Simulation of Half Bridge Z-Source Inverter Constant Voltage With Balencing Capacitor

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Abstract*-Photovoltaic (PV) power generation is becoming more promising since the introduction of the thin film PV technology due to its lower cost, excellent high temperature performance, low weight, flexibility, and glass-free easy installation. However, there are still two primary factors limiting the widespread application of PV power systems. The first is the cost of the solar cell/module and the interface converter system; the second is the variability of the output (diurnal and seasonal) of the PV cells. A PV cell's voltage varies widely with temperature and irradiation, but the traditional Voltage Source Inverter (VSI) cannot deal with this wide range without over-rating of the inverter, because the VSI is a buck converter whose input dc voltage must be greater than the peak ac output voltage. Because of this, a transformer and/or a dc/dc converter is usually used in PV applications, in order to cope with the range of the PV voltage , reduce inverter ratings, and produce a desired voltage for the load or connection to the utility.*

The Z-Source Inverter (ZSI) has been reported suitable for residential PV system because of the capability of voltage boost and inversion in a single stage. Recently, four new topologies, the quasi-Z-Source Inverters (qZSI), have been derived from the original ZSI. This project analyzes one voltage fed topology of these four in detail and applies it to PV power generation systems. By using the new quasi-Z-Source topology, the inverter draws a constant current from the PV array and is capable of handling a wide input voltage range. It also features lower component ratings and reduced source stress compared to the traditional ZSI. A prototype which provides three phase 50-Hz, 230Vrms ac has been built in laboratory. It is demonstrated from the theoretical analysis and MATLAB/SIMULATION results that the proposed qZSI can realize voltage buck or boost and dc-ac inversion in a single stage with high reliability and efficiency, which makes it well suited for PV power systems.

Keywords-PV Array, Z -Source Inverter (ZSI), HB-ZSI

I. INTRODUCTION

The Z-Source Inverter(ZSI) has been reported suitable for residential PV system because of the capability of voltage boost and inversion in a single stage. Recently, four new topologies, the Half bridge-Z-Source Inverters (HB-ZSI), have been derived from the original ZSI .This project analyses one voltage fed topology of these four in detail and applies it to PV power generation systems. By using the new Half bridge-Z-Source topology, the inverter draws a constant current from the PV array and is capable of handling a wide input voltage range. It also features lower component ratings and reduced source stress compared to the traditional ZSI. It is demonstrated from the theoretical analysis and simulation results that the proposed HB-ZSI can realize voltage buck or boost and dc-ac inversion in a single stage with high reliability and efficiency, which makes it well suited for PV power systems.

Following are some electrical conditions that affect both side utility and customer. The new Z-Source Inverter (ZSI) advantageously utilizes the shoot through state to boost the dc bus voltage by gating on both upper and lower switches of a phase leg and produce a desired output voltage that is greater than the available dc bus voltage. In addition the reliability of the inverter is greatly improved because the shoot-through due to miss gating can no longer destroy the circuit. Thus it provides a low-cost, reliable, and high efficiency single stage structure for buck and boost power conversion

II. TOPOLOGY AND PRINCIPLE

1. Half bridge-Z-Source Inverter

The Half bridge-Z-Source inverter circuit differs from that of conventional Z Source Inverter in LC impedance network interface between the source and inverter. Half bridge-Z-source inverter acquires all the advantages of traditional Z-Source Inverter. Fig. 3.4 shows the basic topology of Half bridge Z-source inverter. The Half bridge Z-Source inverter extends several advantages over Z-Source inverter such as continuous input current, reduced component rating, and enhanced reliability. These advantages make the

Half bridge Z-source inverter suitable for power conditioning in renewable energy system.

A PV cell's voltage varies widely with temperature and irradiation, but the traditional voltage Source Inverter (VSI) cannot deal with this wide range without over-rating of the inverter, because the VSI is a buck converter whose input dc voltage must be greater than the peak ac output voltage. Because of this, a transformer and/or a dc/dc converter is usually used in PV applications, in order to cope with the range of the PV voltage , reduce inverter ratings, and produce a desired voltage for the load or connection to the utility. This leads to a higher component count and low efficiency, which opposes the goal of cost reduction. The Z-Source Inverter (ZSI) has been reported suitable for residential PV system because of the capability of voltage boost and inversion in a single stage. Recently, four new topologies, the Half bridge-Z-Source Inverter (HB-ZSI), have been derived from the original ZSI. This project analyzes one voltage fed topology of these four in detail and applies it to PV power generation systems.

