PERFORMANCE ANALYSIS OF THREE PHASE Z-SOURCE INVERTER FOR INDUCTION MOTOR DRIVE

A DISSERTATION

Submitted in partial fulfilment of the requirements for the award of the degree of

INTEGRATED DUAL DEGREE

in

ELECTRICAL ENGINEERING

(with specialization in Power Electronics)

By

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MAY, 2016

CANDIDATE'S DECLARATION

I hereby declare that the work carried out in this dissertation entitled **"PERFORMANCE ANALYSIS OF THREE PHASE Z SOURCE INVERTER FOR INDCUTION MOTOR DRIVE"** submitted in partial fulfillment of the requirements for the award of the degree of Integrated Dual Degree (IDD) in Electrical Engineering with specialization in Power Electronics, submitted to the Department of Electrical Engineering, Indian Institute of Technology Roorkee, is an authentic record of my own work carried out under the guidance and supervision of Dr. Sumit Ghatak Choudhari, Assistant Professor, Department of Electrical Engineering, Indian Institute of Technology Roorkee and all the works embodied in this thesis has not been submitted elsewhere for the award of any other degree.

Date: May 2016

Place: **Roorkee** **(MARKARI NAVATEJA)**

CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge and belief.

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ACKNOWLEDGEMENT

This report is the result of the project “Performance Analysis of Three Phase Z Source Inverter For Induction Motor Drive” for the partial fulfillment of Integrated Dual Degree in Electrical Engineering. I wish to affirm my deep sense of gratitude to my guide Mrs. Sumit Ghatak Choudhari, Department of Electrical Engineering, IIT Roorkee, for intuitive and meticulous guidance in completion of this seminar report. I want to express my profound gratitude for his genial and kindly co-operation in scrupulously scrutinizing the manuscript and his valuable suggestions throughout the work. His knowledge is very useful for me to do the project appropriately.

I convey my gratitude to Dr. S.P.Srivastava, Head of Department, Department of Electrical Engineering, IIT Roorkee, for providing me this opportunity to undertake this project. I also acknowledge the blessings my parents for encouragement and moral support rendered to me throughout my life.

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ABSTRACT

This report is a study on Z Source Inverter. Traditional Voltage-source inverter is limited by its only voltage step down operation. In order to add an extra boosting flexibility while keeping the number of active semiconductors unchanged, a new family of voltage-type inverters namely Z-source inverter (ZSI) came into picture. The Z-source inverter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source inverter and current-source inverter and provides a novel power conversion concept. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The operating principle of the converter and the various control strategies are discussed.

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LIST OF FIGURES AND TABLES

CHAPTER 1

INTRODUCTION

1.1 Research Motivation

In Power Electronics different inverter topologies have been used in the past, focusing on the source voltage levels and characteristics. Each of these inverter topologies have their own limits and advantages as far as some issues like, number of components used, boosting capabilities, efficiency, cost, stress on semiconductor switches etc., are concerned. Unlike before, now a days efficient power conversions have found their place in the industry because of the alternative energy sources like solar energy, wind energy, fuel cells and ocean wave energy in which the adaptation of different loads require proper power conditioning. Most of them are variable voltage sources. Therefore the necessity of designing inverters which can operate with these kind of variable voltage sources has been increased. The traditional voltage source inverters have one major disadvantage i.e. they cannot boost the voltage of input source. So we need a cascaded arrangement of dc-to-dc boost converter and traditional voltage source inverter to boost the voltage of variable-voltage input source.

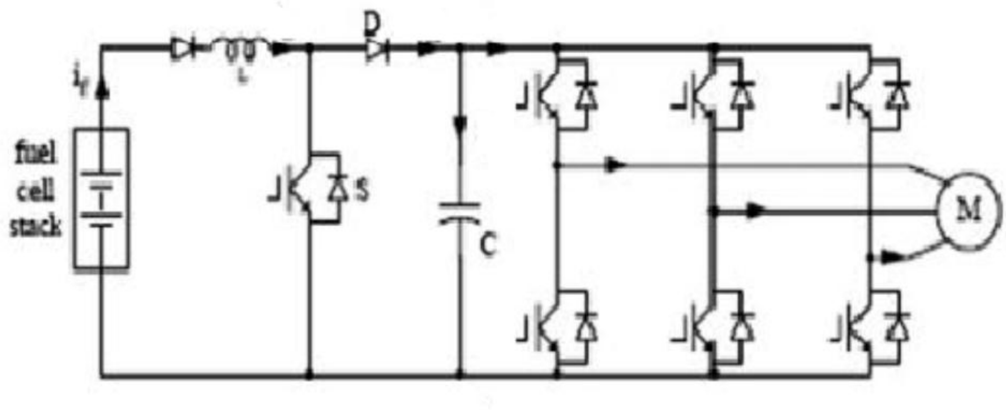

Figure 1.1: dc-to-dc boost converter cascaded with VSI

But this kind of two stage conversion not only increases the complexity but also the cost. Hence we need a single converter which can boost the voltage and also the dc-to-ac conversion. Hence the Z source inverter came into picture.

1.2 Objective of Thesis

1. The very objective of this thesis is to study a Z source inverter and to highlight the importance of it over traditional Voltage source inverters.
2. To study the dc link voltage boost of the Z source inverter.
3. To understand different control strategies.
4. MATLAB/SIMULINK simulation results and tabulation of data

1.3 Outline of report

This thesis has a total of 5 chapters each covering a particular aspect of Z source inverter.

Chapter 1 discusses the necessity of Z Source inverter, objective of thesis and the chapter wise organization of the thesis.

Chapter 2 discusses the disadvantages of Voltage Source Inverter and Current Source Inverter and how ZSI can overcome them. It explains the modes of operation and the network design of Z-Source Inverter.

Chapter 3 discusses the various methods of implementing control strategies for ZSI and how the zero states are modified to include shoot through states.

Chapter 4 presents the MATLAB simulation results for Z Source Inverter with different loads as RL load and an induction motor.

Chapter 5 presents the conclusion of the thesis and some recommended future wok.

CHAPTER 2

Z SOURCE INVERTER

First before we dig deep into the Z Source inverters, let us discuss a bit about traditional Voltage Source Inverter (VSI) and Current Source Inverter (CSI) and their theoretical barriers and limitations.

In a Voltage Source Inverter (VSI) it is necessary to keep the input voltage constant regardless of the load current. In a voltage source inverter (VSI), the load voltage is controlled by the inverter but the current drawn by the load is dependent on the load itself. In the same way, in a CSI the control of the output Current waveform is done independently.

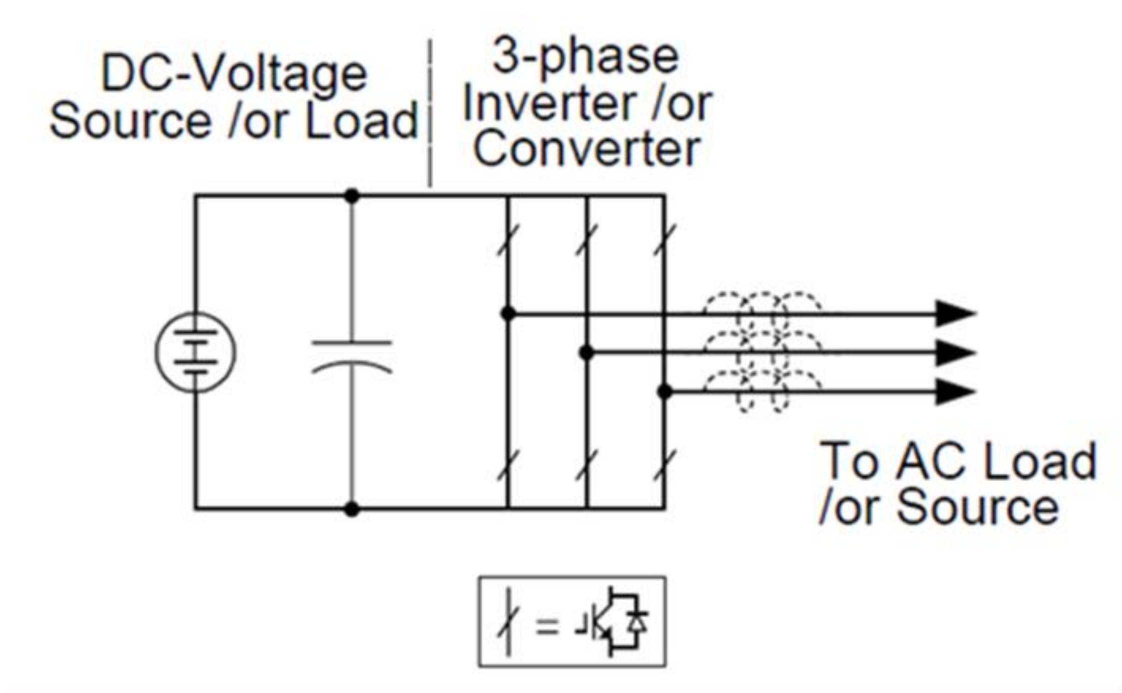

Figure 2.1: traditional VSI

Figure-2.1 shows a traditional 3-phase VSI structure. A large capacitor supports the dc voltage source which feeds the main converter circuit which is nothing but a three phase bridge. The dc voltage source used here can be any of the stated: a battery, fuel-cell stack, diode rectifier, or a capacitor. In this bridge we use 6 IGBTs (basically switches) with an anti-parallel diode. By this kind of arrangement the main circuit can supply bidirectional flow of current and capable of unidirectional voltage blocking. The VSI has the following limitations:

- For those applications where sufficient dc voltage is not available to get the desired ac output, an additional dc-to-dc boost converter is required. However, use of these additional converter stages lower down the efficiency and increase the cost.
- For each phase leg the upper devices cannot be gated on with the lower phase ones in order to avoid shoot through, which could destroy the devices. The shoot through problem by electromagnetic interference (EMI) noise's miss-gating-on creates hindrances in long term reliability of the converter.
- An output LC filter is needed in order to get a sinusoidal voltage compared with the CSI, which leads to extra power loss.

