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Simulation Of Sensorless Induction Motor Based On Model Reference Adaptive System (MRAS)

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ABSTRACT

Over the past two decades technological advances in power electronics and an increasing demand for high performance industrial machinery has contributed to rapid developments in digital motor control. The aim of this paper is to develop a vector controlled induction motor drive operating without a speed or position sensor but having a dynamic performance comparable to a sensored vector drive. This thesis presents the control of an induction motor through sensorless vector control. The theoretical basis of each algorithm is explained in detail and its performance is tested with simulations implemented in MATLAB/SIMULINK. Vector control of induction motor is based upon the field-oriented co-ordinates aligned in the direction of the rotor m.m.f. However, there is no direct means of measuring the rotor flux linkage position ρ and therefore an observer is needed to estimate ρ for the implementation of sensorless vector control. First the Dynamic model of induction machine was developed in the arbitrary reference frame. With the help of synchronous reference frame model the indirect field oriented vector control, which is very popular and convenient method in real time implementation was developed. Third, Model Reference Adaptive System is studied as a state estimator. Rotor flux estimation scheme is applied to MRAS algorithm to estimate rotor speed.

I. INTRODUCTION:

Induction motor (IM) can be considered as the 'workhorse' of the industry because of its special features such as low cost, high reliability, low inertia, simplicity and ruggedness. Even today IMs especially the squirrel cage type, are widely used for single speed applications rather than variable speed applications due to the complexity of controlling algorithm and higher production cost of IM variable speed drives. However, there is a great interest on variable speed operation of IM within the research community mainly because IMs can be considered as a major industrial load of a power system. On the other hand the IMs consume a considerable amount of electricity generated. The majority of IMs are operated at constant speed, determined by the pole pair number and the stator supply frequency.

The two names for the same type of motor, induction motor and asynchronous motor, describe the two characteristics in which this type of motor differs from DC motors and synchronous motors. Induction refers to the fact that the field in the rotor is induced by the stator currents, and asynchronous refers to the fact that the rotor speed is not equal to the stator frequency. No sliding contacts and permanent magnets are needed to make an IM work, which makes it very simple and cheap to manufacture. As motors, they rugged and require very little maintenance. However, their speeds are not as easily controlled as with DC motors. They draw large starting currents, and operate with a poor lagging factor when lightly loaded.

II. MODELLING OF INDUCTION MOTOR

The control and speed sensorless estimation of IM drives is a vast subject. Traditionally, the IM has been used with constant frequency sources and normally the squirrel-cage machine is utilized in many industrial applications, A typical construction of a squirrel cage IM is illustrated in Figure 2.1. Its main advantages are the mechanical and electrical simplicity and ruggedness, the lack of rotating contacts (brushes) and its capability to produce torque over the entire speed range.

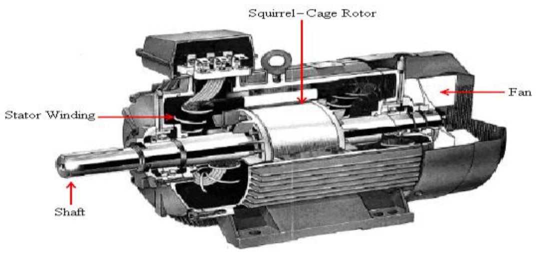

Figure 2.1: A cut-away view of a squirrel cage IM

Before going to analyze any motor or generator it is very much important to obtain the machine in terms of its equivalent mathematical equations. Traditional per phase equivalent circuit has been widely used in steady state analysis and design of induction motor, but it is not appreciated to predict the dynamic performance of the motor. The dynamics consider the instantaneous effects of varying voltage/currents, stator frequency, and torque disturbance. The dynamic model of the induction motor is derived by using a two-phase motor in direct and quadrature axes. This approach is desirable because of the conceptual simplicity obtained with two sets of windings, one on the stator and the other in the rotor. The equivalence between the three phase and two phase machine models is derived from simple observation, and this approach is suitable for extending it to model an n-phase machine by means of a two phase machine.

