Single-Phase Quasi-Z-Source Based Isolated DC/AC Converter

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Abstract—**This paper presents a new Single-Phase Quasi-Z source based Isolated DC/AC converter topology preferably suitable for residential/distributed generation applications. Quasi-Z source inverter provides additional benefits of reduced component ratings, improved input current profile and enhanced reliability in comparison with other topologies of Z source network. A new modulation technique is developed to minimize the switching loss and to increase the overall efficiency of Quasi-Z source inverter. An Indirect voltage control scheme is employed for control of DC link voltage. A Multi winding High frequency transformer is used for galvanic electrical isolation, improved power density and better gain. A seven level inverter with reduced switches is used for realizing DC/AC power conversion at the secondary side of the transformer. The proposed model is developed in Matlab/Simulink environment and the simulation results are presented for changes in load and for step changes in input voltage.**

Keywords—Isolated DC/AC converter, High frequency transformer, Quasi-Z source inverter, Pulse width modulation

I. INTRODUCTION

Z Source inverter has emerged as an active research area in the recent years due to its suitability for wide range of applications such as distributed generation, avionics, electric vehicles, adjustable speed drives, and uninterruptible power supply (UPS) etc. Various topologies based on impedance source network are developed to address the issues of system size, cost, boost ratio, number of active and passive components and to cater wide range of applications. In this paper, Quasi-Z source inverter (qZSI) is adopted as it offers additional benefits of low inrush current, reduced voltage stress across the capacitor and continuous input current which makes it suitable for distributed power generation [1].

Z-source network design in a single phase qZSI based on low frequency ripple and high frequency ripple is presented in [2]. The low frequency ripple is generated due to the instantaneous nature of the output power in single phase circuit and the high frequency ripple is generated due to the shoot through states. However, the low frequency ripples are the main harmonics and affects both the capacitor voltage and inductor current. The oscillations can be attenuated by increasing the capacitance and decreasing the inductance value. Careful design of impedance network is necessary to mitigate the oscillations in the LC network[3]. Hence different modulation techniques proposed by researchers such as Carrier-based PWM, Hysteresis band current control are reported in literature for the control of single phase H-Bridge qZSI [4],[5]. Shoot through states are inserted in the null state without altering the active state duration in a switching cycle such that normalized volt-sec average remains same. The desired output voltage can be attained by proper control of shoot through duty cycle. Therefore, in this paper, a new PWM control with shifted shoot through in one leg is developed in order to equalize the switching frequencies, and reduce the switching losses which results improvement in overall efficiency of the system.

In general the DC-link voltage of a Z-source network is pulsating in nature due to the presence of shoot through states. Therefore, direct measurement of DC link voltage requires additional special circuitry, increasing the cost and complexity of control. Indirect measurement of DC link voltage is done by sensing both the capacitor voltages and input voltages [6]. Here the peak value of DC link voltage can be obtained by summation of the two capacitor voltages. A PI Controller is designed to take care of the changes in DC link voltage with corresponding changes in shoot through duty cycle.

Recently Z-Source based Multilevel topologies, qZSI based NPC and cascaded multilevel qZSI are presented in [7] which overcomes some of the limitations of conventional multilevel topologies because it enables better gain, buck-boost capability, low THD and enhanced reliability. However, there is not much work reported in Z-Source based isolated DC/AC inverter topologies. Hence, this paper presents a new Quasi Z-Source based isolated DC/AC inverter topology with high frequency isolation which enables improved reliability, simple control suitable for distributed power generation. The complete operation and proposed new control technique is presented. Further the performance of the proposed model developed in Matlab/Simulink environment is studied for changes in load and step changes in input voltage.