Figure-2.2 shows a traditional 3-phase CSI structure. Even here we use 6 switches .IGBTs with diodes in series are generally used. Other devices such as a gate-turn-off thyristor (GTO) or Silicon-Controlled Rectifier (SCR) or a power transistor with a diode in series can also be used as switch in order to give unidirectional current flow and bidirectional voltage blocking capability.

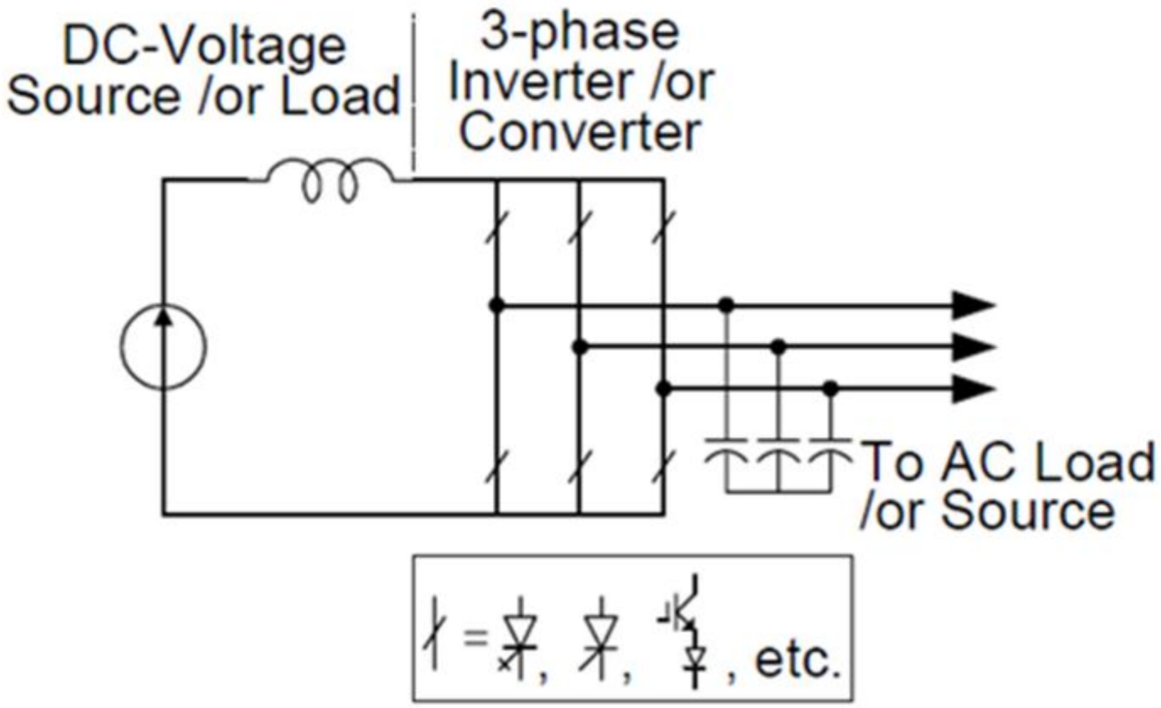

Figure 2.2: traditional CSI

But the following limitations cannot be ignored in the CSI:

- The output ac voltage should exceed the original dc voltage which is used to feed the dc inductor. Therefore, the CSC is a buck rectifier (or buck converter) for ac-to-dc power conversion and boost inverter for dc-to-ac power conversion.
- Wide range of voltage is needed. This additional stage for power conversion decreases the efficiency and increases the system cost.
- At minimum, one of the lower devices and one of the upper devices must be turned on and maintained on at any time, so that an open circuit of the dc inductor can be avoided to save the devices. The open-circuit problem by EMI noise miss-gating-off is a main concern in terms of reliability of the converter.

There are a few common problems which both VSI and CSI share:

1. Both of them lack the buck-boost features and are limited to either a buck converter or boost converter. That is the output voltage to be obtained is bounded to either greater or smaller as compared to the input value.
2. The VSC and CSC main circuits are not interchangeable i.e. one cannot be used in place of other.
3. Both of them are prone to EMI noise in terms of reliability.

To surmount the above mentioned restriction of conventional inverter, an improved version named Z-source converter (ZSC) is proposed.

2.1 Introduction

Considering the limitations of the above mentioned VSI and CSI a new kind of inverter has been proposed. As VSI and CSI are voltage source and current source inverters, this new one is an impedance source inverter and hence the name Z-Source Inverter. The Z-Source Inverter has a unique impedance circuit between the DC input source and the inverter bridge and with the help of this extra impedance network it will overcome the problems of traditional inverters.

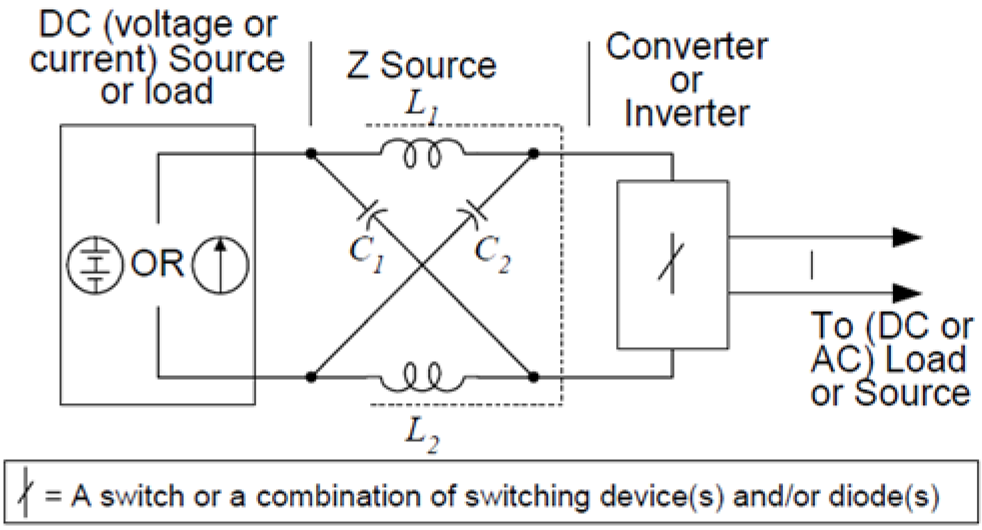

Figure 2.3 General structure for Z source Inverter

If we start to describe about the impedance network, it is nothing but a two-port network which consists of inductors L1 and L2 and capacitors C1 and C2 which are connected in the shape of an X. The only difference between a traditional VSI and ZSI is this one extra two port network.

But with the help of this two port network it gains the most unique feature of producing output ac voltage of any value between zero and infinity (theoretically). It can produce such a wide range of the output ac voltage regardless of the input dc voltage. VSI serves as an exclusive buck converter and CSI serves as an exclusive boost converter but the Z-source inverter serves as a buck-boost inverter.

Unlike the traditional 3-phase VSI bridge which has 8 permissible switching states the three phase ZSI has 9.These permissible states of a traditional VSI can be grouped into two.

- Active
- Zero

When an active vector is executed a dc voltage appears across the load and when a zero vector is executed the load terminals are shorted. So a total of 6 active vectors and 2 zero vectors constitute the total 8 permissible switching states of the traditional VSI.

Apart from the two groups active and zero the Z-source inverter has another group by which it gains the unique ability of producing an output ac voltage of any desired value between zero and infinity and that state or group is called shoot-through.

- Active
- Zero
- Shoot-through

The ZSI can produce this shoot-through in 7 different ways. These additional 7 shoot through states are used to boost the input DC voltage. . The 3-phase Z-source inverter bridge produces shoot-through by short-circuiting any one of the phase legs (i.e.,E1 , E2, E3), any two phase legs(ie.,E4,E5,E6) or all three phase legs(ie.,E7). It is called a third zero state (vector) the shoot-through zero state (or vector), and the 7 ways by which it can be produced are E1 to E7.

State (Output Voltage)	S_1	S_2	S_3	S_4	S_5	S_6
Active {100} (finite)	1	0	0	1	0	1
Active {110} (finite)	1	0	1	0	0	1
Active {010} (finite)	0	1	1	0	0	1
Active {011} (finite)	0	1	1	0	1	0
Active {001} (finite)	0	1	0	1	1	0
Active {101} (finite)	1	0	0	1	1	0
Null {000} (0V)	0	1	0	1	0	1
Null {111} (0V)	1	0	1	0	1	0
Shoot-Through E1 (0V)	1	1	S_3	$!S_3$	S_5	$!S_5$
Shoot-Through E2 (0V)	S_1	$!S_1$	1	1	S_5	$!S_5$
Shoot-Through E3 (0V)	S_1	$!S_1$	S_3	$!S_3$	1	1
Shoot-Through E4 (0V)	1	1	1	1	S_5	$!S_5$
Shoot-Through E5 (0V)	1	1	S_3	$!S_3$	1	1
Shoot-Through E6 (0V)	S_1	$!S_1$	1	1	1	1
Shoot-Through E7 (0V)	1	1	1	1	1	1

Table 1 Switching states of ZSI

- We see that the ZSI and traditional VSI both uses the same eight switching states where ZSI has an additional state. Therefore all the traditional Pulse Width Modulation techniques (sine Pulse Width Modulation and space vector Pulse Width Modulation) can be used with ZSI but by slightly modifying the zero states.
- In a ZSI when compared to the VSI the active state remains the same but the zero states of a traditional VSI are modified a bit in order to insert the extra ST

states. Since the active state remains the same, the output AC voltage of ZSI remains similar to that of VSI.

- Since the Shoot-through states are only inserted in the Zero states but not in Active states, the Shoot-through states are limited by zero states. They can replace some of the zero states or all of the zero states which depends on other factor called modulation index, M.

2.2 Z SOURCE INVERTER OPERATION:

In an inverter if the available DC link voltage is well and sufficient to generate the desired AC output voltage then there is no need of boosting the DC link voltage and therefore no need of extra shoot through states into the zero states. But if the case is different i.e. the available DC link voltage cannot produce the required AC output voltage there comes the picture of boosting the DC link voltage and hence the necessity of shoot through states. All the traditional pulse width modulation (PWM) techniques can be modified a little and used to control ZSI. The relations between input and output remains the same inspite of modifying the zero state. There are three operation modes based on the switching states of inverter and are classified as follows.

