

Control of Single Phase Z-Source Inverter Fed Induction Motor Using Simple Boost Controller

M. Jayalakshmi, G. Asha and K. Keerthana

Abstract: In this paper development, modeling and simulation of control strategy for Z-source inverter is presented. The performance of single-phase induction motor with the control of single phase Z-source inverter using Simple boost controller is studied. This controller senses the motor speed feedback signal and consequently provides the pulse width modulated (PWM) signal that sets the gate voltage of the inverter, which in turn provides the required voltage for the desired speed. The proposed drive system is simulated using MATLAB/Simulink. The simulation results were compared with the experimental results.

Keywords: Pulse width modulation, Simple boost controller, Single phase induction motor, Z-source inverter.

I. INTRODUCTION

Induction motors have many advantages compared to DC motors and synchronous motors in many aspects, such as size, efficiency, cost, life span and maintainability. Low cost and ease of manufacturing have made the induction motors a good choice for electric and hybrid vehicles. The simple boost control PWM technique is used to simulate the single phase Z-source inverter for induction motor control. The speed control of such motors can be achieved by controlling the applied voltage on the motor by the use of power electronic devices. Z-Source inverter is used for power control of single phase induction motor as compared to the traditional voltage source inverter (VSI) and current source inverter (CSI) inverters. The control strategy of Z-source inverter is simulated in MATLAB environment and implemented using Simple Boost Controller. It is used to sense and control the motor speed. The simple boost pulse width modulated signal are applied to the control operation of ZSI.

Inverters are the dc to ac converters. The input dc supply is either in the form of voltage or current is converted in to variable output ac voltage. The output ac voltage can be controlled by varying input dc supply or by varying the gain of the inverter. There are two types of traditional inverters based on input source used in industries for variable speed drive and many other applications; those are

- a) Voltage-source inverter
- b) Current-source inverter.

In traditional voltage source inverter (VSI), the DC voltage source connected at the input side across a large capacitor. DC link voltage produced across this capacitor feeds the main bridge. The input dc supply can be a battery or fuel cell stack or diode rectifier, and/or capacitor. The bridge inverter circuit consists of four switches; each is composed of a power transistor and an anti-parallel diode to provide bidirectional current flow and reverse voltage blocking capability.

In traditional current-source inverter (CSI), the DC current source is formed by a large dc Inductor fed by a voltage source such as a battery or fuel-cell stack or diode rectifier or converter etc. Like VSI bridge inverter circuit consists of four switches; each is composed of a switching device with reverse block capability such as a gate-turn-off thyristor and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. For voltage source inverter and current source inverter the on/off time the switching devices is controlled by applying control voltage (PWM) to the control terminal i.e. gate of the device. Disadvantages of existing system are 1) They either a buck or a boost converter and cannot be a buck-boost converter. That is, the output voltage is either greater or smaller than the input voltage. The output voltage of voltage source inverter is always less than input voltage so it is called a buck inverter; hence additional voltage booster circuit needs to be added. While for current source inverter the output voltage is always greater than input voltage so it is called a boost inverter, hence additional voltage regulator circuit needs to be added. 2) For VSI and CSI main bridge inverter circuits cannot be interchangeable. In other words the voltage-source inverter main circuit cannot be used for the current-source inverter or vice versa. 3) The shoot-through problem for Voltage source inverter and open circuit problem for current source inverter by electromagnetic interference (EMI) noises reduce the inverter's reliability. In case of voltage source inverter both upper and lower transistors should not be switched on simultaneously, otherwise it would cause shoot-through, which may damage inverter circuit due to large current. Hence dead time to block both upper and lower devices needs to be provided in the V-source inverter, which causes waveform distortion. 4) In case of current source inverter both upper and lower transistors should not be switched off simultaneously, otherwise it would cause open circuit along the bridge arm, which may damage inverter circuit due large voltage drop across open circuit. Hence overlap time where both upper and lower devices conduct simultaneously needs to be provided for safe operation, which causes waveform distortion.

