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Highly efficient Z source inverter

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ABSTRACT

This project deals with the design, analysis, simulation, and development of Highly Efficient Boost Inverter using Z Source Network. The boost capabilities of the traditional Z-source networks are limited; the proposed converters are composed of combined traditional Z-Source networks in different ways to enhance the boost abilities of the traditional Z-source networks. The proposed converter are satisfied the traditional benefits of Z-source networks with stronger voltage boost abilities which can also be applied to dc-ac, ac-ac, and ac-dc power conversions. Analysis, MATLAB Simulation, and the Experimental result were illustrated in this paper.

Keywords: *DC-DC Converters; Z Source; Inverter; Voltage Boosting.*

1. INTRODUCTION

A system involving power converters are being often used in applications like alternative energy sources and hybrid electric vehicle (HEV). A major objective for power electronics designers is efficiency, low cost & reliability. In a PV power system, the output voltages of the PV panels are usually low and vary widely under the influences of climate and environment, therefore, a step-up stage is required.An Z-source inverter can perform buck-boost functions, as compared to the traditional voltage–source inverter. An additional shoot-through zero state is added to the switching states in order to boost the voltage. The design of the step-up dc-dc converters is very important to the PV power systems[2]. The unregulated low dc voltage of PV panels, which cannot be provided for inverters, must be boosted and regulated through the high-gain converters[1]. Then, the step-up converters output regulated high dc voltage to the grid-connected inverters. The application of Z-source networks in dc-dc power conversion is a fastest growing area for research. Therefore, this paper applies the Z-source networks to dc-dc converters with their boost abilities and proposes a family of hybrid Z-source boost dc-dc converters, which are obtained by combining the traditional Z-source/quasi-Z-source networks in different ways[1].The Z-Source inverter(ZSI) has been introduced in order to overcome the limitations of the traditional converter.The ZSI has the unique buck-boost capability which ideally gives an output voltage range from zero to infinity regardless of the input voltage. The additional functionality of ZSI over the traditional inverter can be stated not only in terms of boost for DC to AC power conversion but a short circuit across any phase leg is allowed & dead band is not required[11]. The second order filter is provided which is more efficient in suppressing output voltage ripples. The inrush current and harmonics can be reduced.

In this paper, operating principle of Z-source dc-dc Converter is explained, at present, the studies on Z-source networks mainly focus on the field of dc-ac power conversion, while the application of Z-source networks in dc-dc power conversion is essentially required. Therefore, this paper applies the Z-source networks to dc-dc converters with their boost abilities and proposes highly efficient Z-source boost dc-dc converters [10-13].

The proposed converter is very suited for PV power systems, where the dc-dc converter with the high step-up ability is required.
The remainder of this paper is structured as follows. The operating principles and parameters design are presented in Sections II. The design Parameter is Presented in III. Finally, the simulation results are given in Sections V and Experimental results are given in section VI to verify the features of the proposed Inverter.

2. OPERATING PRINCIPLES OF THE PROPOSED CONVERTER

The following Conditions are assumed for the operating principles.

- All the components are ideal.
- All Capacitor Voltages are treated as constant.
- The proposed converter operates in CCM.