MODE 1: Here the ZSI will be in one of the 6 active states. And it is in this mode where the DC source voltage appears across the inductor and capacitor. In this mode the DC source voltage appears across the 'inductor and the capacitor'. The Capacitor stays charged and energy is supplied to the load through the inductor which makes the inductor to discharge in this mode.

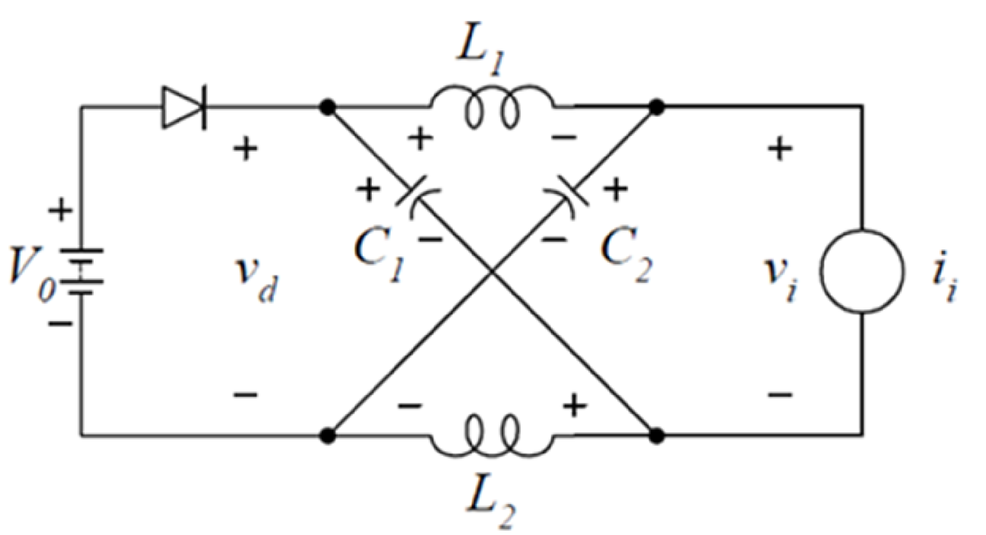

Figure 2.4 Equivalent circuit of the ZSI viewed from the dc link.

Mode 2: The mode 1 is composed of active states and this mode constitutes the ZSI operating in one of the two zero states. In this mode no voltage is applied across the load and hence can be viewed as an open-circuit.

Mode 3 : The mode 1 and 2 are of active and zero states respectively. Since we are left with shoot through states, the mode 3 deals with them. Here the ZSI will be operated in one of 7 Shoot-through states. Here similar to that of a Zero state a zero voltage appears across the load but this state is mainly used to boost the capacitor voltage.

2.3 Circuit analysis and Obtainable Output Voltage:

Here the inductors *L1* and *L2* and capacitors *C1* and *C2* are assumed to be of same value i.e. inductance (*L*) and capacitance (*C*), respectively, which makes ZSI two port impedance network symmetrical. Using the symmetry and the equivalent circuits, we get

$$L_1 = L_2 \text{ and } C_1 = C_2$$

This makes us to accept that voltages across these elements to be same

$$v_{l1} = v_{l2} = v_l \text{ and } V_{c1} = V_{c2} = V_c$$

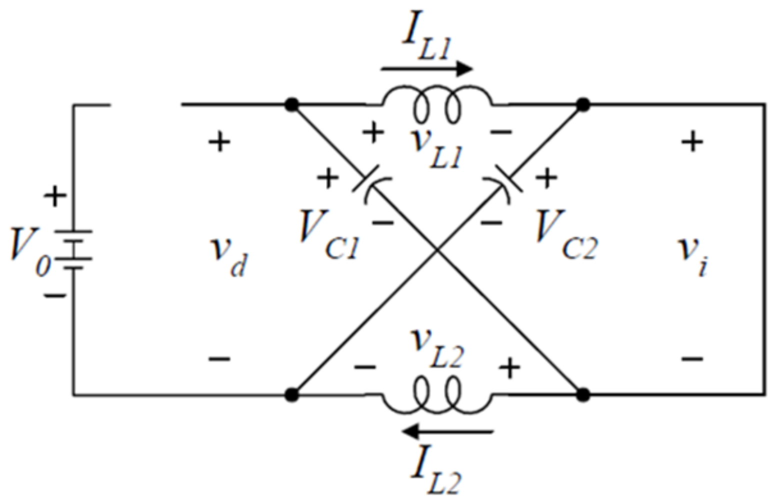

Figure 2.5 ZSI when the inverter bridge is in the ST state

During shoot through state of ZSI

$$v_l = V_c \, , v_d = 2V_c \text{ and } v_i = 0$$

When the ZSI is one of the eight non shoot through states

$$v_L = V_0 - V_C \, , v_d = V_0 \, , v_i = V_C - v_L = 2V_C - V_0$$

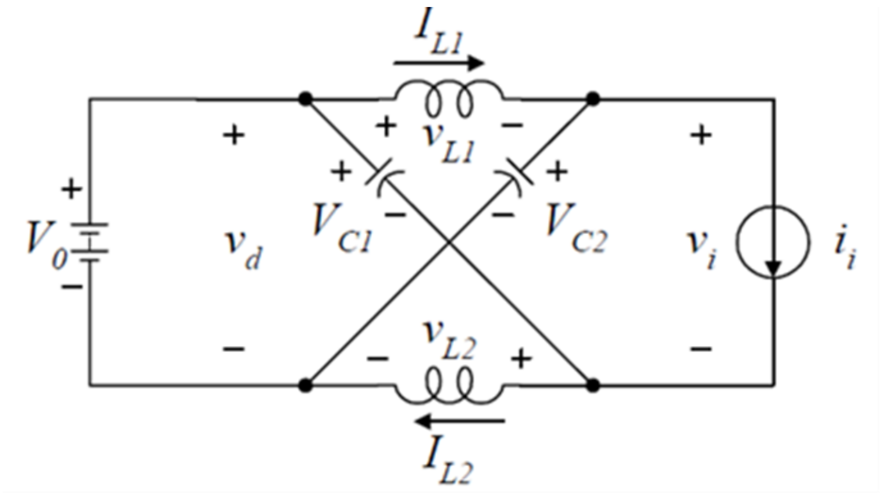

Figure 2.6 ZSI when the inverter bridge is in one of the 8 non ST states

Let the ST state time be T_0 and the time for which it is in eight non shoot through states is T_1

Now the total time period is:

$$T = T_0 + T_1$$

The average voltage across the inductor is given as:

$$V_L = \overline{vL} = (T_0.V_C + T_1.(V_0 - V_C))/T = 0$$

Or

$$\frac{V_C}{V_0} = \frac{T_1}{T_1 - T_0}$$

The average DC link voltage is found as:

$$V_i = \overline{v_i} = (T_0.0 + T_1.(2V_C - V_0))/T = T_1/(T_1 - T_0)V_0 = V_C$$

The peak DC link voltage is expressed as:

$$\widehat{v_i} = V_C - v_L = 2V_C - V_0 = T/(T_1 - T_0)V_0 = B.V_0$$

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - \frac{2T_0}{T}} \geq 1$$

Where B is the boost factor resulting from the shoot zero state.

On the AC side the peak output phase voltage is given as

$$\widehat{v_{ac}} = M.\frac{\widehat{v_i}}{2}$$

OR

$$\widehat{v_{ac}} = M.B.\frac{V_0}{2}$$

$$Buck\text{-}Boost\ factor = M \cdot B = (0 \sim \infty)$$

2.4 Impedance Network Component Design:

Inductor design

If we don't use shoot through states i.e. if we are not in the need of boosting up the dc link capacitor voltage then Input voltage and capacitor voltage are same. During this period the inductor voltage becomes zero resulting in pure DC current to flow through the inductor. The main operation of the inductor during Z-source mode is limiting the current ripple during the boost mode. The voltages are equal across inductor and capacitor in ST mode, but during non-ST mode their sum is equal to the dc input voltage. Inductor current is linearly increased during ST mode while it decreases during non-ST mode (traditional eight states)

The average current $\overline{I_L}$ through the inductor is

$$\overline{I_L} = \frac{P}{V_o}$$

Where V_o is the input dc voltage and P is the total power.

For a maximum shoot through current ripple reaches its peak through the inductor. Hence the peak to peak current ripple of the inductor is to be determined. 30% (60% peak-peak) current ripple is optimum choice for a Z-source inverter.

Inductor Max Current = $\widehat{I_L} = \overline{I_L} + 30\%$

Inductor Min Current = $\breve{I_L} = \overline{I_L} - 30\%$

During Shoot through

$$V_L = V_C = \frac{T_1}{T_1 - T_0} V_0 = \frac{1 - \frac{T_0}{T}}{1 - 2\frac{T_0}{T}} V_0$$

where T_0 is the shoot through time period. Now since we know the change in current and the time period for that change we can find the value of inductance as

$$\boxed{L = \frac{V_L * T_0}{\Delta I_L}}$$

Capacitor design

The sinusoidal output voltage is given by the stable voltage of capacitor achieved by absorbing the current ripple. Mode 3 of ZSI operation explains the charging of inductor during ST by the capacitor and

$$I_L = I_C$$

The voltage ripple ΔV_C is limited to 3 % at peak power, therefore the capacitor value is approximately given by

$$\boxed{C = \frac{\overline{I_L} T_0}{\Delta V_C}}$$

Where T_0 is shoot through time period $\overline{I_L}$ is the average current through the inductor calculated as

$$\overline{I_L} = \frac{P}{V_o}$$

And ΔV_C = Vc * 3%

Example :

Given an induction motor of 5.4 HP (4 kW) , 400 line to line rms voltage , 50 hz and 1430 rpm.

Input voltage is taken as 350 volts.