2.1 Reference Frames

The required transformation in voltages, currents, or flux linkages is derived in a generalized way. The reference frames are chosen to be arbitrary and particular cases, such as stationary, rotor and synchronous reference frames are simple instances of the general case. R.H. Park, in the 1920s, proposed a new theory of electrical machine analysis to represent the machine in d – q model. He transformed the stator variables to a synchronously rotating reference frame fixed in the rotor, which is called Park's transformation. He showed that all the time varying inductances that occur due to an electric circuit in relative motion and electric circuits with varying magnetic reluctances could be eliminated.

The voltages $v_{ds}{}^{s}$ and $v_{qs}{}^{s}$ can be resolved into as-bs-cs components and can be represented in matrix from as,

$$\begin{bmatrix} V_{as} \\ V_{bs} \\ V_{cs} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos(\theta-120^0) & \sin(\theta-120^0) & 1 \\ \cos(\theta+120^0) & \sin(\theta+120^0) & 1 \end{bmatrix} \begin{bmatrix} V_{qs}{}^{s} \\ V_{ds}{}^{s} \\ V_{os}{}^{s} \end{bmatrix} \quad (2.1)$$

Here $v_{os}{}^{s}$ is zero-sequence component, convenient to set θ = 0 so that q^s axis is aligned with as-axis. Therefore ignoring zero-sequence component, it can be simplified as-

$$V_{qs}{}^{s} = \frac{2}{3}v_{as} - \frac{1}{3}v_{bs} - \frac{1}{3}v_{cs} = v_{as} \qquad 2.3$$

2.2

$$V_{ds}{}^{s} = \frac{-1}{\sqrt{3}}v_{bs} + \frac{1}{\sqrt{3}}v_{cs} \qquad 2.4$$

Equations 2.2consistively called as Clark Transformation.

Figure 2.1shows the synchronously rotating d^e-q^e axes, which rotate at synchronous speed w_e with respect to the d^s-q^s axes and the angle $\theta_y = \omega_e * t$. The two-phase d^s-q^s windings are transformed into the hypothetical windings mounted on the d^e-q^e axes. The voltages on the d^s-q^s axes can be transformed (or resolved) into the d^e-q^e frame as follows:

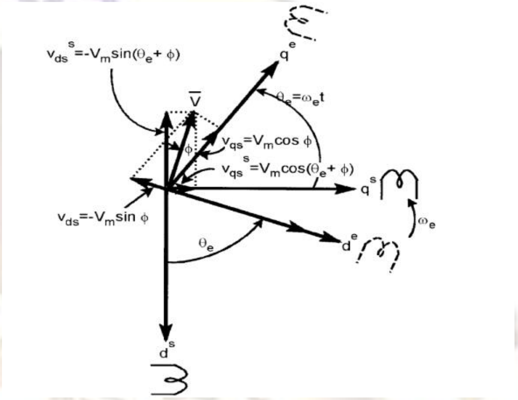

Fig 2.1stationary frame d^s-q^s to dynchronously rotating frame d^e-q^e transformation

2.4 Dynamic equations of induction machine

Generally, an IM can be described uniquely in arbitrary rotating frame, stationary reference frame or synchronously rotating frame. For transient studies of adjustable speed drives, it is usually more convenient to simulate an IM and its converter on a stationary reference frame. Moreover, calculations with stationary reference frame are less complex due to zero frame speed. For small signal stability analysis about some operating condition, a synchronously rotating frame which yields steady values of steady-state voltages and currents under balanced conditions is used.

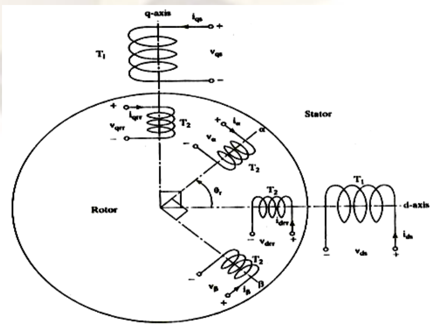

Fig 2.2 Two-phase equivalent diagram of induction motor

From the above figure the terminal voltages are as follows, $V_{qs} = R_q i_{qs} + p\,(L_{qq} i_{qs}) + p\,(L_{qd} i_{ds}) + p\,(L_{q\alpha} i_{\alpha}) + p\,(L_{q\beta} i_{\beta})$

$V_{ds} = p\,(L_{dq} i_{qs}) + R_d i_{ds} + p\,(L_{dd} i_{ds}) + p\,(L_{d\alpha} i_{\alpha}) + p\,(L_{d\beta} i_{\beta})$ 2.3