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The Z-source inverter is a buck–boost inverter that has a wide range of obtainable voltage. The traditional VSI and CSI cannot provide such obtainable voltage. In the Z-source inverter, the bridge has seven permissible switching states (vectors) unlike the traditional inverter bridge that has six switching states. 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) or two phase legs shoot through zero state occurs. This shoot-through zero state (or vector) is forbidden in the traditional V-source inverter, because it would cause a shoot-through. The Z-source network makes the shoot-through zero state possible. This shoot-through zero state provides the unique buck-boost feature to the inverter. The inverter bridge is equivalent to a short circuit when the inverter bridge is in the shoot-through zero state, whereas the inverter bridge becomes an equivalent current source, when in one of the four active states. This shoot through states are provided by simple boost controlled PWM technique.

II. BLOCK DIAGRAM OF THE SYSTEM

The block diagram of single phase Z induction motor is shown in figure.1 inverter, Driver Z-source inverter is utilized to realize inversion and boost function. It contain a unique impedance network of inductors and capacitors, the Z shoot through states by gating on both the upper and lower switches in the same legs, to boost the dc voltage without DC/DC converter fig1:shows that the symmetrical lattice network most commonly used in filter and attenuator circuit. The lattice network contains L1 and L2 which are series arm inductances, C1 and C2 which are diagonal arm capacitances connected between the rectifier legs. Each leg consists of two switches and their anti parallel diodes. The each leg are switched in such a way that when one of them is in off state, the other is in on state. The output current will flow continuously through load and the output voltage is solely dictated by the status of the switches. The Simple boost controller vary the PWM signal of the control.

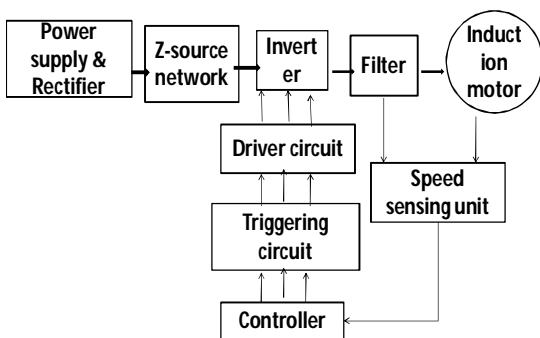


Fig. 1 Block diagram of the system

A. Operation and Analysis of Z-Source Inverter

The Z-source inverter consists of a unique impedance network which couple the converter main circuit to the power

source, load, or other converter. The impedance network consists of two inductors and two capacitors connected to each other as shown in the fig.2 forms the second order filter network. The values of both inductor and both capacitor are equal. The two inductors can be two separate inductors or two inductors inductively coupled to each other on a single core. For size and cost reduction film capacitors of desired value and voltage rating can be selected.

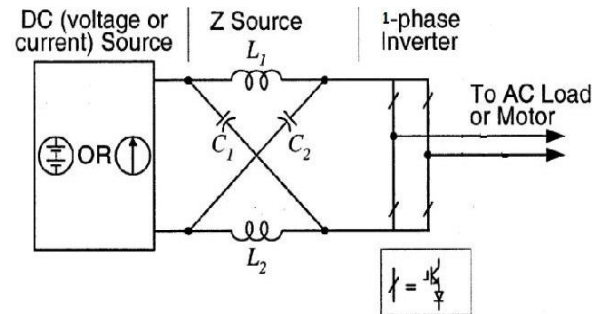


Fig. 2 circuit diagram of ZSI

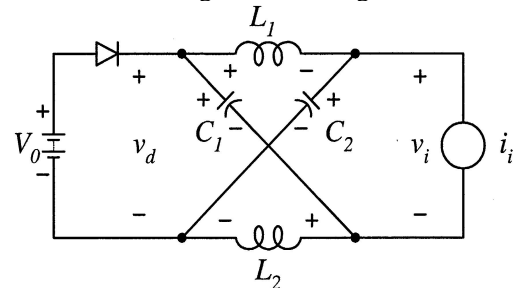


Fig. 3 Equivalent circuit of ZSI

We have three operating states in Z source inverter. They are active state, zero state, shoot through zero state

The switching states of these operating states are explained in table :1

B. Active state

In this mode, the inverter bridge is operating in one of the four traditional active vectors; the equivalent circuit is as shown in figure 4. The inverter bridge acts as a current source viewed from the DC link. Both the inductors have an identical current value because of the circuit symmetry. This unique feature widens the line current conducting intervals, thus reducing harmonic current.

