A Single-Phase Type-Boost Integrated Inverter for Photovoltaic Applications

Tan-Tai Tran, Minh-Khai Nguyen, Seong-Ha Oh, Pil-Ju Ko, and Geum-Bae Cho

***Abstract*—Photovoltaic, fuel cell, and wind energy are renewable energy sources that generate their power at very low voltage. Therefore, the distributed generation (DG) systems are powered by micro sources such as fuel cells, photovoltaic and wind energy are unsuitable for grid connection directly without transformer. Therefore, this paper proposes a single phase type-boost integrated inverter (TBII) that merges a dc-dc boost converter and a dc-ac inverter in a single-stage. In the inverter, one of the H-bridge legs is shared with a boost converter. AC output voltage of the inverter can be higher than the dc source voltage. This paper shows the operating principles and analysis of the single phase type boost integrated inverter. Also, A pulse width modulation strategy is shown to control the inverter. Simulation results by PSIM software are shown to verify the operating principle of the inverter.**

***Index Terms*—H-bridge inverter, dc-dc boost converter, single stage dc-ac converter, photovoltaic system.**

I. Introduction

Perhaps no subject in the contemporary society is as attractive as the matter of energy crisis. Therefore, the use of renewable energy sources is good solutions. Renewable energy has some advantages i.e. its pollution free and cheaper. However, most renewable energy sources produce a DC power output. An inverter is used for converting the DC electric energy from the renewable energy source into AC electric energy. The inverters are either stand alone or grid connected. In case of grid-connected inverter, the output voltage and frequency of the inverter have to be the same as that of the voltage and frequency of grid.

High-performance voltage-source inverters (VSIs) are widely used in various applications such as AC motor drives, uninterruptible power supplies (UPSs), distributed power systems, and hybrid electric vehicles [1], [2]. However, the traditional voltage source inverters are buck DC-AC power conversion, where the total DC source voltages are higher than the peak AC output voltage.

For fuel cell and Photovoltaic applications where a low input voltage is inverted to a high AC output voltage, an additional DC-DC boost converter [3]-[9] is needed to obtain a desired AC output. The additional power converter performs two-stage power conversion with high cost and low efficiency. The existing inverter topologies which can be used as boost type inverter have the following drawbacks: (a) high switch count (≥5) [10]-[12], and (b) complex control [13], [14].

In order to overcome the aforementioned drawbacks of these inverters, this paper proposes a new topology of a boost inverter. Because this new topology is derived by integrating a dc–dc boost converter with a dc-ac inverter, the proposed inverter is termed as a single phase type-boost integrated inverter (TBII). The proposed TBII requires only four controllable switches, one diode, one dc-link capacitor, and one inductor. The proposed inverter is applicable to fuel cells or photovoltaic applications where a low input voltage must be inverted to a high AC output voltage. Therefore, it is suitable for grid connection directly without using transformer. Grid synchronization algorithm is of great importance in control of grid connected power inverter as Hasty and accurate detection of grid voltage parameters such as amplitude, phase and frequency is crucial in order to execute stable control strategies for the interconnection of grid with renewable energy. The operating principles and analysis of the single-phase type-boost integrated inverter is presented. Also, a control strategy for the proposed system is shown. Simulation results are shown to verify the operating principle of the proposed inverter.

II. Single-Phase Type-Boost Integrated Inverter

Fig. 1 illustrates a conventional topology for the renewable energy generation system, such as the fuel cell, when the minimum input dc voltage is less than the peak voltage of the utility grid. The former-stage boost converter is composed of MOSFET S_0, boost inductor L_1, and capacitors C_1. Diode D_a can prevent the current from flowing back into the fuel cell. The grid-connected inverter is composed of MOSFET S_1–S_4. The advantage of this topology is that the boost converter and the inverter are operated separately and the controller design is easy. However, a two-stage structure leads to low efficiency.

