Maximum Boost Control of Diode-Assisted Buck-Boost Voltage Source Inverter with Minimum Switching Frequency

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Abstract: ***This paper proposes a diode-assisted buck-boost voltage source inverter with unique X-shaped diode-capacitor network inserted between dc source and inverter bridge for producing high voltage gain. Using the diode-assisted network, the proposed inverter can naturally configure themselves to perform capacitive charging in parallel and discharging in series to give higher voltage multiplication factor without compromising waveform quality. In order to maximize voltage gain and increase efficiency, this paper proposes a novel PWM strategy. It regulates the average value of intermediate dc-link voltage in one switching time period (Ts). Then, the equivalent switching frequency of power devices in the inverter bridge can be reduced to 1/3f_s (f_s=1/T_s). The operating principle and closed-loop controller design are analyzed and verified by simulations using MATLAB/Simulink.***

Keywords: Closed-loop control, DC/AC conversion, high efficiency, minimum switching frequency, modulation strategy, voltage gain.

1. Introduction

Due to the efficiency and environmental benefits of emerging solar and fuel cell technology, the distributed generation (DG) systems based on the renewable energy sources have rapidly developed in recent years [1-2]. In photovoltaic (PV) systems, it is difficult to realize a series connection of the PV cells without incurring a shadow effect. Fuel cells and light-weight battery power supply systems are promising in future hybrid electric vehicle, more-electric aircraft and vessel. However, the obvious characteristic of these dc sources is low voltage supply with wide range voltage drop.

Power electronic interface has to regulate the amplitude and frequency to obtain required high ac utility voltage. These applications raise stringent requirements for power converters such as low cost, high efficiency and wide range voltage buck-boost regulation ability. Traditional voltage source inverter (VSI) can only perform buck voltage regulation.

The PV grid-connected power system in the residential applications is recently becoming a fast growing segment. Unfortunately, the output voltage of the PV arrays is relatively low. In the residential PV grid-connected system, the PV arrays are usually installed on the roof. The generated power of the PV arrays is reduced greatly with PV series connected configuration. When they are covered by the shadows, which may be caused by the clouds, trees, neighbour's house, and even the power line cables. The grid-connected PV power system employing the cascaded H-bridge multilevel inverters or other multilevel configurations is introduced to optimize the PV output power. However, a lot of power devices are necessary, and the cost is increased in these solutions in order to obtain a 220V grid voltage.

For traditional voltage source inverter [3], the peak ac output voltage is lower than the available dc source voltage. Therefore, it can only perform the buck dc-ac power conversion and the maximum ac output phase voltage is limited to 1.15 times half of the dc source voltage. However, for the economic and environmental requirement, more and more power electronic applications demand both the buck and boost conversion at present. For example, in fuel cell power generation and hybrid electric vehicles drive system, low dc source voltage supplied by the stack fuel cell, solar cell or battery with wide range voltage drop should be boosted and inverted into required AC voltage.

2. Proposed Diode-assisted Buck-boost Voltage source inverter

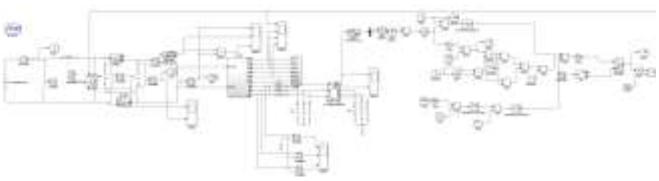


Figure 1: Simulink model

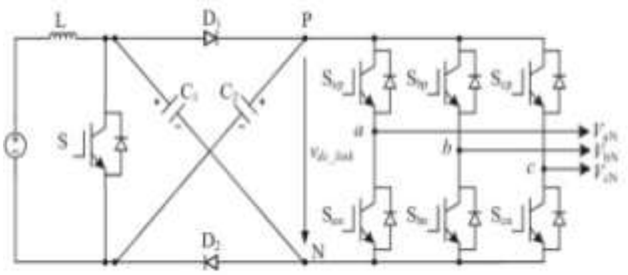


Figure 2: Proposed diode- assisted buck- boost VSI topology

A. Operating principle

The circuit diagram of the proposed diode-assisted buck-boost voltage source inverter is shown in figure 2. The diode-assisted buck-boost voltage source inverter has the capability of both buck and boost power conversion. With the X-shape diode-assisted network, more than double dc source voltage can easily be obtained with the same conductive duty ratio and capacitor rating, since the diodes in the network are naturally conducting to perform parallel capacitive charging and are reverse-biased in the next interval to realize a series capacitive discharging.