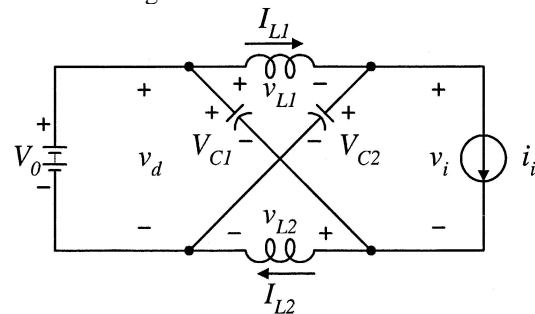


Fig. 4 Active state

C. Zero State

The inverter bridge is operating in one of the two traditional zero vectors and shorting through either the upper

or lower three device, thus acting as an open circuit viewed from the Z-source circuit. Again, under this mode, the inductor carry current, which contributes to the line current's harmonic reduction as shown in below fig 5.

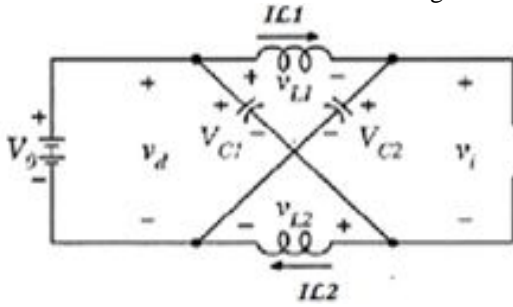


Fig. 5 Zero state

D. Shoot through state

The inverter bridge is operating in one of the seven shoot-through states. The equivalent circuit of the inverter bridge in this mode is as shown in the below fig: 6. In this mode, separating the dc link from the ac line. This shoot-through mode to be used in every switching cycle during the traditional zero vector period generated by the PWM control. Depending on how much a voltage boost is needed, the shoot-through interval (T0) or its duty cycle (T0/T) is determined. It can be seen that the shoot-through interval is only a fraction of the switching cycle.

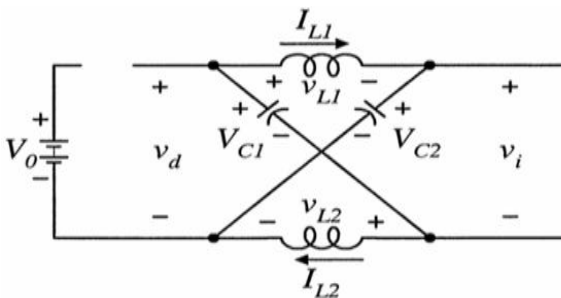


Fig.6 Shoot through state

SWITCHING STATES	S1	S2	S3	S4	OUTPUT VOLTAGE
Active states	1	0	0	1	Finite voltage
	0	1	1	0	
Zero states	1	0	1	0	Zero
	0	1	0	1	
Shoot through state	1	1	S3	S4	Zero
	S1	S2	1	1	
	1	1	1	1	

Table 1: Switching states of ZSI

III. ANALYSIS OF Z-SOURCE INVERTER

The dc voltage source Vdc that is applied to the Z Source inverter through reverse blocking diode D. All traditional PWM techniques are applicable for Z-Source inverter. During the reverse flow of current. The detailed analysis of Z-source inverter is given below. The average dc-link voltage across the inverter is given by:

$$V_{dcl} = V_c = ((1-T_0/T) / (1-2T_0/T)) V_{dc} \tag{1}$$

Where,

V_{dcl} is the average dc link voltage equal to capacitor voltage V_c, T is a switching period and T₀ is shoot-through time over a switching period.

The peak dc-link voltage across the inverter is expressed as

$$V_{dclp} = (T / (T_1 - T_2)) V_{dc} = B V_{dc} \tag{2}$$

Where,

$$B = T / (T_1 - T_0) = 1 / (1 - 2T_0/T) \geq 1 \tag{3}$$

is the boost factor resulting from the shoot-through zero state.

The output peak phase voltage from the inverter can be expressed as;

$$V_{acp} = M V_{ip} / 2 \tag{4}$$

Where,

M is the modulation index of PWM waveform,

V_{acp} is output peak phase voltage zinverter.