T_s sampling time period is taken as 10^{-4} seconds (10khz frequency)

First equation to use is $\overline{I_L} = \frac{P}{V_o}$

P = 5.4 hp = 5.4 * 746 = 4028.4

V_o = 350 V
average I_L = 4028.4/350 = 11.509

V_C = (B+1)/2 where $B = \frac{T}{T_1 - T_0} = \frac{1}{1 - \frac{2T_0}{T}}$

Taking T_0 / T = 0.276 we get V_C = 565.625

During shoot through $V_C = V_L$

Therefore for evaluating L from the equation $\boxed{L = \frac{V_L * T_0}{\Delta I_L}}$ we have all the required values.

V_L = 565.25 and To = 0.276 * 10^{-4}

And ΔI_L = 60 % of average value of I_L = 0.6 * 11.509

Therefore **L = 2.26 * 10^-3 H**

Now for evaluating the value of C we use the formula $\boxed{C = \frac{\overline{I_L} T_0}{\Delta V_C}}$ for that all we need is ΔV_C

So ΔV_C = 3 % of V_C = 0.03 * 565.25

Therefore **C = 18.71 * 10^-6 F**

CHAPTER 3

CONTROL METHODS

As it was discussed in a ZSI the only change is the addition of ST states and during these states the output voltage to load terminals is zero. The active state has to be properly maintained in order to get a sinusoidal output voltage. There are many ways of doing so. A few are briefly explained below.

3.1 Simple Boost Control (SBC)

Here the control is simple. This control strategy using 2 straight lines to add ST states into the zero stated. These 2 straight lines (Vp and Vn) are compared to a triangular carrier wave. Vp is a positive quantity whereas Vn is negative. The value of Vn is negative of that of Vp.

$$Vp = -Vn$$

The value of Vp should be than that of M in order to make sure that the active states are not affected. Now whenever the triangular carrier wave is higher than the upper line Vp all the upper switches (S_{ap} ,S_{bp} , S_{cp}) are turned on thereby forming a shoot through . Similarly when the triangular carrier wave is less than lower line Vn all the lower switches (S_{an} ,S_{bn} , S_{cn}) are turned on forming a shoot through. Here not all the zeroes are converted into shoot through states so it is not a method where the least stress appears on the devices. And this method is also easy to implement. Also for the shoot through period, the maximum Duty cycle is restricted to (1-M) where M is the modulation index. This Duty cycle becomes zero when the modulation index approaches 1.

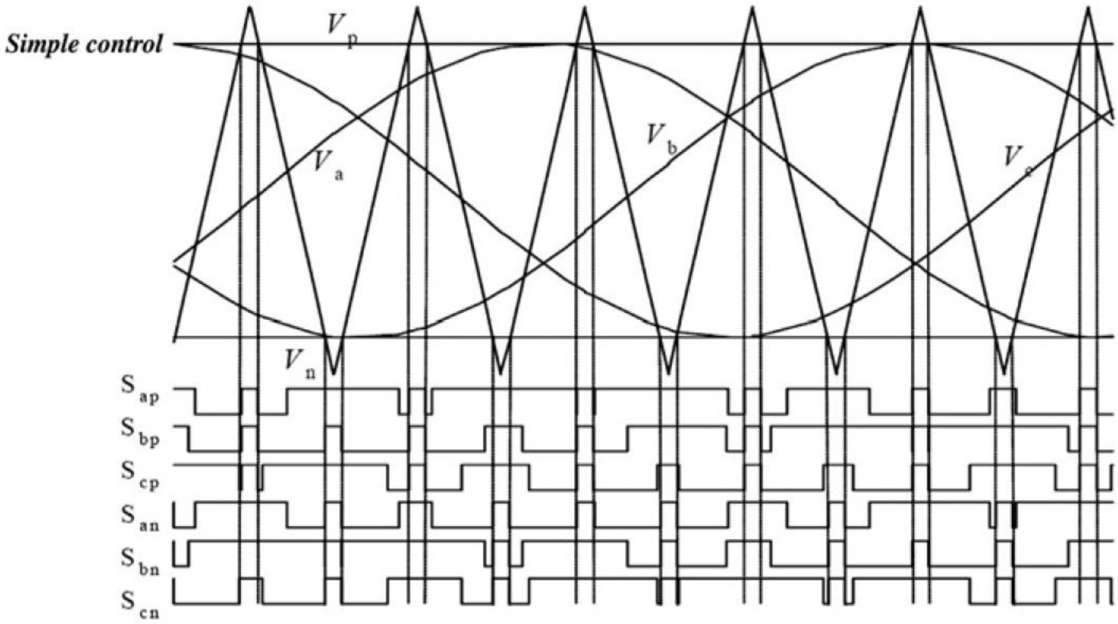

Figure 3.1 Simple boost control technique

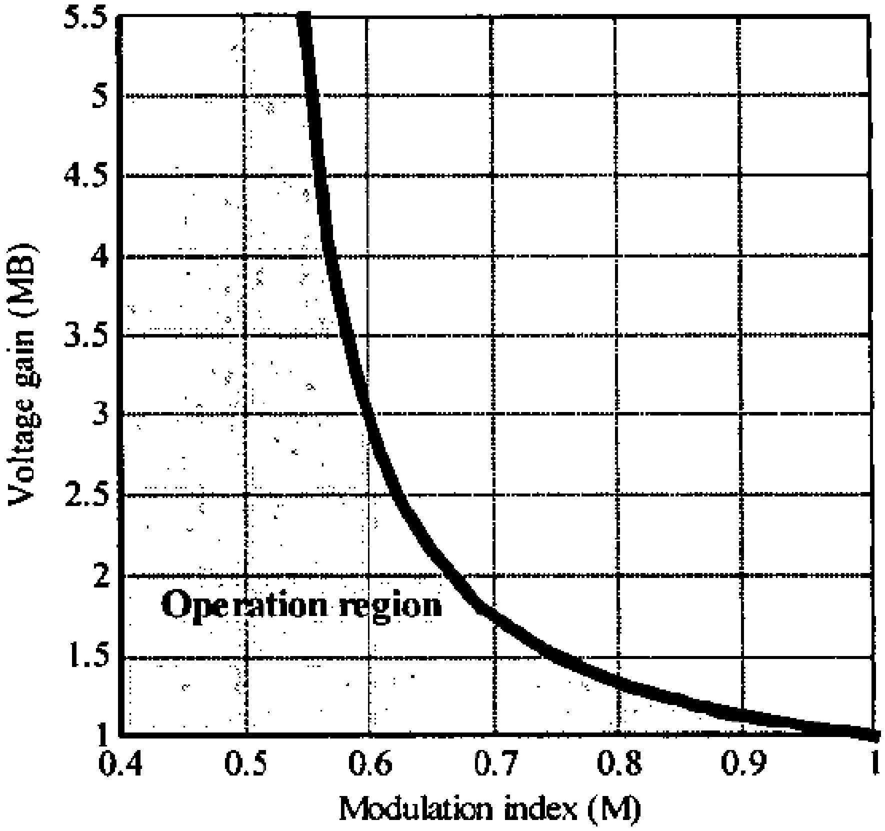

Figure 3.2 Voltage gain vs Modulation index for SBC

The voltage gain given by G is as follows. Boost factor B is set to maximum of (1-M) resulting in

$$G = MB = \frac{\widehat{V_{ac}}}{\frac{V_0}{2}} = \frac{M}{2M-1}$$

The modulation index for any desired gain is given by

$$M = \frac{G}{2G-1}$$

The DC link voltage appearing across the switches is equivalent to the capacitor voltage of the inductor network. This voltage is used in the analysis of the voltage stress created across the switches. The voltage stress on the switch can be calculated by

$$V_S = BV_0 = (2G-1)V_0$$

3.2 Maximum Boost Control

Maximum voltage boost is obtained by maximum boost control method. This control method helps reducing the voltage stress developed on the devices by shooting through the entire zero state in a switching cycle. The upper and lower ST references are obtained from the top and bottom three contours of all three sinusoids together, respectively. The references obtained are compared with the triangular waveform in order to perform the ST.

From the graph, we can see that the shoot through duty cycle repeats after every pi/3 interval and is given by:

$$\frac{T_0(\theta)}{T} = \frac{2-\left(Msin\theta - Msin\left(\theta - \left(\frac{2\pi}{3}\right)\right)\right)}{2}$$

To calculate the voltage gain and the stress on the switches we are interested in the average duty ratio

$$\frac{\overline{T_0}}{T} = \int_{\frac{\pi}{6}}^{\frac{\pi}{2}} \left(\frac{2-\left(Msin\theta - Msin\left(\theta - \left(\frac{2\pi}{3}\right)\right)\right)}{2}\right) d\theta$$

$$\frac{\overline{T_0}}{T} = \frac{2\pi - 3\sqrt{3}M}{2}$$

Which gives the boost factor B as:

$$B = \frac{1}{1 - 2\left(\frac{\overline{T_0}}{T}\right)} = \frac{\pi}{3\sqrt{3}M - \pi}$$

And the voltage gain is given as:

$$\frac{\widehat{V_{ac}}}{\frac{V_0}{2}} = MB = \frac{\pi M}{3\sqrt{3}M - \pi}$$

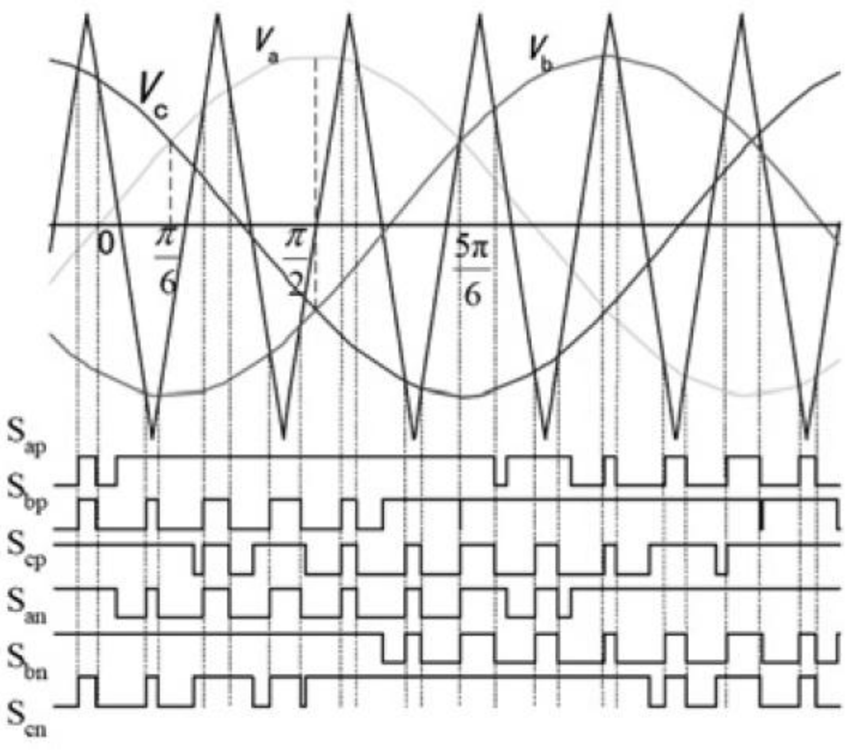

Figure 3.3 Maximum boost control technique

This method utilizes all the Zero states providing the maximum voltage gain. As a result, the shoot through duty ratio changes along the whole cycle which is evident form the graph. This results in a current ripple to occur in the impedance network inductor and would thus require a larger inductor to reduce the ripple.

