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Simulink Implementation of Hysteresis Current ControlledIndirect Field Oriented Drive for Induction Motor

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Abstract —***Here, main purpose of the indirect field oriented control strategy is to decouple the torque and flux vectors in synchronous rotating frame of induction machine, through which we can achieve an independent speed and torque control and good dynamic response. This indirect field oriented control (Now onwards called as IFOC) scheme will also improve the drive performance. Hysteresis current control technique is used here for closed loop control of inverter because of its simplicity of implementation and quick response. PI controller is tuned by trial and error method here, and is used for speed control so that it will track an exact speed given as a reference input and generates torque command accordingly. Due to the several features of this drive it is very useful in industries and now a days they are replacing traditional scalar controlled drive. Simulation results are discussed here and obtained using MATLAB/SIMULINK package.***

Keywords-Indirect Field Oriented Control (IFOC), Hysteresis Current Control (HCC), Induction Motor Drive, Vector Control, PI controller for speed control, Hysteresis Band(HB).

I. INTRODUCTION

Traditionally, electrical drives were mainly installed with dc motors because of their excellent controllability. However, recent high-performance motor drive systems are usually based on 3-ph AC motors, such as the ac induction or the PMSM. These machines have replaced the DC machines as the machine of choices in drive system because of their ruff and tuff construction, high power density, high torque density, low inertia and good performance at high speeds of rotation [1].

Before the vector controlled drive were introduced, V/f control (or Scalar Control) method was the control technique has the base of adjustable speed drive applications.

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 this is a disadvantage of scalar control (V/f control), and hence this control method is not good for some critical applications like servo applications, positioning control etc. Then Vector Controlled drives are introduced to recover these drawbacks of scalar drive.[2]

The basic operating principle of vector controlled drive is to separate flux producing component & torque producing component of stator current; which are direct axis & quadrature axis current components respectively. Now we can independently control torque generated by motor by controlling quadrature axis current without affecting the flux as direct axis current is maintained constant. Similarly decoupled flux control can be achieved by varying direct axis current only. Thus current control is of prime significance in vector control of induction motor.[1]

II. INDIRECT FIELD ORIENTED CONTROL

Principle of FOC is to produce a field that operates induction motor similar to DC motor with optimal torque production.Indirect Field-Oriented Control is nearly same as Direct Field-Oriented Control but the generation scheme of unit vectors (feed-forward manner) is different. Fig.1 shows the phasor diagram which describes the principle of indirect field-oriented control. The d_s-q_s are the stator axis and the d_r-q_r are the rotor axis rotating at speed ω_r as shown below. The d_e-q_e are the synchronously rotating axes ahead of the d_r-q_r axes at slip angle θ_{sl} at frequency ω_{sl}, so we can write[3][7].

$$\theta_e = \int \omega_e dt = \int (\omega_r + \omega_{sl})dt = \theta_r + \theta_{sl} \ldots\ldots(1)$$

IFOC aims for 90’ angle between d and q axis components of stator current and they are controlled in such a manner so that i_{qs} produce the required torque and i_{ds}maintainsthe flux value at rated. Fig. 1 describes phasor diagram showing relations as explained above.[4]

Relation between stator current and d-q axis currents is,

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} sin\theta & \sin(\theta - \frac{2\pi}{3}) & \sin(\theta + \frac{2\pi}{3}) \\ cos\theta & \cos(\theta - \frac{2\pi}{3}) & \cos(\theta + \frac{2\pi}{3}) \\ 1/2 & 1/2 & 1/2 \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