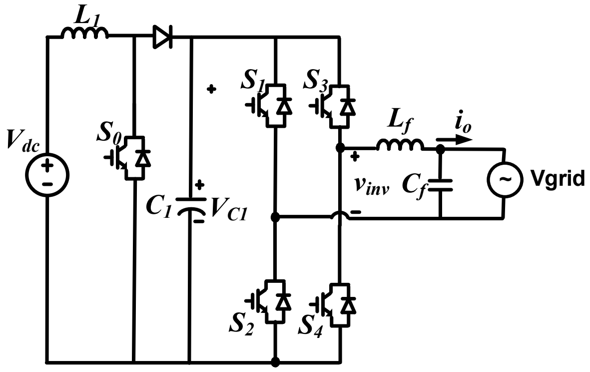

Fig. 1. Construction of conventional two-stage inverter topology.

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The configuration of the single-phase type boost integrated inverter is illustrated in Fig. 2. As shown in Fig. 2, one of the H-bridge legs is shared with a boost converte. Therefore, the proposed system consists of one DC sources, four active switches, one diode, one dc-link capacitor, one inductor, two capacitor filters and an inductor filter connected to the load.

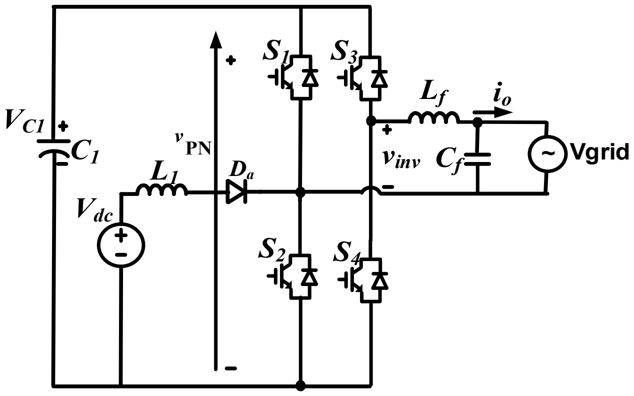


Fig. 2. Construction of single-phase type boost integrated inverter topology.

In shoot-through sate, as shown in Fig. 3(a), the time interval in this state is $D.T$, where D is the duty ratio of switch S_2 of each cycle; T is a switching period.

$$D = 1 - M.\sin 100\pi t. \tag{1}$$

where M is the modulation index of the bridge inverter.

During the shoot-through state, S_2 and diode D_a are turned on, while S_1 are turned off. The capacitor is discharged, while inductor stores energy. We obtain:

$$L_1 \frac{di_{L_1}}{dt} = V_{dc}. \tag{2}$$

In shoot-through sate, as shown in Fig. 3(b), during the shoot-through state, S_1 and diode D_a are turned on, while S_2 are turned off. The capacitor is charged from V_{dc}, while the inductor transfers energy from the DC voltage source to the main circuit. We obtain:

$$L_1 \frac{di_{L_1}}{dt} = V_{C1} - V_{dc}. \tag{3}$$

Applying the volt-second balance principle to L_1 in steady state, (1) and (2) yield:

$$V_{C1} = \frac{V_{dc}}{1-D}. \tag{4}$$

The DC-link voltage that crosses the inverter is expressed as:

$$V_{PN} = V_{C1} = \frac{V_{dc}}{1-D}. \tag{5}$$

The boost factor of the inverter is defined by:

$$B = \frac{V_{PN}}{V_{dc}} = \frac{1}{1-D}. \tag{6}$$

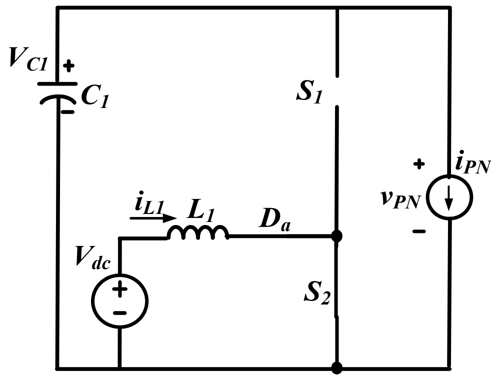
Fig. 4 shows a sinusoidal pulse width modulation strategy for the inverter. With the modulation in Fig. 4, two control waveforms, $V_{control}$ and -$V_{control}$ are compared to a high frequency triangle waveform, V_{tri}, to generate control signals for H-bridge switches. The output voltage of inverter is a 3-level: -V_{PN}, 0 and V_{PN}.