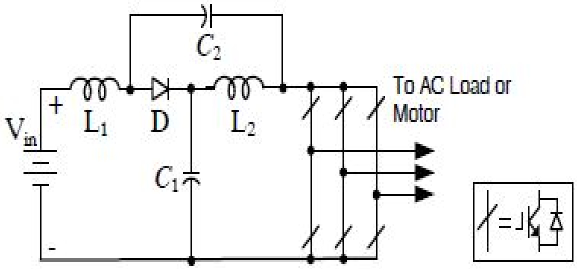

Fig1. Basic Circuit of Half bridge-Z-Source Inverter

By using the new Half bridge-Z-source topology, the inverter draws a constant current from the PV array and is capable of handling a wide input voltage range. It also features lower component ratings and reduced source stress compared to the traditional ZSI. It is demonstrated from the theoretical analysis and simulation results that the proposed HB-ZSI can realize voltage buck or boost and dc-ac inversion in a single stage with high reliability and efficiency, which makes it well suited for PV power systems.

II. MERITS OF HB-ZSI OVER ZSI

1. The two capacitors in ZSI sustain the same high voltage [2]; while the voltage on capacitor C2 in HB-ZSI is lower, which requires lower capacitor rating [1].
2. The ZSI has discontinuous input current in the boost mode, while the input current of the HB-ZSI is continuous due to the input inductor L1, which will significantly reduce input stress.

For the HB-ZSI, there is a common dc rail between the source and inverter, which is

a. easier to assemble and causes less EMI problems.
b. ZSI has more harmonics in the output than HB-ZSI.[1]

III. CIRCUIT ANALYSIS

In the same manner as the traditional ZSI, the HB-ZSI has two types of operational states at the dc side: the non-shoot-through states (i.e. the six active states and two conventional zero states of the traditional VSI) and the shoot-through state (i.e. both switches in at least one phase conduct simultaneously). In the non-shoot-through states, the inverter bridge viewed from the dc side is equivalent to a current source. The equivalent circuits of the two states are as shown in Fig.3.6 and Fig.2. The shoot-through state is forbidden in the traditional VSI, because it will cause a short circuit of the voltage source and damage the devices. With the HB-ZSI and ZSI, the unique LC and diode network connected to the inverter bridge modify the operation of the circuit, allowing the shoot-through state. This network will effectively protect the circuit from damage when the shoot-through occurs and by using the shoot-though state, the Half bridge- Z-source network boosts the dc-link voltage. The major differences between the ZSI and HB-ZSI are the HB-ZSI draws a continuous constant dc current from the source.

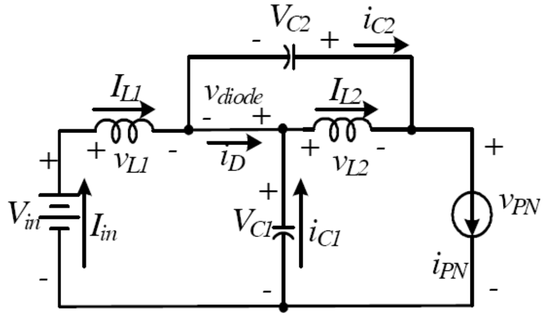

Fig.2. Equivalent Circuit of the HB-ZSI in Non Shoot-through States

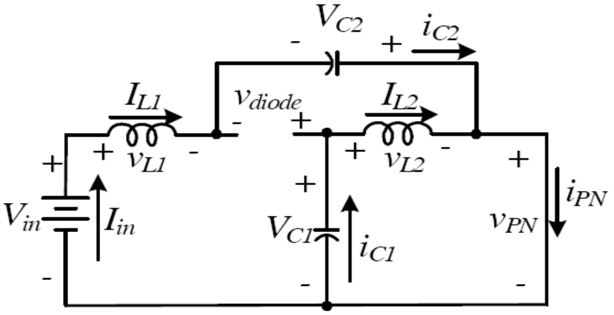

Fig.3. Equivalent Circuit of the HB-ZSI in Shoot-Through States

All the voltages as well as the currents are defined in Fig.2.and Fig.3.and the polarities are shown with arrows. Assuming that during one switching cycle T, the interval of the shoot through state is T0; the interval of non-shoot-through states is T1; thus one has T= T0+T1and the shoot-through duty ratio, D= T0/T. From Fig.2.which is a representation of the inverter during the interval of the non-shoot through states T1, one can get;

$$V_{L1}=V_{in}-V_{C1}, V_{L2}=-V_{C1} \quad (1)$$

and $$V_{PN}=V_{C1}-V_{L2}=V_{C1}+V_{C2} \quad V_{diode}=0 \quad (2)$$

From Fig.3.7.which is a representation of the system during the interval of the shoot-through statesT0, one can get;

$$V_{L1}=V_{C2}+V_{in}, V_{L2}=V_{C1} \quad (3)$$

$$V_{PN}=0 \quad V_{diode}=V_{C1}+V_{C2} \quad (4)$$

At steady state, the average voltage of the inductors over one switching cycle is zero. From (1), (3), one has

$$V_{L1}=\overline{v}_{L1} = \frac{T_0(V_{C2}+V_{in})+T_1(V_{in}-V_{C1})}{T}=0$$

$$V_{L2}=\overline{V}_{L2}=\frac{(V_{C1})T_0+(-V_{C2})T_1}{T}=0$$

Thus,

$$V_{C1}=\frac{T_1}{T_1-T_0}V_{in} \quad V_{C2}=\frac{T_0}{T_1-T_0}V_{in} \quad (5)$$

