Indirect Vector Controlled Induction Motor Drive with PI Controller & Current Controlled VSI

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Abstract—This paper describes Induction motor (IM) control techniques. The underlying operating principle of control schemes are described and Indirect vector controlled (IDVC) IM drive has been simulated in MATLAB/Simulink environment. The mathematical modelling of IM is presented along with its implementation in Simulink. Also current controlled VSI has been implemented using Simpowersystem blocks & the same is used to supply the IM as per the Indirect vector control scheme with PI controller thereby implementing complete IDVC drive in closed loop operation.

Keywords-Field oriented control, Vector control, HBPWM, Closed loop motor drive, PI control

I.   INTRODUCTION

The last decade has seen rapid growth in the field of electrical drives. This growth can be attributed mainly to the advantages offered by both power and signal electronics; hence giving rise to powerful microcontrollers and DSPs. These technological improvements have allowed the development of very effective AC drive controls.

Nowadays many industrial applications which require electrical drives demand precise speed and torque control, to increase production quality. Moreover proper control of these drives using modern control schemes also improves system efficiency. For applications requiring precise control previously DC drives were preferred because of their inherent ability to give independent speed and torque control [2]. But these drives have higher maintenance costs because of brush and commutator construction.

Ever since its development IM have dominated the market of constant speed drives. IM are the work horses of the industries. It has lot of advantages over dc motors for industrial applications, among which ruggedness and low maintenance costs are desirable for industries. But owing to its inherent characteristics decoupled control of speed and torque is not possible by conventional control strategies. So IM drives were not preferred where accurate control is required. But recent advances in control strategies like closed loop control with constant V/f method, Vector control (Field oriented control) allows us to control IM better than conventional control. These drives known as Variable Frequency Drives, has made IM the industrial standard for variable speed applications. In this paper Scalar control technique & vector control technique with Voltage source inverter (VSI) for speed control of IM has been discussed. These drives are simulated in MATLAB and tracking of reference speed & torque has been observed.

II.   SCALAR CONTROL

Scalar Control or Volts/Hertz control (V/f Control) is one common speed control technique for variable frequency drives (VFDs) in the industry. In this type of control, the motor is fed with variable frequency signals generated by the Pulse Width Modulation (PWM) control from an

inverter. Here, the V/f ratio is maintained constant in order to get constant torque over the entire operating range. Since only magnitudes of the input variables "frequency and voltage" are controlled, this is known as "scalar control". Generally, the drives offer low cost and is an easy to implement solution.

A disadvantage of scalar control (V/f control) is that the torque developed is load dependent, as it is not controlled directly. Also, the transient response of such a control is not fast due to the predefined switching pattern of the inverter [3]. Of course, this control method is not good for some critical applications. But, in many application cases, these do not warrant the cost of a more sophisticated drive, such as vector control AC drive (VFD) and for some applications, especially for some pumps and fans system, V/f control drive is enough, no need to use a more sophisticated one [8].
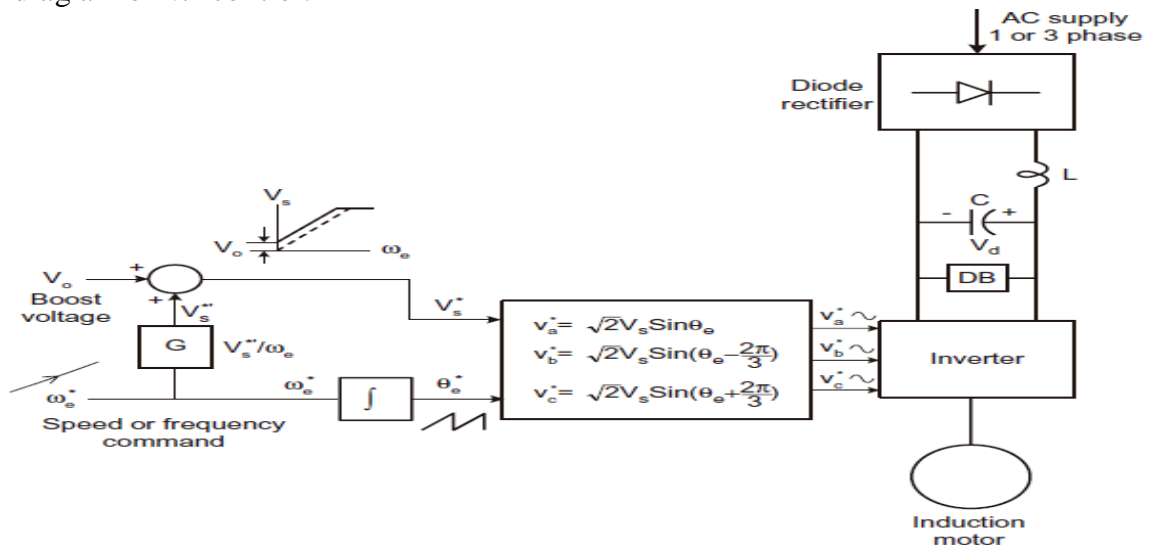
A. Block diagram of V/f control:

Fig. 1 Scalar control block diagram

III.   VECTOR CONTROL

Scalar control of induction motor have provide good steady-state but poor dynamic response. In vector control, an induction motor is controlled like a separately excited dc motor. In a dc motor, the field flux Ψ_f and armature flux Ψ_a, established by the respective field current I_f and armature or torque component of current I_a, are orthogonal in space so that when torque is controlled by I_a, the field flux is not affected, thus giving fast torque response.