The peak value of the output voltage is given by:

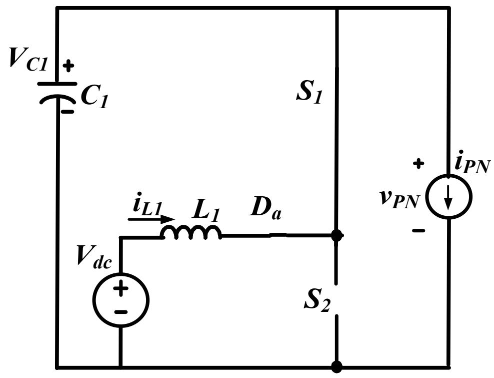
$$V_o = M.V_{PN}. \tag{7}$$

where M is the modulation index of the bridge inverter From (6) and (7), we obtain:

$$V_o = M.B.V_{dc}. \tag{8}$$



(a)



(b)

Fig. 3. Operating states of TBII;
(a). shoot-through, and (b). non-shoot-through.

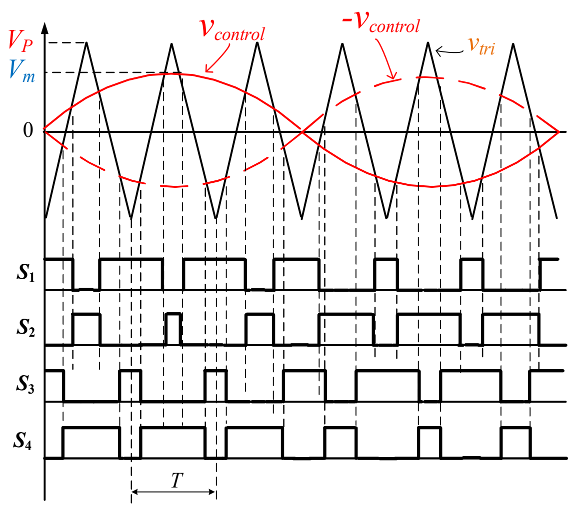


Fig. 4. PWM strategy for the inverter.

III. Control System Algorithm for Grid Connection

To deliver energy to the grid, the phase and frequency of the inverter have to equal those of the grid. Therefore, a grid synchronization method is required. The objective the synchronization algorithm is to get the phase angle of the grid voltage. The synchronization methods should respond immediately to changes in the utility grid. Furthermore, they must have the ability to reject noise and the higher order harmonics. Many synchronization methods have been to get the phase angle of the grid voltage such as zero crossing detection [15], phase-locked loop (PLL) [16]-[19]. A phase locked loop is a closed loop system in which an internal oscillator is controlled to keep the time and phase of an external periodical signal using a feedback loop. The PLL as shown in Fig. 5 is simply a servo system that controls the phase of its output signal such that the phase error between the output phase and the reference phase is the minimum. The quality of the lock directly affects the performance of the control loop in grid tied applications. The PLL can successfully detect the phase angle of the grid voltage even in the presence of noise or higher order harmonics in the grid.

