

A CLOSED LOOP ANALYSIS OF Z-SOURCE INVERTER FED INDUCTION MOTOR DRIVE WITH VARIABLE LOAD TORQUE

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Abstract - This paper presents performance characteristics of Z-source inverter (ZSI) fed Induction Motor (IM) drives. ZSI has unique impedance network coupled between the power source and converter circuit to provide voltage buck and boost properties which cannot be achieved with conventional voltage source and current source inverters. To facilitate understanding of speed control for ZSI fed IM drives v/f control with simple boost PWM technique used. Simulation results of ZSI fed IM drives are compared with traditionally used VSI fed IM drives gives better performance for variable load torque, speed, rotor current characteristics.

Key Words: SPWM, Simple-boost control, Induction Motor drives, Voltage source inverter, Z-source inverter.

1. INTRODUCTION

A ZSI is a type of power inverter, a circuit that converts direct current to alternating current. It functions as a buck-boost inverter without making use of DC-DC converter bridge. Generally there two types of traditional inverter: Voltage Source Inverter (VSI) and Current Source Inverter (CSI). In conventional Voltage-Source Inverter, the dc capacitor is the sole energy storage and filtering element to suppress voltage ripple and serve temporary storage. The AC voltage limited below and cannot exceed the dc-rail voltage the VSI is a buck (step-down) inverter. As upper and lower devices of each phase leg gated simultaneously either by any reason or by Electromagnetic Interference (EMI) noise causes a shoot-through problem which effect on reliability of inverter and dead time to block both upper and lower devices provided in VSI which cause waveform distortion because of this VSI has relatively low efficiency.

The VSI fed IM Drives suffers from some common problems like

- Obtained output voltage is limited quite below the input voltage.
- Voltage sag can interrupt the drive system and shut down critical loads as dc-capacitors in VSI

fed IM drives is small energy storage element which cannot hold dc voltage above level under such voltage sag.

- Inrush and harmonic current can distort the line.
- Miss-gating cause shoot-through problem and common mode voltage causes shaft current reason in failures of the motor and dead time cause low reliability and has unstable operation at low speeds.

A recently developed new inverter, Z-source inverter for motor drives overcome all above mentioned problems.

2. EQUIVALENT CIRCUIT AND OPERATING PRINCIPLE OF ZSI

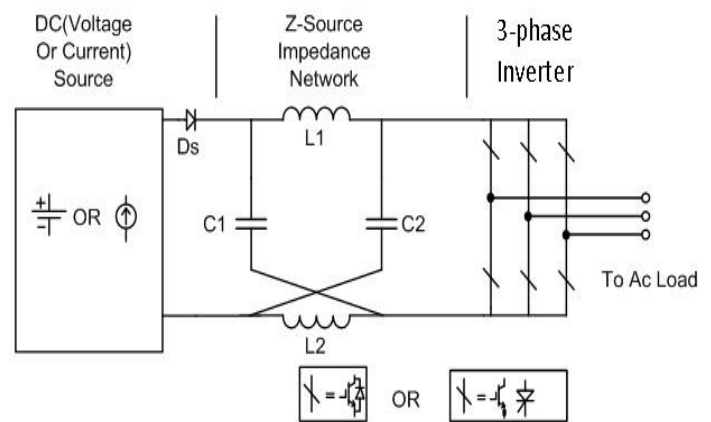


Fig -2.1: General Structure of Z-Source Inverter

Figure 2.1 shows general circuit diagram of Z-SOURCE INVERTER. The ZSI having Z-impedance network as it consists of two inductors and two capacitors connected in a X-fashion. Unlike in traditional three-phase inverter has eight switching states a ZSI bridge has nine switching states. The VSI has six active states when the DC voltage is impressed across load and two zero states where load terminals are shorted else ZSI has one extra zero state where both the upper and lower switches of a phase leg gating at same time, this extra zero-state is called as shoot-through zero state to boost the DC bus voltage. The shoot through state is not allowed in VSI as it occur shoot-through. This shoot-through zero state in ZSI can

be generated by different ways via anyone phase leg, combination of any two legs and all three legs.

