

# FIELD ORIENTED SPEED CONTROL OF INDUCTION MOTOR DRIVES

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## ABSTRACT

This paper presents the field oriented control of a three phase induction motor up to base speed to investigate the improved performances of an induction motor driven by a PI controller by using a commercially available software package Matlab/Simulink. The concept of field – orientated control (FOC), an indirect method of vector control method, has been selected to be the motion control technique because it produces controlled results that have a better dynamic response to torque variations in a wider speed range compared to other scalar methods. A PI type speed controller has been designed to investigate the performance of IM drives.

**Keywords:** Field-oriented control (FOC), PI controller and Induction motor (IM) drives.

## 1. INTRODUCTION

Applications of field oriented control techniques [1-5], in particular, offer an excellent opportunity of using ac motors in modern variable speed drive systems. The main objective of this control method is, as in separately excited DC machines, to independently control the torque and the flux, choosing a d-q rotating reference frame synchronously with the rotor flux space vector does this[1-2]. Now -a- days, it is a common practice to evaluate the system performances through computer simulation before real time implementation. For this purpose, we simulate IM below base speed using PI controller by vector control method.

The coupling between the flux and the torque component currents in the ac motor has been pointed out as one of the main reason for the sluggish response of a closed loop control. If, for example, the torque is increased by incrementing the frequency, the flux tends to decrease. The vector control technique has been accepted as one of the most effective methods for decoupling the flux and torque. The main objective of this control technique is that an ac machine is controlled like a separately excited dc machine. In dc machine, neglecting the armature demagnetization effect and field saturation, the torque is given by [1]

$$T_e = KI_a I_f \quad (1)$$

Where  $I_a$  is the armature or torque component of current and  $I_f$  is the field or flux component of current. In a dc machine, the control variables  $I_a$  and  $I_f$  can be considered as orthogonal or decoupled vectors. In normal operation, the field current  $I_f$  is set to maintain the rated field flux and torque is changed by changing the armature current. Since the current  $I_f$  or the corresponding field flux is decoupled from the armature current  $I_a$ , the torque sensitivity remains maximum in both transient and steady- state

operations. This mode of control can be extended to an induction motor if the machine operation is considered in a synchronously rotating reference frame where the sinusoidal variables appear as dc quantities.

## 2. FIELD ORIENTED CONTROL TECHNIQUE PRINCIPLES

The equivalent circuit of IM in the synchronously rotating d-q axis rotor reference frame [1].

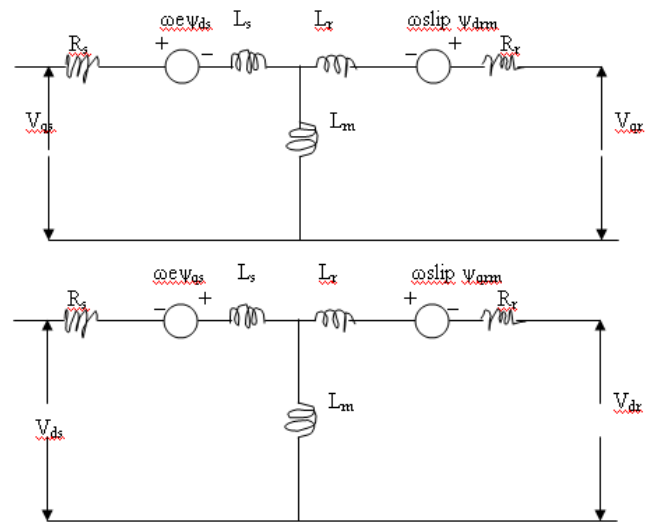


Fig. 1 Equivalent circuit of IM in synchronously rotating rotor reference frame

$$V_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \omega_e \psi_{ds} \quad (2)$$

$$V_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} + \omega_e \psi_{qs} \quad (3)$$

$$V_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + (\omega_e - \omega_r) \psi_{dr} \quad (4)$$

$$V_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} - (\omega_e - \omega_r) \psi_{qr} \quad (5)$$

$$\frac{d\psi_{qr}}{dt} + R_r i_{qr} + (\omega_e - \omega_r) \psi_{dr} = 0 \quad (6)$$

$$\frac{d\psi_{dr}}{dt} + R_r i_{dr} - (\omega_e - \omega_r) \psi_{qr} = 0 \quad (7)$$

$$\text{Again, } \psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (8)$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (9)$$

from equation (8) and (9)