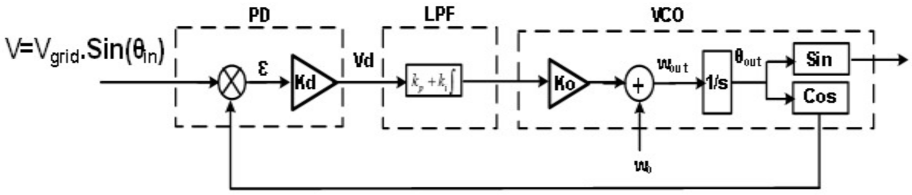


Fig. 5. Phase locked loop basic structure.

IV. Simulation Results

In order to verify the operating principle of the TBII as shown in Fig. 2, PSIM simulation is used. Table I provides a list of the simulation parameters for the single-phase type boost integrated inverter.

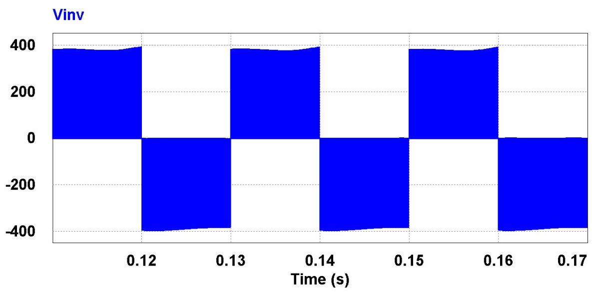
The input DC voltage is set to 96 V in the inverter in order to test properties of inverter.

TABLE I: Parameters of the Inverter

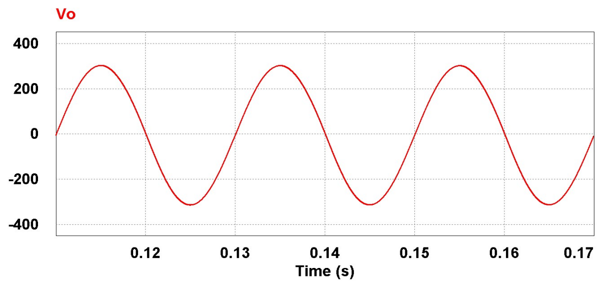
Parameter	Value
Output voltage	220 Vrms
Grid voltage	220 Vrms
Output frequency	50 Hz
Inductors (L_1)	1 mH
Capacitors (C_1)	1000 µF
Filter inductor (L_f)	3 mH
Filter Capacitors (C_f)	10µF
Resistive load (R)	40 Ω
Switching frequency	10KHz

Fig. 6 and Fig. 7 illustrate the simulation results for the TBII without using PLL.

From Fig. 6(a) and (b), we can see that the output voltage of the inverter is 220Vrms with 3-level. The AC output current is 5.4 Arms as shown in Fig. 6(c). The THD of output voltage with using filter is 1.78%.



(a)



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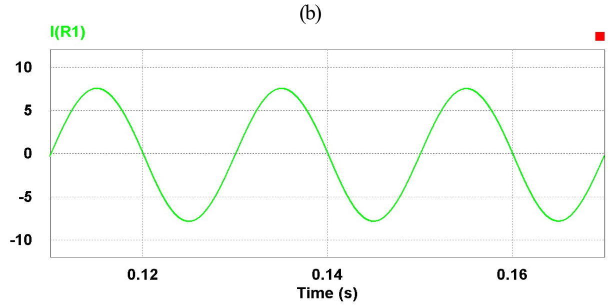
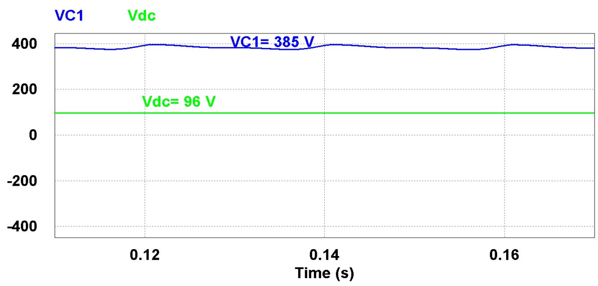
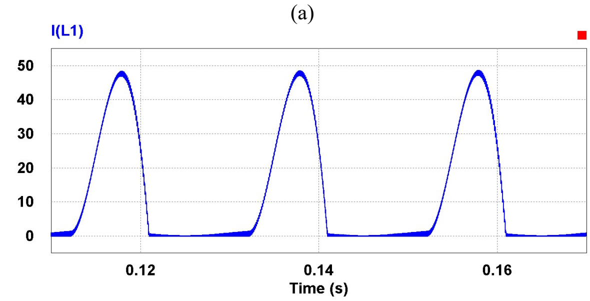


