Quasi Single-Stage Buck-Boost Inverter with PID Controller

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Abstract— To regulate a standard output ac voltage in inverter having wide input dc voltage variation with buck-boost power conditioning system. In this paper, the buck-boost inverter with reduced power electronics components with improved conduction loss is proposed. The proposed topology requires only four active switches. It has no shoot-through problem and has improved reliability. The performance of proposed multilevel inverter is measured by using simulation software MATLAB/Simulink, and laboratory based experimental test has been conducted. Here, the half-cycle PWM switching scheme is used where only two switches are switching at high frequency at a time and two switches are at low frequency. Finally, the comparison between the simulation output and experimental result is discussed to prove the superiority of proposed topology.

Key words: Buck-Boost, Inverter, Switching Cell, Efficiency, Reliability, IGBT, Single-Stage

I. Introduction

An inverter is a device that changes D.C. voltage into A.C. voltage. A Direct current (D.C) flows in only one direction. An alternating current (A.C) is a current that which flows in both the positive and negative directions. To meet the power demand, different forms of renewable were developed as an alternative solution. As a result of this, some electrical components like convertors, rectifiers, inverters and others were developed. An inverter is a high power electronic oscillator. The name inverter was given because in early stage the mechanical AC to DC converters was inverted in operation i.e., DC to AC to obtain inverter operation. As a result of the introduction of the thin film photovoltaic technology, the PV power generation became more promising feature at present. The PV technology has very good high temperature performance, low weight and flexibility.

The cost of the solar cell or the module is high and the output of the PV cells shows greater variability. These are the two disadvantages or hindrance in using photovoltaic cells for power generation. Due to the temperature and irradiation there is a variation of voltage which cannot be controlled using Voltage Source Inverter (VSI). This is because the input dc voltage must be greater than the peak output ac voltage. Since, the VSI is a buck converter. To overcome this a transformer or a dc/dc converter is used in the photovoltaic power applications. This helps to manage the wide range of the PV voltage and produce a desirable output voltage required for the load. This leads to increase in number of component used, thereby reducing the efficiency.

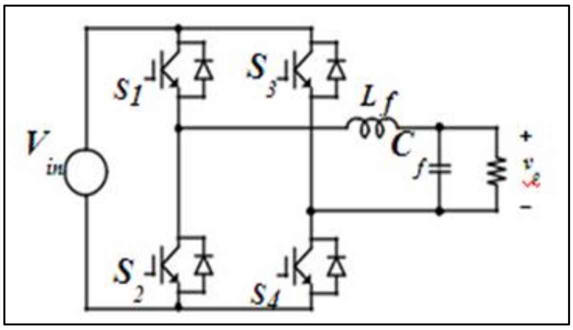

Fig. 1: Traditional Voltage Source Inverter

A. Z-Source Inverter

The Z-source Inverter has the capability of voltage boost and also the inversion is taken place in a single stage. Thus, the ZSI are suitable for residential photovoltaic application. Recently there are four new topologies derived from the original Z-source inverter. Out of those in this inverter one voltage fed topology is applied. As a result of the use of new quasi-Z-Source topology, constant current is drawn from the PV array. It is also capable of handling a wide range of input voltage. Compared to traditional ZSI, it also reduces source stress and has lower component rating. Thus the proposed qZSI inverter can realize buck or boost voltage and inversion can take place in single stage thereby providing high reliability and efficiency.