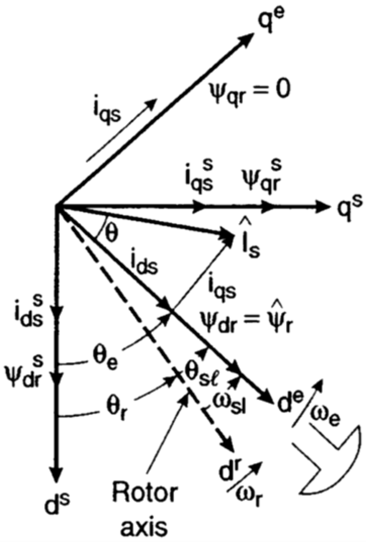


Fig.1 Phasor diagram for IFOC drive

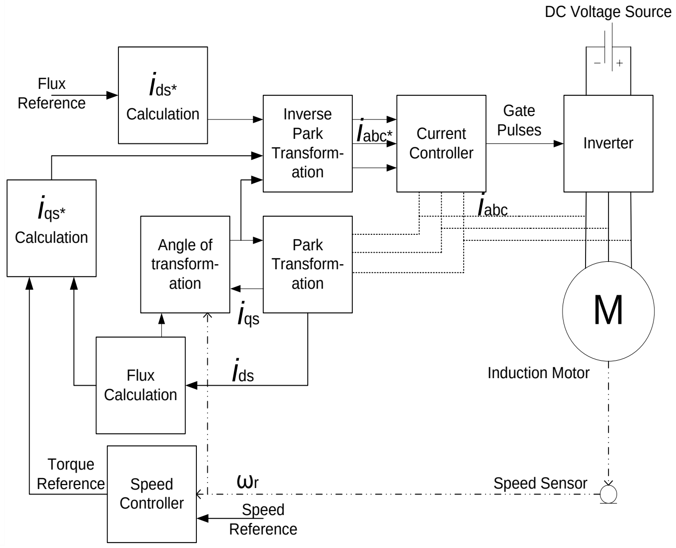


Fig.2 Block diagram of Indirect Vector Controlled Drive

For decoupling control the total rotor flux ψ_r needs to be aligned with the de-axis and thus quadrature axis flux must be zero; so we want

$$\psi_{qr} = 0 \text{.........(2)}$$

$$\text{And so, } \frac{d\psi_{qr}}{dt} = 0 \text{.......(3)}$$

So the total flux is directed along the direct axis (d_e axis).

If we now substitute values from equation 2&3 into the rotor circuit equation of induction motor, we get,

$$\frac{\mathcal{L}_r}{\mathcal{R}_r}\frac{d\psi_r}{dt} + \psi_r = \mathcal{L}_m i_{ds} \text{.......(4)}$$

Now if rotor flux is constant; which is generally in the case, we have,

$$\psi_r = \mathcal{L}_m i_{ds} \text{.......(5)}$$

$$\text{Hence, } \psi_r = \psi_{dr}$$

So rotor flux is directly proportional to ids in steady state

$$\omega_{s\ell} = \frac{\mathcal{L}_m}{\psi_r} * \frac{\mathcal{R}_r}{\mathcal{L}_r} i_{qs} \text{.......(6)}$$

Equation of torque is given as $\mathcal{T}_e = \frac{3}{2}\frac{\mathcal{P}}{2}\frac{\mathcal{L}_m}{\mathcal{L}_r}(\psi_{dr} i_{qs} - \psi_{qr} i_{ds})$.......(7)

Replacing value from equation 2 in equation 7 we get

$$\mathcal{T}_e = \frac{3}{2}\frac{\mathcal{P}}{2}\frac{\mathcal{L}_m}{\mathcal{L}_r}\psi_r i_{qs} \text{ ....(8)}$$

III. FEATURES OF THIS IMPLEMENTATION

- Hysteresis-band current control.
- Speed control loop generates the current, i_{qs}*.
- Constant rotor flux is maintained by the desired i_{ds}*.
- The slip frequency ω_{sl}*is generated from desired i_{qs}*.

IV. HYSTERESIS CURRENT CONTROL SCHEME

This current control technique is also known as Hysteresis Band (HB) PWM control and it's a simplest current control technique for closed loop control of inverter. HBPWM is used for instantaneous feedback control in which actual ac line current forced to follow a given reference current within pre-defined tolerance of Hysteresis band. [3]