(c)

Fig. 6. Simulation results for the inverter. (a) 3-level output voltage; (b) output voltage with using Filter, output current.



(a)



(b)

Fig. 7. Simulation results for the inverter. (a). capacitor voltage C_1 , input voltage V_{dc},; and (b). input current i_L.

As shown in Fig. 7(a), we can see that the capacitor voltage C_1 is boosted to 385V. A discontinuous input current with the ripple of input current is 48A as shown in Fig. 7(b). Analysing theory above agrees well with the simulation results.

Fig. 8 and Fig. 9 illustrate the simulation results for the TBII with using PLL.

The simulation result of PLL as shown in Fig. 8 shows that the PLL can successfully extract, without errors, the phase angle of the grid voltages, which allows for synchronization with the grid.

As shown in Fig. 9, phase voltage of grid and phase voltage of the inverter is completely same after 0.28s.

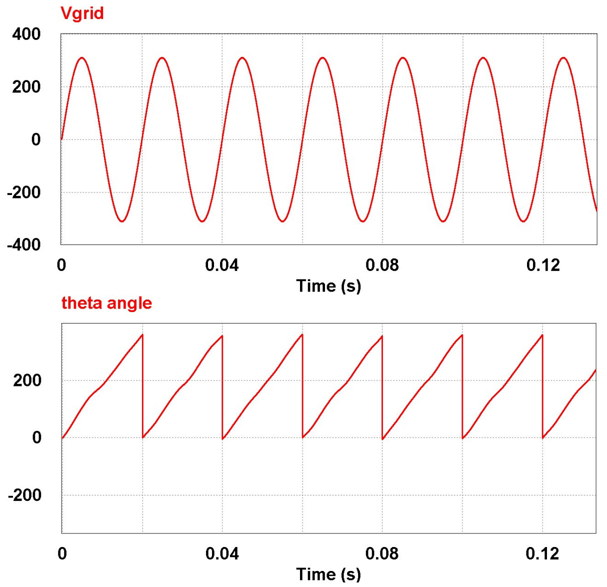


Fig. 8 Simulation results for PLL. From top to bottom: phase voltage of the grid voltage, PLL phase angle.

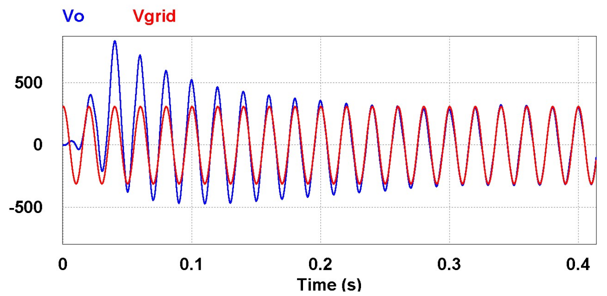


Fig. 9. Grid voltage and output voltage of the inverter with using PLL.

V. Conclusion

This paper presents the operating principles and analysis of the a single phase type boost integrated inverter. In the inverter, one of the H-bridge legs is shared with a boost converter. The TBII requires only four controllable switches, one diode, one dc-link capacitor, and one inductor. Also, A pulse width modulation strategy is shown to control the inverter. Since ac output voltage of the inverter is higher than source DC input voltage, the 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. Therefore, it is suitable for grid connection directly without using transformer. Simulation results prove the validity of the PWM technique for controlling the single phase type boost integrated inverter.

Acknowledgments

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