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Simulation of Quasi Cascaded H-Bridge Five-Level Boost Inverter

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Abstract:
Multilevel inverters have become more attractive for researchers due to low total harmonic distortion in the output voltage and low electromagnetic interference. This paper proposes a novel single-stage quasi-cascaded H-bridge five-level boost inverter. The proposed quasi cascaded h-bridge five-level boost inverter has the advantages over the cascaded H-bridge quasi-Z-source inverter in cutting down passive components. Consequently, size, cost, and weight of the proposed inverter are reduced. A capacitor with low voltage rating is added to the proposed topology to remove an offset voltage of the output AC voltage when the input voltages of two modules are unbalanced. Besides, sinusoidal pulse width modulation techniques used here. PID controller is used to control the capacitor voltage of each module. This paper presents circuit analysis, the operating principles, and simulation results of the proposed system.

Keywords: z-source inverter, five level inverter, sinusoidal pulse width modulation, boost inverter, PID controller, Module.

I. Introduction

Multilevel inverters have recently received many attentions from researchers due to their advantages over the conventional three-level pulse-width modulation inverters. The advantages of the multilevel inverters are as follows: improved quality output waveforms with lower total harmonic distortion (THD),[1]-[10], smaller filter size and lower electromagnetic interface (EMI).

Three general multi level inverter topologies are: flying capacitors, neutral point clamped (NPC), and cascaded H-bridge (CHB) inverters. Among these topologies[12]-[15], the CHB inverter has unique advantages in modularity and its contribution of high power. These advantages make the CHB inverter an attractive option for many applications such as uninterruptible power supplies UPS), grid-connected system, Stat Com system, motor drive, etc. However, the traditional CHB multilevel inverter is a buck DC-AC power conversion,[22]-[25] where the converter is demanded for each module in the CHB topology to achieve the high AC output voltage when the DC input voltages are low. Adding DC-DC boost power converter results in low efficiency and high cost[26]-[30].

The conventional two-stage CHB boost-five-level inverter has two capacitors two boost inductors, two diodes, ten switches, one filter inductor and a resistive load are utilized in the conventional CHB-BFLI. The boost DC-DC converter is used to control the DC-link voltage on each H-bridge circuit[5]-[40]. Both the top and bottom switches in the same leg cannot be switched on simultaneously because the DC-link capacitor is connected to each leg in parallel. And a dead-time between two switches in the leg must be used to avoid short circuit in the DC source

Conventional CHB five-level inverters

The traditional CHB multilevel inverters a buck DC-AC power conversion, where the peak AC output voltage is limited by the total DC source voltages. An additional DC-DC boost converter is demanded for each module in the CHB topology to achieve the high AC output voltage when the DC input voltages are low. Adding DC-DC boost power converter results in low efficiency and high cost.

The conventional two-stage CHB boost-five-level inverter (CHB-BFLI) has Two capacitors, two boost inductors, two diodes, ten switches, one filter inductor and a resistive load are utilized in the conventional CHB-BFLI. The boost DC-DC converter is used to control the DC-link voltage on each H-bridge circuit.

Both the top and bottom switches in the same leg cannot be switched on simultaneously because the DC-link capacitor is connected to each leg in parallel. And a dead-time between two switches in the leg must be used to avoid short circuit in the DC source.

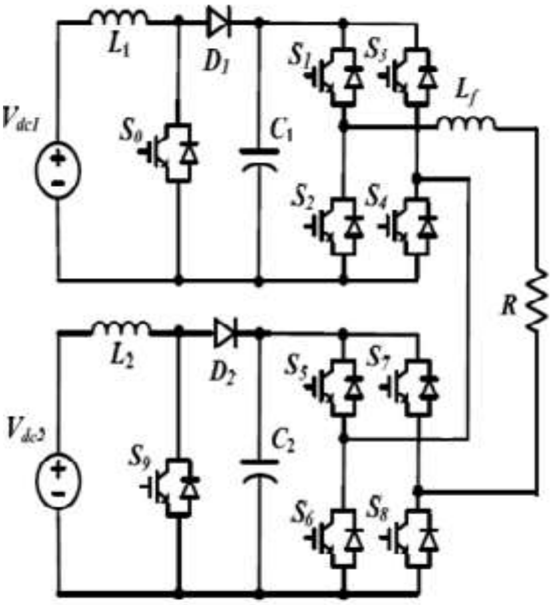

Figure 2.1 Conventional CHB five-level inverters

In the conventional CHB-BFLI, the boost DC-DC converter is used to control the DC-link voltage on each H-bridge circuit. As shown in Fig.(a), both the top and bottom switches in the same leg cannot be switched on simultaneously because the DC-link capacitor is connected to each leg in parallel. And a dead-time between two switches in the leg must be used to avoid short circuit in the DC source.