$V_{\alpha} = p\,(L_{\alpha q} i_{qs}) + p\,(L_{\alpha d} i_{ds}) + R_{\alpha} i_{\alpha} + p\,(L_{\alpha\alpha} i_{\alpha}) + p\,(L_{\alpha\beta} i_{\beta})$

$V_{\beta} = p\,(L_{\beta q} i_{qs}) + p\,(L_{\beta d} i_{ds}) + p\,(L_{\beta\alpha} i_{\alpha}) + R_{\beta}\, i_{\beta} + p\,(L_{\beta\beta} i_{\beta})$

Where *p* is the differential operator *d/dt*, and v_{qs}, v_{ds} are the terminal voltages of the stator *q* axis and *d* axis. V_{α}, V_{β} are the voltages of rotor α and β windings, respectively. i_{qs} and i_{ds} are the stator *q* axis and *d* axis currents. Whereas i_{α} and i_{β} are the rotor α and β winding currents, respectively and L_{qq}, L_{dd}, $L_{\alpha\alpha}$ and $L_{\beta\beta}$ are the stator q and d axis winding and rotor α and β winding self-inductances, respectively.

The following are the assumptions made in order to simplify the equation

i. Uniform air-gap
ii. Balanced rotor and stator windings with sinusoidally distributed mmfs
iii. Inductance in rotor position is sinusoidal and
iv. Saturation and parameter changes are neglected

The rotor equations in above equation 2.12 are refereed to stator side as in the case of transformer equivalent circuit. From this, the physical isolation between stator and rotor d-q axis is eliminated.

dynamic equations of the induction motor in any reference frame can be represented by using flux linkages as variables. This involves the reduction of a number of variables in the dynamic equations. Even when the voltages and currents are discontinuous the flux linkages are continuous. The stator and rotor flux linkages in the stator reference frame are defined as

$$\left.\begin{aligned} \psi_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \psi_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \psi_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \psi_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned}\right\} \quad 2.4$$

$$\left.\begin{aligned} \psi_{qm} &= L_m (i_{qs} + i_{qr}) \\ \psi_{dm} &= L_m (i_{ds} + i_{dr}) \end{aligned}\right\} \quad 2.5$$

From (2.4) and (2.5) we get

$$\left.\begin{aligned} v_{ds} &= R_s i_{ds} + p\psi_{ds} \\ v_{qs} &= R_s i_{qs} + p\psi_{qs} \\ v_{dr} &= R_r i_{dr} + \omega_r \psi_{qr} + p\psi_{dr} \\ v_{qr} &= R_r i_{qr} - \omega_r \psi_{dr} + p\psi_{qr} \end{aligned}\right\} \quad 2.6$$

Since the rotor windings are short circuited, the rotor voltages are zero. Therefore

$$\left.\begin{aligned} R_r i_{dr} + \omega_r \psi_{qr} + p\psi_{dr} &= 0 \\ R_r i_{qr} - \omega_r \psi_{dr} + p\psi_{qr} &= 0 \end{aligned}\right\} \quad 2.7$$

From (2.15), we have

$$\left.\begin{aligned} i_{dr} &= \frac{-p\psi_{dr} - \omega_r \psi_{qr}}{R_r} \\ i_{qr} &= \frac{-p\psi_{qr} + \omega_r \psi_{dr}}{R_r} \end{aligned}\right\} \quad 2.8$$

2.20

By solving the equations 2.17, 2.18, 2.19 and 2.20 we get the following equations

$$\psi_{ds} = \int (v_{ds} - R_s i_{ds})dt \quad 2.9$$

$$\psi_{qs} = \int (v_{qs} - R_s i_{qs})dt \quad 2.10$$

$$\psi_{dr} = \frac{-L_r \omega_r \psi_{qr} + L_m i_{ds} R_r}{R_r + sL_r} \quad 2.11$$

$$\left.\begin{aligned} \psi_{qr} &= \frac{L_r \omega_r \psi_{dr} + L_m R_r i_{qs}}{R_r + sL_r} \\ i_{ds} &= \frac{v_{ds}}{R_s + sL_s} - \left[\frac{\psi_{dr}.sL_m}{L_r.(R_s + sL_s)}\right] \\ i_{qs} &= \frac{v_{qs}}{R_s + sL_s} - \left[\frac{\psi_{qr}.sL_m}{L_r.(R_s + sL_s)}\right] \end{aligned}\right\} \quad 2.12$$

The electromagnetic torque of the induction motor in stator reference frame is given by

$$T_e = \frac{3}{2}\frac{p}{2} L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \quad 2.13$$

or

$$T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{L_r}(i_{qs}\psi_{dr} - i_{ds}\lambda_{qr}) \quad 2.14$$

III. Principle of Vector Control

The fundamentals of vector control can be explained with the help of figure 3.5, where the machine model is represented in a synchronously rotating reference frame.

