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IMPLEMENTATION OF IMPEDANCE SOURCE INVERTER SYSTEM FOR PHOTOVOLTAIC APPLICATIONS

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Abstract- This paper presents a high performance, low cost inverter for photovoltaic systems based on Impedance-source concept. Traditional Voltage-source inverter and Current-source inverter has improved to the new Z-source inverter, with a unique X-shaped network in it. This Impedance-source inverter can provide a single stage power conversion concept where as the traditional inverter requires two stage power conversion for renewable energy applications. A new low cost solar cell powered Z-source inverter system is simulated and the results are compared with the traditional Voltage-source inverter system. Performance analysis, simulation and comparison have been confirmed that the Z-source inverter system is more appropriate for photovoltaic application than their counterparts. Hardware implementation is done to validate the proposed system.

Keywords*- Current-source inverter (CSI), Voltage-source inverter (VSI), Photovoltaic, Pulse width modulation (PWM). Z-source inverter (ZSI)*

I. INTRODUCTION

As people are much concerned with the fossil fuel exhaustion and the environmental problems caused by the conventional power generation, an application of renewable energy resources has higher attractive; more specially, photovoltaic cell. The solar cell technologies have been developed to improve the efficiency and the production cost of a photovoltaic cell has been reduced. Solar cells are used today in many applications such as battery charging, satellite power systems etc. They have the advantage of pollution free and less maintenance cost. But their installation cost is high and in most applications, they require a power conditioner (dc/dc or dc/ac converter) for load interface. Since photo voltaic modules still have relatively low conversion efficiency, the overall system cost can be reduced by using high efficiency power conditioners [1]. Power electronics inverters for renewable energy utilization applications would require both voltage buck and boost capabilities for riding through load current and supply voltage variation. A common way of implementing buck-boost inverter is to cascade a dc-dc converter to either a buck voltage source or boost current source inverter to form a two stage power conversion solution but this cascaded topology usually gives rise to increased system complexity and reduced reliability [2]. Conventional VSI and CSI support only current buck DC-AC power conversion and need a relatively complex modulator [3].

As an alternative, the single stage Z-source inverter is proposed in [4], where it is explicitly shown that the Z-source inverter gains its voltage tuning flexibility by introducing a unique LC impedance network between its input source and inverter circuitry. Besides flexible gain tuning the inserted impedance network is stated to have the advantage of protecting the inverter phases from short circuit damages even with no dead time delay inserted [5].In addition power loss is reduced due to low number of switching devices. The boost control strategy is quite similar to carrier based pulse width modulation control method [6]. The idea behind control is to turn null states into shoot-through states and active states are unaltered [7][8][9].

The Z-source inverter is attractive for three main reasons; first the traditional PWM inverter has only one control freedom, used to control the output AC voltage. However the Z-source inverter has two independent control freedoms; shoot through duty cycle and modulation index**,** providing the ability to produce any desired output AC voltage [10]. Second, the Z-source inverter provides the same features of a DC-DC boosted inverter, yet its single stage is less complex and more cost effective. Third, the z-source inverter has the benefit of enhanced reliability due to the fact that momentary shoot-through can no longer destroy the inverter [11].

It can be used as a single phase PV-PCU [12]. However the above literatures do not deal with the performance evaluation of ZSI fed induction motor drive system powered by solar cell. This paper also provides a detailed analysis and design of impedance source network. Finally the designed system is simulated using Matlab Simulink for verification purpose and hardware implementation is done to validate the results.

II. IMPEDANCE-SOURCE INVERTER

The Z-source inverter system is shown in Fig. 1. It employs a symmetrical LC impedance network to replace the dc -link capacitor in traditional VSI. Furthermore, with the help of series diode D embedded in the source side, the input dc source can be effectively disconnected from the Z-source network by naturally reverse-biasing the diode D during the unique shoot-through interval, which can be initiated by turning ON all switches of one phase-leg simultaneously. The 3-phase Z-source inverter bridge has nine permissible switching states unlike the traditional three phase Voltage source inverter that has eight states. The traditional three-phase V-source inverter has six active vectors when the load

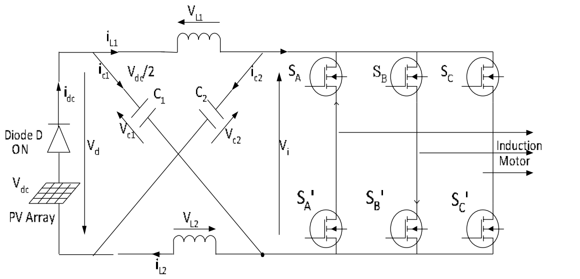


Fig. 1. Impedance –source inverter fed Induction Motor.

terminals are shorted through either the lower or upper three devices, respectively. However, the three-Phase Z- source inverter bridge has one extra state when the load terminals are shorted through both the upper and lower devices of any one phase leg (i.e., both devices are gated on), any two phase legs, or all three phase legs. This shoot-through zero state is forbidden in the traditional Voltage-source inverter. Such special operation provides the ability of voltage boosting as well as the unidirectional power conversion (desired in PV and fuel cell systems) [13], [14].