Similarly, in vector control, stator current is resolved in direct & quadrature axis components in synch ref frame. The synchronous reference frame currents i_{ds} and i_{qs} are analogous to I_f and I_a, respectively, and ids is oriented in the direction of rotor flux Ψ_r. Note that Ψ_r is used instead of Ψ_m or Ψ_s because with Ψ_r orientation true decoupling is obtained. Therefore, when torque is controlled by i_{qs}, the rotor flux is not affected thus giving fast dc motor-like torque response [1]-[8].
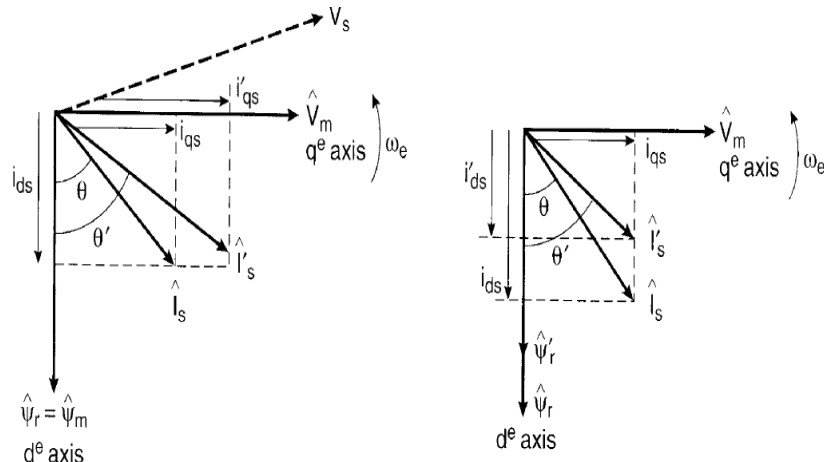
A. Phasor diagram:

Fig. 2 Phasor diagram explaining principle of Vector Control

There are two methods of vector control depending on the derivation of the unit vector. These are the direct (or feedback) method and indirect (or feed forward) method.

B. Direct VC

In the direct vector control the flux vector is estimated from the values of machine voltage & currents or using flux sensors. This data is used to align the direct axis current along rotor flux. The inverter currents are synthesized according to the reference given by vector controller.
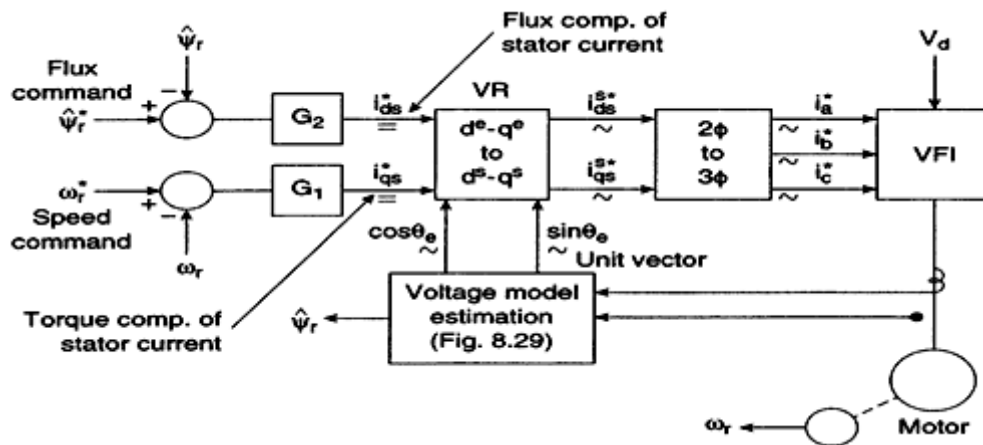
Fig. 3 Direct vector control block diagram

C. Indirect VC

In indirect vector control, the slip command signal $w_{sl}*$ is derived from the command $I_{qs}*$ through the slip gain. This signal is then added to the speed signal w_r, integrated, and then the unit vector components are derived as explained below.