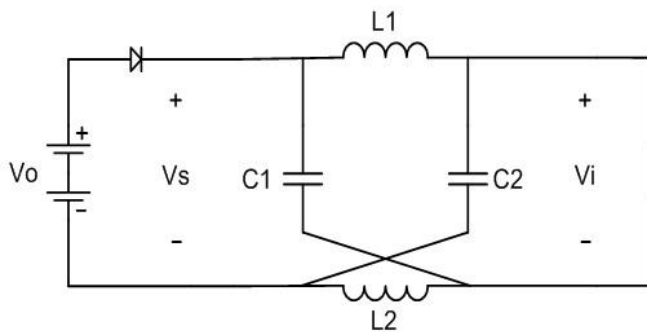


Fig -2.2: Equivalent circuit of ZSI in shoot-through zero switching state.

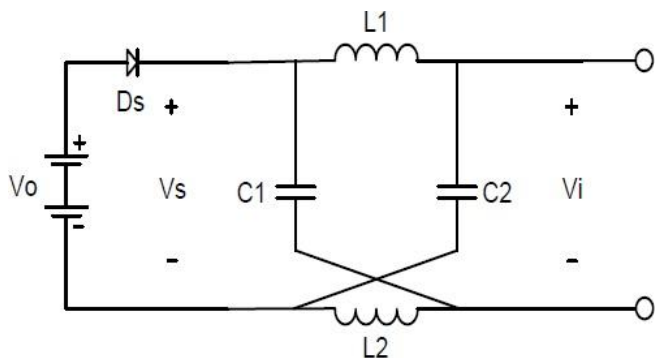


Fig -2.3: Equivalent circuit of ZSI in Traditional zero switching state.

To know the operating principle of the ZSI, figure 2.2 shows equivalent circuit of the Z-Source Inverter viewed from DC link. Figure 2.3 shows the inverter bridge is equivalent to a short circuit when inverter bridge in shoot-through zero state, whereas the inverter bridge becomes an equivalent current source as shown in figure 2.4 when in one of the six active states.

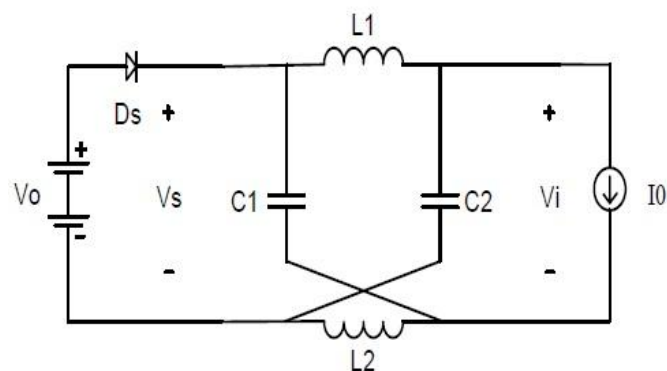


Fig -2.4: Equivalent circuit of ZSI in non-shoot through zero switching state.

For circuit analysis to get output voltage assuming that the inductors L1 and L2 and capacitors C1 and C2 have same

inductance (L) and capacitance (C) respectively. As summarized all equations. The output peak phase voltage from the traditional inverter can be expressed as

$$\hat{v}_{ac} = M (V_0/2)$$

In ZSI one more additional control parameter is introduced, named as the Boost Factor (B), which modifies the AC output voltage equation of Z-Source Inverter as following

$$\hat{v}_{ac} = BM(V_0/2)$$

Where,

\hat{v}_{ac} = Maximum sinusoidal inverter output voltage

M = Modulation Index

V_0 = DC input voltage

The Boost factor is given as

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

Where, T_0 is the shoot-through interval over one switching cycle T.

3. SIMPLE BOOST CONTROL METHODS

There are various methods can be used to control ZSI. This can be classified into two according to the different shoot-through states insertion methods. In first method shoot-through are generated by properly level shifting the modulation signals of voltage source inverter. Shoot-through states then will be inserted at every state transition. In second method, there is direct replacement of null states (111 and 000) by shoot-through states. In this paper we used simple boost control method which is illustrated in figure 3.1. In this two straight lines are employed to realize the shoot-through duty ratio. The first line is equal to the peak value of the three-phase sinusoidal reference voltages while other line is the negative of the first one. Whenever the triangular carrier signal is higher than the positive straight line or lower than the negative straight line, the inverter will operate in shoot-through else wise it work as a traditional PWM inverter. Figure 3.1 shows the modulation, the driver signals for two switches and shoot-through signals of simple boost control method and figure 3.2 shows the sinusoidal PWM technique which is use in VSI fed IM drives.