III. CIRCUIT ANALYSIS

Assuming that the inductors L1 and L2 and capacitors C1 and C2 have the same inductance (L) and capacitance(C) respectively, the Z-source network becomes symmetrical. From the symmetry and equivalent circuits we have

$$V_{L1} = V_{L2} = V_L; V_{C1} = V_{C2} = V_C \tag{1}$$

Shoot-Through (Sx = Sx' = ON, x = A, B or C; D = OFF)

$$v_L = V_C; v_i = 0; v_d = 2V_C; v_D = V_{dc} - 2V_C \tag{2}$$

$$i_L = -i_C; i_i = i_L - i_C; i_{dc} = 0 \tag{3}$$

Nonshoot-Through (Sx ≠ Sx', x = A, B or C; D = ON)

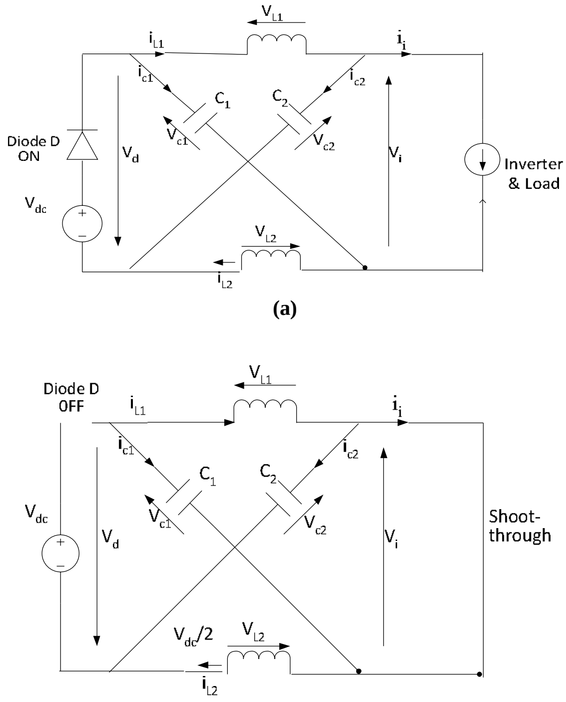
$$v_L = V_{dc} - V_C; v_i = 2V_C - V_{dc}; v_d = V_{dc}; v_D = 0; \tag{4}$$

$$i_{dc} = i_L + i_C; i_i = i_L - i_C; i_{dc} \neq 0 \tag{5}$$

Averaging the inductor voltage to be zero, the capacitor voltage Vc, peak DC-link voltage $v_{i1}$and peak ac output voltage v_{x1}(x=a, b or c) can be derived as:

$$\begin{cases} V_C = \dfrac{1 - T_0/T}{1 - 2T_0/T} V_{dc} \\ V_{xi} = \dfrac{V_{dc}}{1 - 2T_0/T} = BV_{dc} \\ v_{x1} = \dfrac{MV_{dc}}{2((1 - 2T_0/T)} = B\left(\dfrac{MV_{dc}}{2}\right) \end{cases} \tag{6}$$

Where M refers to the conventional modulation index, B represents the boost factor induced by shoot-through operation and $T_0/T< 0.5$ defines the shoot-through duty ratio.



(b)

Fig. 2 Equivalent circuits of Impedance-source inverter
(a)non shoot-through (b) shoot-through states

IV. IMPEDANCE SOURCE NETWORK DESIGN

During shoot-through mode, the purpose of the inductor is to limit the current ripple through the device and capacitor voltage is equal to inductor voltage. During active mode the inductor current decreases linearly and inductor voltage is equal to the difference between input voltage and capacitor voltage (but V_c=V_i).Hence inductor voltage is zero and only a pure dc current flows through the inductor. The average current through the inductor is

$$\overline{I_L} = \frac{P}{V_{dc}} \tag{7}$$

Where P is the total power and Vdc is the input voltage.