The d_s-q_s axes are fixed on the stator and the d_r-q_r axes are fixed on the rotor. The d_e-q_e axes are rotating at synchronous speed and so there is a slip difference between the rotor speed and the synchronous speed given by:

$$\theta_e = \int \omega_e \, dt = \int (\omega_r + \omega_{sl}) dt = \theta_r + \theta_{sl}$$

The speed signal is obtained from an incremental encoder. In the constant torque region, the rated flux is generated by constant ids command. A hysteresis-band current control is used, although other types of PWM are entirely possible. The control operates smoothly from zero speed. The indirect VC is used widely in industry. However, one disadvantage is that the slip gain parameters, particularly R_r, vary widely with temperature, causing a coupling effect that deteriorates transient response and affects the flux and torque transfer characteristics [7].

In order to ensure decoupling between the stator flux and the torque, the torque component of the current, i_{qs}, should be aligned with the q_e axis and the stator flux component of current, ids, should be aligned with the de axis.
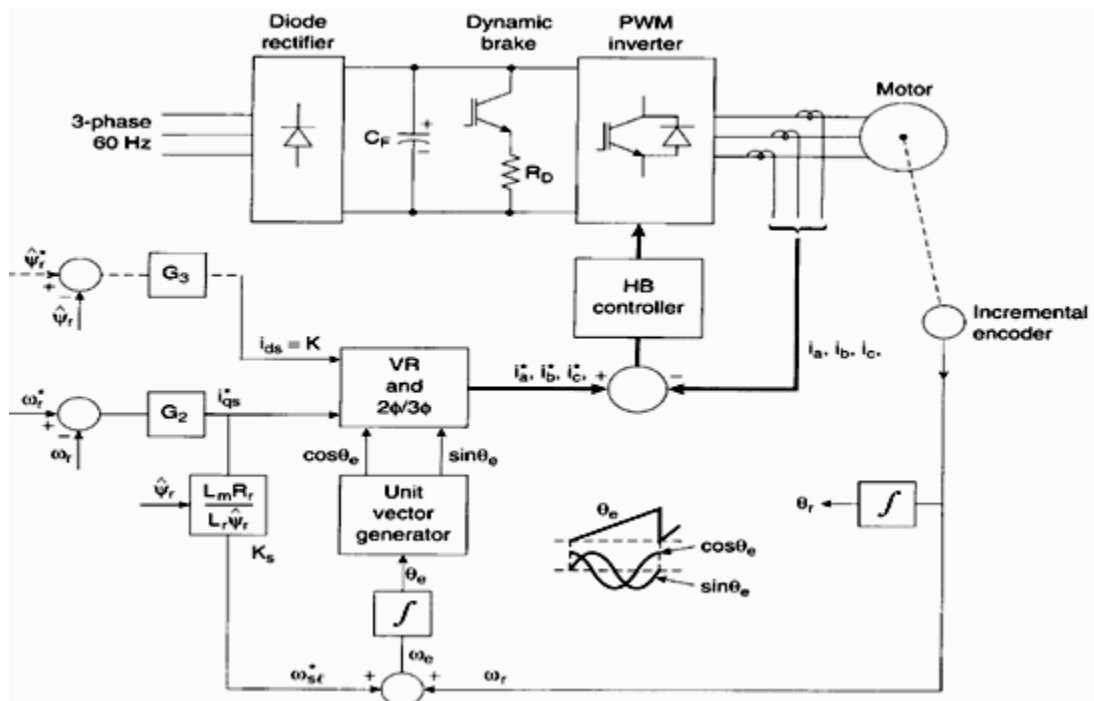

Fig. 4 Indirect vector control block diagram

Features of this implementation:
- ✓ Hysteresis-band current control.
- ✓ Constant rotor flux is maintained by using the desired i_{ds}*.
- ✓ The slip frequency w_{sl}* is generated from the desired i_{qs}*.

IV. SIMULATION OF VECTOR CONTROL

A. Mathematical Modelling of Induction Motor

The mathematical model of induction motor using the equations as shown below has been implemented in Matlab/Simulink blocks [5].

1) *Electrical sub-model:*

$$\begin{bmatrix} V_{ds} \\ V_{qs} \end{bmatrix} = \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix}$$

$$I = \int \{B^{-1} \times (V - CI)\}\,dt$$

$$\text{Where } I = \begin{bmatrix} i_{ds} \\ i_{qs} \\ i_{dr} \\ i_{qr} \end{bmatrix};$$

$$B = \begin{bmatrix} L_s & 0 & L_m & 0 \\ 0 & L_s & 0 & L_m \\ L_m & 0 & L_r & 0 \\ 0 & L_s & 0 & L_r \end{bmatrix};$$