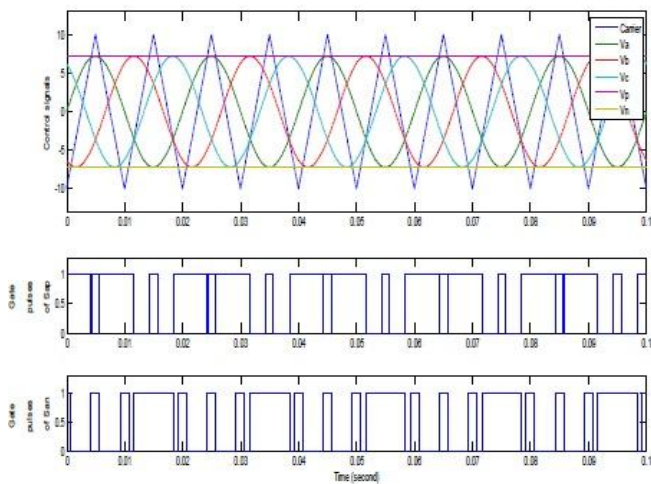


Fig -3.1: PWM Signal of Simple Boost Control.

In three-phase SPWM, a triangular voltage waveform (carrier waveform) is compared with three sinusoidal control voltages (reference waveform), which are 120° out of phase with each other and the relative levels of the waveforms are used to control the switching of the devices in each phase leg of the inverter.

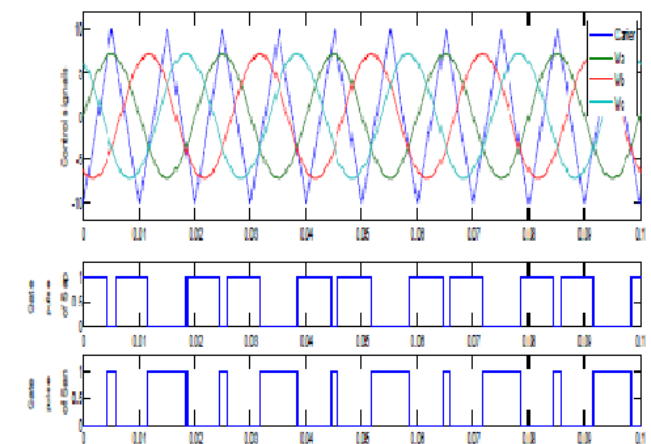


Fig -3.2: Sinusoidal PWM technique

4. CLOSED LOOP V/F CONTROLLED INDUCTION MOTOR DRIVE

The volts per hertz (V/F) induction motor drives with inverters are widely used in a number of industrial applications leading not only to energy saving, but also to improvement in productivity and quality. This is the effective way of producing a variable speed drive is to supply the induction motor with variable magnitude and variable frequency AC supply and variable frequency is required because rotor speed depends on the speed of rotating magnetic field provided by stator which depends on supply frequency. A variable voltage is required because the motor impedance reduces at low frequencies

and consequently the current has to be limited by means of reducing the supply voltage is given by this method. The main advantage of V/F control is its simplicity. This paper presents V/F control for speed control of a three phase IM fed by a high performance ZSI. A simplified diagram of the V/F controlled induction motor is shown in Fig.4. When accuracy in speed response is a concern, closed-loop speed control can be implemented with the constant fv principle through the regulation of slip speed. A PI controller is employed to regulate the slip speed of the motor to keep the motor speed at its set value.

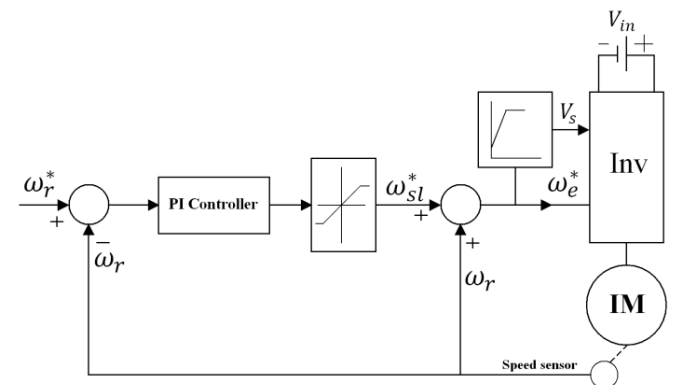


Fig -4: V/F based closed loop speed control scheme of an Induction Motor.

The closed loop control by slip regulation of the combined inverter induction motor improves the dynamic performance. The speed loop error generates the slip command ω_{sl}^* through a proportional integral (PI) controller and a limiter. The slip is added to the speed feedback signal to generate the slip frequency command ω_e^* . Thus the frequency command generates the voltage command through a Volts/Hz generator.