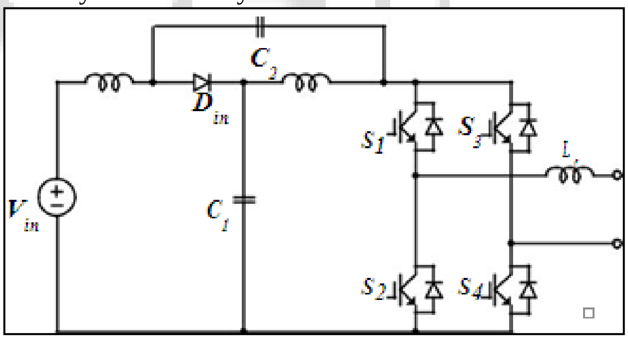

Fig. 2: Quasi Z-Source Inverter

B. Existing System

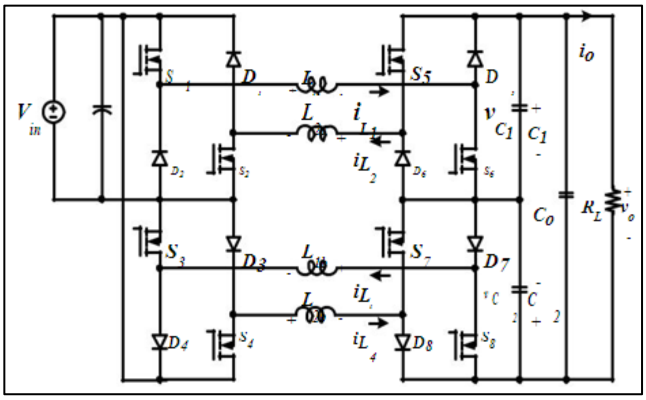

Fig. 3: Quasi Single-Stage Buck-Boost Inverter

Fig. 3 shows the circuit topology of the quasi single-stage Buck-boost Inverter with eight MOSFET switches. However, this BBI inverter requires more number of switches. It is composed of SC structure and dual buck-boost structure. The dual-buck structure controls the input dc of this eight switching inverter and the SC structure controls the ac output part of this inverter. This inverter is resistant to electromagnetic interference noise which characteristic is similar to the quasi-Z-source inverter and the dual-buck invert

In contrary this inverter also consists of one dissimilar character with the qZSI, i.e. it requires low voltage/current rating devices. This inverter is designed with MOSFET as switching devices, hence it has high frequency and it is efficient in operation. The circuit consists of an external diode which is connected in series with each switching device, hence there is no possibility of shoot-through current problem. When there is an occurance of dead-time in the gate signals of the switches (S_5, S_8) or (S_5, S_6) or (S_7, S_8) in the output side the capacitance C_1 and C_2 provides the inductor current safe path by adding the capacitance. They serve as a output filter capacitor. They reduces the voltage spikes in the circuit caused by the stray inductances, hence acts as a lossless snubbers.

This eight switching quasi buck-boost inverter controls the input dc side by dual-buck structure and the ac output side by the switching cell structure. Hence it avoids both the short-circuit and open-circuit issues. This inverter uses power MOSFETs as switching device along with external fast recovery diodes, hence this reduces conduction loss, thereby resulting in high frequency and high efficiency operation. Also eliminating the PWM dead-times, this inverter results in high quality output voltage.

C. *Proposed System*

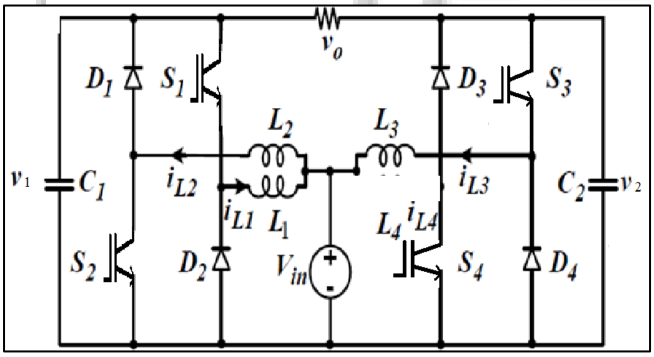

Fig. 4: Proposed Single –Phase Buck-Boost Inverter

Fig. 4. Shows the circuit topology of the proposed single-phase quasi buck-boost inverter. . It can provide a regulated Ac output voltage for wide input dc voltage variation owing to its buck–boost capability, and can solve the limited gain problem of the VSIs and CSIs. Unlike the conventional two-stage BBI, it does not require intermediate power decoupling capacitor. The proposed inverter has no current shoot-through problem and can eliminate the pulse width modulation (PWM) dead time, which lead to greatly enhanced system reliability. Each switching device is connected in series with an external diode. Here, we design inverter for high power applications, hence we use IGBT as switching device. In each leg the junction of the IGBT and an external diode is connected to an inductor. When all the switches are turned-on simultaneously, there occurs shoot-through current problem. Since an inductor is connected to each junction, the above mentioned shoot-through problem can be eliminated. When the upper and lower switches are turned-on simultaneously, the inductors L_1 and L_4 acts as filter inductors as it provides opposition to shoot-through current problem by stopping the current flow through the body diodes. Thus the diodes D_1 –D_4 acts as a freewheeler diode for the inductor currents.