Using (2) and (4) peak phase voltage can be expressed as

$$V_{acp} = M B V_{dc} / 2 \tag{5}$$

For the traditional V-source PWM inverter, the output peak phase voltage is given by

$$V_{acp} = M V_{dc} / 2.$$

Where,

Modulation index M is always less than unity hence in traditional inverter the output voltage is always less than input dc voltage. Equation (5) shows that in Z-Source inverter the output voltage can be stepped up and down by choosing an appropriate buck-boost factor B.

The buck-boost factor is determined by the modulation index M and boost factor B. For Z-source inverter the boost factor is shoot-through time (T₀) the DC link voltage V_{dcl} is boosted to a value greater than input voltage, hence input diode will be reverse biased blocking always greater than or equal to unity. When boost factor is equal to unity the Z source inverter acts like traditional inverter. The boost factor B as expressed in (3) can be controlled by varying shoot through duty cycle T₀/T of the inverter PWM input.

IV. SIMULATION OF SINGLE PHASE Z-SOURCE INVERTER FED INDUCTION MOTOR WITH BOOST CONTROLLER

The single phase Z-source inverter Matlab / Simulink model for speed control of induction motor is shown in figure 6, it has two inductors L1=L2, capacitors C1=C2. Simple boost control technique is used for PWM signal. The

simulation parameters are: 1) Z-source network: $L1 = L2 = 1\text{mH}$, $C1 = C2 = 1000\ \mu\text{F}$; 2) Output filters: $L_f = 1000\text{mH}$, $C_f = 5\text{-}50\ \mu\text{F}$; 3) switching frequency: $10\ \text{kHz}$. Figure 6 shows the AC 165 vrms input is rectified using a diode rectifier. The rectified DC pulsating signal is applied to the Z-source inverter then the output of the inverter is fed to the auxiliary winding and the motor's main winding is directly connected to the 165 V utility supplies. The reference value of the magnitude and phase of voltage applied to the auxiliary winding are computed by the reference voltage block. By varying the auxiliary winding voltage magnitude and phase, the torque ripples are alleviated at all operating points.