In order to achieve the increased efficiency as well as to maximize the voltage gain, this paper proposes a novel modulation strategy. It regulates the average value of intermediate dc-link voltage in one switching time period T_s the same as the instantaneous maximum value of three-phase line voltage by controlling the front boost circuit. Then, the equivalent switching frequency of power devices in the inverter bridge can be reduced to $1/3f_s$ ($f_s=1/T_s$). Compared with the existing modulation strategies, new proposed maximum boost control strategy contributes to less switching device requirement and higher efficiency in high voltage gain applications.

B. Modes of operation

The operation of the proposed topology is divided into two modes. These are explained as follows:

During S = ON interval (mode 1): When switch S is turned ON, during this interval the two diodes are reverse biased as shown in figure 2(a) therefore, the inductor absorbs energy from DC source by increasing the charging current and both of capacitors are connected in series to supply the inverter bridge $V_{dc\text{-}link} = 2V_C$.

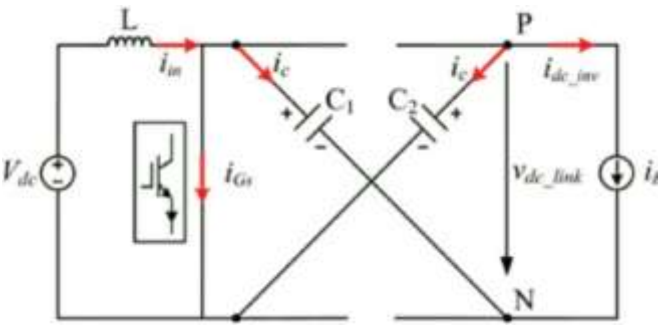


Figure 2(a): Equivalent circuit in mode-1

During S = OFF interval (mode2): When switch S is turned OFF, during this two diodes are forward biased. Therefore, the energy stored in inductor is transferred to capacitors and both capacitors are connected in parallel to supply the inverter bridge $V_{dc\text{-}link} = V_C$.

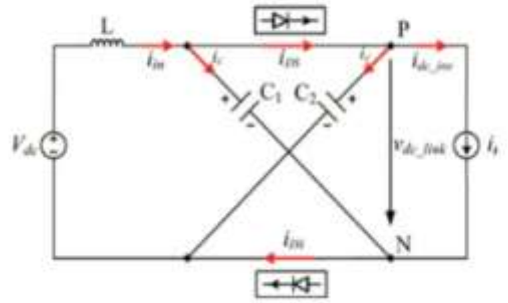


Figure 2(b): Equivalent circuit in mode-2

C.Modulation principle of conventional three -phase VSI

The switching states of three-phase VSI in each sixtant are listed in Table 1.

Table 1: Switching states of power devices in the inverter bridge

Phase angle	0°≤θ≤60°	60°≤θ≤120°	120°≤θ≤180°	180°≤θ≤240°	240°≤θ≤300°	300°≤θ≤360°
Mod A	S_{ap}=1; S_{an}=0	S_{ap}, S_{an}=PWM	S_{ap}=0; S_{an}=1	S_{ap}=0; S_{an}=1	S_{ap}, S_{an}=PWM	S_{ap}=1; S_{an}=0
Mod B	S_{bp}, S_{bn}=PWM	S_{bp}=1; S_{bn}=0	S_{bp}=1; S_{bn}=0	S_{bp}, S_{bn}=PWM	S_{bp}=0; S_{bn}=1	S_{bp}=0; S_{bn}=1
Mod C	S_{cp}=0; S_{cn}=1	S_{cp}=0; S_{cn}=1	S_{cp}, S_{cn}=PWM	S_{cp}=1; S_{cn}=0	S_{cp}=1; S_{cn}=0	S_{cp}, S_{cn}=PWM

Taking the first sixtant for example, the instantaneous dc-link voltage is the line voltage (V_{ao}-V_{co}). Thus, S_{ap} and S_{cn} are always turned on, S_{bp} and S_{cn} are controlled with PWM to regulate the output phase voltage V_b. In each sixtant, only one phase leg operates under complementary PWM mode.

D. Closed loop control strategy

Control strategy of the proposed diode-assisted buck-boost VSI is as shown in figure 3.

