Speed Control Of Z Source Converter Fed V/F Controlled Induction Motor Drive With Peak DC Link Voltage Control

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Abstract

A closed loop speed control of z source converter fed induction motor drive with peak dc link voltage control is proposed here. It can overcome the limitations of voltage source inverter and can offer better speed control and drive operation during voltage sags and normal working conditions. The peak dc link voltage employed in order to achieve excellent transient performance which enhances rejection of disturbance, including thee input voltage ripple and load current variation, and have good ride through for voltage sags. A simple boost control PWM is used in switching algorithm. The performance of proposed speed control method is verified through PSIM simulation of 1.8kW induction motor fed by Z source inverter. The simulation results of proposed scheme presents good dynamic and steady state performance over traditional voltage source inverter fed induction motor drive.

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1. Introduction

The use of induction motors has increased tremendously since the day of its invention. They are being used as actuators in various industrial processes, robotics, house appliances and other similar applications. The reason for its day by day increasing popularity can be primarily attributed to its robust construction, simplicity in design and cost effectiveness. Speed control is one of the application imposed constraints for the choice of a motor. Out of all the speed control mechanisms, the Volts/Hertz control scheme is very popular because it provides a wide range of speed control with good running and transient performance. This control mechanism is referred to as scalar control mode.

The traditional adjustable speed drives system is based on the voltage source inverter (VSI), which consists of a diode rectifier front end, dc link capacitor, and an inverter bridge. It suffers from common limitations and problems, such as: the obtainable output is limited below the input line voltage, the voltage sags can interrupt an adjustable speed drive (ASD) system and shut down critical loads and processes and the performance and reliability are compromised by the VSI structure.

In order to satisfy the pressing needs for a single converter capable of both voltage boosting and inversion, many new inverter topologies have been proposed in the recent past. Among these new topologies, Z-Source Inverter (ZSI) is the most promising and competitive technology over the others mainly because it continues to employ a conventional VSI as the power converter yet with a modified dc link stage. The impedance source inverter employs a unique impedance network coupled with inverter and rectifier; it overcomes the conceptual barriers and limitations of the traditional converters. The Z-source inverter intentionally utilizes the shoot through zero states to boost dc voltage and to produce an output voltage greater than the original dc voltage. At the same time, the Z-source structure enhances the reliability of the inverter greatly because the shoot-through states, which might cause by EMI noise, can no longer destroy the inverter. Control strategies of the ZSI are important issue and several feedback control strategies have been investigated in recent publications. There are four methods for controlling the dc-link voltage of the ZSI: capacitor voltage control [3], indirect dc-link voltage control [4], direct dc-link control [5], and unified control [6]. Out of this, peak dc link voltage control is the simple method to design and easy to implement.

The paper presents detailed analysis of closed loop speed control of z source converter fed induction motor drive from low speed to rated speed. The peak dc link voltage control is used to enhance the performance of the system. The closed loop operation of a scalar controlled induction motor drive is presented in section II. The configuration, operating principle and control method of the proposed electric drive system is explained in section III. A detailed analysis of z source converter fed induction motor drive and design of impedance network is carried out in this section. The theoretical and modulation concepts presented in the paper have been verified through detailed PSIM simulation in section IV. Finally the derived conclusions are presented in section V.

2. Closed loop speed control of scalar controlled induction motor drive

A simplified diagram of the V/f controlled induction motor is shown in Figure 2. The closed loop control by slip regulation of combined inverter & induction machine improves the dynamic performance. The speed loop error generates the slip command through a proportional integral (PI) controller and limiter. The slip is added to the speed feedback or observer signal to generate the frequency command. Thus frequency command generates the voltage command through a volts/hertz generator which incorporate low frequency stator drop compensation .Since slip generated is proportional to the developed torque at constant flux ,the scheme considered as open loop with speed control loop.[7]