The Inductor value can be given as:

$$L = \frac{V * T_0}{\Delta I} \qquad (8)$$

Where ΔI=Inductor maximum current-Inductor minimum current

The purpose of capacitor is to keep the output voltage sinusoidal [15]. During shoot-through the capacitor charges the inductor and $I_L=I_C$.The voltage ripple across the capacitor can be calculated as

$$C = \frac{\overline{I_L} * T_0}{\Delta V_C} \qquad (9)$$

For capacitor design, it is assumed that the capacitor voltage ripple (ΔVc) is limited to about 3% at maximum power, ΔVc=V*3%

V. SIMULATION RESULTS

Solar cell powered Voltage--source inverter and Z-source inverter systems are modeled and simulated using MATLAB/SIMULINK package.

Voltage-source inverter system is shown in Fig. 5a. The inverter feeds a 3 phase motor load. Solar cell is modeled and the input voltage Vdc=220V is shown in Fig. 5b.Driving pulses are shown in Fig. 5c.The pulse width modulated line voltages are shown in Fig. 5d.They are displaced by 120 degrees. The line currents are shown in Fig. 5e. They are also displayed by 120 degrees. Fig. 5f. shows rotor speed. Fig. 5g shows the FFT analysis of VSI and the THD is 6.17%.

The circuit of Z-source inverter system is shown in Fig. 5h.The simulation is done up with the following parameters: L1=L2=5mH; C1=C2=2200μF; Vdc=110V. Impedance filter is introduced between the source and inverter. Solar cell is modeled and the input voltage Vdc=110V is shown in Fig.5i.Driving pulses are shown in Fig. 5j.Line voltages and line currents for M=0.7 andT0/T=0.4 are shown in Fig .5 k&l respectively. Fig. 5m. shows rotor speed and it settles down at 1450 rpm. Fig.5n& 0 shows the driving pulse and output voltage of single phase ZSI. FFT analysis of Z-source inverter is shown in Fig. 5p and the THD is 4.81%.