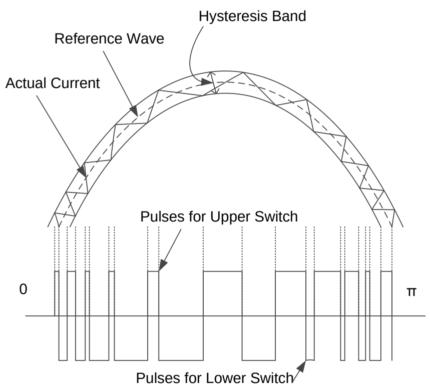


Fig 3. Pulse Generation scheme for HCC

In fig.3 it is shown that if actual current i_a exceeds the value of reference current i_a* ± HB , status of power switches will be changed. If actual current exceeds HB upper switch of the leg is turned off and lower switch is turned on and if actual current decreases than the value of lower band lower switch is turned off and upper switch is turned on. [6]

To reduce the harmonics we can decrease the value of HB, in turn it will increases the switching losses. 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.[6]

V. SPEED CONTROLLER

Here PI Controller is used to control the speed and hence to generate electromagnetic torque command. For closed loop operation the speed error is fed in to PI controller which gives output in terms of torque reference which is used to calculate Iq reference value. The Proportional-Integral action can be described as equation, shown below[5]

$$\mathcal{T}_e = K_p e(t) + K_i \int e(t)dt$$

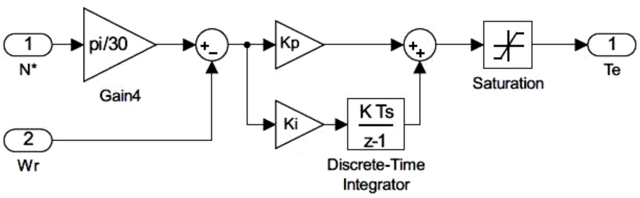
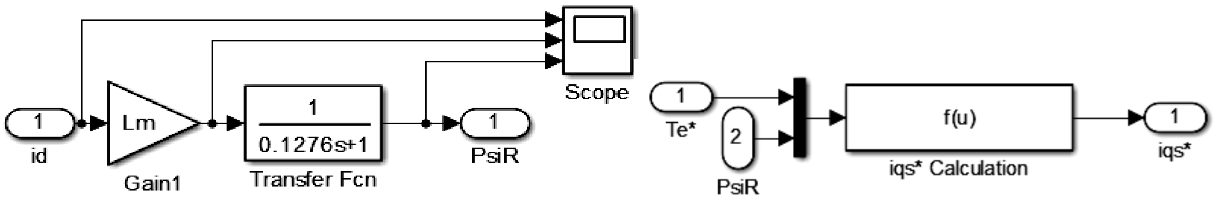


Fig.4 PI based Speed Controller

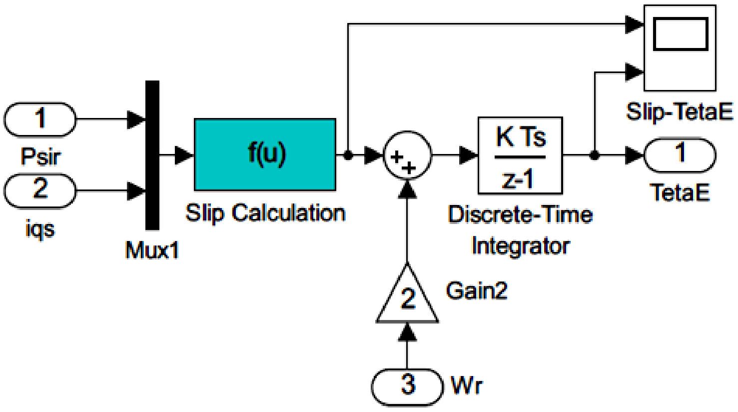
Gain K_p and K_i are tuned manually by trial and error method. First, K_p is set to 1 and k_i is set to 0, then proportional gain increased until the output have significant changes, then after integral gain is changed to get proper response from system and to reduce steady state error. If response is still not as desired than again K_p will be changed and accordingly K_i, this process will be continued until proper response has achieved by the system. Here K_p is set to 5 and K_i is set to 35.[5]