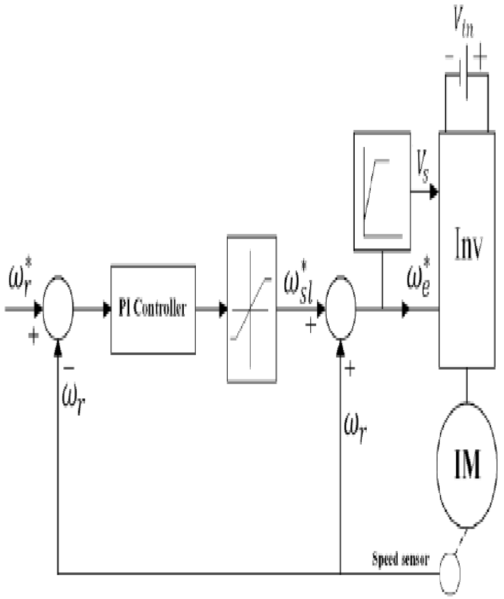

Figure 1.Closed loop scalar controlled induction motor drive

3. Z source inverter fed induction motor drive

3.1. Z source Inverter

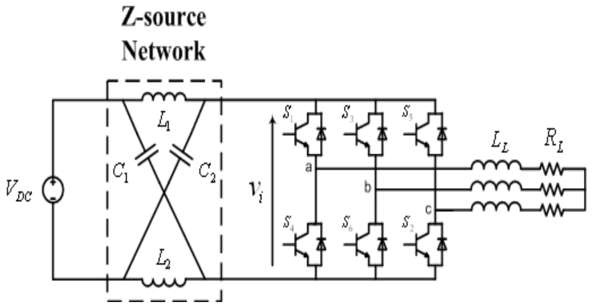

Figure 2 .Z source converter

Figure 2 show the topologies of voltage type three phase Z-source inverter, where a dc voltage source and a conventional VSI with three phase legs are connected at opposite ends of the Z-source impedance network. A diode is connected in series with the power source to block the reverse flow of current. A voltage type Z-source inverter can assume all active and null switching states of VSI. Unlike conventional VSI, a Z-source inverter has a unique feature of allowing both power switches of a phase leg to be turn ON simultaneously (shoot-through state) without damaging the inverter[1] ,[2].

The impact of the phase leg shoot-through on the inverter performance can be analyzed by considering the equivalent circuits shown in Figure .3. When in a shoot-through state during time interval T_0, the inverter side of the Z-source network is shorted as in Figure 3(a). Therefore (assuming $L1 = L2 = L$ and $C1 = C2 = C$):

$$\left.\begin{aligned} v_{L1} = v_{L2} = v_L = V_{c1} = V_{c2} = V_c \\ v_d = v_L + V_c = 2V_c \\ v_i = 0 \end{aligned}\right\} \qquad (6)$$

Alternatively, when in a non-shoot-through active or null state during time interval T_1, current flows from the Z-source network through the inverter topology to the connected ac load. The inverter side of the Z-source network can now be represented by an equivalent current source, as shown in Figure. 3(b).

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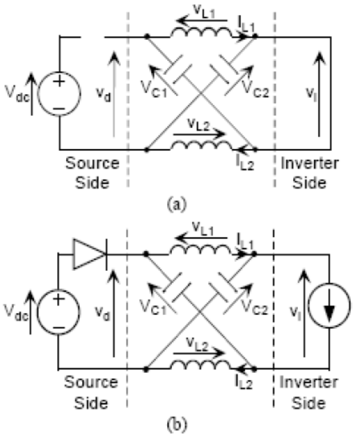

Figure 3. Z source inverter equivalent circuits when in (a) shoot through state and (b) non shoot through state

This current source sinks a finite current when in a non-shoot-through active state and sinks zero current when in a non-shoot-through null state. From Figure 3(b), the following equations can be written:

$$\left.\begin{aligned} v_L &= V_{dc} - V_c \\ v_d &= V_{dc} \\ v_i &= V_c - v_L = 2V_c - V_{dc} \end{aligned}\right\} \qquad (7)$$

Averaging the voltage v_L across a Z-source inductor over a switching period (0 to $T=T_0+T_1$) then gives:

$$V_c = \frac{T_1}{T_1 - T_0} V_{dc} \qquad (8)$$

Using (7) and (8), the peak dc voltage v_i across the inverter phase-legs and the peak ac output voltage v_x can be written as:

$$v_i = 2V_c - V_{dc} = \frac{1}{1-\dfrac{2T_0}{T}} V_{dc} = BV_{dc} \qquad (9)$$

$$v_x = M\frac{v_i}{2} = B\left\{M\frac{V_{dc}}{2}\right\} \qquad (10)$$

where, B is the boost factor introduced by the shoot-through state, M is the modulation ratio commonly used for conventional VSI modulation and the term $M(V_{dc}/2)$gives the ac output of a conventional VSI. Obviously, equation (10) shows that the ac output voltage of a Z-source inverter is boosted by a factor of B (always ≥ 1), which cannot be achieved with a conventional VSI.