$$V = \begin{bmatrix} V_{ds} \\ V_{qs} \\ V_{dr} \\ V_{qr} \end{bmatrix};$$

$$C = \begin{bmatrix} R_s & 0 & 0 & 0 \\ 0 & R_s & 0 & 0 \\ 0 & \dfrac{P}{2}\omega_0 L_m & R_r & \dfrac{P}{2}\omega_0 L_r \\ -\dfrac{P}{2}\omega_0 L_m & 0 & -\dfrac{P}{2}\omega_0 L_r & R_r \end{bmatrix}$$
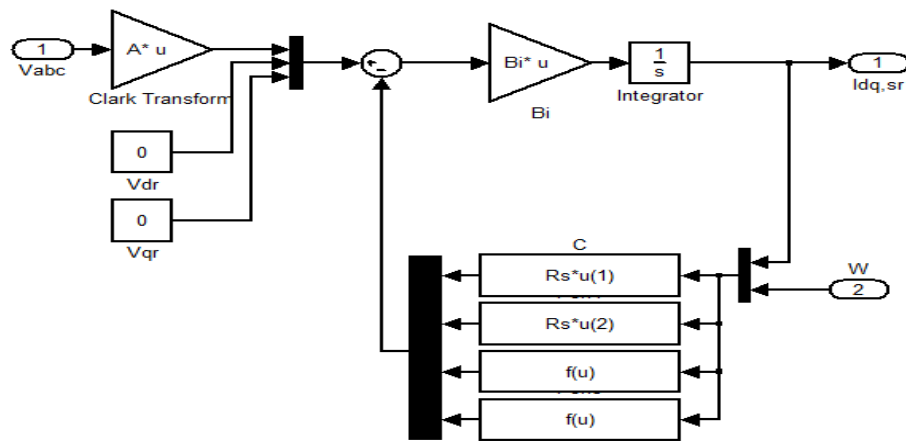

Fig. 5 Simulink model of electrical sub-model

2) *Torque sub-model:*

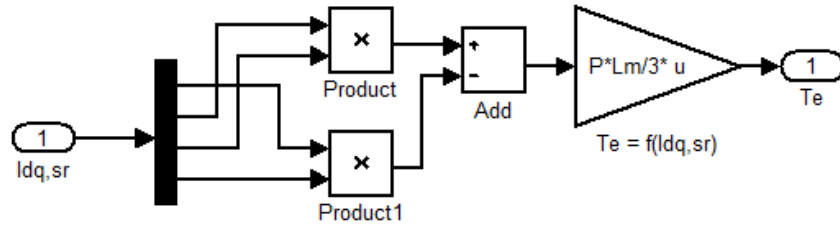$$T_e = \frac{PL_m}{3}(i_{dr}\,i_{qs} - i_{qr}\,i_{ds})$$

Fig. 6 Simulink model of torque sub-model

3) Speed sub-model:

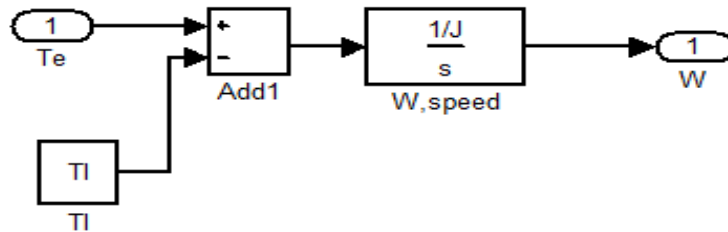$$\omega_0 = \int \frac{T_e - T_l}{J} dt$$

Fig. 7 Simulink model of mechanical sub-model
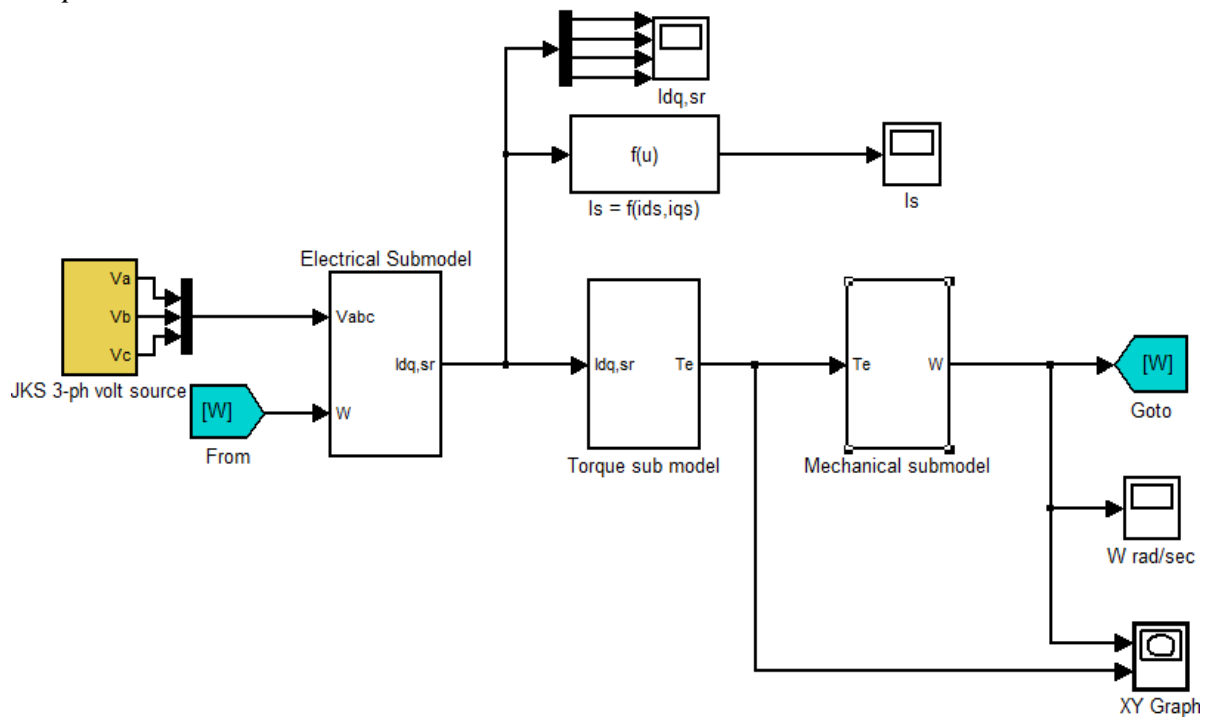
4) The complete IM model :