VI. SIMULINK MODEL IMPLEMENTATION

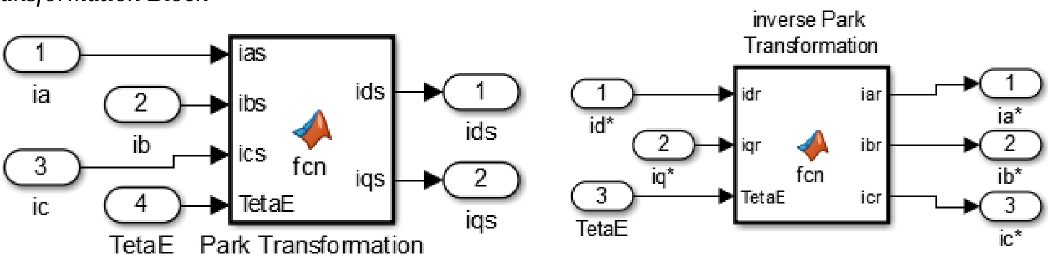
A. Flux calculation and Current Iqs calculation block*



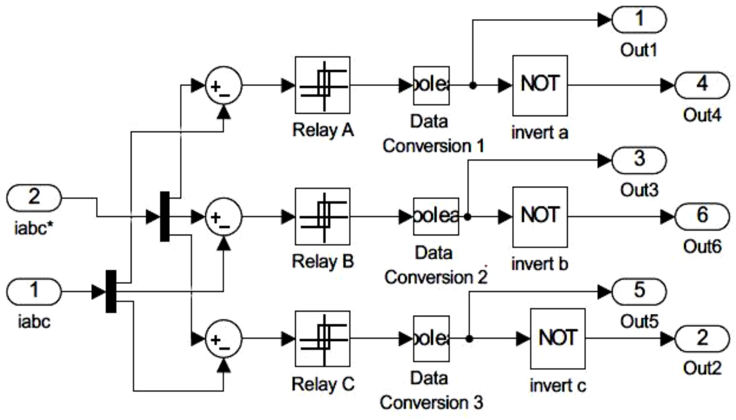
B. Slip and Angle Calculation Block



C. Transformation Block

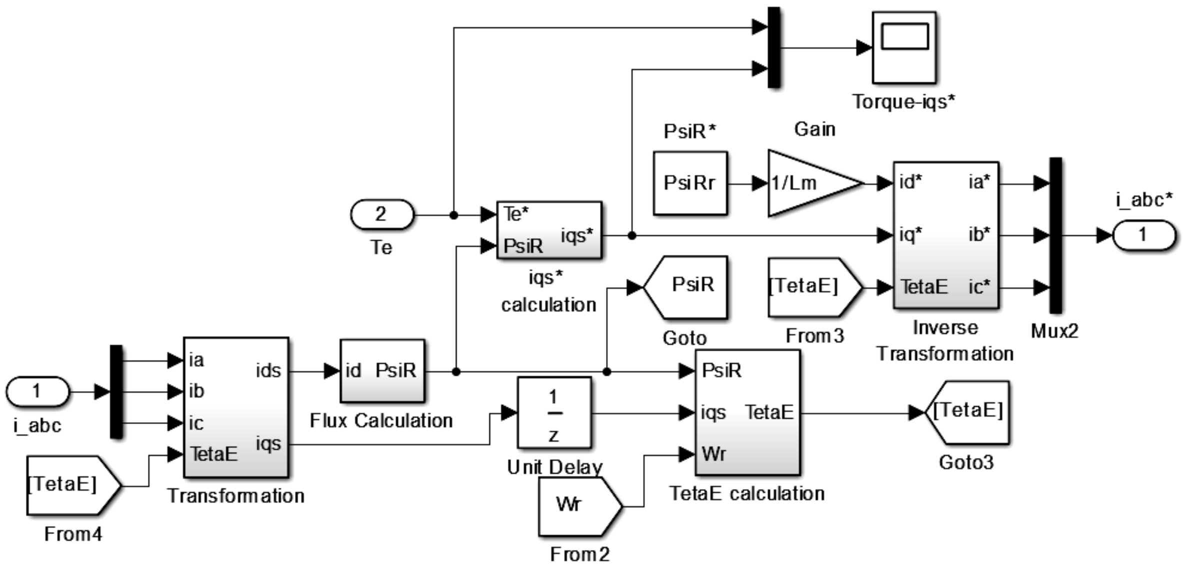


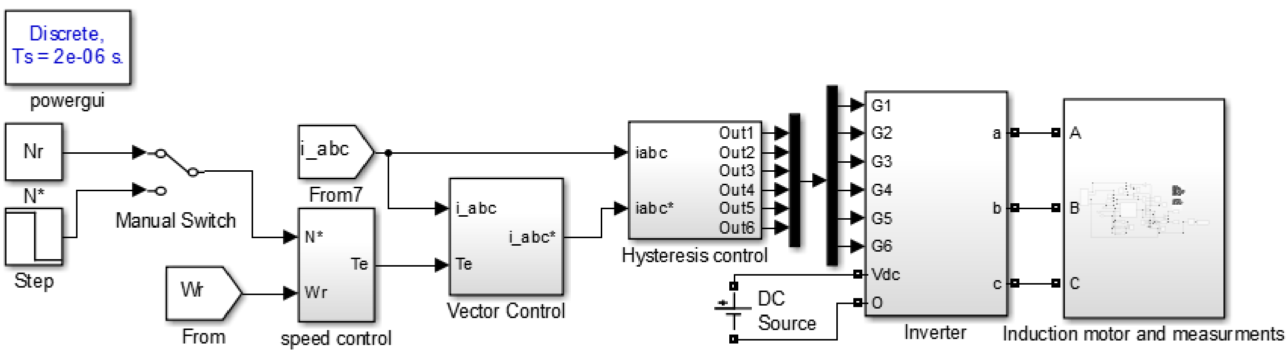
D. Hysteresis Current Control Block



Hysteresis Control Block

E. Indirect Vector Control Block





VII. SIMULATION RESULTS

A. Case:1 Step change in load torque

From t=0 to 1sec T_L=0 Nm, t=1 to 2sec T_L=13Nm, after t=2sec T_L=26Nm, Command Speed(N^*)=1400 rpm, V_{dc}=650V.