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3.2. Simple boost control algorithm

The simple boost control method, uses two straight lines equal to or greater than the peak value of the three phase references to control the shoot-through duty ratio in a traditional sinusoidal PWM, as shown in Fig.4 and 5. When the triangular waveform is greater than the upper line, V_p, or lower than the bottom line, V_n, the circuit turns into ST state. Otherwise it operates just as traditional carrier based PWM [11]. This method is very straightforward and is a simple control strategy.

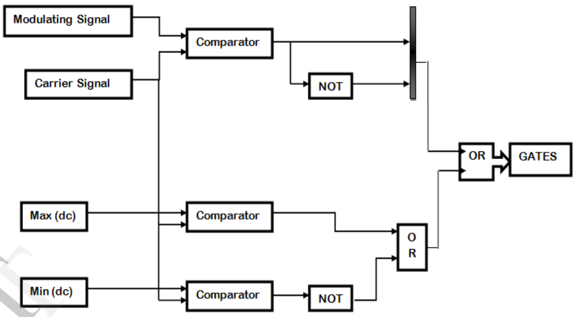

Figure 4.Implementation of simple boost control strategy

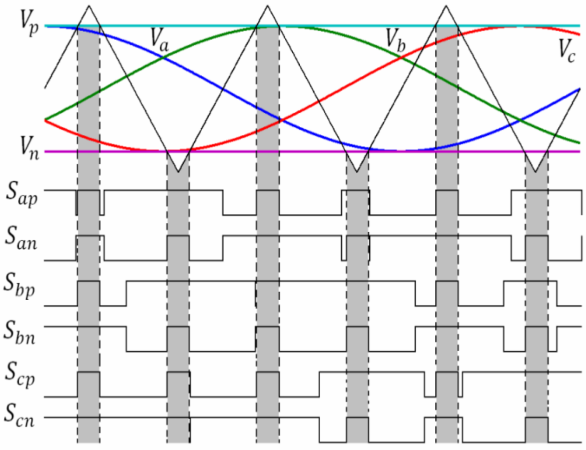

Figure 5.Waveforms of simple boost control

3.4 .Peak dc link voltage control

In order to obtain good performance, the feedback control for dc link voltage of z source inverter is used [9] .This will help in achieving good reference tracking and disturbance rejection and can improve dynamic response. The capacitor voltage V_c is equivalent to the dc link voltage of inverter, and can be boosted by controlling the shoot-through time duty ratio. The ZSI utilizes the shoot-through state to step up the dc link voltage by conducting both upper and lower switches of any phase legs. Thus, the ZSI can boost voltage to desired ac output voltage, which is greater than the available dc link voltage. The relationship between the capacitor voltage and the dc link voltage bears a non linear relationship, which can affect the transient response of the system.

In order to overcome the problem, an algorithm is proposed to control the capacitor voltage linearly [10]. The block diagram for the control can be represented as follows.

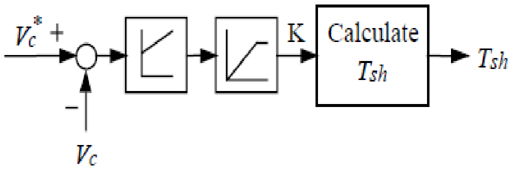

Figure 6. Linearization of capacitor voltage

The K factor can be defined as

$$K = \frac{V_c}{V_{dc}} \tag{11}$$

Thus, the shoot through time can be calculated by the equation

$$T_{sh} = \frac{K-1}{2K-1} T_s \tag{12}$$

The output of the PI controller equals K, from which it is possible to find out the shoot through duty ratio. As the *K* is proportional to the capacitor voltage, the good transient performance of capacitor voltage can be obtained. The shoot through signals can be obtained can be OR ed with the PWM signal to obtain the desired response.

3.5. Proposed closed loop Z source inverter fed induction motor drive

The closed loop speed control and peak dc link voltage strategies of the proposed Z source inverter ASD system is shown in figure.

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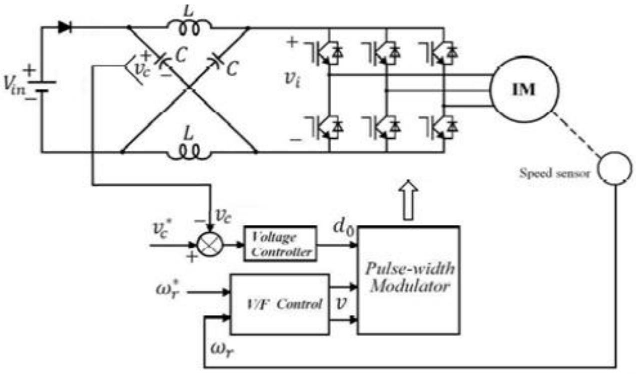

Figure 7. Proposed closed loop Zsource inverter fed induction motor drive

4. Simulation results

To assess the performance of the novel Z–source inverter for induction motor drive scheme, simulation schematic is developed in PSIM. The main parameters of the simulation model are listed in Table I.