5. VSI FED IM DRIVE AND ZSI FED IM DRIVE

In this paper, for the comparison of VSI and ZSI, two models are prepared in MATLAB/SIMULINK. ZSI fed IM drive model is based on simple boost control technique. Whereas, the VSI fed IM drive model is based on sinusoidal pulse width modulation (SPWM). All the traditional pulse width modulation (PWM) schemes can be used to control the ZSI and their theoretical input-output relationships.

6. SIMULATION MODEL IN MATLAB

Both systems are developed in MATLAB software. Figure 6.1 shows the complete developed closed loop model of ZSI fed IM drive with v/f control. In this simple boost control method is used and speed which occurred is given to closed loop block for comparing with required speed and figure 6.2 shows the developed model of VSI fed IM drive in MATLAB.

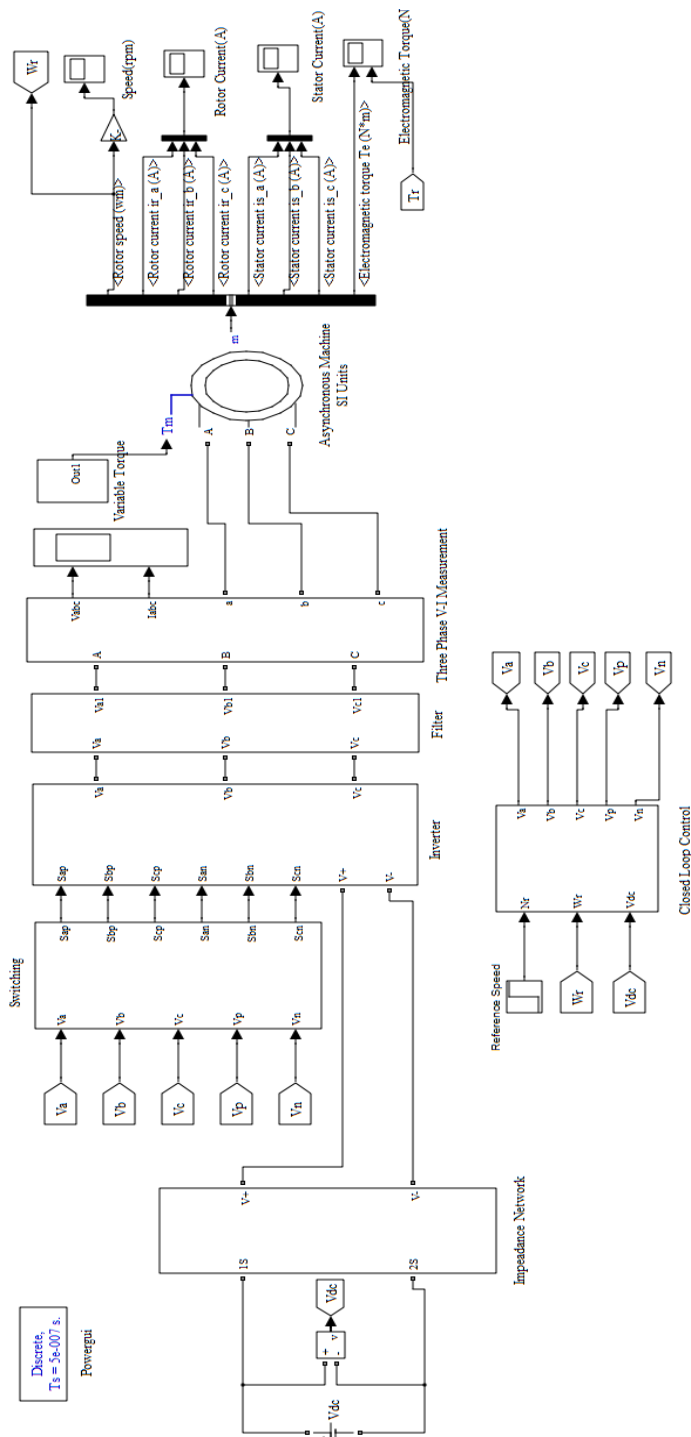


Fig -6.1: MATALB model of ZSI fed Induction Motor Drive

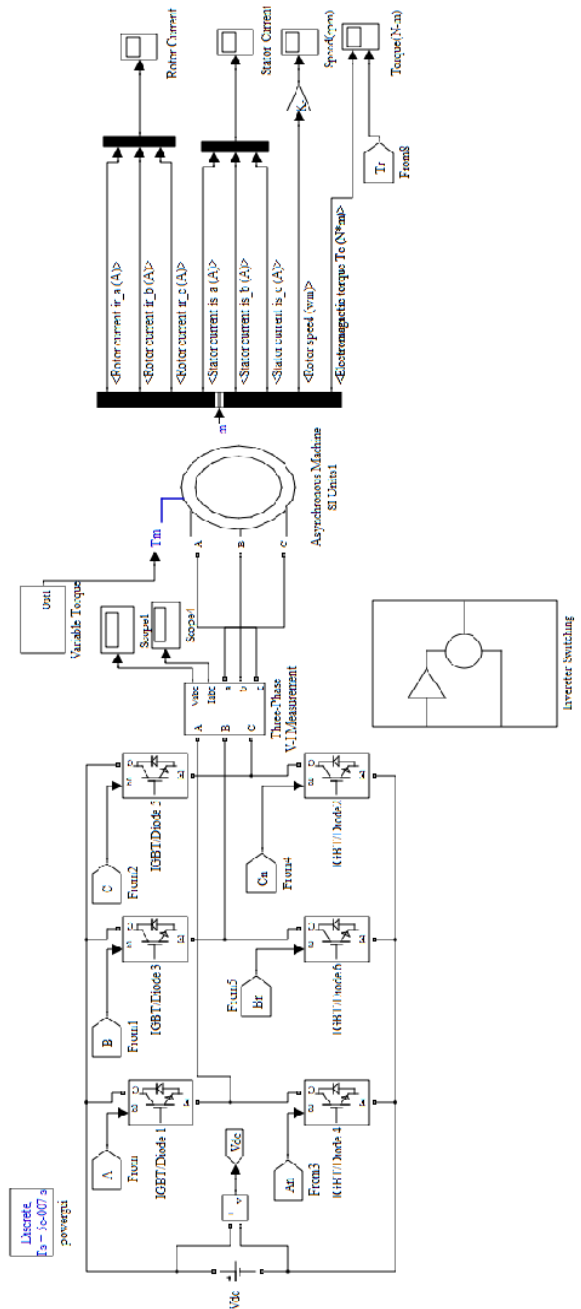


Fig -6.2: MATALB model of VSI fed Induction Motor Drive

7. SIMULATION RESULT