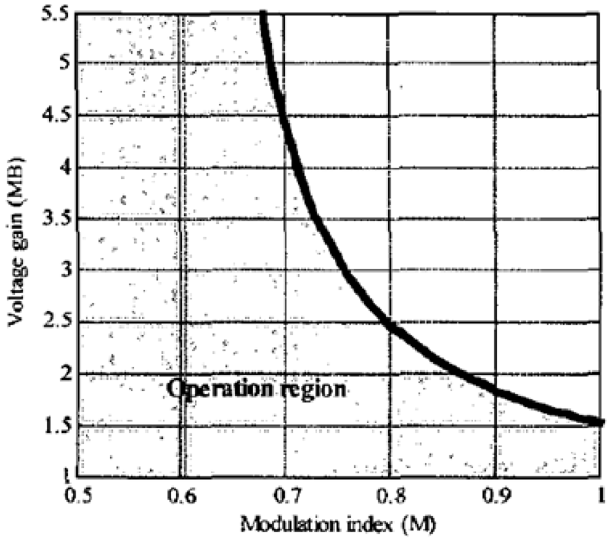

Figure 3.4 Voltage gain vs Modulation index for Maximum boost control

3.3 Maximum constant boost control

While maintaining a constant ST duty ratio throughout, Maximum constant boost control method achieves maximum boost resulting in no line frequency current ripple through the inductors. In Fig.3.5, the PWM control map of maximum constant boost control along with third harmonic injection is shown. Within the limit of the device voltage, the inverter can change the voltage (from zero to any desired value) by buck and boost control of this method. This maximum constant boost control using third harmonic injection is implemented by adding 1/6 of the third harmonic. As can be seen from Fig. 6, V_a reaches its peak value $\frac{\sqrt{3}}{2}M$ while V_b is at its minimum value -$\frac{\sqrt{3}}{2}M$.

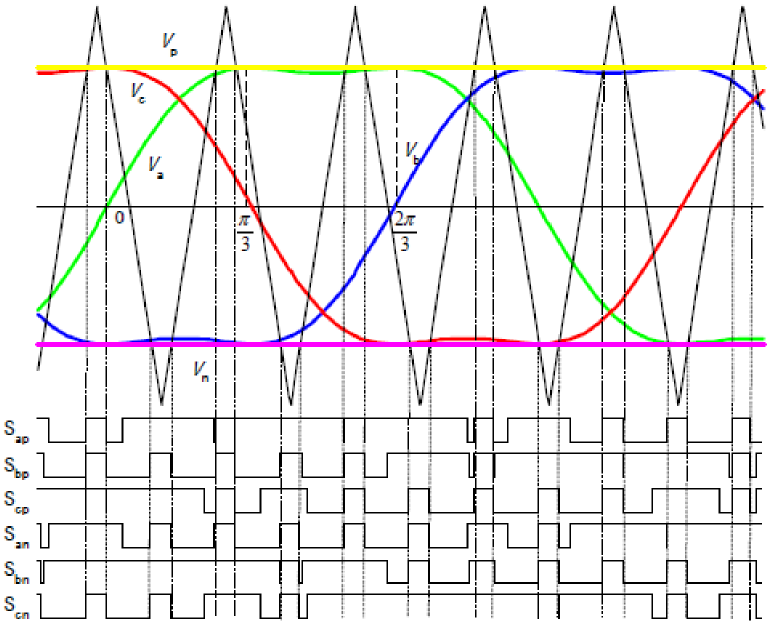

Figure 3.5 Maximum constant boost control technique

Thus the shoot through duty ratio, which is constant, can be expressed as

$$\frac{T_0}{T} = 1 - \frac{\sqrt{3}M}{2}$$

The boost factor and the voltage gain is calculated as:

$$B = \frac{1}{1 - \frac{2T_0}{T}} = \frac{1}{\sqrt{3}M - 1}$$

$$\frac{\widehat{v_0}}{\frac{V_{dc}}{2}} = MB = \frac{M}{\sqrt{3}M - 1}$$

The voltage gain is

$$G = MB = \frac{M}{\sqrt{3}M - 1}$$

And the voltage stress on the switches is given by

$$V_S = BV_{dc} = (\sqrt{3}G - 1)V_{dc}$$

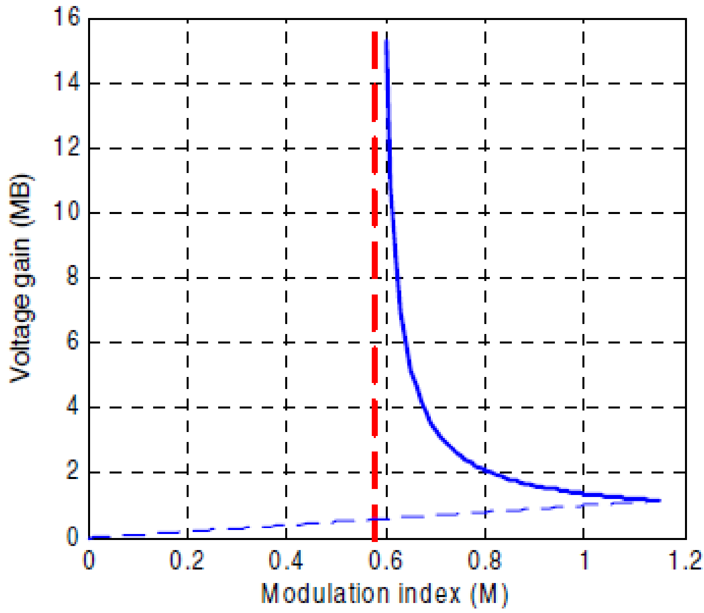

Figure 3.6 Voltage gain vs. Modulation index for Maximum constant boost control

Maximum voltage gain is achieved by the maximum constant boost control which simultaneously always keeps the shoot-through duty ratio constant.

3.4 Space Vector Modulation:

Generally the maximum modulation index taken is 1. But we can make it to a maximum of 1.15 if we use the third harmonic injection method where the 1/6 of the magnitude of the third harmonic is injected into the modulating wave. Generally in a traditional VSI dead-time is added in order to give sufficient time for the commutation of a switch before the other switch of the same phase leg is turned on. This dead-time is added in order to prevent short-circuit of a phase leg or phase legs. But in a Z-Source inverter no such delays are needed. Because the unique feature of boosting the dc link voltage is achieved only through these short-circuiting of the phase leg or phase legs. The dc link voltage boost can be controlled using the duty ratio (T_0/T). Not only the dead-time delay is removed but an additional and unique feature of boosting up the dc link voltage is added by introducing the 2 port impedance network and thus the Z-source inverter has gained its importance.