$$i_{qr} = \frac{1}{L_r} \psi_{qr} - \frac{L_m}{L_r} i_{qs} \quad (10)$$

$$i_{dr} = \frac{1}{L_r} \psi_{dr} - \frac{L_m}{L_r} i_{ds} \quad (11)$$

The rotor currents from equation (2) and (3) can be eliminated by substituting equation (10) and (11) as

$$\frac{d\psi_{qr}}{dt} + \frac{R_r}{L_r} \psi_{qr} - \frac{L_m}{L_r} R_r i_{qs} + \omega_{sl} \psi_{dr} = 0 \quad (12)$$

$$\frac{d\psi_{dr}}{dt} + \frac{R_r}{L_r} \psi_{dr} - \frac{L_m}{L_r} R_r i_{ds} + \omega_{sl} \psi_{qr} = 0 \quad (13)$$

Where  $\omega_{sl} = \omega_e - \omega_r$

For decoupling control it is desirable that

$$\psi_{qr} = \frac{d\psi_{qr}}{dt} = 0 \quad (14)$$

$$\psi_{dr} = \psi_r = \text{constant}$$

$$\frac{d\psi_{dr}}{dt} = 0 \quad (15)$$

Substituting the first two conditions, equations (12) and (13) can be simplified as

$$\omega_{sl} = \frac{L_m}{\psi_r} \left( \frac{R_r}{L_r} \right) i_{qs} \quad (16)$$

$$\frac{L_r}{R_r} \frac{d\psi_r}{dt} + \psi_r = L_m i_{ds} \quad (17)$$

$$\psi_r = L_m i_{ds} \quad (18)$$

Again the torque as a function of rotor flux and stator current can be derived as follows. The stator flux linkage relations can be written as

$$\left. \begin{aligned} \psi_{qs} &= L_m i_{qr} + L_s i_{qs} \\ \psi_{ds} &= L_m i_{dr} + L_s i_{ds} \end{aligned} \right\} \quad (19)$$

Substituting equation (19) in equation (8) and (9), we get

$$\psi_{qs} = \left( L_s - \frac{L_m^2}{L_r} \right) i_{qs} + \frac{L_m}{L_r} \psi_{qr} \quad (20)$$

$$\psi_{ds} = \left( L_s - \frac{L_m^2}{L_r} \right) i_{ds} + \frac{L_m}{L_r} \psi_{dr} \quad (21)$$

The torque equation as a function of stator currents and rotor flux is

$$T_e = \frac{3}{2} \left( \frac{p}{2} \right) \left( \psi_{qs} i_{ds} - i_{qs} \psi_{ds} \right) \quad (22)$$

Equation (3.19) and (3.20) can be substituted in equation (3.21) to eliminate stator fluxes. Therefore,

$$T_e = \frac{3}{2} \left( \frac{p}{2} \right) \frac{L_m}{L_r} (i_{qs} \psi_{dr} - i_{ds} \psi_{qr}) \quad (23)$$

Substituting  $\psi_{qr} = 0$  and  $\psi_{dr} = \psi_r$ , the torque expression is

$$T_e = \frac{3}{2} \left( \frac{p}{2} \right) \frac{L_m}{L_r} i_{qs} \psi_r \quad (24)$$

$$\left( \frac{2}{p} \right) J \frac{d\omega_r}{dt} = T_e - T_l \quad (25)$$

describes the machine model in decoupling control. If this orientation is correctly achieved, the torque producing current that is q-component of the stator current controls the torque and at the same time, the flux is controlled by the flux producing current, which is the d-axis component of stator current.

### 3. IMPLEMENTATION STRATEGY FOR THE VECTOR CONTROL SCHEME FOR INDUCTION MOTOR

The practical configuration of a FOC controlled IM drive is shown in figure 3.3. The basic configuration of the drive system consists of an induction motor (IM) fed by a pulse width modulation inverter.