QCHB-FLBI topology

In this paper, AQZS modular cascaded converter is addressed in for dc integration of high-power PV system. Energy stored CHB-QZSI based PV power generation system is proposed. Fault-tolerant CHB inverters using Z-sourced network are investigated. A cascaded transformer-based multilevel inverter using single Z-source network is presented. An active-front-end (AFE) CHB multilevel inverter based on dual-boost/buck converter is proposed.

Like the CHB-QZSI, the AFE-CHB inverter also has the shoot-through immunity and buck/boost voltage. However, the CHB-QZSI in and the AFE-CHB inverter use a large number of passive elements with raising the size, cost, and weight of the power cascaded system.

A quasi-switched boost (QSB) network is used to replace the QZS network. In comparison to the QZS network, the QSB network uses one less capacitor, one less inductor, one more diode and one more switch in front of the main H-bridge circuit. An isolated high step-up DC-DC converter is proposed in based on the QSB network. In this paper, a new single-stage quasi-cascaded H-bridge five-level boost inverter (QCHB-FLBI) is proposed. In the proposed QCHB-FLBI, the QSB network as presented is used in each module.

The main features of the proposed QCHB-FLBI are five-level output voltage with boost voltage ability, reduction in a number of passive components and shoot-through immunity. The proposed inverter consists of two separate DC sources, two quasi-boost inverter (QBI) modules and an inductor filter connected to the resistive load in series. Each QBI module contains one capacitor, one boost inductor, four switches and two diodes. The output voltage of the proposed QCHB-FLBI has five levels.

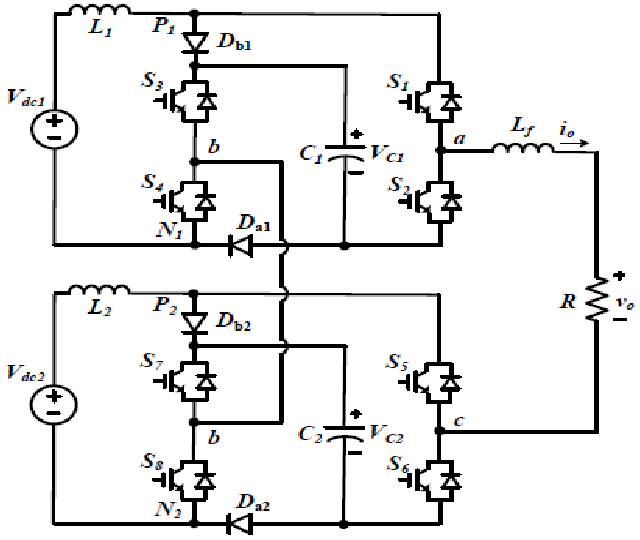

Figure 3.1 Proposed QCHB-FLBI topology

Single-stage quasi-cascaded H-bridge five-level boost inverter (QCHB-FLBI) is proposed. The proposed inverter consists of two separate DC sources, two quasi-boost inverter (QBI) modules and an inductor filter connected to the resistive load in series. Each QBI module contains one capacitor, one boost inductor, four switches and two diodes. The output voltage of the proposed QCHB-FLBI has five levels. In the CHB-QZSI, the operating frequency of the inductors is to fold the switching frequency.

Therefore, the high-frequency current ripple on inductors of the proposed QCHB-FLBI is a half that of the CHB-QZSI. Capacitor voltages of the proposed inverter are higher than those of the CHB-QZSI .However, total capacitor voltage stresses in each module of both inverters are the same. The voltage stress on diodes and switches of the proposed inverter equals to that of the CHB-QZSI.