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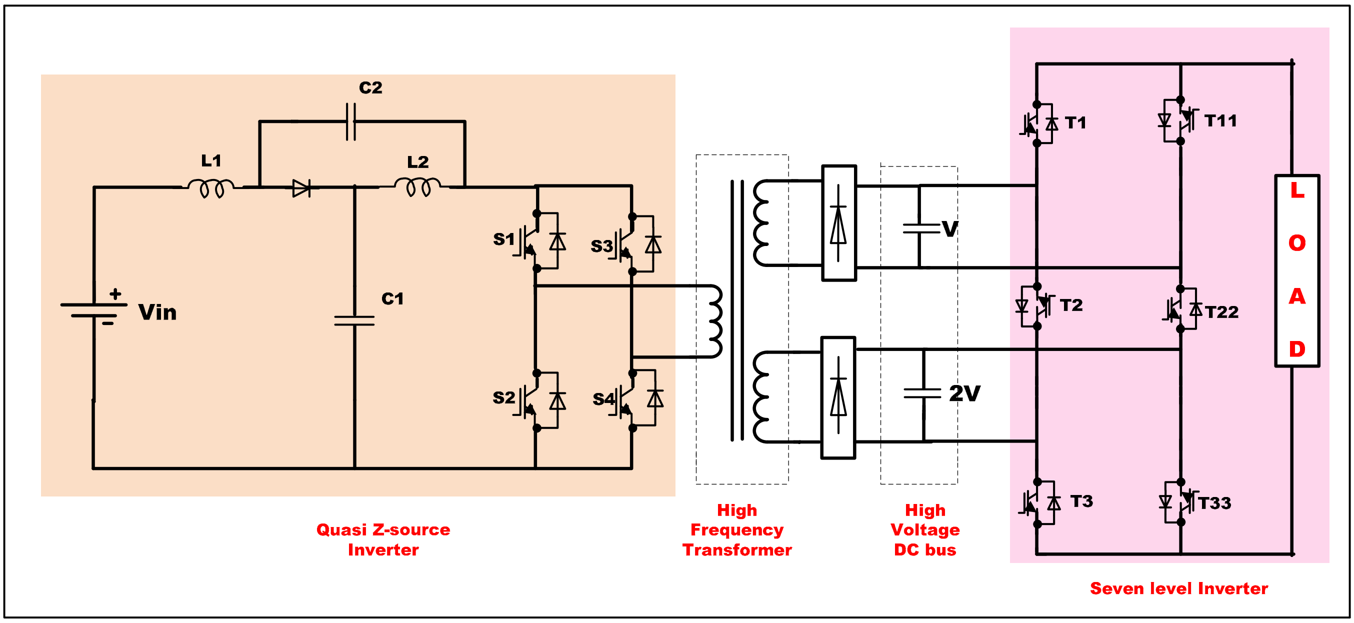

Fig. 1. Proposed Single phase qZSI based Isolated DC/AC Converter.

II. Proposed Topology

The schematic arrangement of the proposed single phase qZSI based isolated DC/AC converter is shown in Fig.1. It consists of qZSI, a multi winding high frequency transformer, rectifier and inverter. The Quasi Z-Source inverter provides the necessary boosting to the input voltage V to attain a DC link voltage of 125V by inserting proper shoot through across the full bridge inverter. High frequency transformer is used to boost the input voltage as well as to provide electrical isolation between source and load. In order to produce variable DC output V and 2V, two secondary windings with turns ratio of 1:2 is taken and cascaded with uncontrolled diode rectifier blocks to generate the required high voltage DC bus. Further it is connected with the seven level inverter with reduced number of switches to generate the required 230 Vrms output voltage for residential/distributed generation applications. The different modes of operation of the seven level inverter along with the Multi carrier Sinusoidal Pulse width modulation technique is presented in [8]. The proposed topology reduces the size of the overall system due to qZSI-boosting capability as well as its own step up operation of transformer and reduced switching devices.

III. Switching Scheme

Fig. 2 shows the proposed optimized PWM control with shifted shoot through in one leg for gating of qZSI H-Bridge topology. A Modulation technique is presented in [9] in which saw tooth waveforms are used for the generation of PWM signals and shoot through states. However, shoot through states are inserted through simultaneous conductions of both the inverter legs at an instant and the bottom switches operate at double the frequency with respect to upper switches which leads to increased switching losses. In this paper, shoot through state is inserted alternatively in one leg at an instant, thus reducing the switching losses. All the switches operate at the same switching frequency *fs*, equalizing switching losses in the qZS inverter leads to improvement in overall efficiency. The shoot through states are uniformly distributed on either side of the active state, and hence reducing the input ripple current. There are six switching states in a switching cycle. The shoot through states occurs twice in a switching cycle. The switching state sequence is given in Table I.

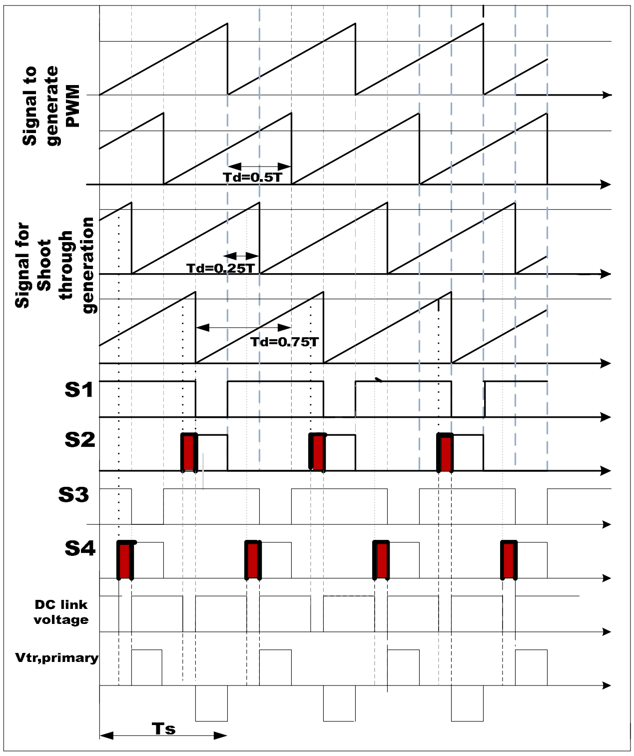

Fig. 2. Optimized PWM control with shifted shoot through in one leg.