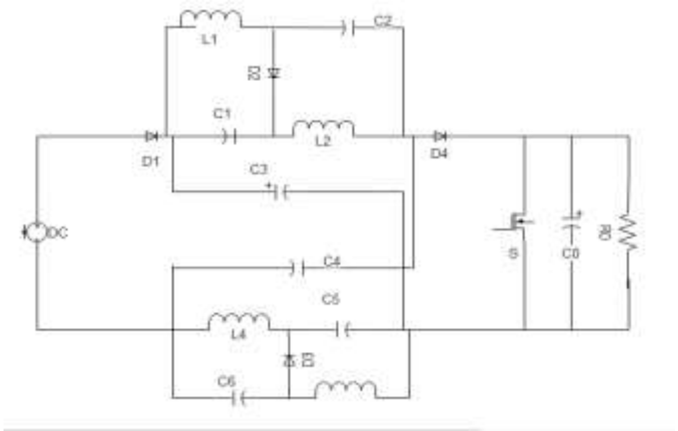

Fig.1 Proposed Boost Converter

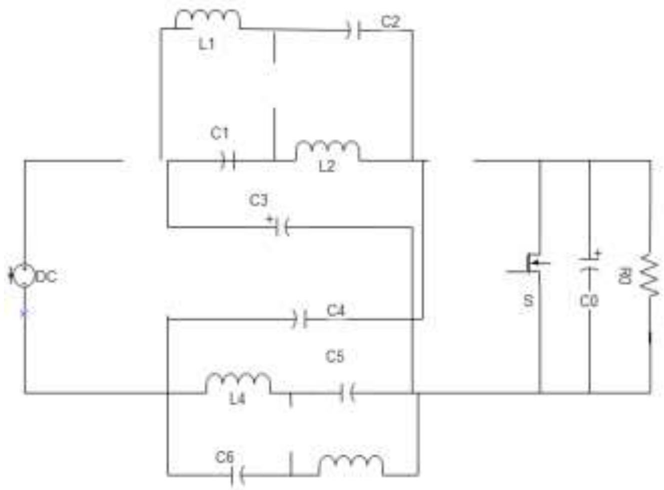

Fig.2 Proposed Converter during operating mode 1

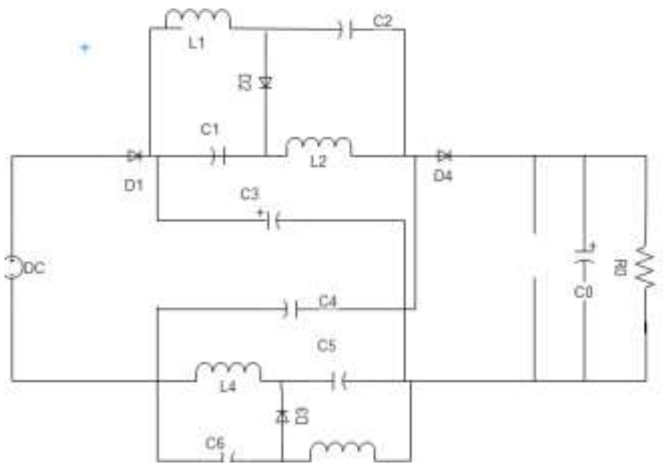

Fig.3 Proposed Converter during operating mode 2

The Proposed Converter has two Operating modes:

Mode 1*:* Fig. 2 shows the equivalent-circuit diagram for state 0. During this state, switch *S* is on, while diodes D_1, D_2, D_3, and D_4 are off. All the capacitors discharge the energy to all the inductors.

The following equations can be derived because of the symmetries of the Z-source network ($C_3 = C_4$) and quasi-Z-source network II ($L_1 = L_2 = L_3 = L_4$, $C_1 = C_2 = C_5 = C_6$).

$$v_{L1} = v_{L2} = v_{L3} = v_{L4}$$

$$V_{c1}=V_{c2}=V_{c5}=V_{c6}; V_{c3}=V_{c4}$$

$$V_{L1} = V_{c2}+V_{c3}$$

Mode 2: Fig. 3 shows the equivalent-circuit diagram for state 1. During this state, switch S is off, while diodes D1, D2, D3, and D4 are on. The voltage source Vin and inductors transfer the energy to the capacitors and the load R. The following relationships can be obtained.

$$V_{L1}=-V_{c1}$$

$$V_{in}=V_{C4}-V_{c1}-V_{c2}$$

$$V_{0}= V_{C3}+V_{c4}-V_{in}$$

$$V_{c1}= V_{C2}=V_{c5}= V_{c6}=D/ (1-4D)*Vin$$

$$V_{c3}= V_{C4}=1-2D/(1-4D)*Vin$$

$$V_{0}=1/ (1-4D)*Vin$$

$$\text{Voltage Gain, } M=V_0/V_{in}=1/(1-4D)$$

3. DESIGN OF COMPONENTS

Inductor Design

The Proposed Converter Operates in State 0, the Derivation of equation is

$$L = \frac{v_L dt_L}{di_L} = \frac{v_L DT}{x_L \% I_L} = \frac{v_L D}{x_L \% I_L f} \quad (1)$$

Where $dt_L = DT$ is the time interval of state 0, $di_L = x_L\%I_L$ is the current ripple of the inductor during state 0, $f = 1/T$ is the switching frequency.

$$L_1 = L_2 = L_3 = \frac{D(1-D)V_{in}}{(1-4D)x_L \% I_{in} f} \quad (2)$$

Capacitor Design

The Proposed Converter Operates in State 0, the Derivation of the equation is

$$C = \frac{i_C dt_C}{dv_C} = \frac{i_C DT}{x_C \% V_C} = \frac{i_C D}{x_C \% V_C f} \quad (3)$$

Where $dt_C = DT$ is the time interval of state 0, $dv_C = x_C\%V_C$ is the voltage ripple of the capacitor during state 0.