All the simulation results will be discussed in the following part, the simulated results obtained from the models of ZSI fed IM drive and VSI fed IM drive has been given. The different performance characteristics such as speed, torque, rotor current characteristics of ZSI fed IM drive and VSI fed IM drive are compared for the time period 0-0.3 seconds, constant torque of value 0 N-m is applied to the motor drive of VSI and ZSI. For the time period of 0.3-

0.42 seconds, the variable torque of the range between 15-30N-m is applied in the step of 0.02 seconds.

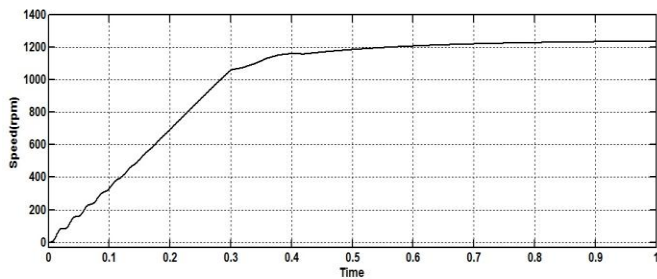


Fig -7.1: Speed of VSI fed IM Drive

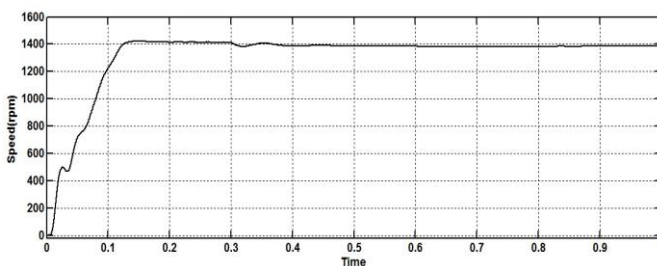


Fig -7.2: Speed of ZSI fed IM Drive

Figure 7.1 and 7.2, shows the speed of VSI fed IM drive and ZSI fed IM Drive respectively. From the results, it is clear that the ZSI gives better speed control than the VSI model. ZSI also provides less jerky motion at the starting of the motor as compared to VSI. When the variable torque is applied the change in the speed in VSI fed IM drive is greater and sudden as compared to ZSI fed IM drive. Figure 7.3 and 7.4 shows the rotor current for VSI fed and ZSI fed IM Drive resp. It shows that with ZSI, settling time for rotor current is decreased as compared to VSI. It is also clearly seen that VSI has more ripple component as compared to ZSI.