Operation of Proposed Sysytem

Multilevel inverters have recently received many attentions from researchers due to their advantages over the conventional three-level pulse-width modulation (PWM) inverters. The advantages of the multilevel inverters are as follows: improved quality output waveforms with lower total harmonic distortion (THD), smaller filter size and lower electromagnetic interface (EMI). Three general multilevel inverter topologies are: flying capacitors, neutral point clamped (NPC), and cascaded H-bridge (CHB) inverters.

Among the set topologies, the CHB inverter has unique advantages in modularity and its contribution of high power. These advantages make the CHB inverter an attractive option for many applications such as uninterruptible power supplies A CHB quasi-Z-source inverter (QZSI) with single-stage power conversion was proposed .

The CHB five-level QZS network with two capacitors and two inductors is connected to each H-bridge circuit. In the CHB-QZSI, a shoot-through (ST) state is used to boost voltage without any damages in the power circuit. In one switching period, the number of the ST states in the single-phase QSBI is two. Therefore, the operating frequency of the inductors is twofold the switching frequency. In the CHB-QZSI, the input DC current is continuous with low ripple. Each module in the CHB QZSI can produce the same DC-link voltage by control the ST duty cycle.

An effective control method, including system-level control and PWM for single-phase CHB-QZSI based grid-tie photovoltaic (PV) power system. Three-phase CHB-QZSI's control is proposed and demonstrated for application to PV power systems. A QZS modular cascaded converter is addressed for dc integration of high-power PV systems. Energy stored CHB-QZSI based PV power generation system is proposed. Fault-tolerant CHB inverters using Z-sourced network are investigated.

A cascaded transformer-based multilevel inverter uses a single Z-source network. An active-front-end (AFE) CHB multilevel inverter based on dual-boost/buck converter is proposed. Like the CHB-QZSI, the AFE-CHB inverter also has the shoot-through immunity and buck/boost voltage.

Module Operation

Phase-shifted sinusoidal pulse-width modulation (PS-SPWM) strategy for the proposed QCHB-FLBI, For module 1, two control voltages, are compared to a high-frequency triangle voltage to produce control signals for the *S1 and S2* switches.

Two DC Voltage, are compared to produce the S0acontrol signal. Then *S0a* is added to the control signals of switches S1 and S2 to produce the ST states. Likewise, the voltage control is shifted in 90° to create another high-frequency triangle voltage, produce control signals for the S3 and S4switches. Voltages are compared to produce a*S0b* control signal. The S0bis then added to the control signals of switches *S3* and*S4* to produce the ST states.

As a result, the output voltage v of H-bridge module 1 has three levels. Similar for the second H-bridge module, two control voltages are shifted in 180° to produce the output voltage vcb of the H-bridge module 2.

The output voltage vac of the cascaded system is a subtraction of vab and vcb .Therefore, the output voltage of the proposed QCHB-FLBI produces Five-level cascaded H-Bridge Quasi Z-Source Inverter with Quasi Impedance Network to each DC link of the PV module.

The impedance network consists of two inductors L1, L2 and two Capacitors C1 and C2 at each stage of the inverter bridge. This unique LC network connected to the inverter bridge modifies the operation of the circuit, allowing the shoot-through states and will effectively protect the circuit from damage when the short circuit occurs. By effectively utilizing the shoot-though state, the QZS network boosts the dc-link voltage. The major advantages of

QZSI compared to other Z-inverters are .It draws a continuous constant dc current from the source.

The voltage on capacitor C2 is greatly reduced. The continuous and constant dc current drawn from the source make this topology well suited for PV power conditioning systems.

The proposed inverter consists of two separate DC sources, two quasi-boost inverter (qBI) modules and an inductor filter connected to the resistive load in series. Each qBI module contains one capacitor, one boost inductor, four switches and two diodes. The output voltage of the proposed qCHB-FLBI has five levels. Assuming that two qBI modules have the same parameters, the qBI module 1 in the proposed system is used to analyze the operating principle. Fig. 3 shows the operating modes of the qBI module 1 in the proposed inverter. In the shoot-through (ST) state 1, as shown in Fig. 3(a), both S1 and S2 are turned on. Da1 is conducting, while Db1 is blocking. If S3 is turned on, the output voltage of the qBI module 1 is – VC1. Else, it equals zero. The inductor L1 is charged from the Source. we have