Fig. 8 Simulink model of IM combining above shown submodels
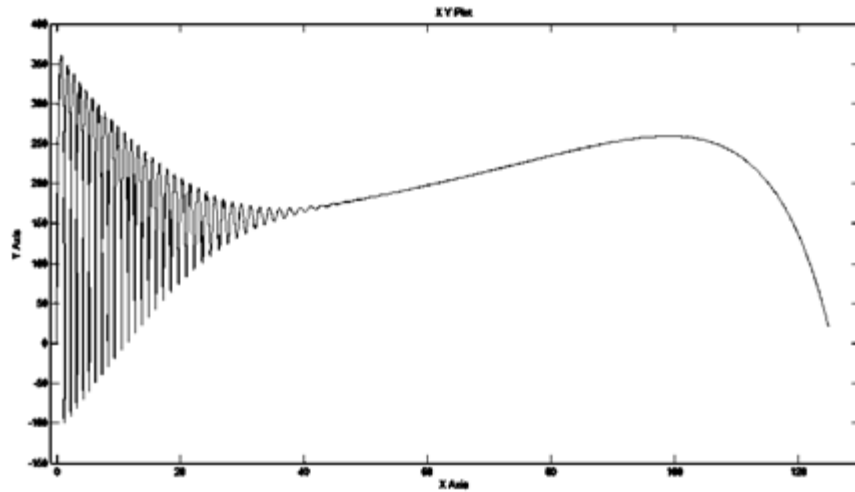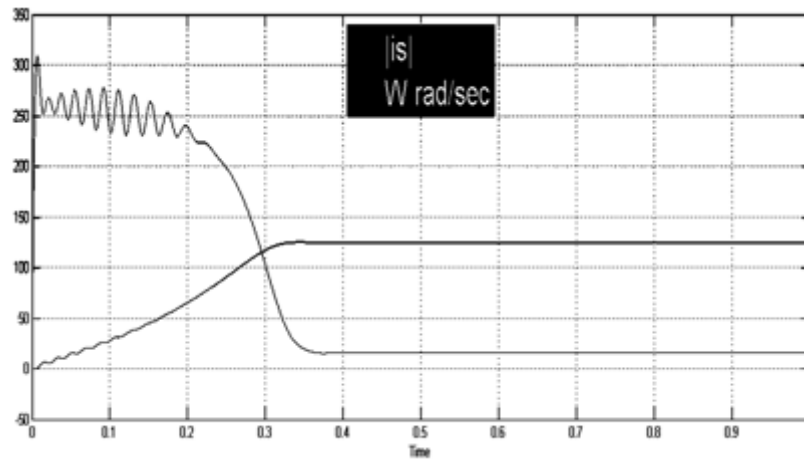
Fig. 9 Torque-Speed characteristic

Fig. 10 Stator current(A) & Rotor speed(rad/sec)

B. Hysteresis Band Inverter

The hysteresis band current control PWM has been used because of its simple implementation, fast transient response, direct limiting of device peak current and practical insensitivity of dc link voltage ripple that permits a lower filter capacitor.