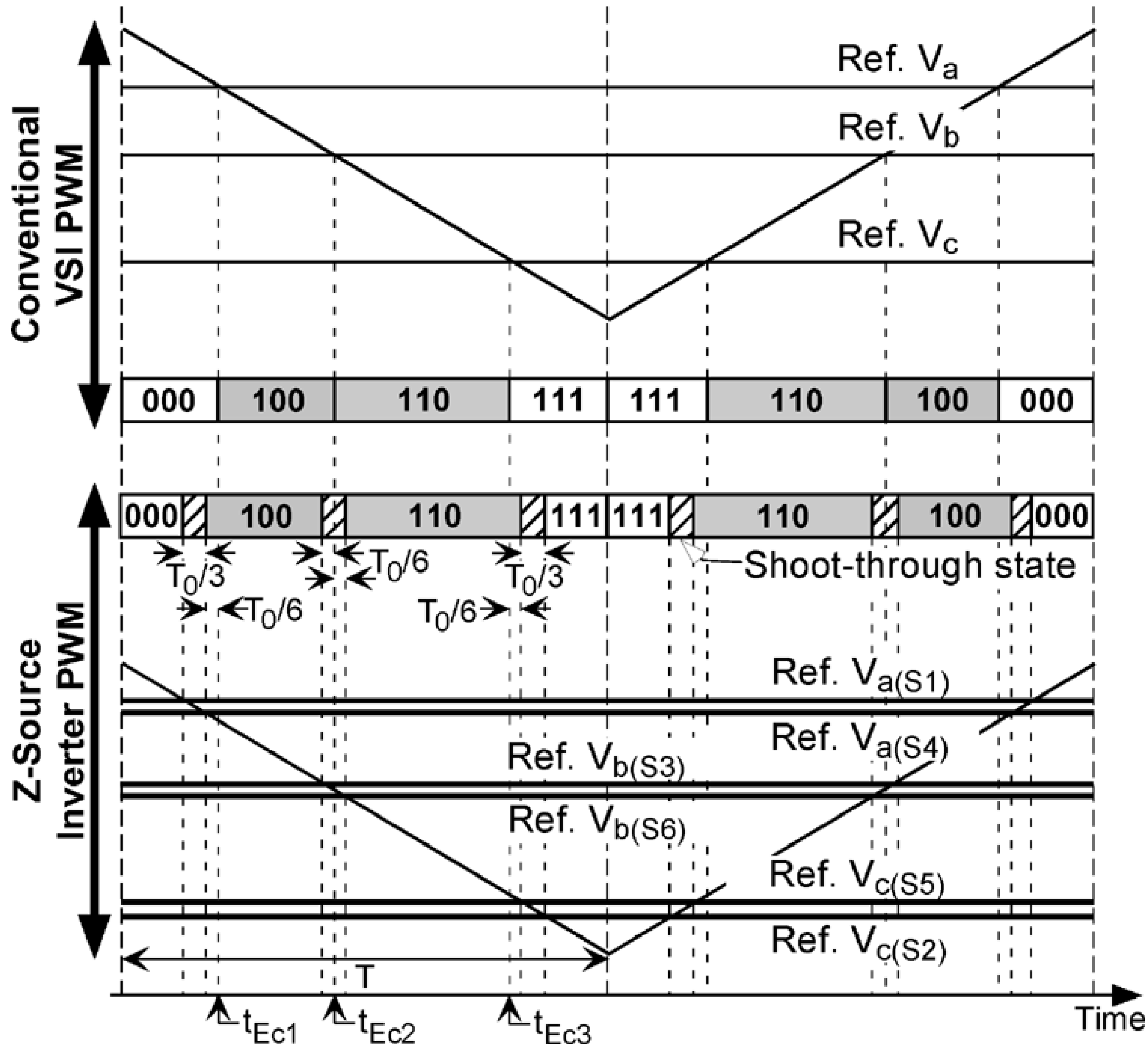

Figure 3.7. Modulating reference waves for VSI and ZSI

3.4.1 State Sequence, Placement and Carrier-Based Implementation:

As we have already discussed in section 2.1, a traditional 3-phase VSI bridge has 8 permissible switching states but the three phase ZSI has 9.These permissible states of a traditional VSI can be grouped into two. Active and Zero states. When an active vector is executed a dc voltage appears across the load and when a zero vector is executed the load terminals are shorted. So a total of 6 active vectors and 2 zero vectors constitute the total 8 permissible switching states of the traditional VSI. Apart from the two groups active and zero the Z-source inverter has another group by which it gains the unique ability of producing an output ac voltage of any desired value between zero and infinity and that state or group is called shoot-through. The ZSI can produce this shoot-through in 7 different ways. These additional 7 shoot through states are used to boost the input DC voltage. The 3-phase Z-source inverter bridge produces shoot-through by short-circuiting any one of the phase legs (i.e.,E1 , E2, E3), any two phase legs(ie.,E4,E5,E6) or all three phase legs(ie.,E7). It is called a third zero state (vector) the shoot-through zero state (or vector), and the 7 ways by which it can be produced are E1 to E7.

In a Zero state 0 (zero) voltage is applied over the load which is the same in the case of a shoot-through state. So if you insert shoot-through states only into the zero states the voltage-sec average will be maintained the same and the input-output relations and equations can be the same as that of traditional VSI but with a boosted input dc voltage. The only disadvantage is that the shoot-through state is limited by zero state. From the Fig.4 we can three state transitions (null{000} → active{100} → active{110} → null{111}) where the null states are at the beginning and ending of switching cycle with the active states in between. This kind of state transition helps to achieve optimal harmonic performance. So now three shoot through states of equal time interval are added between each state transition thereby forming equal zero or null states at the start and end of the switching cycle. Instead of using three reference modulating waves as that in the case of a traditional VSI we use 6 and the way by which they are formed is given below.

$$V_{\max(SX)} = V_{max} + V_{off} + \frac{T_0}{T}$$

$$V_{\max(SY)} = V_{max} + V_{off} + \frac{T_0}{3T}$$

$$V_{mid(SX)} = V_{mid} + V_{off} + \frac{T_0}{3T}$$

$$V_{mid(SY)} = V_{mid} + V_{off} - \frac{T_0}{3T}$$

$$V_{\min(SX)} = V_{min} + V_{off} - \frac{T_0}{3T}$$

$$V_{\min(SY)} = V_{min} + V_{off} - \frac{T_0}{T}$$

$$\{X, Y\} = \{1,4\},\ \{3,6\} \text{ or } \{5,2\}.$$

CHAPTER 4

SIMULATION RESULTS OF Z SOURCE INVERTER

4.1 with a RL load

Simulation of a Z source inverter fed RL load output was performed using a ode45 matlab simulation to verify the boost of the input dc voltage to any described value.

Table 2: parameters of ZSI

parameters	**Value**
Input voltage	70V
load (R,L)	5 ohms, 2 mH
Z network inductor	6.3 mH
Z network capacitor	2200 uF
Modulation index(M)	0.6
Duty ratio	0.3
Boost factor(B)	2.25