From (2), (4) and (5), the peak dc-link voltage across the inverter bridge is

$$\overline{V}_{PN}=V_{C1}+V_{C2}=\frac{T}{T_1-T_0}V_{in}=\frac{1}{1-2\frac{T_0}{T}}V_{in}=BV_{in} \quad (6)$$

Where, B is the boost factor of the HB-ZSI. This is also the peak voltage across the diode

The average current of the inductors L1, L2 can be calculated by the system power rating P.

$$I_{L1}=I_{L2}=I_{in}=\frac{P}{V_{in}} \quad (7)$$

According to Kirchhoff's current law and (7), we also can get that

$$I_{C1}=I_{C2}=I_{PN}-I_{L1} \quad I_D=2I_{L1}-I_{PN} \quad (8)$$

In summary, the voltage and current stress of the HB-ZSI are shown in Table 3.1. The stress on the ZSI is shown as well for comparison, where

(1) M is the modulation index; $\hat{v}_{1n}$ is the ac peak phase voltage; P is the system power rating.

(2) $m=\frac{T_1}{T_1-T_0}$; $n=\frac{T_0}{T_1-T_0}$ thus $m>1$; $m-n=1$;

(3) $B=\frac{T}{T_1-T_0}$ thus $m+n=B$, $1<m<B$

From Table 3.1. we can find that the HB-ZSI inherits all the advantages of the ZSI. It can buck or boost a voltage with a given boost factor. It is able to handle a shoot through state, and therefore it is more reliable than the traditional VSI. It is unnecessary to add a dead band into control schemes, which reduces the output distortion.

Table 1. Voltage and Average Current of the HB-ZSI and ZSI Network

	$v_{L1}=v_{L2}$		v_{PN}		v_{diode}	
	T_0	T_1	T_0	T_1	T_0	T_1
ZSI	mV_{in}	$-nV_{in}$	0	BV_{in}	BV_{in}	0
qZSI	mV_{in}	$-nV_{in}$	0	BV_{in}	BV_{in}	0
	V_{C1}		V_{C2}		$\hat{v}_{1n}$	
ZSI	mV_{in}		mV_{in}		$MBV_{in}/2$	
qZSI	mV_{in}		nV_{in}		$MBV_{in}/2$	
	$I_{in}=I_{L1}=I_{L2}$		$I_{C1}=I_{C2}$		I_D	
ZSI	P/V_{in}		$I_{PN}-I_{L1}$		$2I_{L1}-I_{PN}$	
qZSI	P/V_{in}		$I_{PN}-I_{L1}$		$2I_{L1}-I_{PN}$	

In addition, there are some unique merits of the HB-ZSI when compared to the ZSI:

(1) The two capacitors in ZSI sustain the same high voltage; while the voltage on capacitor.C2in HB-ZSI is lower, which requires lower capacitor rating.

(2) The ZSI has discontinuous input current in the boost mode; while the input current of the HB-ZSI is continuous due to the input inductor L1, which will significantly reduce input stress.

(3) For the HB-ZSI, there is a common dc rail between the source and inverter, which is easier to assemble and causes less EMI problems.

IV. CONTROL METHODS

So, the compensation ability of the SPB-AVQR is theoretically unlimited as long as the grid is strong enough to provide the needed power. However, as the boost circuit is parasitic on the series inverter, and the two switches are actually controlled according to the missing voltage, there still exist some restrictions. The relationships between the dc-link voltage and other system parameters will be discussed in the next section. In Figs. 3 and 4, two endpoints of the inverter are marked as a and b. Parts of the waveforms obtained at the inverter side and load side under four operating conditions can be drawn. So, the load voltage will be maintained at its rated value if the inverter is properly controlled according to the required missing voltage during sags.