$$L_1\frac{di_{L_1}}{dt} = V_{dc1}. \qquad (1)$$

In the ST state 2, *S*3 and *S*4 are turned on as shown in Fig. 3(b). *Da1* is blocking, while *Db1* is conducting. If *S*2 are turned on, the output voltage of the qBI module 1 is –*VC*1. Else, it equals zero. The inductor *L1* is also charged in this state, and its voltage is calculated as (1). In the non-shoot-through (NST) state 1, as shown in Fig. 3(c), both *S*1 and *S*3 are turned on. In the NST state 4, as shown in Fig. 3(f), both *S*2 and *S*4 are turned on. The output voltage of the qBI module 1 in both NST states 1 and 4 is zero. In the NST state 2, as shown in Fig. 3(d), both *S*2 and *S*3 are

Turned on. The output voltage of the qBI module 1 is –*VC*1. In the NST state 3, as shown in Fig. 3(e), both *S*1 and *S*4 are turned on. The output voltage of the qBI module 1 is *VC*1. During the non-shoot-through (NST) states as shown in Figs. 3(c)–3(f), *Da1* and *Db1* are conducting. The capacitor *C1* is charged from *Vdc*, while the inductor *L1* transfers energy from the DC voltage source to the main circuit. The H-bridge circuit is equivalent as a current source, *iPN*1. We get:

$$L_1\frac{di_{L_1}}{dt} = V_{dc1} - V_{C1}. \qquad (2)$$

In one switching period, *T*, each leg has twice short circuits alternatively. From (1) and (2), the average inductor voltage is

$$\bar{V}_{L1} = \left(1-2\frac{T_0}{T}\right)\left(V_{dc1}-V_{C1}\right)+2\frac{T_0}{T}V_{dc1}, \qquad (3)$$

Where *T0*/*T* = *D*1 is a ST duty ratio in each leg of module 1; *T*0 is total ST time intervals in one leg.
In a steady state, the average inductor voltage should be zero. We get:

$$V_{C1} = \frac{1}{1-2T_0/T}V_{dc1} = \frac{1}{1-2D_1}V_{dc1}. \qquad (4)$$

Similarly, we also obtain the capacitor voltage on the module 2 as

$$V_{C2} = \frac{1}{1-2D_2}V_{dc2}. \qquad (5)$$

Advantages of Proposed System

High-frequency current ripple is less
Increase the efficiency
Reduced number of components
Reduce in cost

Simulation Theory

General

MATLAB (**mat**rix **lab**oratory) is a numerical computing environment and fourth-generation programming language. Developed by Math Works, MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages, including C, C++, Java, and FORTRAN. Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the Mu PAD symbolic engine, allowing access to symbolic computing capabilities. An additional package, adds graphical multi-domain simulation and Model-Based Design for dynamic and embedded systems.

In 2004, MATLAB had around one million users across industry and academia. MATLAB users come from various backgrounds of engineering, science, and economics. MATLAB is widely used in academic and research institutions as well as industrial enterprises.

Simulink

Simulink, developed by Math Works, is a commercial tool for modeling, simulating and analyzing multi-domain dynamic systems. Its primary interface is a graphical block diagramming tool and a customizable set of block libraries. It offers tight integration with the rest of the MATLAB environment and can either drive MATLAB or be scripted from it. Simulink is widely used in control theory and digital signal processing for multi-domain simulation and Model-Based Design Simulink is a block diagram environment for multi-domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems. Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems. It is integrated with MATLAB, enabling you to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

Building The Model

Simulink provides a set of predefined blocks that you can combine to create a detailed block diagram of your system. Tools for hierarchical modeling, data management, and subsystem customization enable you to represent even the most complex system concisely and accurately.