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TABLE I. SWITCHING-STATE SEQUENCE PER PERIOD

	Top Switches		Bottom Switches	
	T1	T3	T2	T4
zero state	x	x	---	---
Shoot-through	x	x	---	x
active state	x	---	---	x
zero state	x	x	---	---
Shoot- through	x	x	x	---
active state	---	x	x	---

The Indirect DC link voltage control developed for qZSI is shown in Fig. 3. The reference DC link voltage is compared with the measured peak value obtained from (Vc1+Vc2) and fed to the PI controller. The output of the PI controller adjust the shoot through duty cycle, which required for corresponding changes in load or input voltages to produce the desired output voltage. The logic implemented for the gating of qZSI is shown.

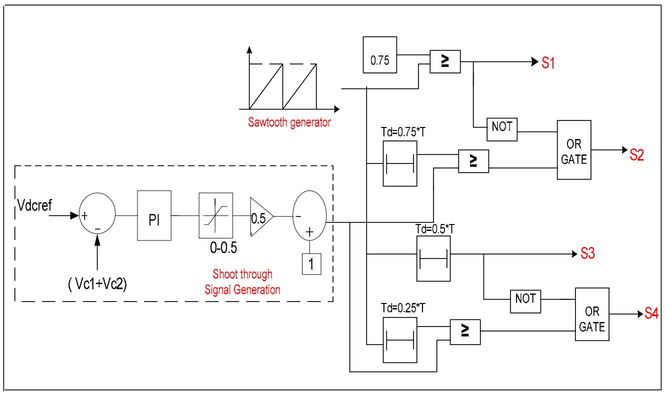

Fig. 3. Indirect DC link voltage control.

IV. SIMULATION RESULTS

The proposed model is simulated in Matlab/Simulink environment and the performance of the model is tested for two different cases of (i) change in loads with constant input voltage and (ii) change in input voltages with constant load. The parameters and the specifications considered for the simulation is given in Table II. In order to study the proposed system, the load is changed from R load of 106Ω to RL load of (59+j122)Ω at 0.5 sec. The measured pulsating DC link voltage waveform for one switching cycle period is shown in Fig. 4. To implement the PI controller the capacitor voltage Vc1 and Vc2 are added to get the peak DC link voltage and compared with the reference voltage as shown in Fig. 5. The measured peak DC link voltage is almost constant, the rectified DC voltage V of the high voltage DC bus can also be considered as the reference signal. The corresponding change in shoot through duty cycle during load changes is shown in Fig. 6. Fig. 7 shows response of the change in input voltage waveform from 120V to 90 V and corresponding regulated DC link voltage. Fig. 8 shows response of PI controller output to adjust the shoot through duty cycle for step change in input voltage. This shows effectiveness of the proposed control scheme using PI controller. For both the cases, the measured output load voltage and load current waveforms are same and shown in Fig. 9. It is observed that the output voltage is maintained constant during load changes as well as input well changes. The harmonic profile of output voltage and current is shown in Fig.10, the THD of current waveform is less than 5 % as per the IEEE-519 standards.

TABLE II. SPECIFICATIONS OF THE PARAMETERS

Parameters	Values
DC voltage (V)	50 V
Inductor L_1, L_2, r_L	1.3mH, 0.03Ω
Capacitor C_1, C_2, r_C	1000 μF,0.03Ω
Filter Capacitor	500μF
Switching Frequency	10 kHz
High Frequency Transformer	10 kHz

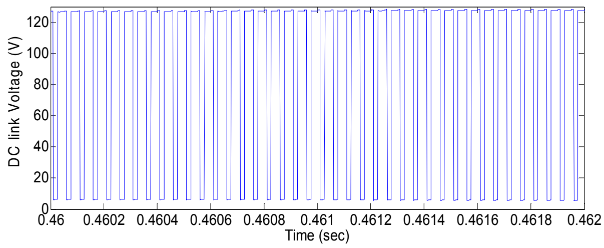

Fig.4. DC Link voltage for a switching cycle.