The HBPWM is basically an instantaneous feedback current control method of PWM where the actual current continually tracks the command current within a specified hysteresis band [7].
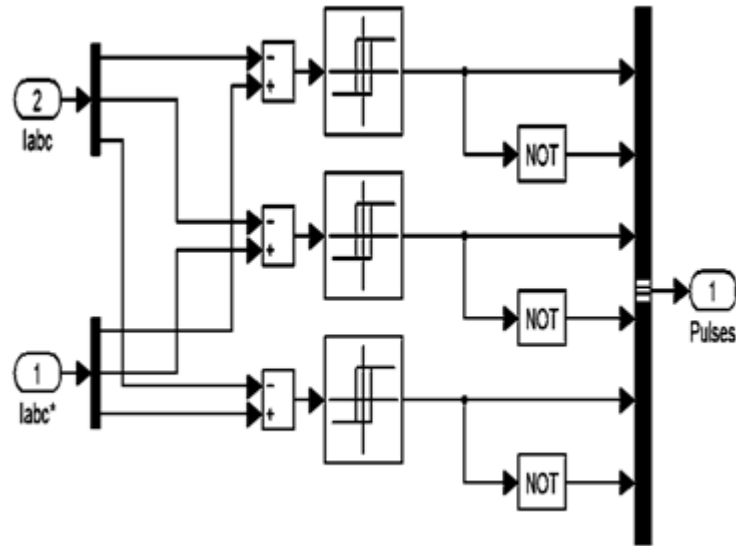
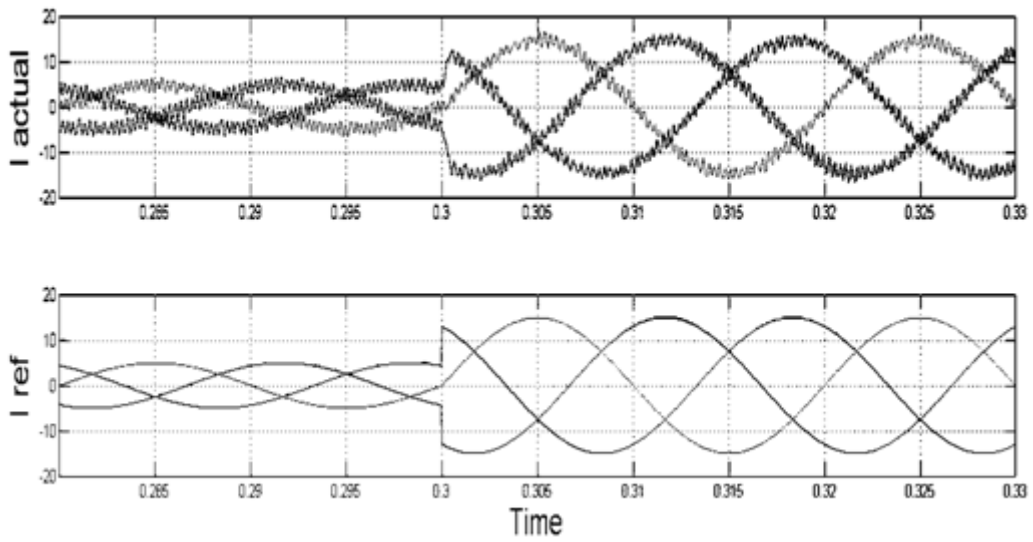*Fig. 11 Switching pulse generation by HB PWM logic for VSI*

Fig. 12 Stator current reference(A) & Actual currents(A)
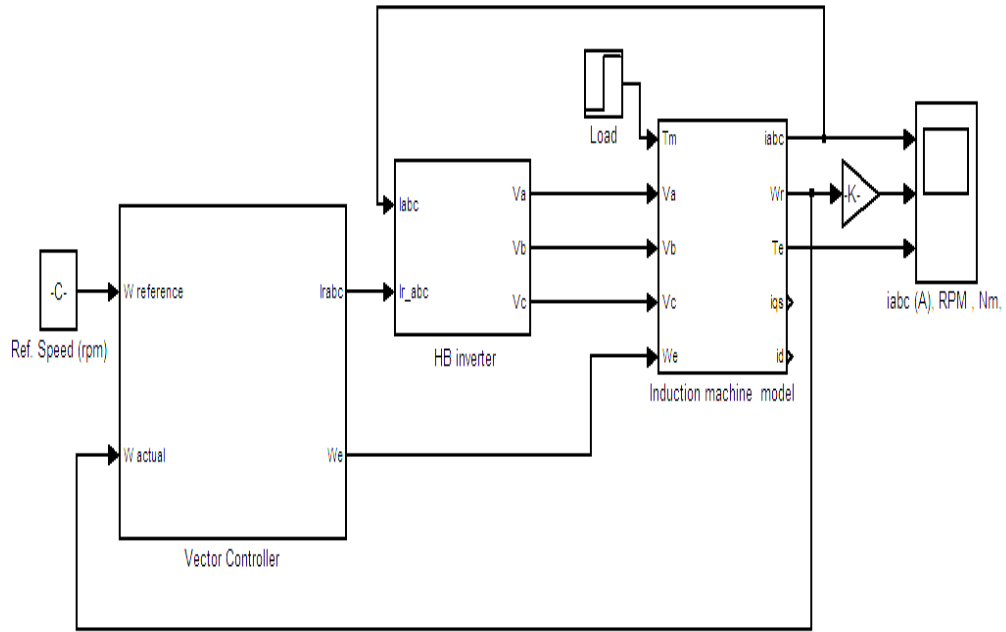
C. Vector control implementation