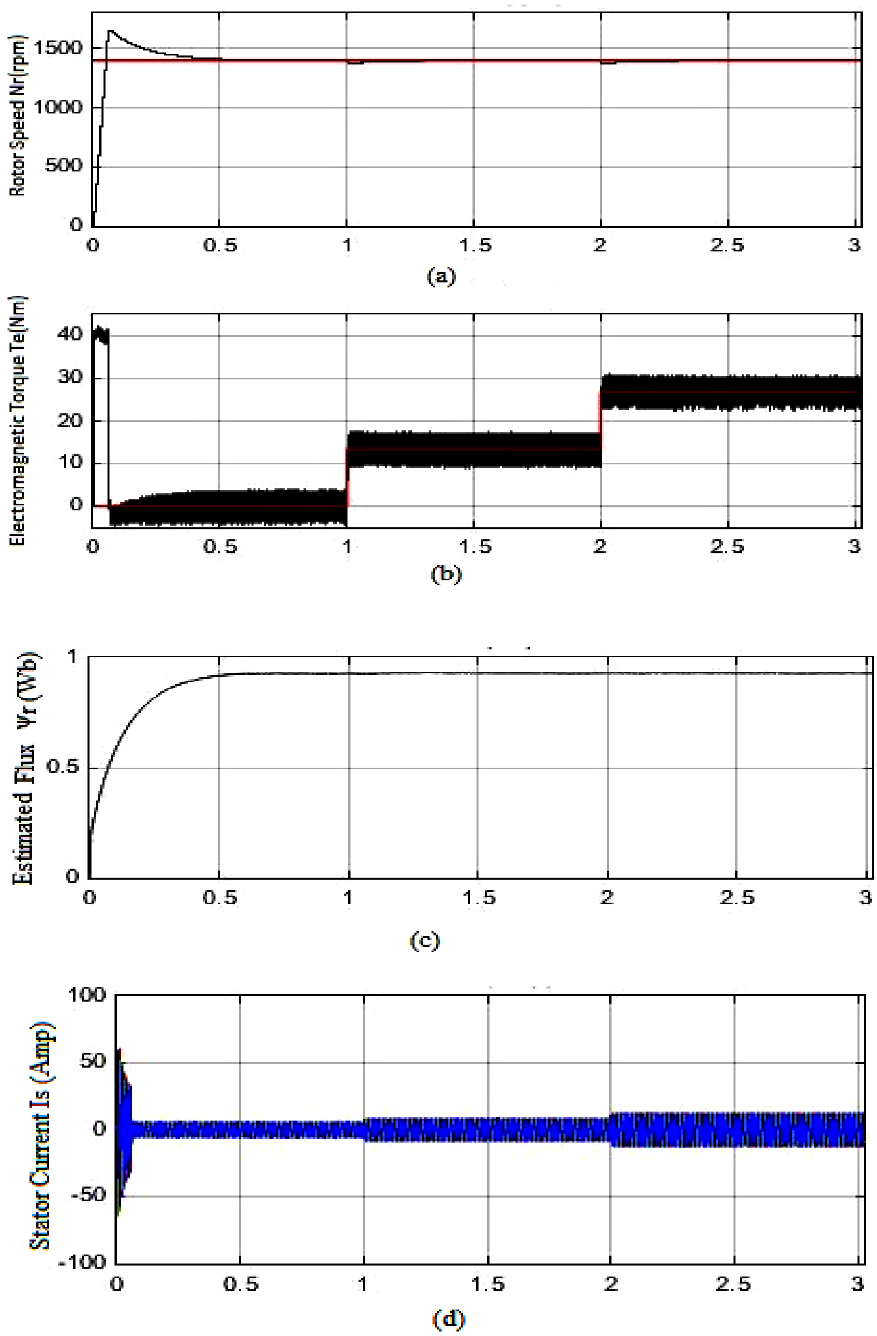


Fig.5 (a) Waveform of actual rotor speed(N_r) with reference speed(N^*), (b) Waveform of Electromagnetic torque(T_e), (c) Waveform of Estimated Rotor Flux(ψ_r), (d) Waveform of 3-phase Stator Current(I_s).

