and ω is angular frequ ency. With switch states, the relationship between DC-source voltage and output voltage for one cell (Cell-1) is listed in Table I.

TABLE I
THREE-LEVEL NPC BOOST INVERTER SWITCH STATES (ONE *CELL*)

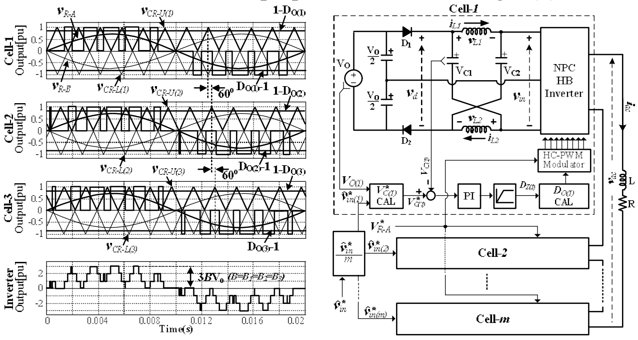
Leg-A			Leg-B			Output Voltage
S_{A1}	S_{A2}	V_{AG}	S_{B1}	S_{B2}	V_{BG}	v_{ac}
1	1	$+BV_O$	0	0	0	$+BV_O$
0	1	$+BV_O/2$	0	1	$+BV_O/2$	0
0	0	0	1	1	$+BV_O$	$-BV_O$

B boost factor, V_O DC-source voltage, $v_{ac} = v_{AG} - v_{BG}$.

B. Modulation and control scheme

A new Hybrid Carrier PWM (HC-PWM) algorithm is proposed for modulating the proposed inverter with Z-Source as shown in Fig. 2(a). This modulation is based on the combination of level-shifted PWM and phase-shifted PWM. The phase opposition disposition (POD) among level- shifted methods is used for modulating NPC H-Bridge inverter and the phase-shifted modulation is applied for connecting each cell in series effectively. In applying Z-Source to the NPC H-Bridge inverter, two shoot-through modulation references, 1-D_o and D_o-1, are introduced into the conventional zero states.

The capacitor voltage, V_C, is equivalent to the DC-link voltage of the inverter and can be boosted by controlling the shoot-through duty ratio (D_o). As the relationship between V_C/V_o and D_o has nonlinear characteristics, the improved boost control scheme using the linearization method is proposed as shown in Fig. 2(b).



(a) (b)

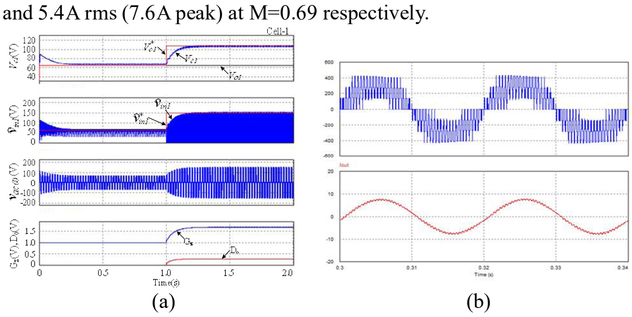
Fig. 2. Modulation and control scheme: (a)Hybrid Carrier PWM (HC-PWM) for the proposed inverter (with three cells), (b)Proposed boost control scheme using the linearization method for a single-phase system.

3. Simulation and Experimental Results

A. Simulation Results

In order to verify the proposed system and its control schemes, the simulations are performed by using PSIM software. A 1.2kW single-phase multilevel inverter, which has *3*-cells and outputs *7*-voltage levels, is built for simulation. The complete parameters for the simulation system are listed in Table Ⅱ.

Fig. 3 (a) shows the transient responses of the Z-source capacitor voltage, peak DC-link voltage, peak ac output voltage, G_z and shoot-through duty cycle (D_o) of Cell-1 when the reference of peak DC-link voltage ($\hat{v}^*_{in1}$) is changed from 65V to 150V at V_O = 65V. The capacitor voltage is boosted to 108V and the peak DC-link value is kept at the reference value 150V, which is 2.3 times greater than the input DC-source voltage. At steady state, the value of G_z and D_o is about 1.68 and 0.29, respectively. Fig. 3 (b) shows the sinusoidal output voltage and current of the proposed single-phase inverter with *3*-cells connected in series are 220V rms (311V peak) and 5.4A rms (7.6A peak) at M=0.69 respectively.



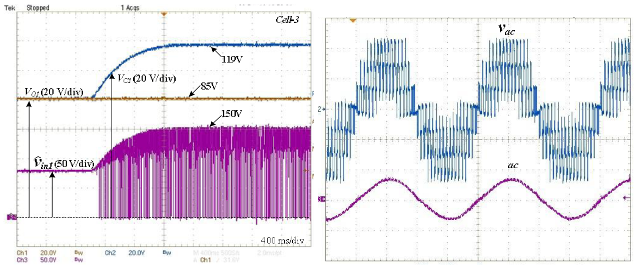
(a) (b)

Fig. 3. Simulation results: (a)Transient responses for the Z-source capacitor voltage, peak DC-link voltage, peak ac output voltage, G_z and shoot-through duty cycle of Cell-1, (b)Output voltage and current of the proposed one-stage single-phase multilevel inverter (Modulation index M=0.69).

B. Experimental Results

Based on a digital experimental system platform combining DSP and FPGA, a 1.2kW prototype single-phase inverter system with 3-power cells has been built in the laboratory. The experimental parameters are the same as those of the simulation listed in Table Ⅱ

Fig. 4(a) shows the transient responses for the DC-link voltage and capacitor voltage of Cell-3, when the reference peak DC-link voltage is changed from 85V to 150V at the DC-source voltage of 85V. The sinusoidal output voltage and current of the experimental system are 223V rms and 5.2A rms at M=0.69 respectively, as shown in Fig. 4(b), which are approximately the same as those of the simulation results. All experimental waveforms are well consistent with the simulation results.



(a) (b)

Fig. 4. Experimental results: (a)Transient responses for the DC-link voltage (v_{in1}) and capacitor voltage (V_{c1}) of Cell-3 controlled at the peak value 150V, (b)Output voltage and current waveforms of the proposed multilevel inverter (Modulation index M=0.69): 1) Inverter output voltage (200 V/div), 2) Inverter output current (10 A /div).

TABLE Ⅱ

INVERTER PARAMETERS IN THE SIMULATION AND EXPERIMENT

Parameter	Value
Inverter Output Voltage	220 V rms
Inverter Output Frequency	60 Hz
Inverter Rated Power	1 2 kW
DC-source voltages	65V/ 75V/ 85V
Peak DC-link Voltage ($\hat{v}_{in}$)	150 V
Number of Inverter Cells	3
Inverter and Z-Source Switching Frequency	2 4k Hz
Output Filter Inductance	3 mH
Z-Source Capacitor(C)	2200 uF
Z-Source Inductor(L/R)	2 mH / 0 1 Ω

3. Conclusion

This paper has presented a new multilevel converter topology for the DG systems, which shows the following excellent performances:

- It generates a much higher output voltage just by using the standard low-voltage switch devices and low voltage DC-sources in a reduced number of power cells.
- It achieves the reduction of cost and complexity.
- It enhances the reliability of the switch devices.

Simulation and experimental results with a 1.2kW system are presented to validate the proposed topology and control method, which is well consistent with theoretical analysis. It is expected that the proposed topology will be used as a competitive alternative for the high voltage application with the renewable sources.

Acknowledgment

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Reference

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