Substituting the expressions of i_C and V_C, the capacitances of *C*1, *C*2, *C*3, and *C*4 can be derived

$$C_1 = \frac{2D(1-3D)I_{in}}{(1-2D)x_C \% V_{in} f} \quad C_2 = \frac{(1-3D)I_{in}}{2x_C \% V_{in} f}$$

$$C_3 = C_4 = \frac{(1-3D)I_{in}}{x_C \% V_{in} f} \quad (4)$$

4. Z SOURCE INVERTER OPERATION

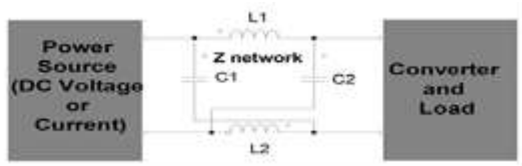

Fig 4.General Configuration of ZSC

The unique feature of the Z-source inverter is that the output ac voltage can be any value between zero and infinity regardless of the d.c. voltage. That is, the Z-source inverter is a buck-boost inverter that has a wide range of obtainable voltage. The traditional V- and I-source inverters cannot provide such feature. It employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, load, or another converter, for providing unique features that cannot be observed in the traditional V- and I-source converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the above mentioned conceptual and theoretical barriers and limitations of the traditional voltage source converter and current source converter and provides a novel power conversion concept. The Z-source inverter has three operation modes: normal mode, zero-state mode, and shoot-through mode. In normal mode and zero-state mode, the ZSI operates as a traditional Pulse-width modulation (PWM) inverter. The Z-source inverter advantageously utilizes the shoot-through states to boost the dc bus voltage by gating on both the upper and lower switches of a phase leg. Therefore, the Z-source inverter can buck and boost voltage to the desired output voltage which is greater than the available dc bus voltage. In addition, the reliability of the inverter is greatly improved because the shoot-through state can no longer destroy the circuit. Thus it provides a low-cost, reliable, and highly efficient single-stage structure for the buck and boosts power conversion. The detailed design analysis, utilization of the shoot through zero states to boost voltage, the effect of Z-network and output LC filter on inverter load voltage and current. The designed values of Z-source inverter is simulated in MATLAB / Simulink environment in order to verify simulation and analysis of single-phase Z-source inverter is presented.

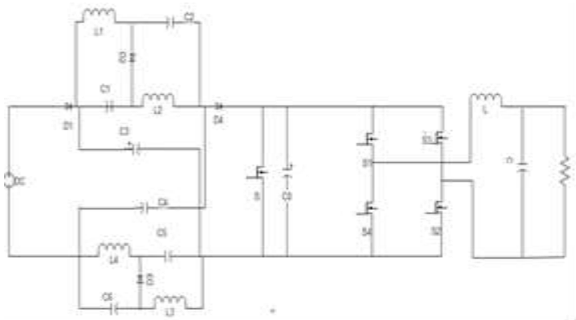

Fig 5. Proposed Inverter

5. SIMULATION RESULTS

To verify the features of the proposed converters, simulations based on the open-loop system are performed. In all the proposed converters, the simulation parameters are selected as presented in Table I.

Table 1 Simulation Parameters

Parameter	Values
Input Voltage	10v
Z-Source Capacitors	330µf
Z-Source Inductors	470 µf
Output Capacitor	470 µf
Output Resistor	530Ω
Switching Frequency	30kHz
Switch (MOSFET)	IRF540
Diode	UF5400

Simulation Results when V_{in}=10V are Shown in the figure, the duty cycle of 0.2 to achieve the output voltages are boosted to 51 V.