V. RESULT

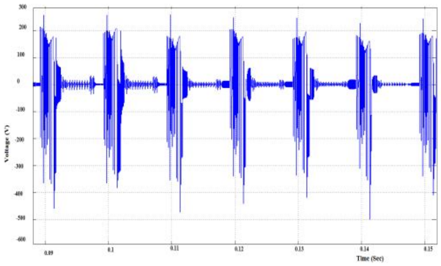

Fig: 4 Output Voltage without HBZ-S Inverter

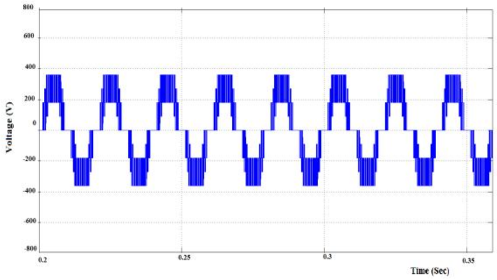

Fig: 5 Output Voltage with HBZ-S Inverter

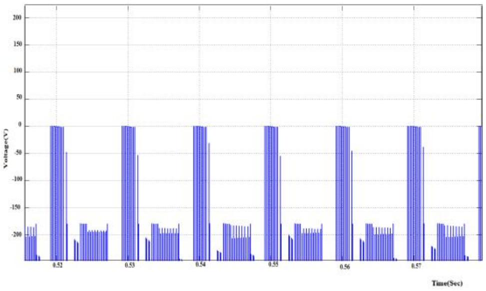

Fig: 6. Reduced Voltage stress on Capacitors

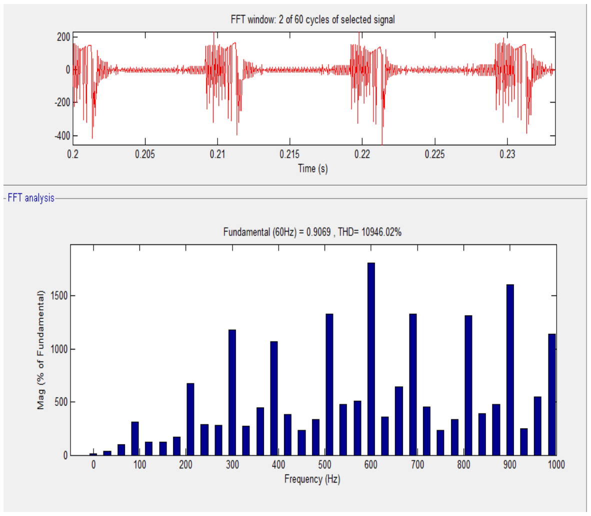

Fig 7. FFT Analysis without HBZ-SI

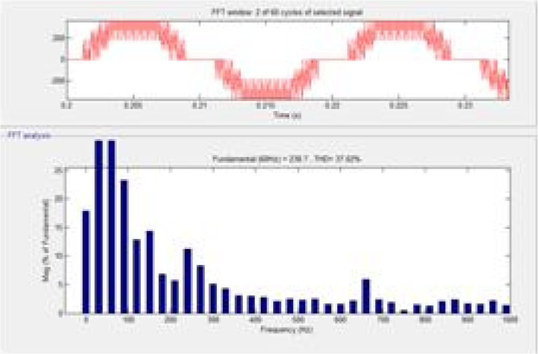

Fig 8. FFT Analysis with HBZ-SI

VI. CONCLUSION

Conclusion By referring to the project objectives, this project has been successful. This project mainly focuses on the study of Z source inverter and simple boost switching control method. The circuit has been designed based on the standard Z source inverter and simulated using MATLAB. The theoretical values has been calculated and the simulation results were gained through MATLAB simulations. The simulation results were almost similar to the calculated values both the output voltages and voltage stress. The output voltage also can be buck or boost depends on the requirement of the electronic or electrical power applications. However, for simple boost switching technique, the modulation index can only be in the range of zero and one. Thus, since the output voltage directly depending on the modulation index, the output voltage has been limited to a certain range for the Z source inverter instead of zero to infinity. From the results and progress throughout the project, Z source inverter has overcome the barrier of traditional inverters. The barrier is to produce AC output waveforms that are greater than the DC input sources. The project also can conclude that the simple boost switching control method still needs some improvement since the voltage stress is high. This makes the inverter demanding a very good switch for inverter operation. This project has presented quasi-Z-Source Inverter with a new topology, which is derived from the traditional ZSI. The proposed qZSI inherits all the advantages of the ZSI and features its unique merits. It can realize buck/boost power conversion in a single stage with a wide range of gain that is suited well for application in PV power generation systems. Furthermore, the proposed qZSI has advantages of continuous input current, reduced source stress, and lower component ratings when compared to the traditional ZSI. Theoretical analysis, control method, and system design guide are presented in this project. Simulation results show that with a voltage range of 1:2 at the PV input (from 200V to 400 V), the qZSI can provide three phase 50Hz, 230 Vrms ac voltage, which verifies the theoretical analysis.

FUTURE SCOPE

A grid-connected PV power generation system is one of the most promising applications of renewable energy sources. The proposed qZSI based PV power generation system is intended as a grid connected system and transfers the maximum power from the PV array to the grid by maximum power point tracking technology. In that case, the efficiency would be improved and the cost would be reduced with the proposed one stage power conversion system.

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