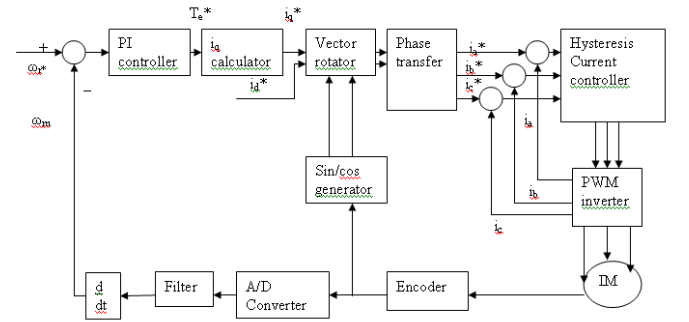


Fig. 2 Block diagram of PI based IM drive

The command torque is obtained from a PI type speed controller. Using equation (3.23) reference q-axis current  $i_{q}^*$  is computed first, subsequently reference d-axis current  $i_{d}^*$  is calculated using equation (3.17). Using these reference currents three phase currents are determined by vector rotator. The hysteresis current controller compares the reference three phase current with actual currents and generates base signals for the transistorized inverters.

## 4. SIMULATION RESULTS

Figure 5(a) shows the speed response of IM drive for flux weakening control with reference speed of 220 rad/sec. It is seen from Fig. 3(a) that the actual speed follows the reference speed without any steady state error and the speed reaches steady state condition after .6 sec. Figure 5(b) shows the current response of IM drive for flux weakening control with reference speed of 220 rad/sec. The current reaches steady state within .1 second.

Figure 6 (a) shows the speed response with step change of reference speed. Initially motor started at a reference speed of 190 rad/sec but after 1sec latter, the reference speed is increased to 300 rad/sec. Figure 6(b) shows the current response of IM drive for flux weakening control with step change of reference speed.

The actual speed of the IM drive almost follows the change of speed. The controller algorithm was promptly able to respond to the speed change. So the transient and steady state performance of the controller is very impressive.

Figure 3 (a) shows the speed response at no load for vector control or field oriented control (FOC) of IM drive using the proposed PI controller. It is seen from Fig. 3 (a) that the actual speed follow the reference speed quite accurately and without any steady state error, the speed reaches steady state condition after .5 sec. Figure 3 (b) shows the current response under no load condition. Current reach steady state within .1 sec. Figure 4 (a) and Figure 4(b) show the speed and current responses under full load condition. Figure 5(a) shows the speed response with step change of reference speed at no load. Initially motor started at a reference speed of 50 rad /sec but after 1sec latter, the reference speed is increased to 120 rad /sec. Figure 5(b) shows current response of IM drive with step change using PI controller at no load. Figure 6(a) and Figure 6(b) show the speed and current response with step change of reference speed under full load condition.

The actual speed of the IM drive almost follows the change of speed. The controller algorithm was promptly able to respond to the speed change.

Figure 7(a) shows the speed response with sudden change in load torque. The motor starts from standstill without load and at 1sec, a sudden full load is applied. The motor speed drops somewhat but within .4 sec it again returns to its set point. So the transient and steady state performance of the controller is very impressive.

Figure 8 shows simulated torque of IM drive with step change of reference speed using PI controller.

The actual speed of the IM drive almost follows the change of speed. The controller algorithm was promptly able to respond to the speed change. So the transient and steady state performance of the controller is very impressive.

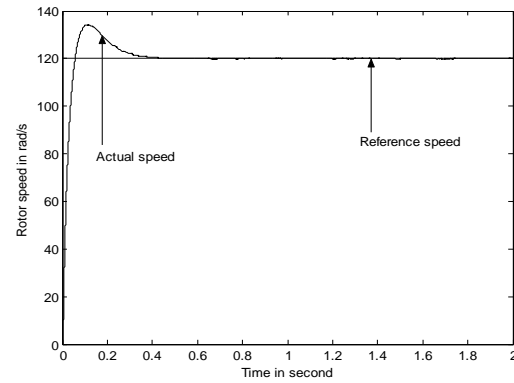


Fig. 3 (a) Simulated speed of IM drive with a reference speed of 120 rad/sec using PI controller at no load.

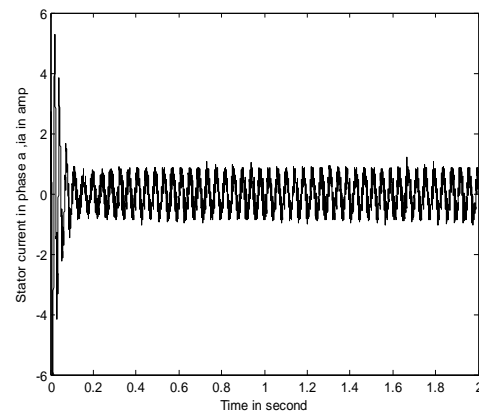


Fig. 3(b) Simulated current of IM drive with a reference speed of 120 rad/sec using PI controller at no load