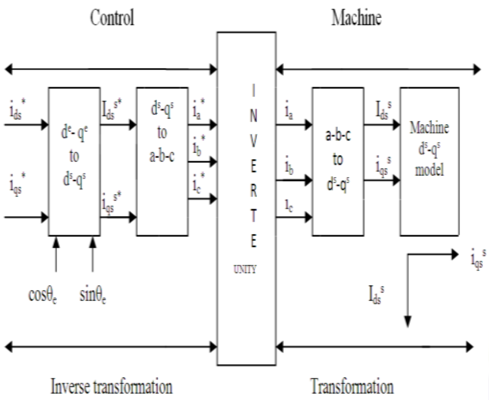

Fig 3.1 Basic block diagram of vector control

3.1 Inverter

Processing of the torque status output and the flux status output is handled by the optimal switching logic. The function of the optimal switching logic is to select the appropriate stator voltage vector that will satisfy both the torque status output and the flux status output.

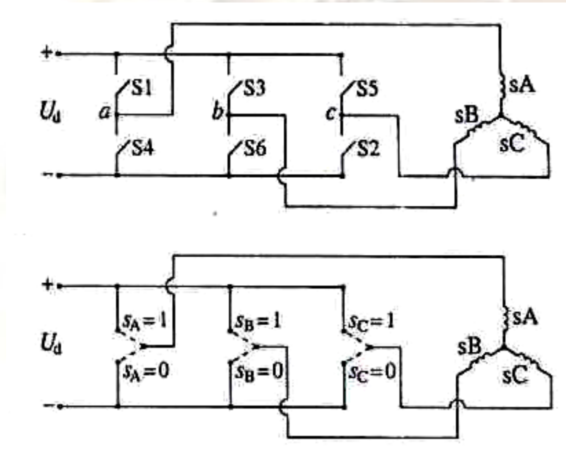

Fig 3.2: Schematic diagram of voltage source inverter

3.2 Basic Theory

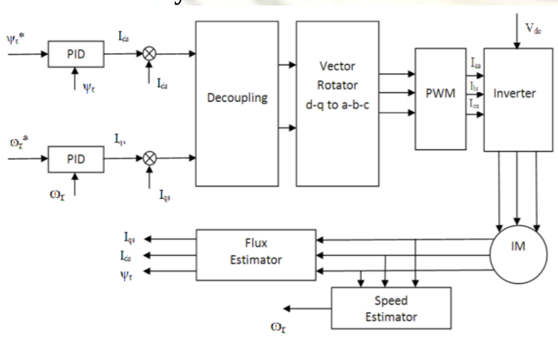

Fig 3.3Block Diagram of Sensorless Control of Induction Motor

The schematic diagram of control strategy of induction motor with sensorless control is shown in Fig 4.1. Sensor less control induction motor drive essentially means vector control without any speed sensor [5, 17]. The inherent coupling of motor is eliminated by controlling the motor by vector control, like in the case of as a separately excited motor. The inverter provides switching pulses for the control of the motor. The flux and speed estimators are used to estimate the flux and speed respectively. These signals then compared with reference values and controlled by using the PI controller.

IV. Model Referencing Adaptive System (MRAS)

Tamai [5] has proposed one speed estimation technique based on the Model Reference Adaptive System (MRAS) in 1987. Two years later, Schauder [6] presented an alternative MRAS scheme which is less complex and more effective. The MRAS approach uses two models. The model that does not involve the quantity to be estimated (the rotor speed, ωr) is considered as the reference model. The model that has the quantity to be estimated involved is considered as the adaptive model (or adjustable model). The output of the adaptive model is compared with that of the reference model, and the difference is used to drive a suitable adaptive mechanism whose output is the quantity to be estimated (the rotor speed). The adaptive mechanism should be designed to assure the stability of the control system. A successful MRAS design can yield the desired values with less computational error (especially the rotor flux based MRAS) than an open loop calculation and often simpler to implement.