Fig. 13 Vector controlled drive simulation

CASE-1:
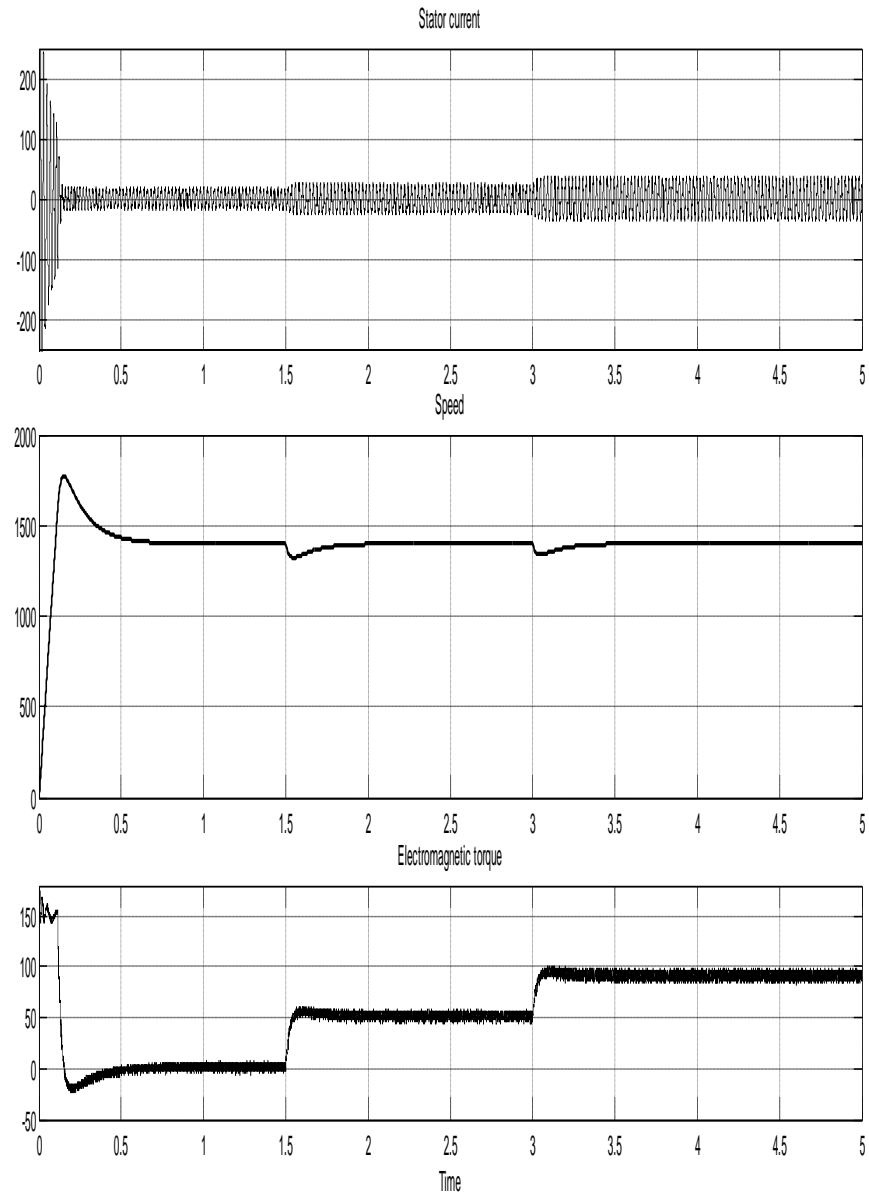Constant speed reference & variation in load:

Fig. 14 Stator currents(A), Rotor speed(rad/sec), Electromagnetic torque(Nm) for Case 1