TABLE I. 1.8 KW INDUCTION MOTOR PARAMETERS

Parameter	***Value***
Output power	1.8kW
RMS line voltage	400 V
Input frequency	50Hz
No. of poles	4
Stator resistance, R_s	2.56Ω
Rotor resistance, R_r	1.97Ω
Stator inductance, L_{ls}	0.01472Ω
Rotor inductance, L_{lr}	0.01124Ω
Mutual inductance, L_m	0.2815Ω
Moment of inertia ,J	0.012024kg m^2
Rated dc input voltage	500 V dc
Capacitors	750μF
Inductors	450μH

The transient and steady state closed loop performance of the drive system over a wide speed range under load conditions are extensively studied. The circuit simulation results obtained for conventional VSI fed induction motor drive and Z-source inverter fed induction motor drive .The drive implements speed feedback in PWM signal generation. The stator current, speed and electromagnetic torque waveforms are obtained for various operating conditions are observed.

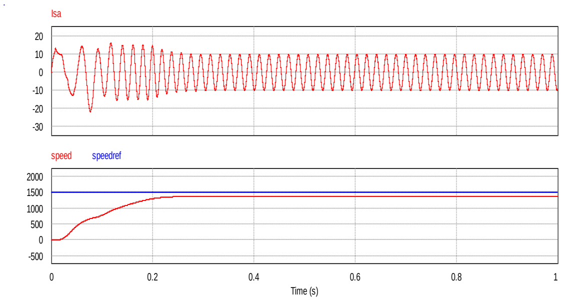

Figure 8. The system response of VSI fed induction motor drive with rated input dc voltage.

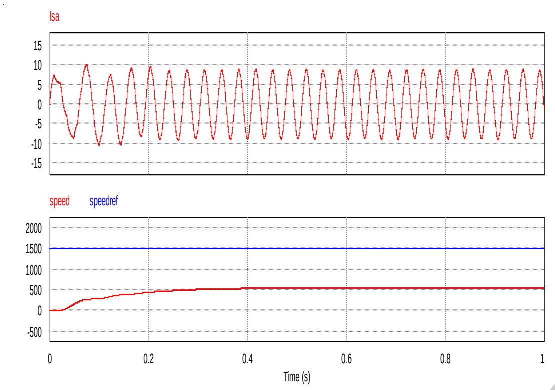

Figure 9. The system response of VSI fed induction motor drive with reduced input dc voltage.

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Figure 8and 9 shows the speed and current waveforms of the scalar controlled voltage source inverter fed induction motor drive applied with rated input voltage and then,reducing the input voltage .It is evident from the wavwform that the speed reduces when input voltage is reduced by 25%.Z source inverter fed induction motor drive can overcome the theoretical and conceptual barriers of the VSI fed induction motor drive and offers a new power conversion concept.

Figure 10 shows the motor speed, torque and stator current, modulation index during motor starting from zero to rated speed with full load torque is proportional to square of speed. The line to line voltage through a low pass filter of 200Hz is also shown. The machine rotates at a speed of 1470 rpm whereas the synchronous speed is 1500 rpm .the machine takes an acceleration time around, 0.12 sec to reach its steady state value.

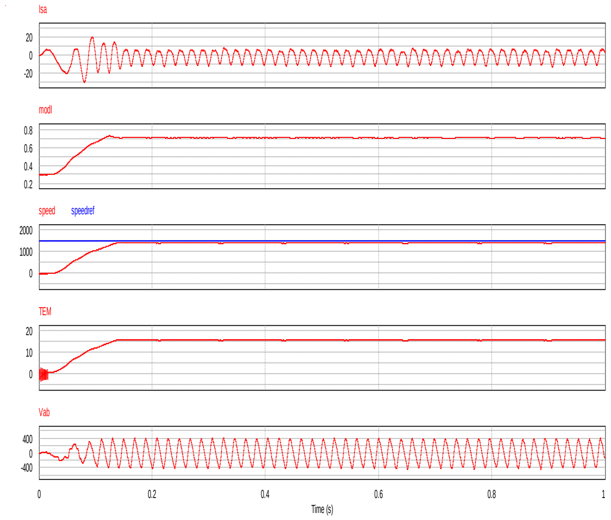

Figure 10. The system response of ZSI fed induction motor drive with rated input dc voltage.