Proposed Simulation Circuit

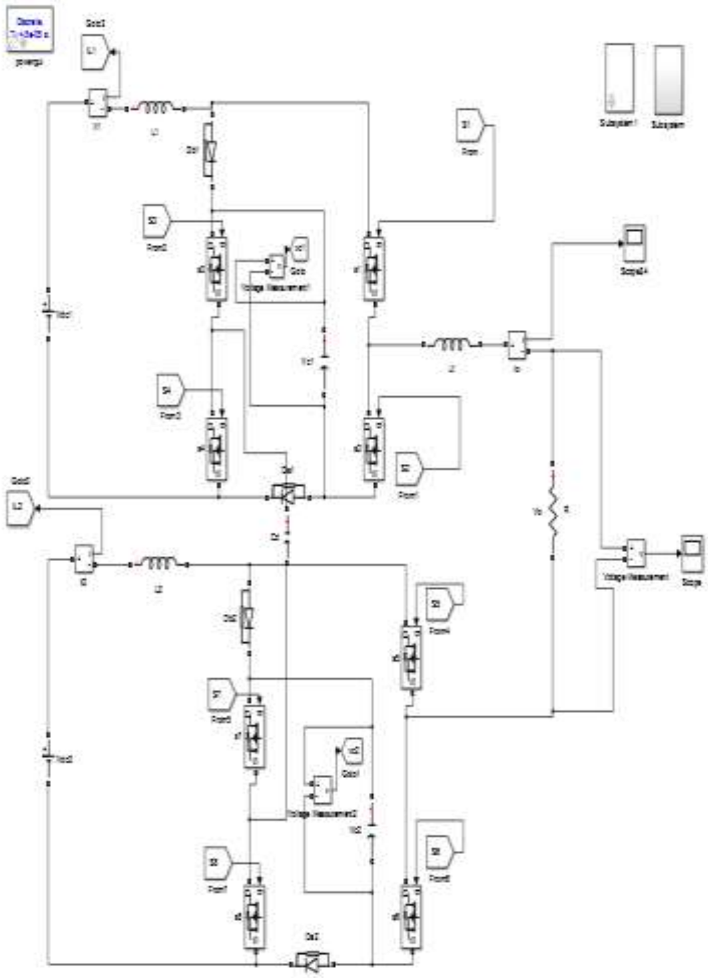

Figure 7.1 Proposed circuit

Simulation Output

Simulink Verification and Validation enables systematic verification and validation of models through modeling style checking, requirements traceability and model coverage analysis. Simulink Design Verifier uses formal methods to identify design errors like integer overflow, division by zero and dead logic, and generates test case scenarios for model checking within the Simulink environment. The systematic testing tool TPT offers one way to perform formal test- verification and validation process to stimulate Simulink models but also during the development phase where the developer generates inputs to test the system. By the substitution of the Constant and Signal generator blocks of Simulink the stimulation becomes reproducible