For further analysis waveform's zoomed view shown in Fig.6

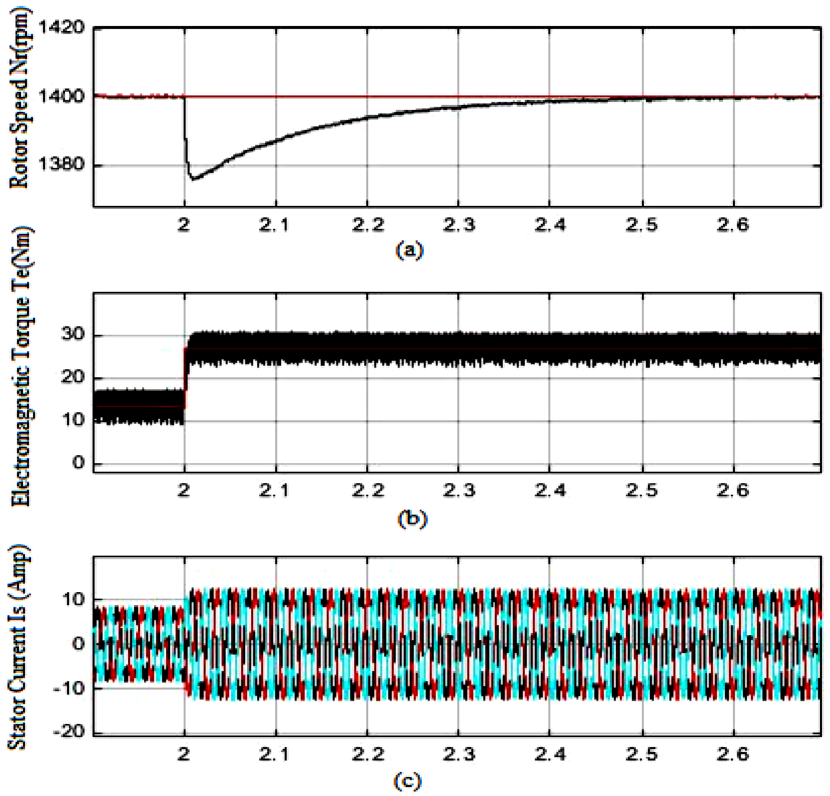


Fig.6 Zoomed view after t=2sec of waveforms (a) actual rotor speed(N_r) with reference speed(N^*), (b) Electromagnetic torque(T_e), (c) 3-phase Stator Current (I_s).