Now the input voltage is reduced by 20% and wave forms are obtained for different frequencies.

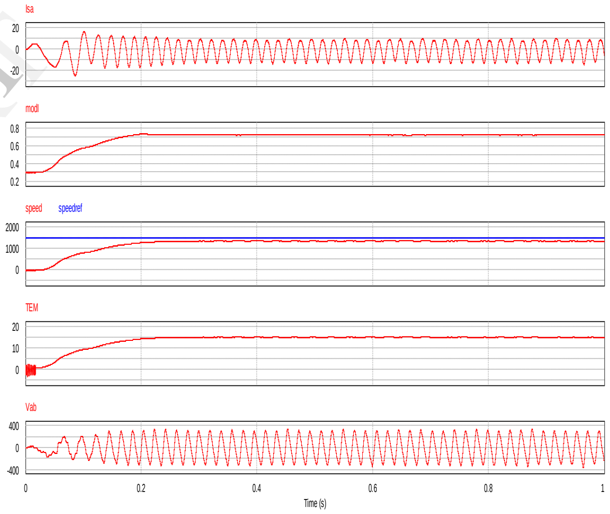

Figure 11.The system response of VSI fed induction motor drive with 20% reduction in input dc voltage at 50Hz

It is observed that speed waveform exhibits large ripples at low frequencies.The curent and voltage waveforms are also slightly distorted .Also speed control beyond the rated speed is limited in scalar control. At base speed, the voltage and frequency reach the rated values as listed in the nameplate. We can drive the motor beyond base speed by increasing the frequency further. However, the voltage applied cannot be increased beyond the rated voltage. Therefore, only the frequency can be increased, which results in the field weakening and the torque available being reduced.

Above base speed, the factors governing torque become complex, since friction and windage losses increase significantly at higher speeds. Hence, the torque curve becomes nonlinear with respect to speed or frequency.

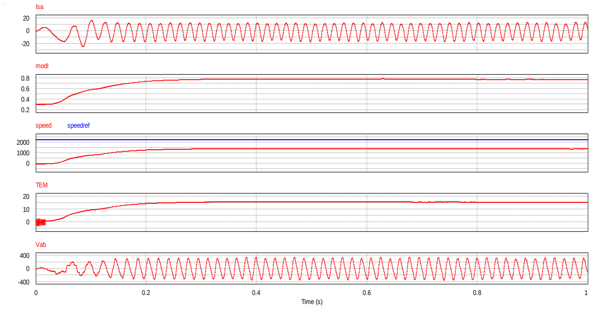

Figure 12. The system response of VSI fed induction motor drive with 20% reduction in input dc voltage at 75 Hz.

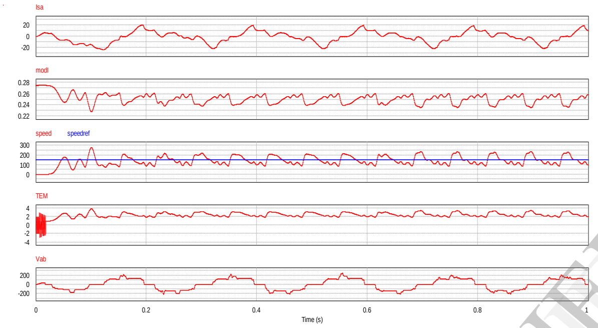

Figure 13. The system response of VSI fed induction motor drive with 20% reduction in input dc voltage. with 5 Hz

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5. Conclusions

This paper presents a new closed loop speed control of an induction motor fed by Z-source inverter based on V/F control. The peak dc link voltage is controlled by a single loop controller. The simulation results verified the validity of the proposed closed loop speed control methods during start up and input voltage change. The ZSI can be improved by controlling linearly the capacitor voltage. The proposed method can achieve the good transient responses of variations of both the reference capacitor voltage and reference output voltage, and also during 20 % dc input voltage sag. Following observations are made:

- Output voltage can be boosted to any desired value by varying shoot-through period T_0, in zero states without changing active state for a fixed modulation index.
- Component size (L & C) and hence cost required is less as compared to traditional PWM inverter.
- Stator current is smooth as compared with traditional PWM inverter.

The drive system can increase the effectiveness of overall performance.

6. References

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