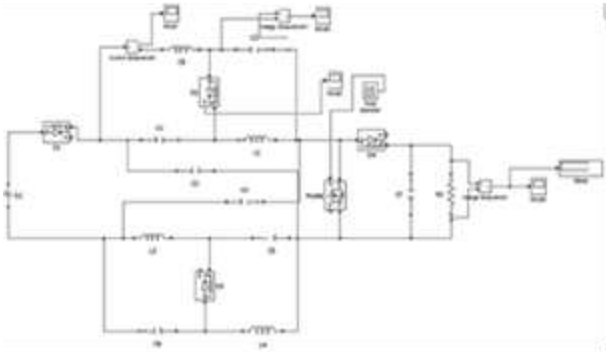

Fig.6 Simulation of Proposed Converter

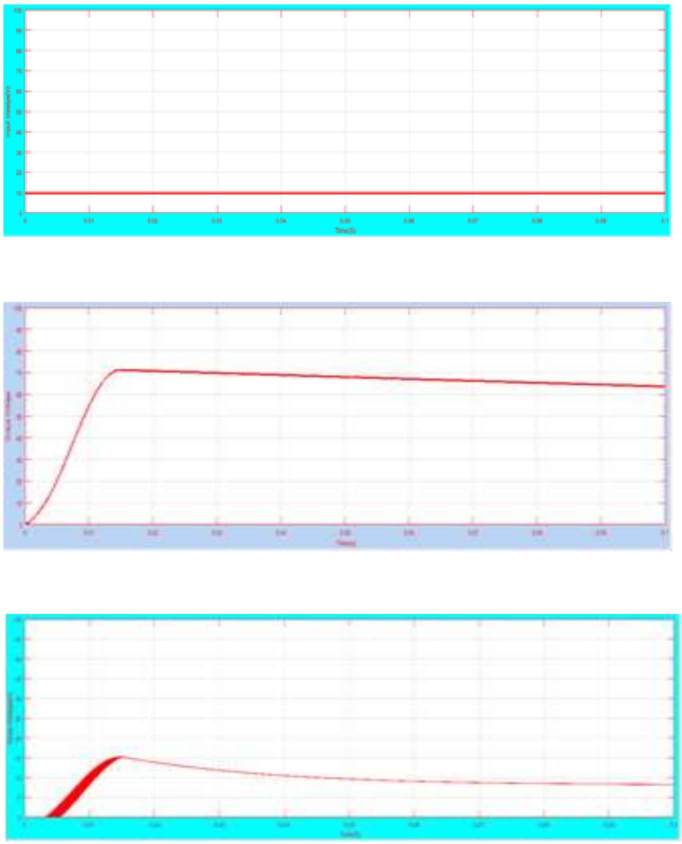

Fig.7 Simulation Results of Proposed Converter

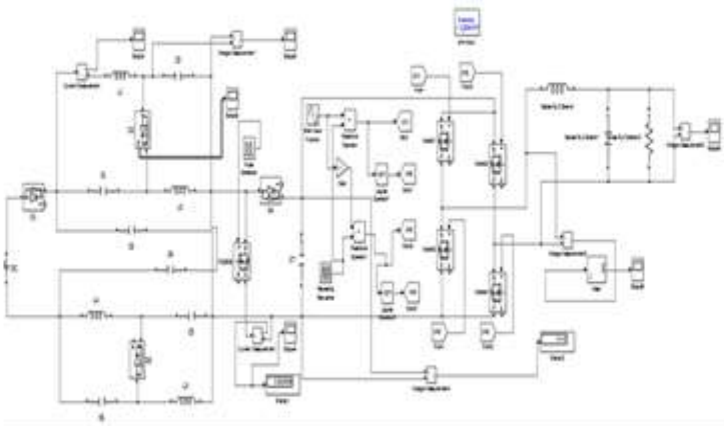

Fig.8 Simulation of Proposed Inverter

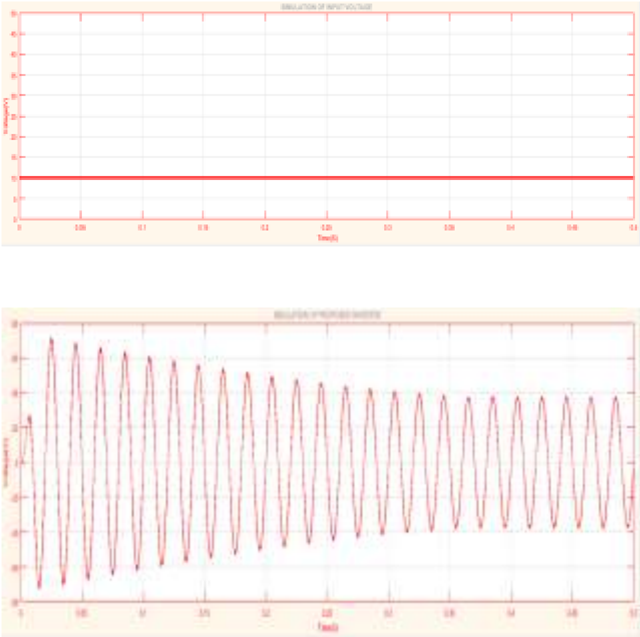

Fig.9 Simulation Results of Proposed Inverter

6. HARDWARE IMPLEMENTATION

Figure 10 shows the block diagram of the hardware. It consists of Z Source Converter and an inverter. The power supply for the control circuit and the driver circuit is 12V. For making this power supply, 230V from AC mains is step down to 12v with the help of 0-12V step-down transformer.DSPIC30F2010 is used for generating switching pulses. The pulses are amplified to the IRF2110 driver circuit for driving the switches. The output of the converter is given to the inverter and from the inverter to the load. The inverter consists of four switches which are driven by TLP 250 driver IC.The pulses are obtained from DSPIC30F2010

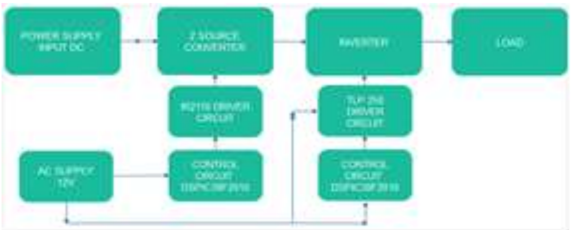

Fig.10 Block Diagram of Proposed Inverter

In order to verify the performance of the proposed converter and for validating the simulation works, the hardware of the proposed system has been set up. Hardware so implemented consists of different