B. Case:2 Step change in Speed Command

From t=0 to 1.5sec N^*=1400 rpm, t=1.5 to 3sec N^*=500 rpm, T_L=26Nm, V_{dc}=650V.

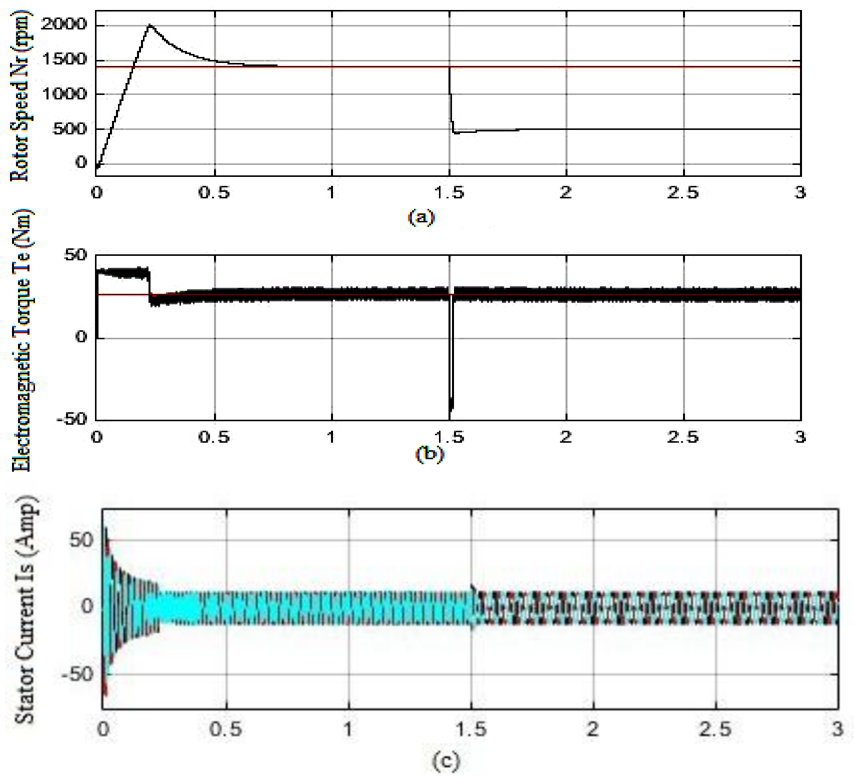


Fig.7 (a) Waveform of actual rotor speed(N_r) with reference speed(N^*), (b) Waveform of Electromagnetic torque(T_e), (c) Waveform of 3-phase Stator Current(I_s).