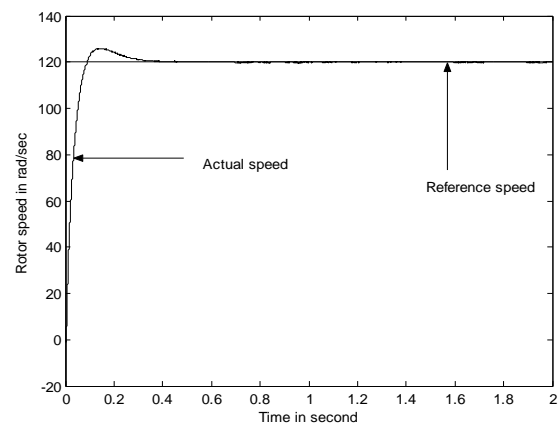


Fig. 4 (a) Simulated speed of IM drive with a reference speed of 120 rad/sec using PI controller at rated load.

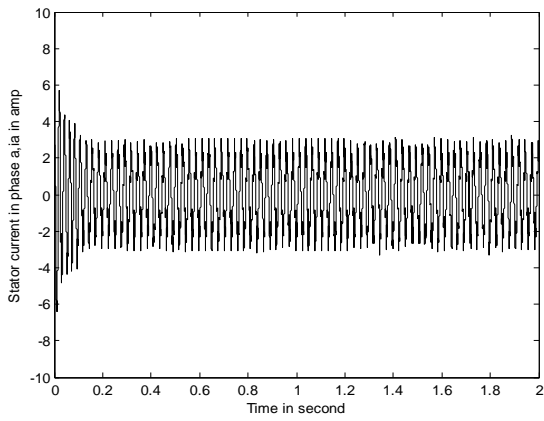


Fig. 4(b) Simulated current of IM drive with a reference speed of 120 rad/sec using PI controller at rated load.

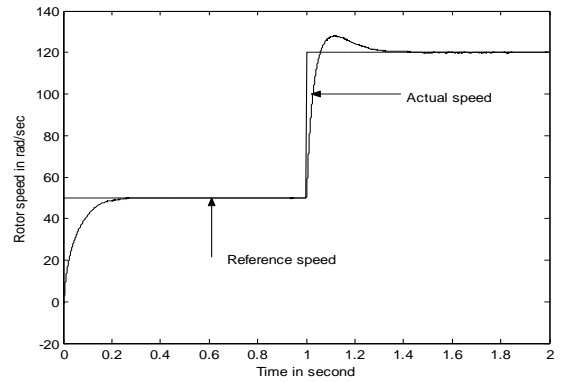


Fig. 6 (a) Simulated Speed of IM drive with step change using PI controller at rated load.

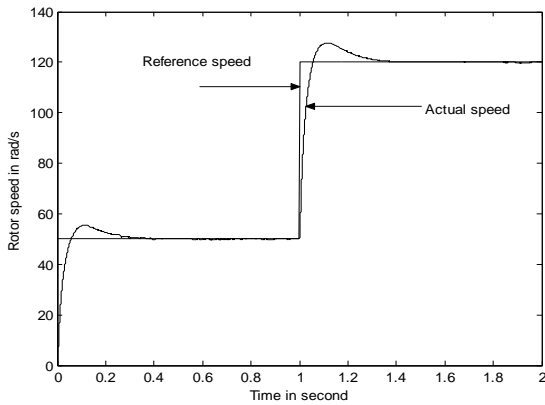


Fig. 5 (a) Simulated Speed of IM drive with step change using PI controller at no load.

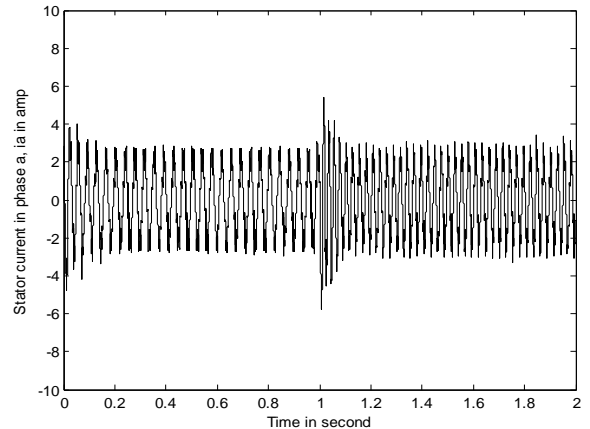


Fig. 6 (b) Simulated current of IM drive with step change using PI controller at rated load.