The two boost converters are combined to produce this proposed single stage buck-boost inverter as shown in Fig. 4. An output voltage V_1 is produced as an output of left side of the converter and an output voltage V_2 is produced as an output of right side of the converter. The output voltage V_{out} is the difference of the voltages V_1 and V_2. V_1 and V_2 with sinusoidal voltage having same dc offset can be obtained by controlling each side of the converters with proper gate signals.

D. *Inductor Design*

Based on the maximum current handling capacity and maximum permitted ripple current the inductors L_1, L_2, L_3 and L_4 are designed. During the boost operation with minimum input voltage $Vi_{n(min)}$, the maximum inductor current $I_{L(max)}$ for output power P_o can be expressed as:

$$I_{Lmax} = \frac{P_o}{V_{in(\min)}} \tag{1.1}$$

During the buck mode with maximum input voltage Vin(max), the maximum inductor ripple current occurs and it is expressed as:

$$\Delta i_{Lmax} = \frac{V_{in(\max)}}{2L} T \tag{1.2}$$

Where T is the switching period.

E. *Capacitor Design*

During dead-time, a safe path for inductor currents is provided by the capacitors C_1 and C_2.They also acts as an output filter capacitors. Regardless of the operation modes the sum of the voltages across C_1 and C_2 is always V_0. During dead-time (t_d), the current i_{L1}($=i_{L2}$) is flowing through C_1 when io >0, and when io <0, then the current i_{L3} ($=i_{L4}$) is flowing through C_2.

Thus the voltages ripples ΔV_1 and ΔV_2 of capacitance C_1 and C_2 can be obtained as:

$$\Delta V_{1=} \frac{i_{L1}}{C} t_d \tag{1.3}$$

$$\Delta V_{2=} \frac{i_{L2}}{C} t_d \tag{1.4}$$

F. *Half-cycle PWM switching scheme*

In this inverter, we use half-cycle PWM switching scheme as shown in Fig. 5. Here, at a time only two switches are switched at high frequency and the two switches are at low frequency. For the positive half cycle, of the converter, the switches S_1 and S_2 of the left sided boost converter are operated at high frequency with small dead-time. The proposed inverter should not require dead-time to get rid of shoot-through problems. To avoid the generation of circulating current, small dead time can be used. Switch S_3 is always made conducting. Switch S_4 of the right sided converter is not triggered at all.

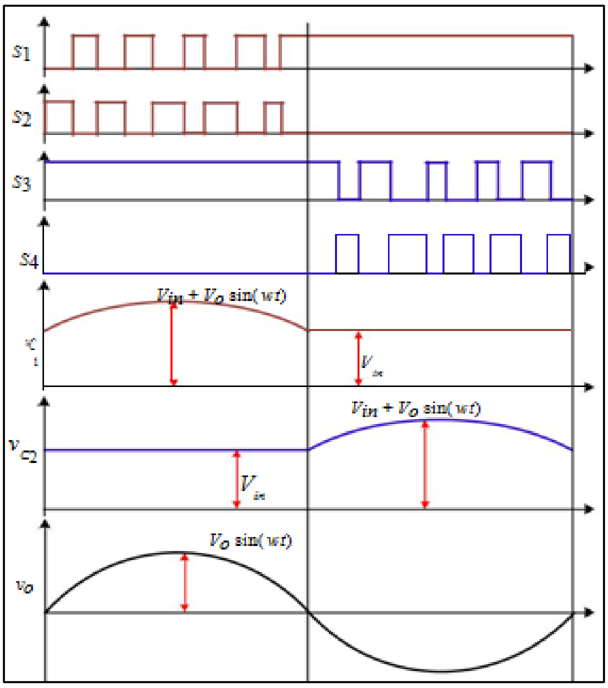

Fig. 5: Half-Cycle PWM Switching Scheme

For negative half cycle, complementary to positive half cycle the swiches S_3 and S_4 are operated at high frequency. Switch S_1 is always in conduction state and switch S_2 is not at all triggered.