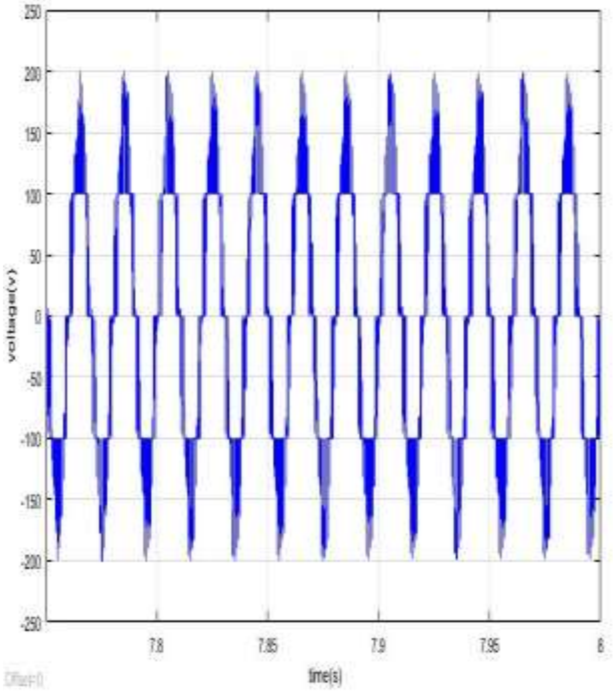

Figure 8.1 The output voltage of the proposed inverter has five levels

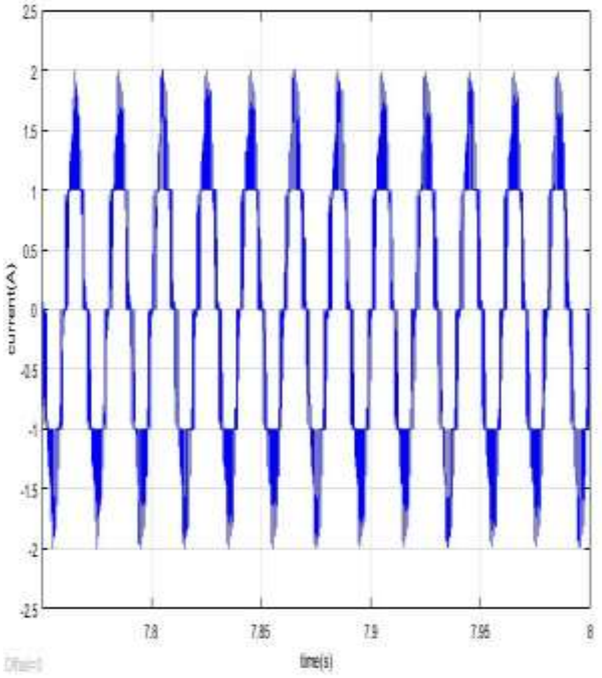

Figure 8.2 Inductor currents

we set *Vdc*1 = *Vdc2* = 50 V to confirm the properties of the proposed inverter under balanced DC-source condition. Fig.5.3 shows the simulation results for the proposed QCHB-FLBI when both input voltages are the same. The output voltage of the proposed inverter has five levels; and the load voltage is 110 Vrms.

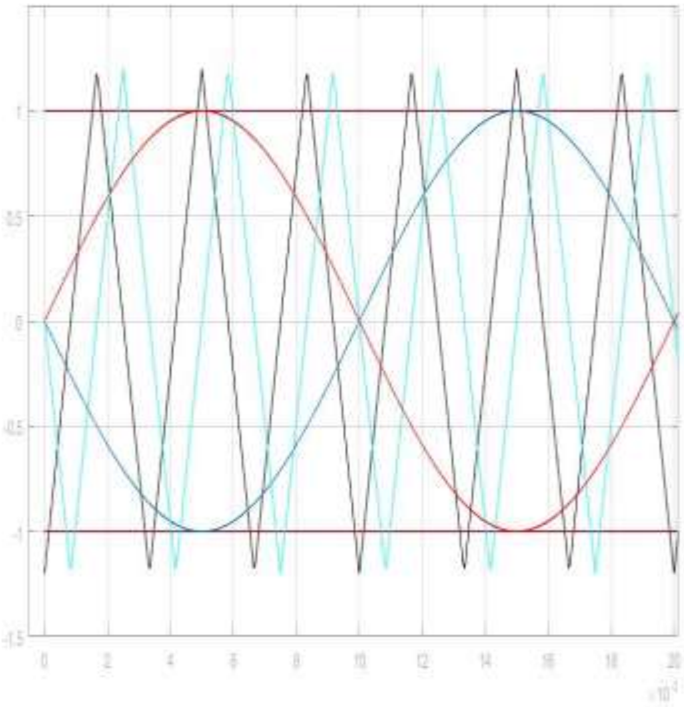

Figure 8.3 PWM scheme for the proposed system

It shows a phase-shifted sinusoidal pulse-width modulation (PS-SPWM) strategy for the proposed QCHB-FLBI. For module 1, two control voltages -vcontrol and vcontrol are compared to a high-frequency triangle voltage, *Vtri1,* to produce control signals for the *S1 and S2* switches. Two DC voltages, *VSH and -VSH,* are compared to vtri1 to produce the *S0a* control signal. Then *S0a* is added to the control signals of switches *S1* and *S2* to produce the ST states. Likewise, the *Vtri1* is shifted in 90° to create another high-frequency triangle voltage, vtri2, vcontrol and -vcontrol are compared to vtri2 to produce control signals for the S3 and S4 switches. *VSH and -VSH* are compared to the *Vtri2* to produce a *S0b* control signal. The *S0b* is then added to the control signals of switches *S3* and *S4* to produce the ST states. As a result, the output voltage vab of H-bridge module 1 has three levels.

Conclusion

Simulation of the single-phase single-stage CHB five-level inverter with boost voltage ability has been verified. The proposed inverter has the following main features as: five-level output voltage, reduction in number of passive components and shoot-through immunity. With the simple PID controller, a constant capacitor voltage can be achieved with an excellent transient performance which enhances the rejection of disturbance, including the input voltage and load current variations. Also, circuit analysis and PWM control strategy for the proposed system are shown. Simulation results are shown to verify the validity of the proposed QCHB-FLBI.

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