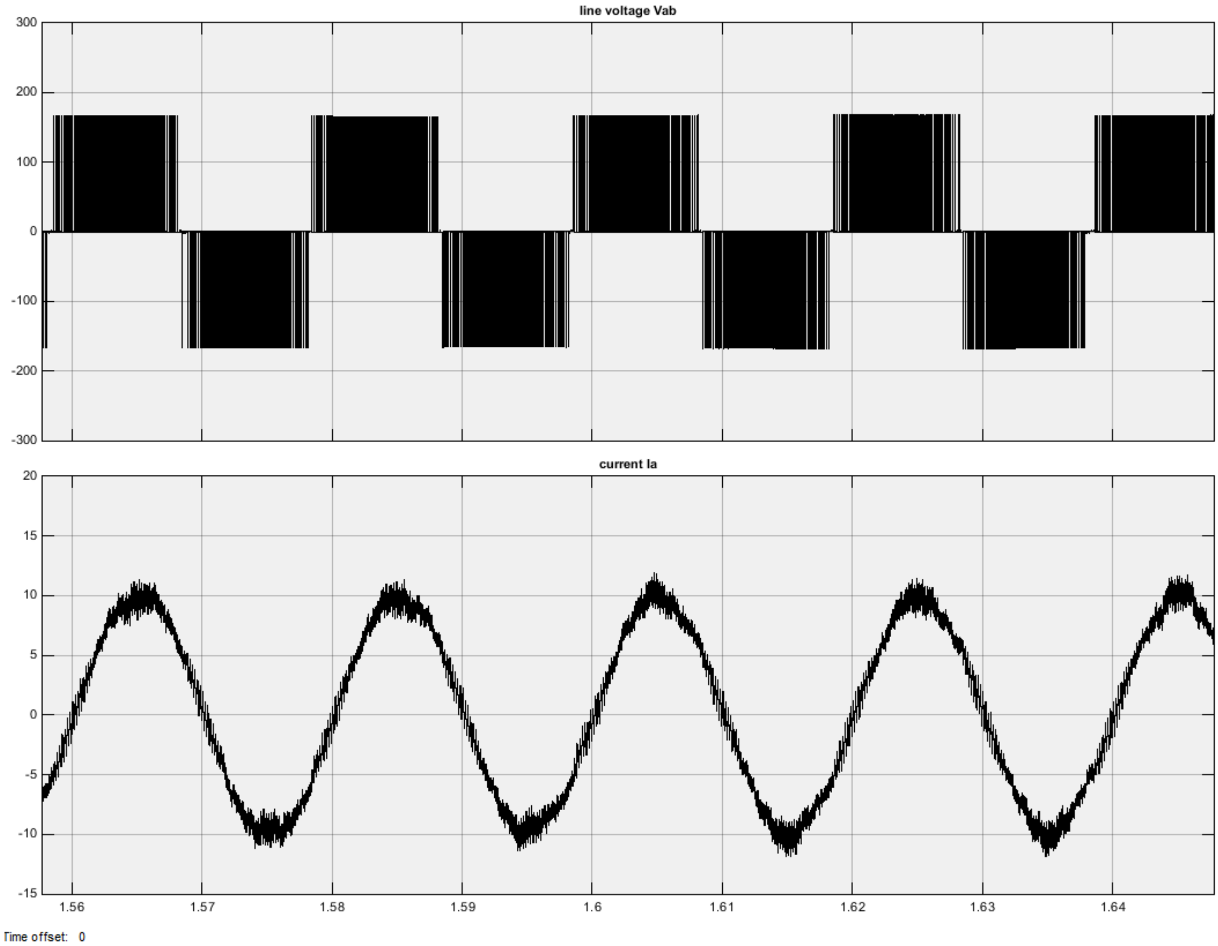

Figure 4.1 line voltage Vab and current Ia of the load

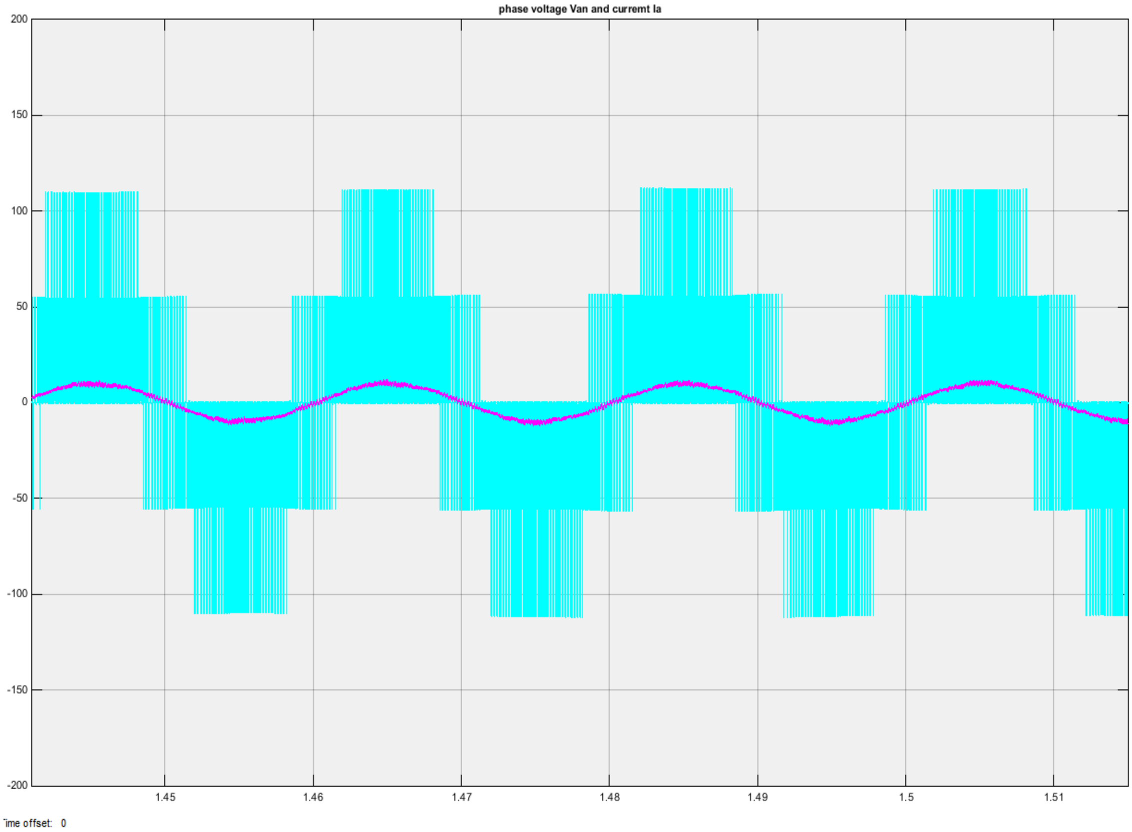

Figure 4.2 Phase voltage Va and current Ia of the load

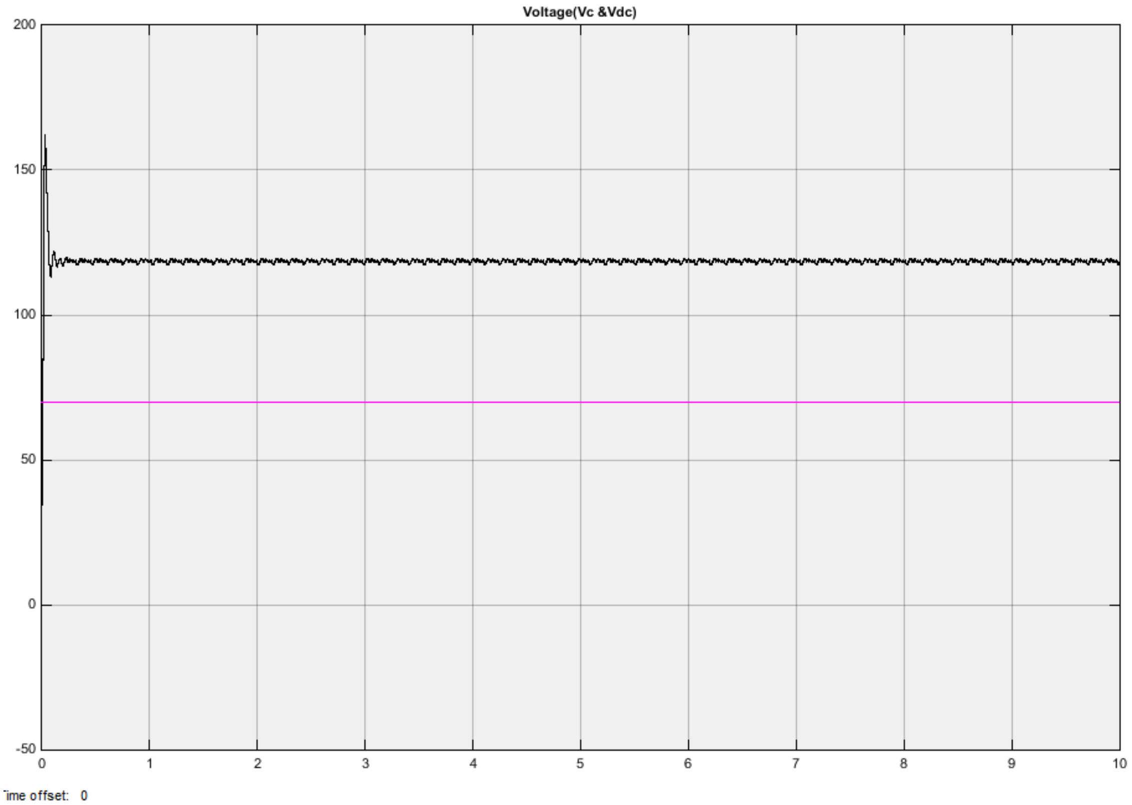

Figure 4.3 Capacitor voltage Vc and input dc voltage Vdc

4.2 Z SOURCE INVERTER FED INDUCTION MOTOR

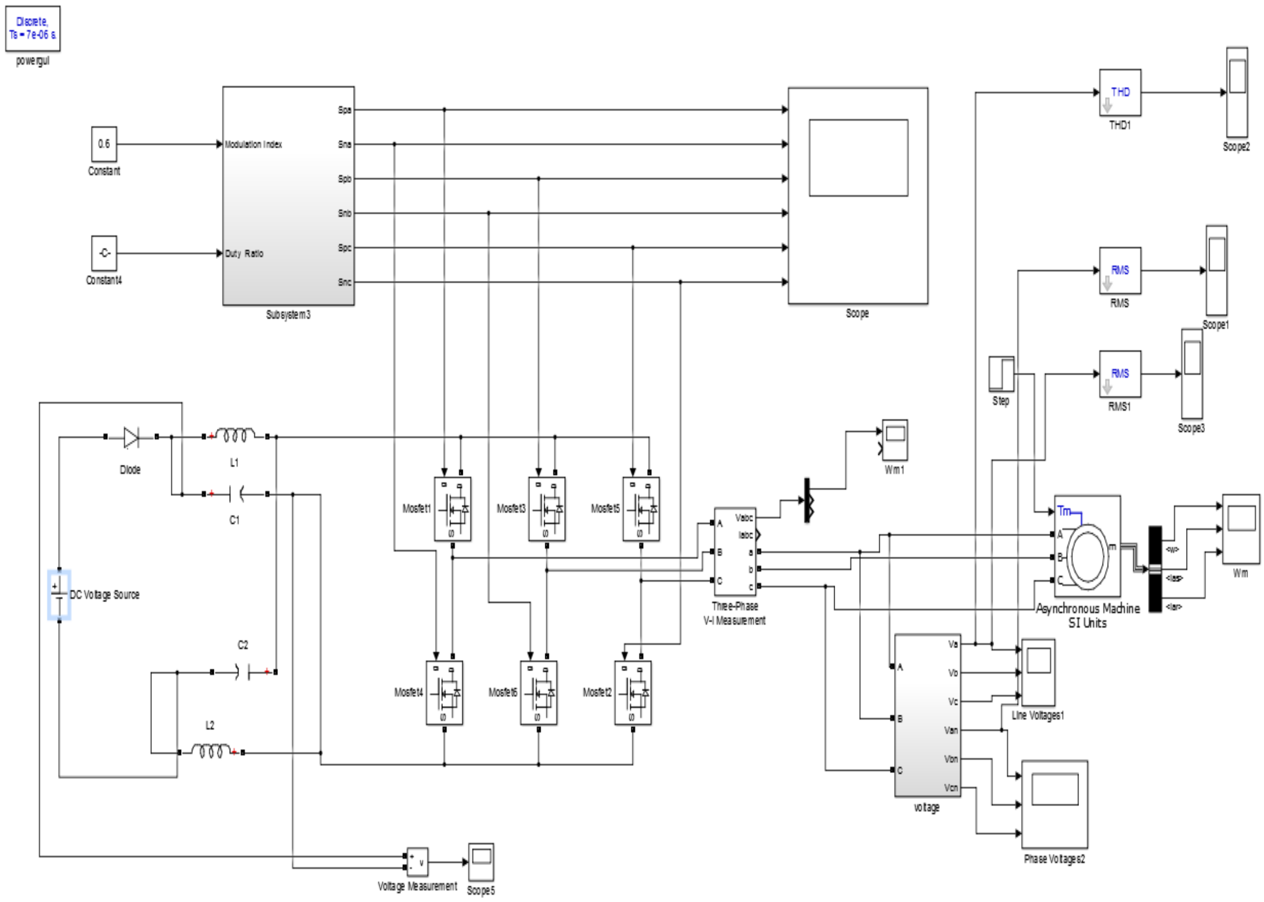

Figure 4.4: Simulink model for ZSI fed induction motor

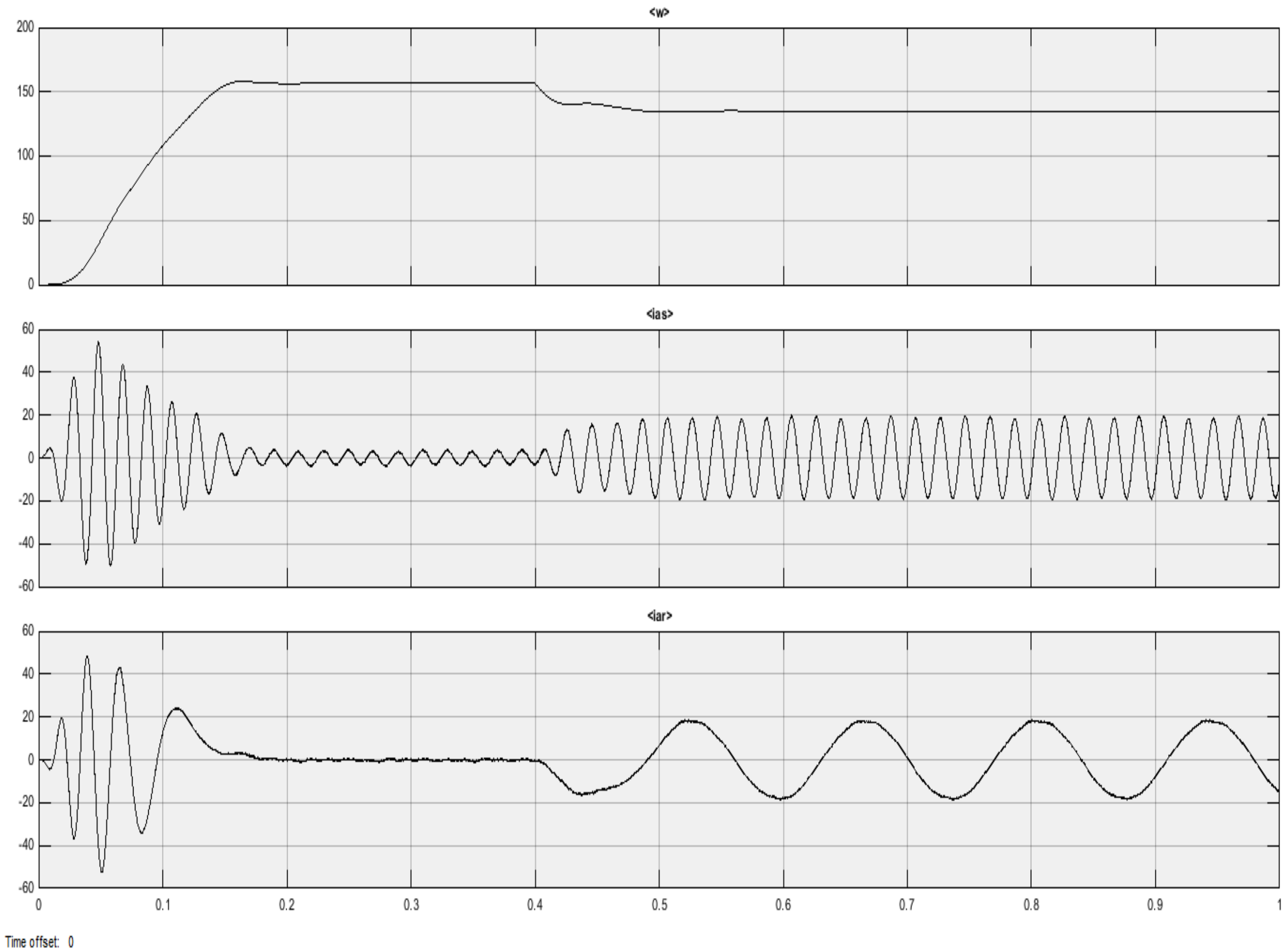

Figure 4.5: speed, stator and rotor currents

4.3 Z SOURCE INVERTER FED V/F CONTROLLED INDUCTION MOTOR

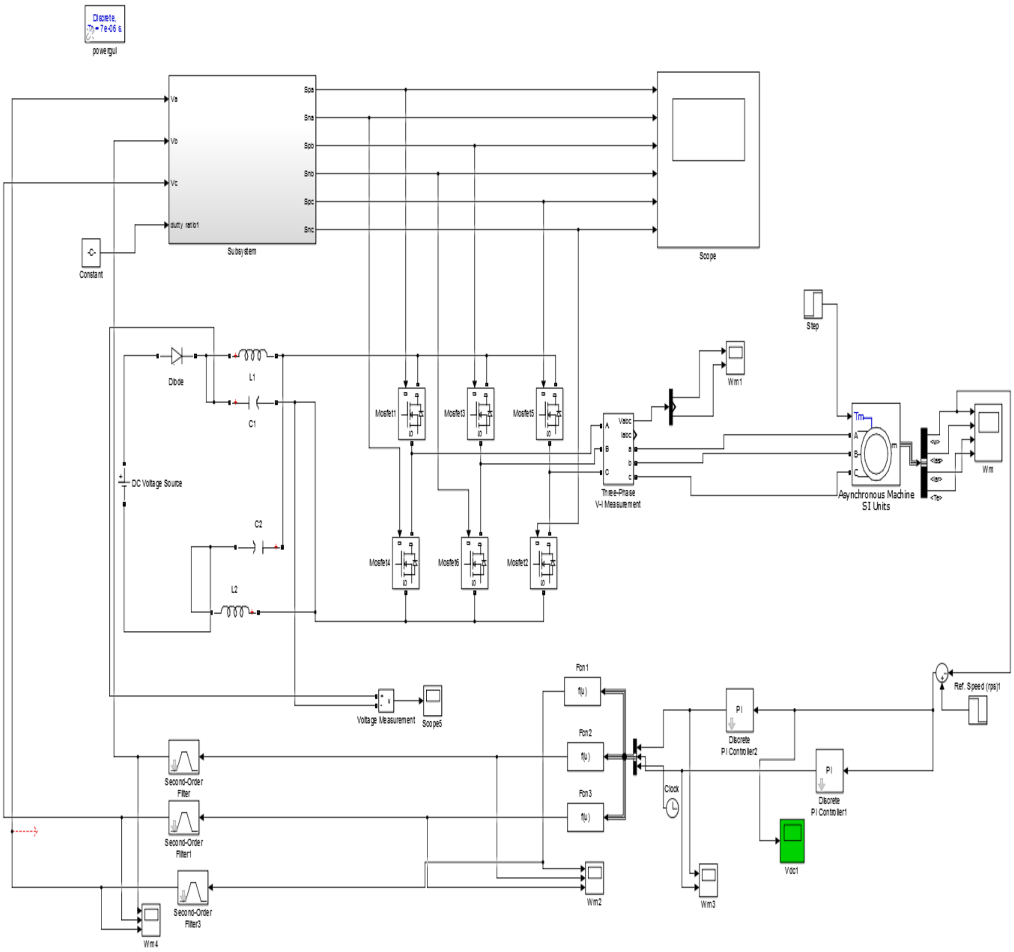