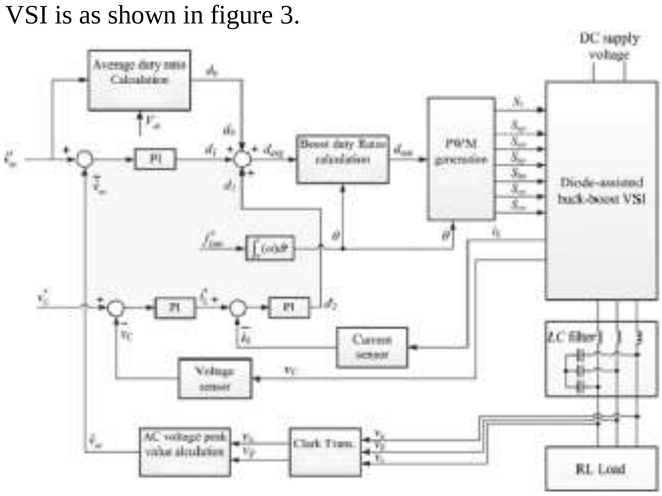


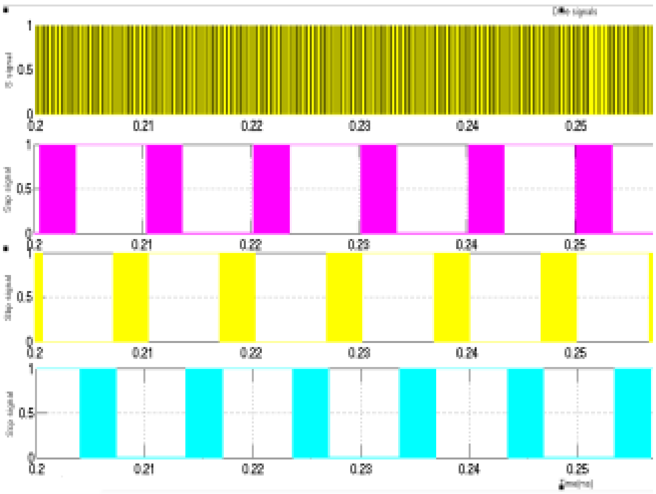
Figure 3: Control strategy used in diode-assisted buck-boost VSI

Reference voltage V_{ac} and input voltage V_{dc} is introduced to generate the related voltage gain G and to calculate the approximate average value of boost duty ratio d_{avg}. That is beneficial to achieve good transient performance. Instead of the ac component, the amplitude of three-phase voltage is feedback because it is dc component. After detecting the three-phase line voltages, the there-phase voltages V_{ao}, V_{bo}, V_{co}, are transformed into the two-axis stationary reference frame V_α and V_β. Amplitude of output three-phase voltage V_{ac} is calculated. The output of PI controller d_1 drives the amplitude of three-phase voltage to zero steady state error. For the front boost circuit, the voltage gain and frequency characteristic of boost duty ratio to intermediate capacitor voltage are similar as conventional boost DC-DC circuit. The typical dual-loop controller is applied to deal with the non-minimum phase system characteristic and obtain the good dynamic response. The output of PI controller d_2 drives the intermediate capacitor voltage follow V^*_c. The phase angle θ determines the sector at which the reference voltage vector is located.

The instantaneous boost duty ratio d_{son} is calculated based on d_{avg} and θ. Then, the PWM module generates S signal for boost circuit and six PWM signals for the inverter bridge.

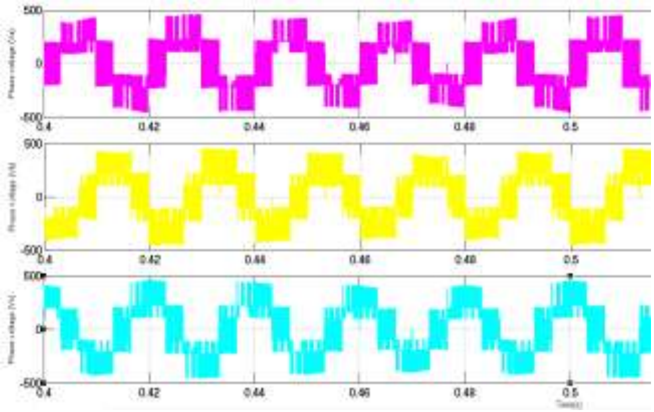
3. Simulation Results

The proposed diode-assisted buck-boost voltage source inverter is simulated in MATLAB/SIMULINK to verify the maximum boost modulation strategy. The 120V dc voltage source is boosted to achieve high intermediate dc link voltage.