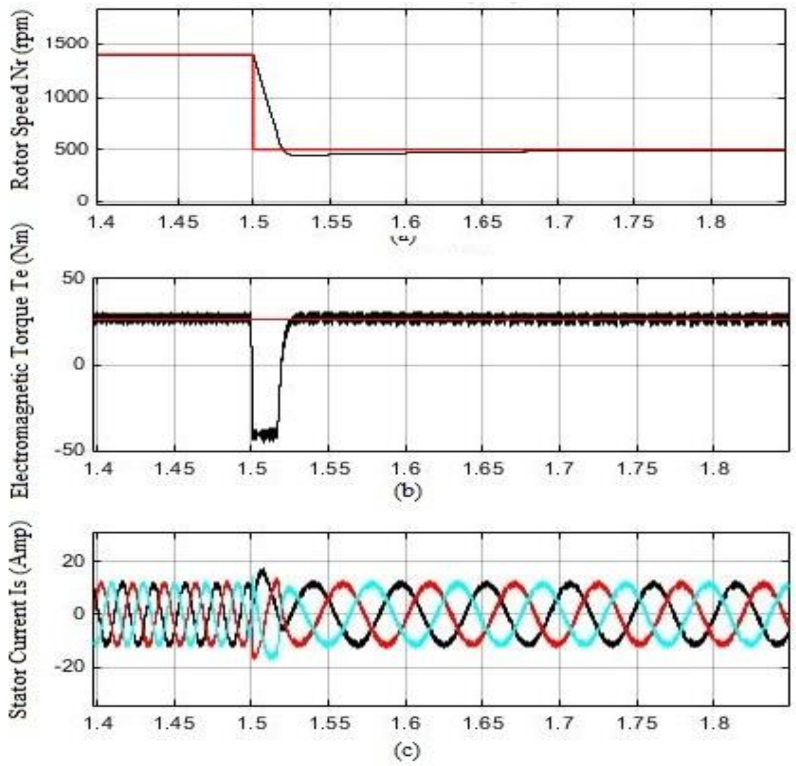


Fig.8 Zoomed view after t=1.4 sec of waveforms (a) actual rotor speed(N_r) with reference speed(N^*), (b) Electromagnetic torque(T_e), (c) 3-phase Stator Current (I_s).

Table 1. 3-ph induction motor specification

Rating	Value	Parameter	Value
Power(P)	4kw	Rotor Resistance (R_r)	1.395 Ω
Line Voltage(V)	400V	Stator Resistance (R_s)	1.405 Ω
Speed(N_r)	1430 rpm	Mutual Inductance (L_m)	0.1722 H
Torque(T_L)	26.72 N-m	Leakage InductancesL_{ls}=L_{lr}	0.0058 H
Frequency(f)	50 Hz	Stator & Rotor InductancesL_s=L_r	0.1780 H
		Moment of Inertia (J)	0.131 Kg-m^2

Here 4kW 3-ph induction motor is used to perform IFOC drive simulation. Other data related to machine is given in table 1. In simulation sampling time is taken 2µsec.In simulation values of some other variable are like, K_p=5, Ki=35, HB=ΔI=2 Amp, Vdc=650V. Also this machine have a full load stator current value of 8.3 Amp.

Table 2. Result analysis

	Speed N^* (rpm)	Torque T_L (Nm)	Settling time (sec)	Recovery time (sec)	Torque ripple(Nm)
Case 1	1400	0	0.7	-	8
	1400	13	-	0.5	8
	1400	26	-	0.5	10

Case 2	1400	26	0.65	-	10
	500	26	-	0.45	10

VIII. RESULTS DISCUSSION

MATLAB/Simulink platform is used to analyze the characteristics of indirect vector control concept with use of hysteresis current controller. Machine ratings are as per Table 1.

From the results of Case 1 which shown in Fig.5, it is seen that response of Hysteresis Current Controlled Indirect Vector Drive having quite good response compare to scalar control and speed response requires only 0.7sec for settling time; with change in torque, Speed and Flux remains same that proves Decoupling Characteristic of IFOC drive.

Figure 5(d) shows the three phase stator current waveform of induction motor which increases with increase in load up to rated value from no load current in steps.

Same way for Case 2 results are as shown in fig. 7 , speed command is changed here in steps but torque remains same throughout the simulation time. From Stator Current waveform in Fig. 7(c) it can be conclude that with reduction of speed requirement switching frequency increases and that can cause saturation of current controller at very low speeds, under very low speed condition, may controller distracts from actual current tracking path and it gives undesirable results.

Here Torque pulsation is in the range of 8 to 10 Nm that can be reduced by reducing sampling time and also by reducing Hysteresis Band width upto some extent.

COCLUSION

Using indirect vector control, we can obtain the response of separately excited DC motor from AC machine and Torque and Speed(Flux) can be decoupled. The dynamic performance of drive has been performed through the different step condition in the load torque. The simulation results shown the excellent performance both in transient state as well as steady state condition at different step. But Torque ripple can be reduced up to certain amount by reducing hysteresis band limit or employing SVPWM technique[4] or using Artificial Intelligence technique in place of conventional PI control.

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