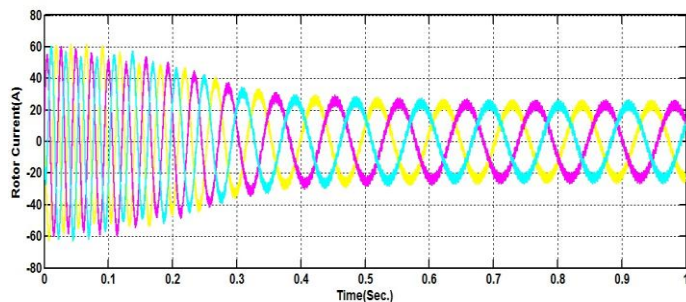


Fig -7.3: Rotor current of VSI fed IM Drive

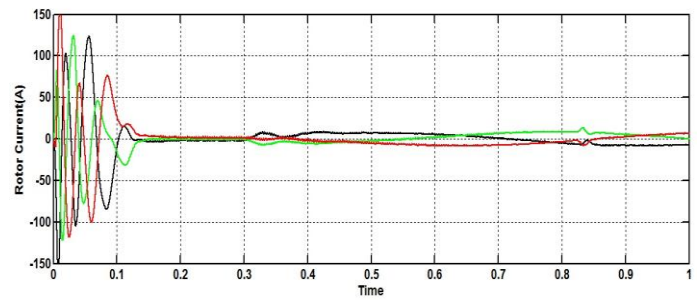


Fig -7.4: Rotor current of ZSI fed IM Drive

Figure 7.5 and 7.6, shows the electromagnetic torque of VSI fed IM drive and ZSI fed IM Drive with variable load torque respectively. From results, it is clear that the torque distortions are more in the VSI fed IM drive as compared to ZSI. It is also noted that with the ZSI fed IM drive attain the load torque with less time as compared to VSI

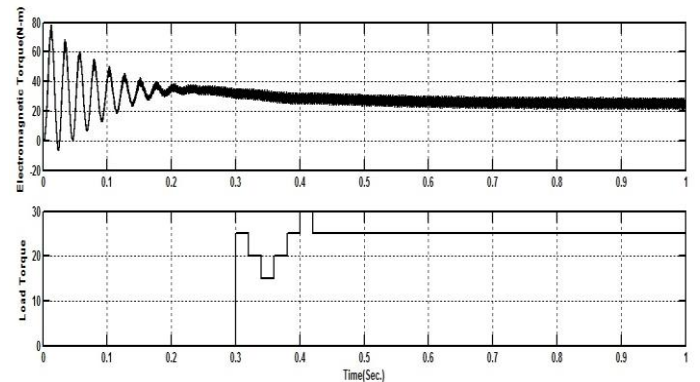


Fig -7.5: Electromagnetic Torque of VSI fed IM Drive

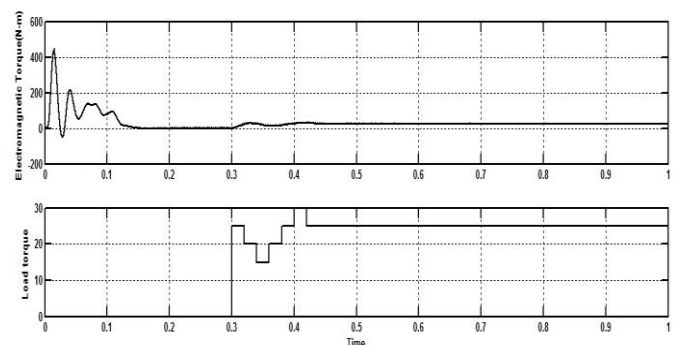


Fig -7.6: Electromagnetic Torque of ZSI fed IM Drive

8. CONCLUSIONS

This paper presents a comparative study of performance characteristics the VSI and ZSI fed induction motor drive using MATLAB. The characteristics of 3-phase induction motor such as speed, rotor current and electromagnetic torque was given on variable load conditions. Simulation

results of ZSI Fed IM Drive under simple boost control method showing better performance than ZSI Fed IM Drive.

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BIOGRAPHIES



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