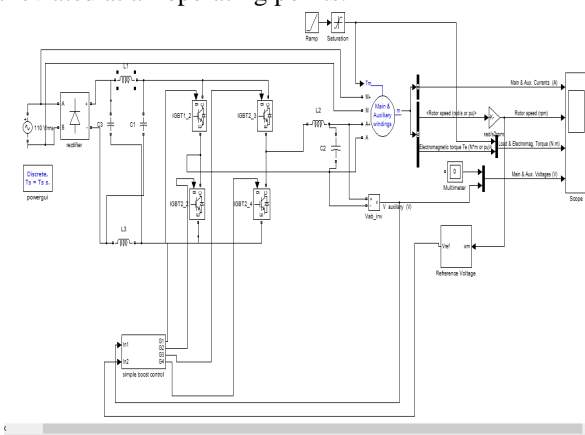


Fig.7 Simulation diagram of ZSI fed induction motor

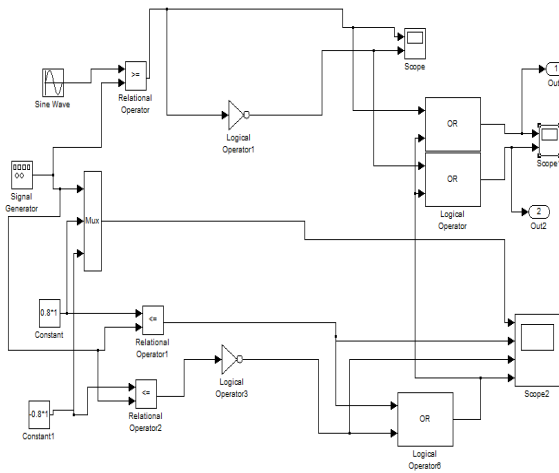


Fig.8 Simulation diagram of shoot through state

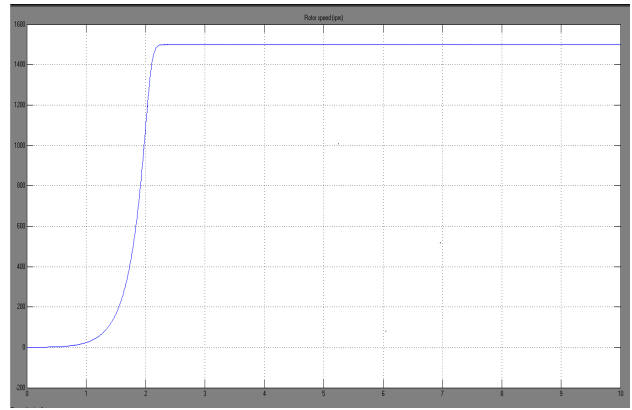


Fig.9 Rotor Speed

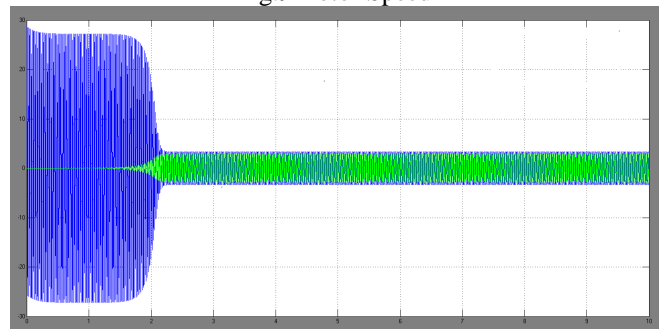


Fig.10 Main & auxiliary winding current

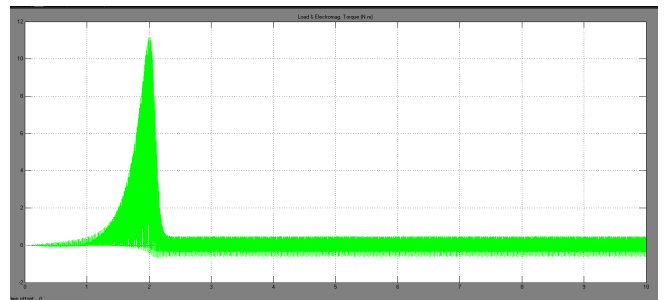


Fig.11: Load & Electromagnetic torque

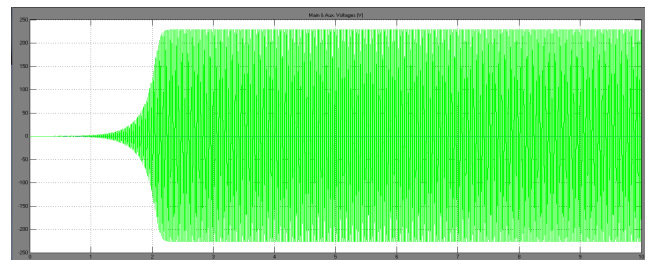


Fig.12 Main & Auxillary voltage

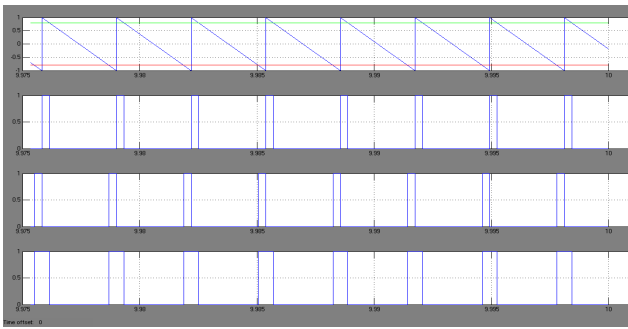


Fig.13 Shoot through state

V. CONCLUSION

The theoretical analysis and design of Z-source inverter is studied. The Z-source inverter employs a unique impedance network to couple the inverter main circuit to the power source and thus providing unique feature. The control methods with the insertion of shoot-through states of Z-source inverter have been studied. The proposed scheme under simple boost control is simulated with the help of MATLAB/SIMULINK and the simulation results are obtained for different values of modulation indices. The simulation results shows that both buck and boost operations can be obtained in Z-source inverter by varying Modulation index (M) or Boost factor (B) and hence we can control the speed of the motor.

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