CASE-2:
Constant load & variation in speed reference:(Step change in speed reference at 1.5 s)
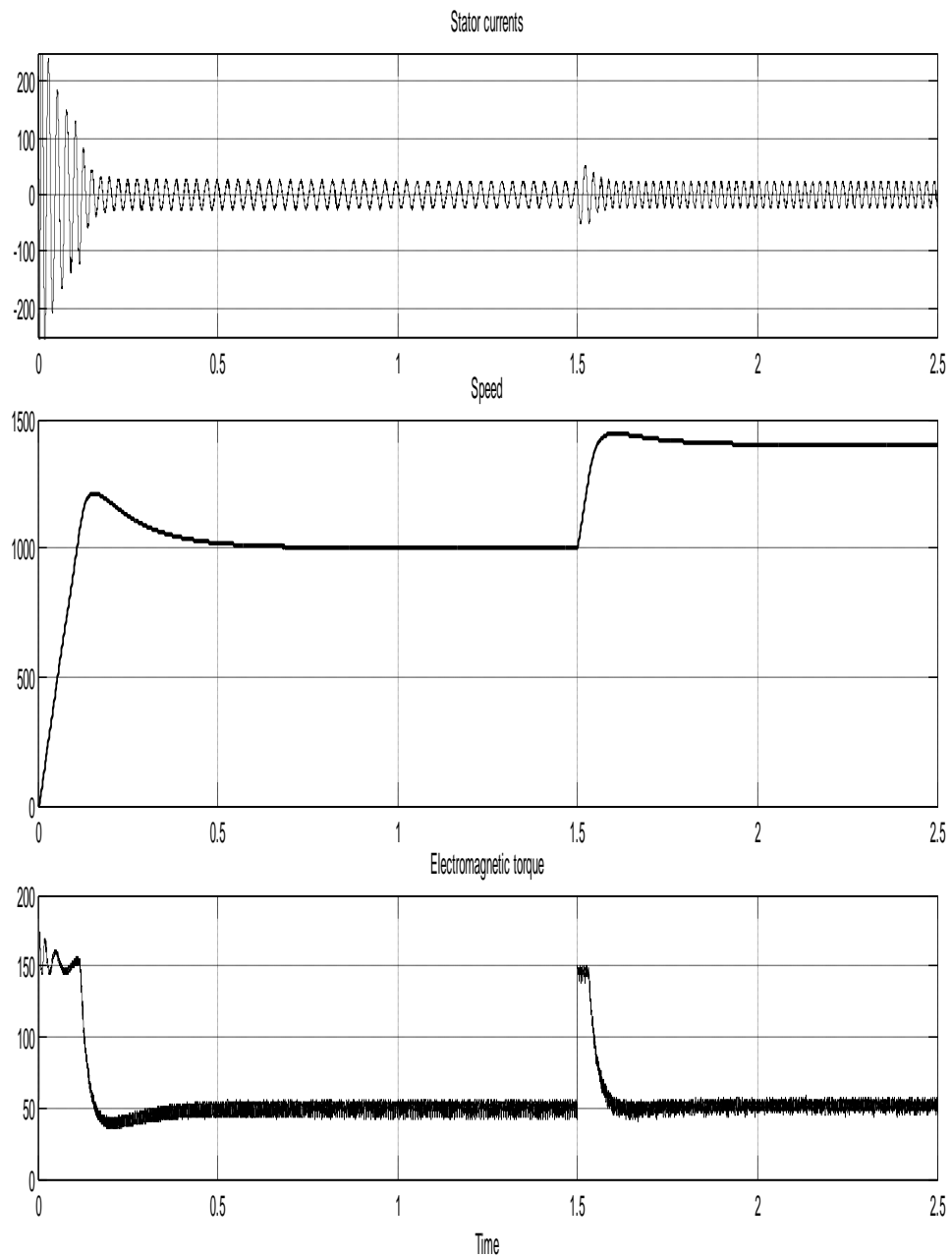
Fig. 15 Stator currents(A), Rotor speed(rad/sec), Electromagnetic torque(Nm) for Case 2

V.   CONCLUSIONS

The simulation results of induction motor mathematical model shows torque speed characteristics which are as per theoretical one. The HB PWM inverter simulation show that it tracks reference currents accurately which is very important in a vector control scheme. The output wave forms of speed & electromagnetic torque for constant speed command shows that in case of variation of load, the speed of motor varies for a small fraction of time remaining very close to reference &

again tracks the reference accurately. In case of step change speed command waveforms shows that it takes very less time to track the change in reference thus concluding that vector control drive gives accurate speed control and gives a better dynamic response.

VI.   APPENDIX

Parameters of Induction Motor:

R_s = 0.2147 Ω /ph R_r = 0.2205 Ω/ph

L_s = 65.101 mH L_m = 64.11 mH

L_r = 65.101 mH   J = 0.102 kg m^2

Other symbols:

R_s	=	Stator resistance
R_r	=	Rotor resistance
L_s	=	Stator inductance
L_m	=	Magnetizing inductance
L_r	=	Rotor inductance
J	=	Rotor inertia
W_r	=	Rotor speed
W_{sl}	=	Slip speed
W_e	=	Synchronous speed
θ_e	=	Rotor angle
P	=	Number of poles
i_{ds}	=	Direct axis stator current
i_{qs}	=	Quadrature axis stator current
i_{as}, i_{bs}, i_{cs}	=	3-phase stator currents
T_e	=	Electromagnetic torque
T_l	=	Load torque
Ψ_r	=	Rotor flux
Ψ_m	=	Air-gap flux
Ψ_s	=	Stator flux

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