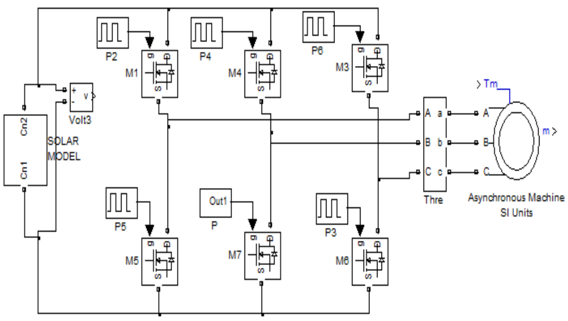


Fig. 5(a) Three phase Voltage source inverter circuit

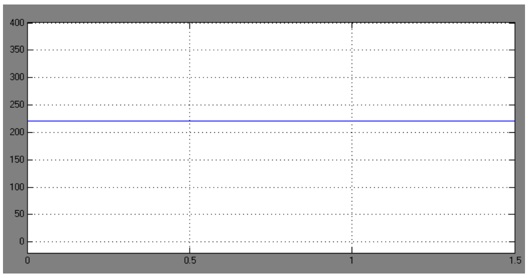


Fig. 5(b) Solar input voltage for VSI

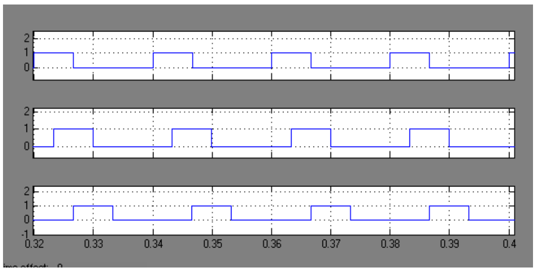


Fig. 5(c) Driving pulses for S1,S3&S6

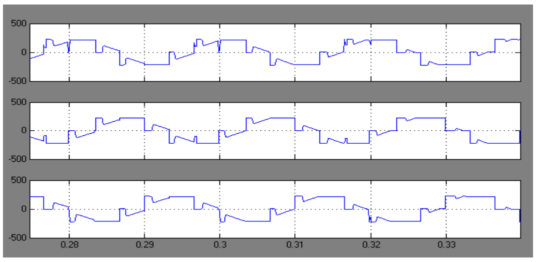


Fig. 5(d) Line Voltage for VSI

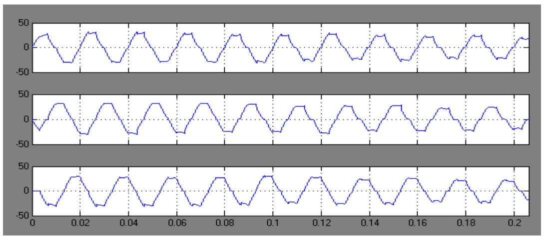


Fig. 5(e) Line current for VSI

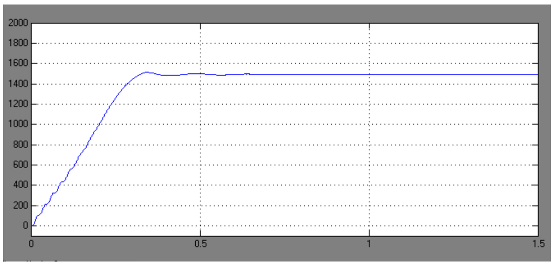


Fig. 5(f) Rotor speed for VSI

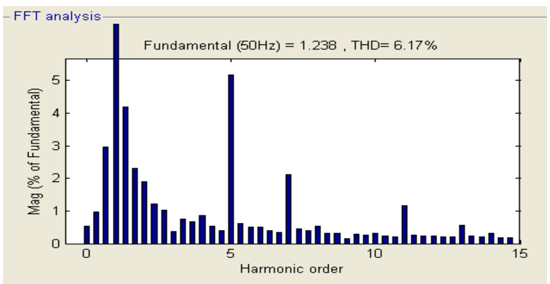


Fig. 5(g) FFT Analysis for current in VSI

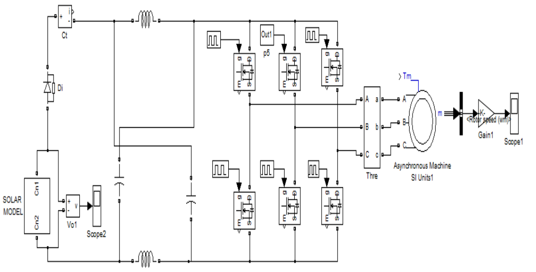


Fig. 5(h) Three phase Z-source inverter circuit

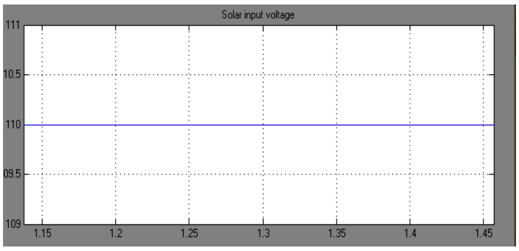


Fig. 5(i) Solar input voltage

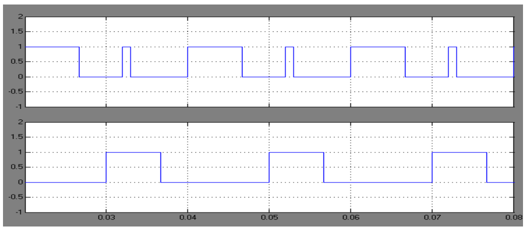


Fig. 5(j) Driving pulses M3 and M6

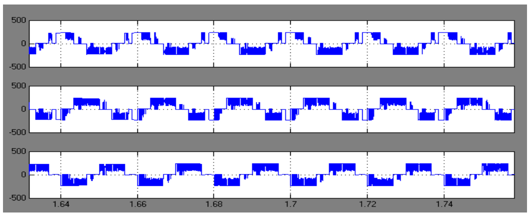


Fig. 5(k) Line voltage when M=0.7 and T_0/T=0.4

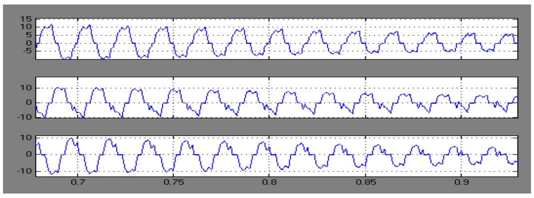


Fig. 5(l)Line current when M=0.7 and T_0/T=0.4

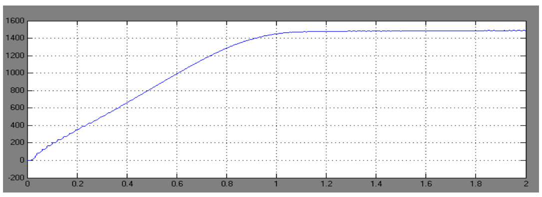


Fig. 5(m) Rotor speed in Rpm

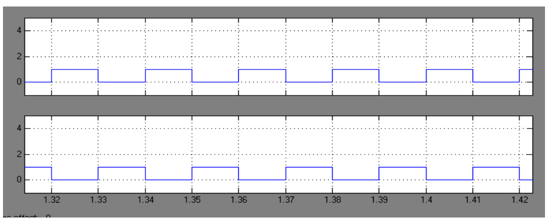


Fig. 5(n) Driving pulses for 1 phase ZSI

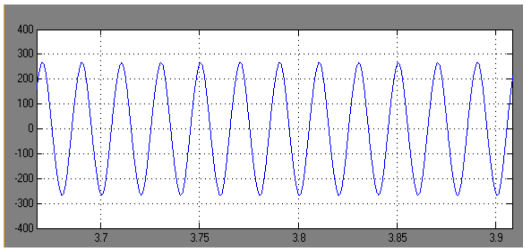


Fig. 5(o) Inverter output voltage for 1phase ZSI

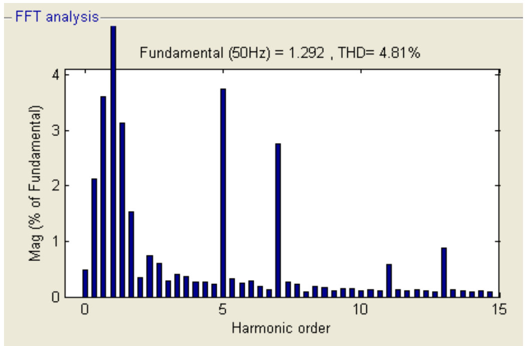


Fig. 5(p) FFT Analysis for current in 3 phase ZSI

VI. EXPERIMENTAL RESULTS

The experimental prototype for single phase Impedance-source inverter fed induction drive powered by solar cell was constructed and tested in laboratory with the hardware components as PIC-16F84A, IR 2110, IRF 840 and passive components selected as those used in simulations. Total hardware system is shown in Fig. 6a, Control module is shown in Fig. 6b.Solar input voltage is shown in Fig. 6c.Output voltage of the inverter is shown in Fig.6d From Figures 5 and 6, it can be seen that the experimental results closely agree with the simulation results.