Figure 4.6 Simulink model for v/f controlled ZSI fed induction motor

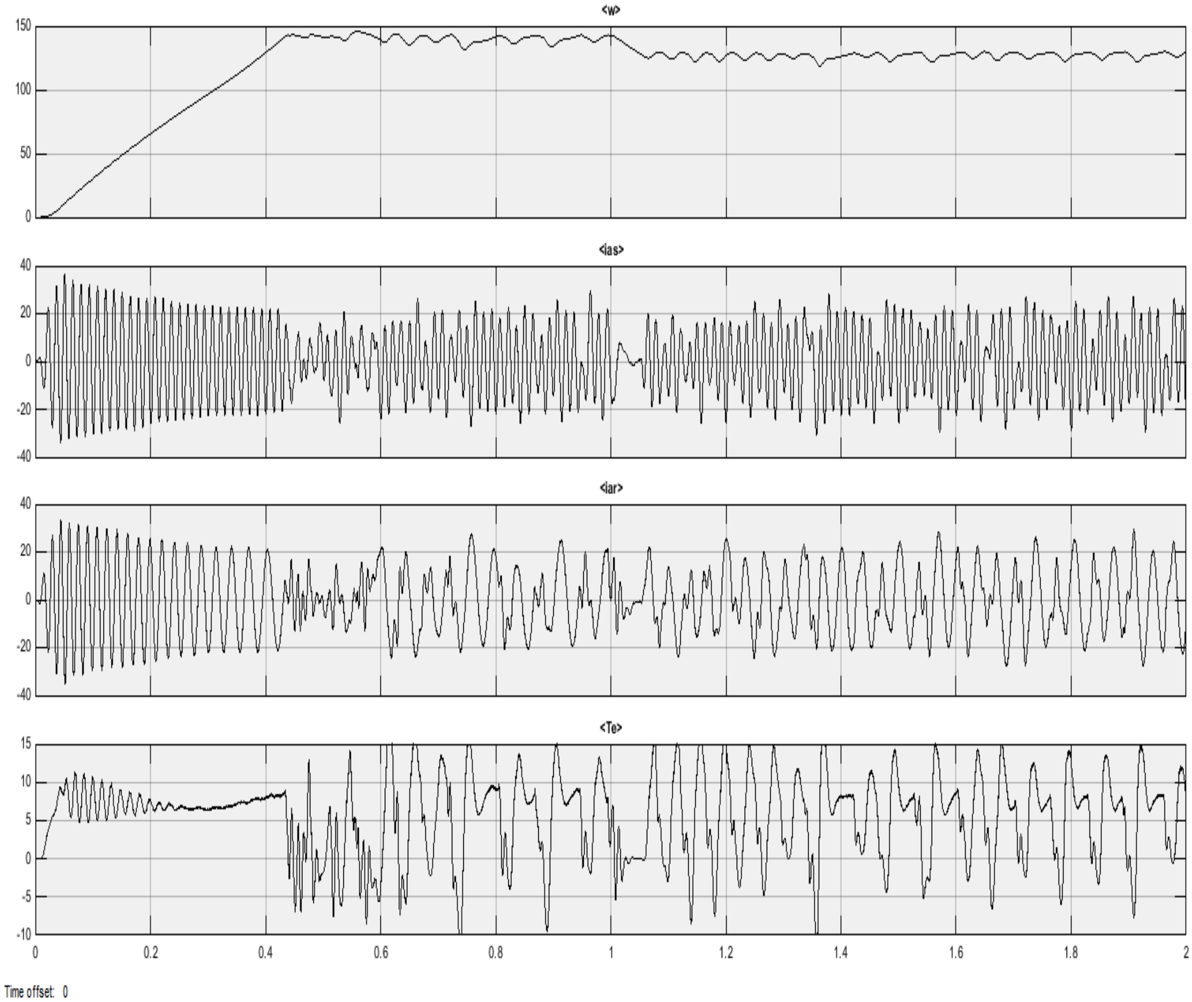

Figure 4.7 speed, stator and rotor currents

CHAPTER 5

CONCLUSION

A detailed analysis on the z source network is done. The various control strategies are thoroughly studied and implemented. A z source inverter fed induction motor drive is implement and the performance analysis is done by considering various loads. Indirect Field Oriented Control (IFOC) of Induction Motor Using SVPWM Fed with Z source Inverter is considered for future work.

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