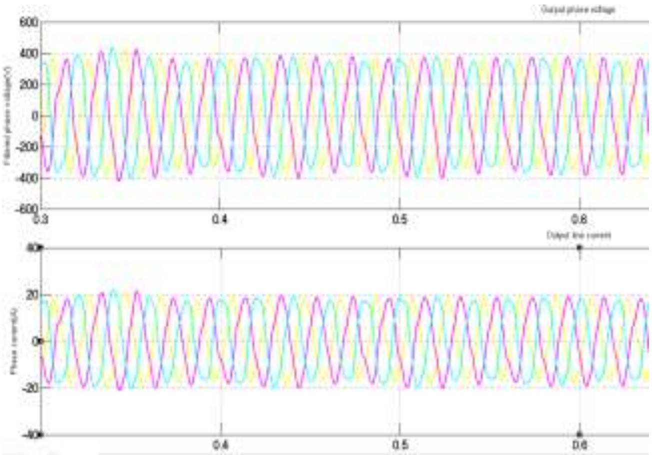
Time(ms)

(a) Drive signal



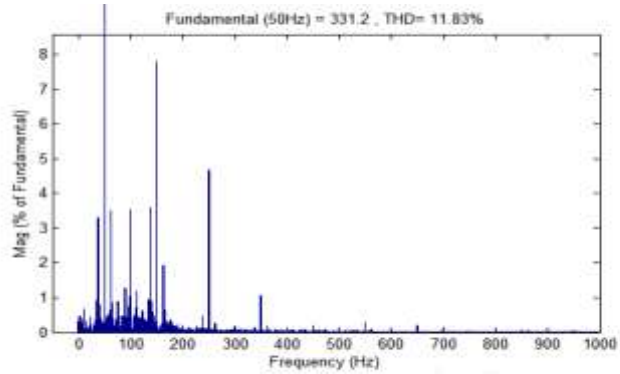
Time(s)

(b)Phase voltage

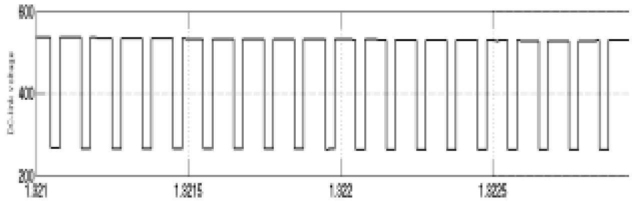


Time(s)

(c) Filtered output phase voltage and output line current

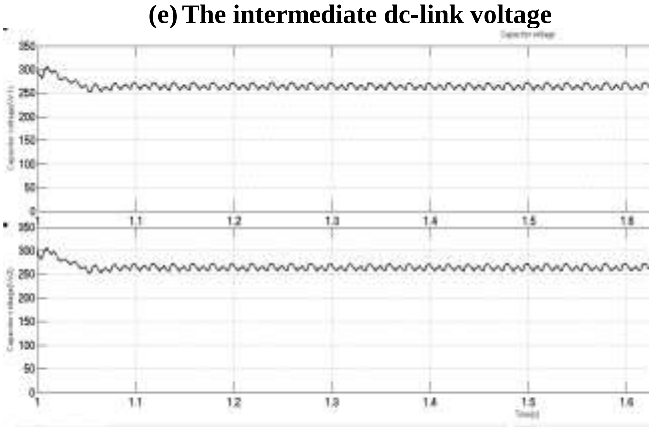


(d)Output phase voltage and spectrum analysis



Time (ms)

(e) The intermediate dc-link voltage



Time(s)

(f) Capacitor voltages

4. Conclusions

The proposed Diode-assisted buck-boost VSI with maximum boost control strategy reduces the voltage stress of switches and demonstrates the optimal efficiency. Therefore, it is a more promising and competitive topology for wide range voltage regulation in renewable energy applications. Furthermore, with the maximum boost control strategy, the dc-side inductor current and capacitor voltage contains six-times line frequency ripples. Therefore, it is also suitable for relatively high output line frequency, including400-800Hz medium frequency aircraft and vessel power supply system.

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