Fig. 6a Hardware circuit

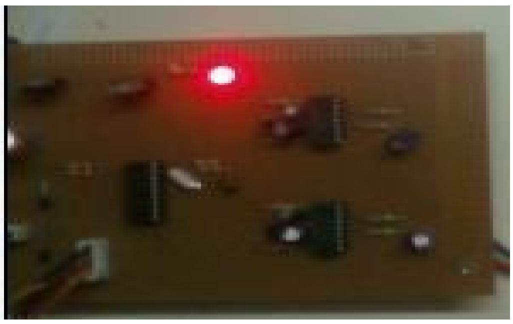


Fig. 6b Control circuit

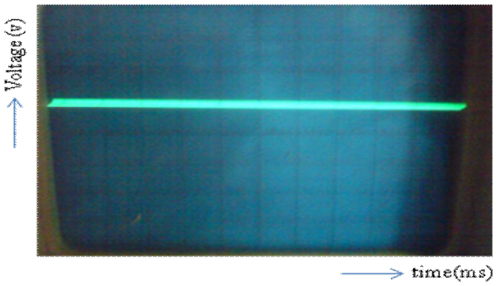


Fig. 6c Solar input voltage waveform

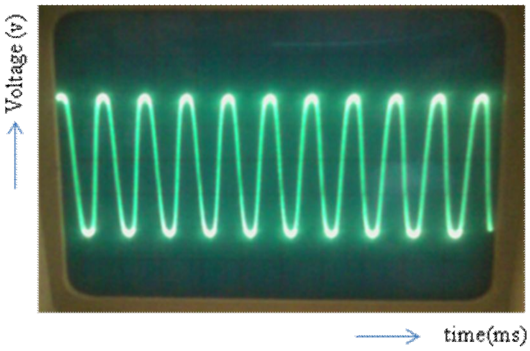


Fig. 6d Output voltage waveform
[In X-axis 1 div = 5ms, Y-axis 1 div = 230V]

VII. CONCLUSION

In this paper Impedance-source inverter fed induction motor drive system for photovoltaic application is analysed, designed, modeled, simulated and tested. Simulation of solar cell powered traditional Voltage source inverter is also performed for comparative evaluation. The result shows that the single stage Z-source inverter has both voltage buck boost capabilities due to its unique impedance network within it whereas the VSI can operate only in buck mode.Z-source network operates in shoot through state and does not need a dead time that leads to improved performance whereas shoot through is a major killer for inverters reliability in VSI. ZSI also has a wide range of input voltage that results in low power losses.FFT analysis is done and the spectrum is obtained. Hardware implementation of ZSI is done in the laboratory and the results are presented. Experiment results closely agree with the simulation results. It also confirms that the THD of Z-source inverter system is far less than its counterpart .Therefore Impedance source topology is the best promising power conversion concept for photo voltaic system in order to increase the overall system efficiency and thereby reducing system complexity and cost.

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