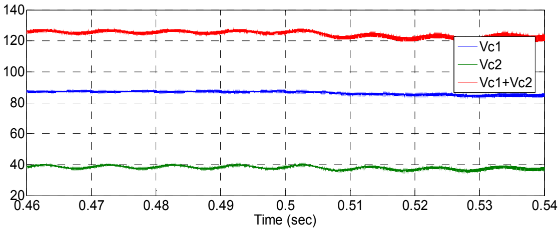

Fig.5. Capacitor voltages and Peak DC link voltage.

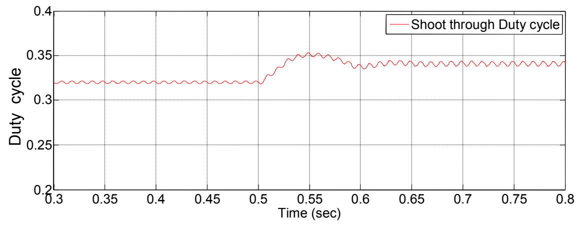

Fig.6. Shoot through duty cycle for load changes.

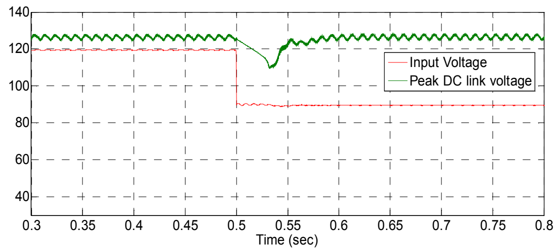

Fig. 7. Input voltage and Peak DC link voltage waveform.

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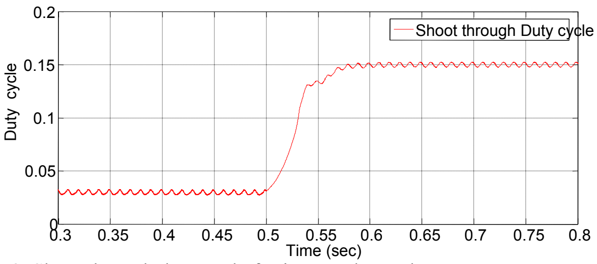
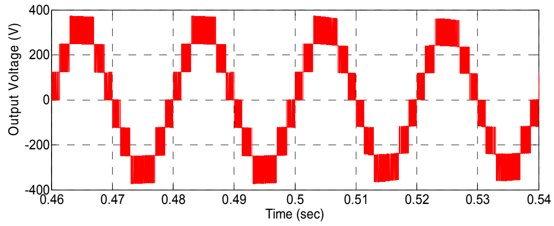
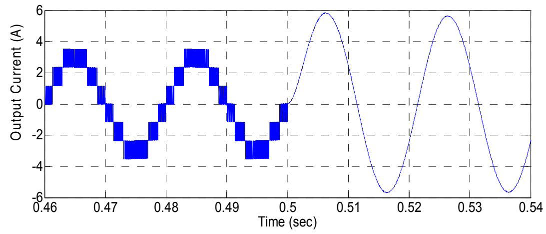


Fig. 8. Shoot through duty cycle for input voltage changes.

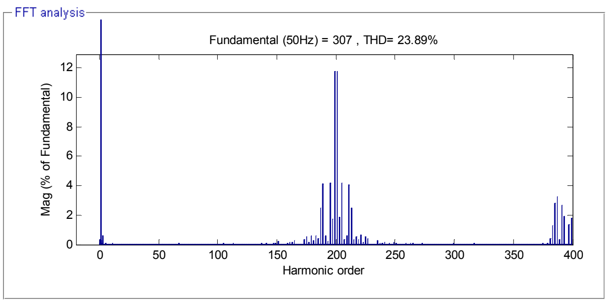


(a)



(b)

Fig. 9. Output load voltage and load current during load transition.



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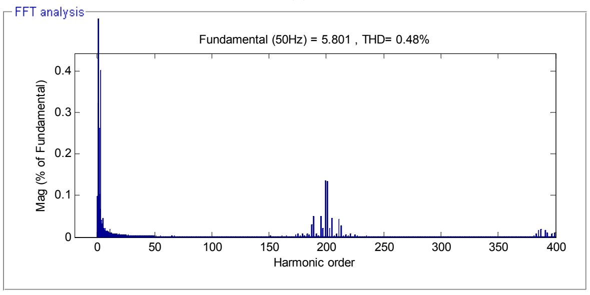

(b)

Fig.10. Harmonic Profile for output load voltage and current.

V. CONCLUSION

A new Quasi-Z source based isolated single phase seven level converter with reduced switches is developed for residential as well as distributed generation applications. Anew modulation technique is developed for qZSI to reduce the switching loss which further improves the efficiency of the system. The size is compact due to the use of high frequency transformer and inherent boosting capability of qZSI and this also enhances the reliability of the system. The proposed model is tested for change in loads and input voltages and their simulation results are presented.

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