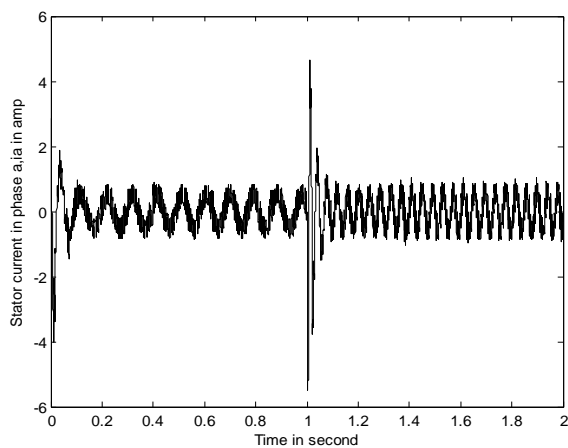


Fig. 5 (b) Simulated current of IM drive with step change using PI controller at no load.

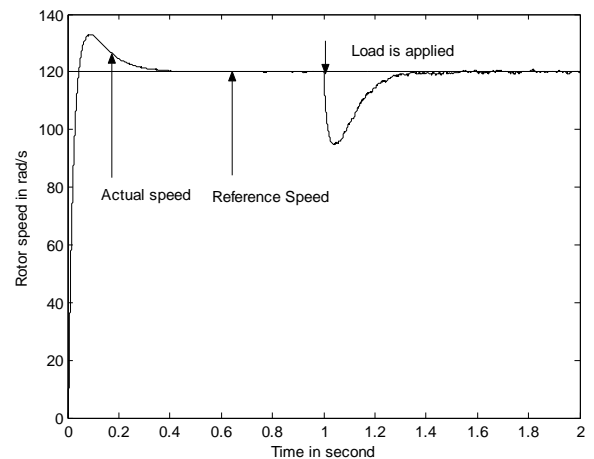


Fig. 7 (a) Simulated speed of IM drive with step change of load torque using PI controller.

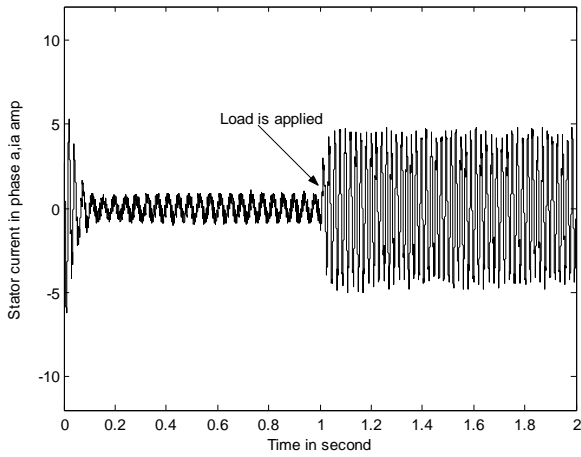


Fig. 7 (b) Simulated current of IM with step change of load torque using PI controller.

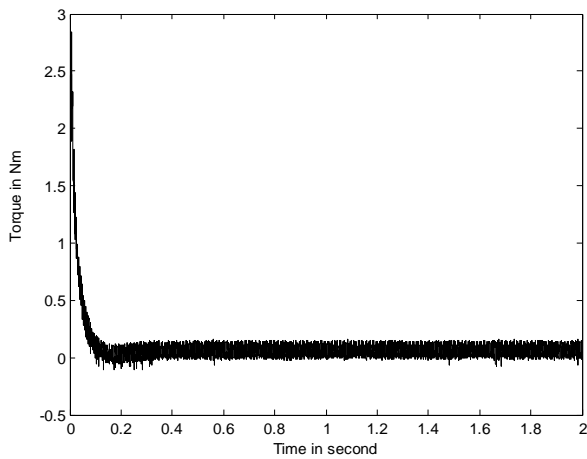


Fig. 8 simulated torque of IM drive with step change of reference speed using PI controller.

## 5. CONCLUSION

The FOC method of control presents a good speed response with an adequate stability. The after FOC speed response closely resembles the input speed command. The amount of overshoot has been perfectly acceptable. On the whole the simulation result is positive. The operating capability at and above the base speed has also been verified successfully. From the simulation results, it has seen that the drive system has fully capable of operating at base speed.

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