sections. They are control circuit, converter section, the driver circuit, inverter section and load. Control part comprises the dsPIC30F2010, Crystal oscillator and 7805 regulators for generating switching pulses . The driver circuit consists of TLP250 IC to drive the MOSFET switches. The converter section consists of one switch (MOSFET - IRFP250N), and diodes (UF5408), four inductors, seven capacitors. The inverter section consists of four switches (MOSFET – IRF840), one inductor and one capacitor as LC Filter. The load used here is 530-ohm rheostat and two 24V, 50 W bulbs.

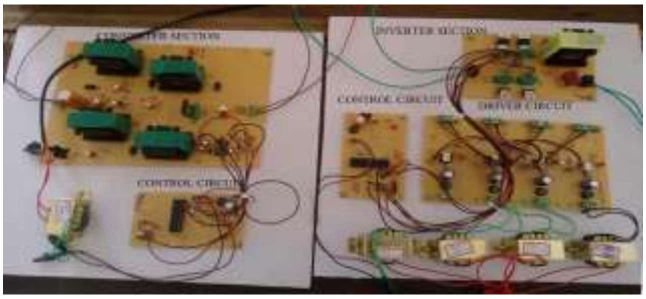

Fig. 11 Hardware Implementation of Proposed Inverter

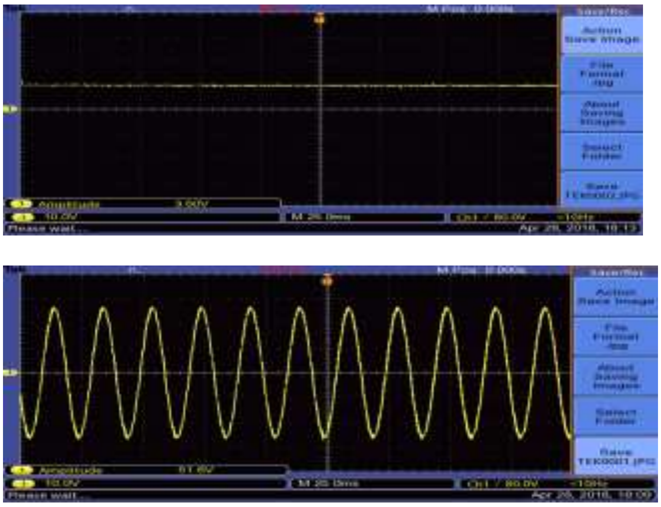

Fig. 12 Experimental results of Proposed Inverter

7. CONCLUSIONS

A Highly efficient Z-Source dc-dc Inverter was proposed here. ZSC can provide all type of power conversion like ac-ac, ac-dc, dc-ac and dc-dc. By duty ratio control, it can buck or boost the input voltage. It can reduce the cost and improve the reliability. Analysis, MATLAB Simulation, and the Experimental result were illustrated in this paper. All the experimental results are in good agreement with the theoretical analyses and simulation results.

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