For V_o >0 we get,

$$V_1 = V_{in} + V_o \sin(\omega t)$$

$$V_1 = \frac{V_{in}}{1-d_1(t)} \quad (1.5)$$

$$V_2 = V_{in}$$

For V_0 <0, we get,

$$V_1 = V_{in}$$

$$V_2 = V_{in} + V_o \sin(\omega t - 180°)$$

$$V_2 = \frac{V_{in}}{1-d_2(t)} \quad (1.6)$$

From (1.5) and (1.6) we get,

$$V_o = V_1 + V_2$$

$$V_o = V_o \sin(\omega t) \quad (1.7)$$

Because of the lower conduction, switching loss the efficiency of half-cycle switching PWM is higher than that of the tradiotional PWM scheme.

G. *Operation of Proposed Buck Boost Inverter*

In this paper, half cycle modulation scheme is considered for the operation. In this operation, For V_0 >0, switch S_3 is in conduction state and switch S_4 is not triggered at all. Similarly, for V_0<0,S_1 is in conduction state and switch S_2 is not triggered. Here four modes of operation is explained below.

1) *Mode 1*

In the mode 1, Switch S_1 is turned OFF and Switch S_2 is turned ON. Inductor L_2 is for energy storing purpose and capacitor C_1 is used to discharge energy to the load. The output current i_0 is flowing through the IGBT Switch S_3 to the input voltage source V_{in}.

2) *Mode 2*

This mode is considered as the dead time interval between Switch S_1 and S_2 .i_{L2} is the inductor current flowing through the diode D_1. The output current i_0 is flowing through the IGBT Switch S_3 to the input voltage source V_{in}.

3) *Mode 3*

In the mode 3, Switch S_1 is turned ON and Switch S_2 is turned off. In this mode Inductor L_2 is used to release energy to the capacitor C_1 and the load through the external diode D_1. The output current i_0 is flowing through the IGBT Switch S_3 to the input voltage source V_{in}. The above three modes are at voltage V_0 >0.

4) *Mode 4*

In the mode 4, Switch S_3 is turned off and Switch S_4 is turned ON. In this mode, Inductor L_4 is for storing energy and Capacitor C_2 is used to discharge energy to the load. i_{L4} is the inductor current. The output current i_0 is flowing through the IGBT Switch S_1 to the input voltage source V_{in}.

5) *Mode 5*

This mode is considered as the dead time interval between Switch S_3 and S_4. I_{L4} is the inductor current which is flowing through the diode$_3$. The output current i_0 is flowing through the IGBT Switch S_1 to the input voltage source V_{in}.

6) *Mode 6*

In the mode 6, Switch S_3 is turned ON and Switch S_4 is turned off. In this mode, inductor L_4 is used to release energy to the capacitor C_2 and the output load through the external diode D_3.i_0 is the output current which is flowing to V_{in} through the IGBT switch S_1.Inductors L_2 and L_4 are the boost inductors in the proposed buck boost inverter. The modes 4,5 and 6 are at voltage V_0 <0.

H. *Experimental Results*

1	Output voltage	230 V/50Hz
2	Input voltage	180-400V dc
3	Output power	2KW
4	Switching frequency	50Hz
5	IGBTs	FGA25N120
6	Diodes	F1H8AJ
7	Inductors	0.5mH
8	Capacitors C_1,C_2	6 μF
9	Output capacitor	3 μF

Table 1: Electrical specifications

To verify and analyse the quasi single stage buck boost inverter, a hardware prototype of 2KW inverter is fabricated and is checked using half cycle modulation scheme. The electrical specifications are given in the above table 1.It is proved that the proposed inverter can operate in high power conveniently because of no EMI and shoot through problems in the proposed buck boost inverter. And also it can be operated without using power decoupling capacitor because using IGBT switch .It reduces noise. Since the proposed inverter has no shoot through problem it can eliminate pulse with modulation (PWM) dead time.

The IGBT switch is used here to reduce the reverse recovery issues and loss occur due to MOSFET body diode. From all the experimental results, we have obtained the efficiency of the proposed system is about 96% in the boost operation and about 95.65% in the buck operation.

II. Conclusion

In this paper, a single-stage single-phase buck-boost inverter was proposed. This proposed inverter has high reliability since it overcomes the shoot-through problems and can eliminate pulse width modulation (PWM) dead-time. The number of switching devices is minimized from eight switching to four switching devices. Since the inverter is used for high power application, we used IGBT as switching device. A PID controller is used, which calculates an error voltage by calculating the difference between measured variable voltage and a desired set point. The proposed inverter is for 2KW solar panel. Due to the high efficiency, high reliability and reduced complexity, the proposed inverter is well suitable for transformerless grid connected PV applications

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