The model reference adaptive system (MRAS) is one of the major approaches for adaptive control [6]. The model reference adaptive system (MRAS) is one of many promising techniques employed in adaptive control. Among various types of adaptive system configuration, MRAS is important since it leads to relatively easy- to-implement systems with high speed of adaptation for a wide range of applications.

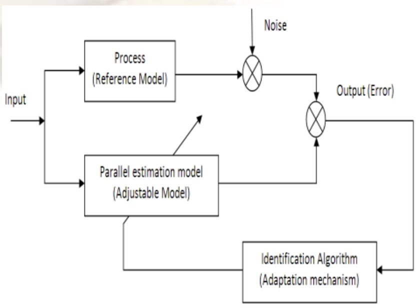

Fig 4.1 basic identification structures and their correspondence with MRAS

V. Vector Control of Induction Motor

The Vector Control or Field orientation control of induction motor is simulated on MATLAB®/SIMULINK - platform to study the various aspects of the controller. The actual system can be modeled with a high degree of accuracy in this package.. This chapter discusses the realization of vector control of induction motor using Simulink blocks.

Fig. 5.1 shows the Vector controlled Induction Motor block simulink diagram for simulation. This system consisting of Induction Motor Model, Three Phase to Two phase transformation block, Two phase to Three phase block, Flux estimator block and Inverter block.

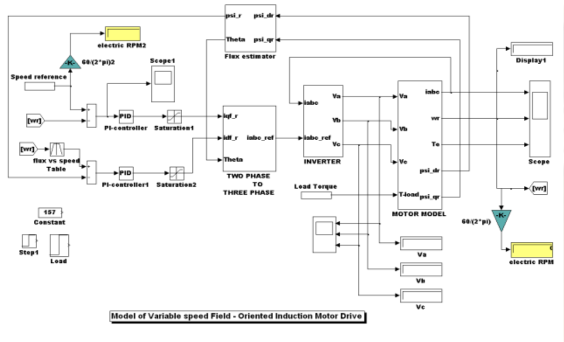

Fig 5.1 Simulink Model of Vector Controlled Induction motor

5.1 Induction Motor Model:

The motor is modeled in stator reference frame. The dynamic equations are given using these equations we can develop the induction motor model in stator reference frame. Fig 5.2 shows the simulink block diagram for motor model. Inputs to this block are direct and quadrature axes voltages and load torque. The outputs are direct and quadrate axis rotor fluxes, direct and quadrature axes stator currents, electrical torque developed and rotor speed.

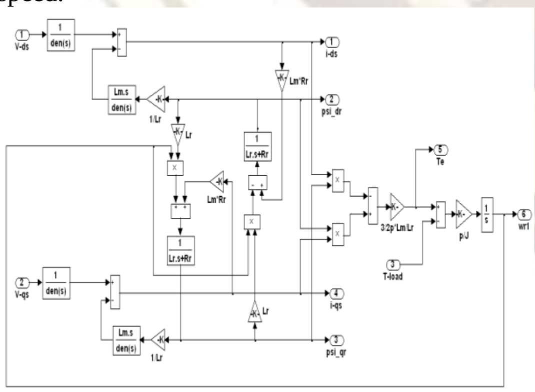

Fig.5.2: Simulink block diagram for induction motor model

5.2 Inverter

The function of the optimal switching logic is to select the appropriate stator voltage vector that will satisfy both the torque status output and the flux status output. Processing of the torque status output and the flux status output is handled by the optimal switching logic.

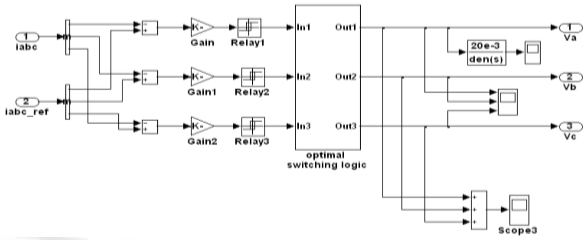

Fig 5.3 Voltage Source Inverter

5.3 Sensorless control of induction motor

The Sensorless control of induction motor using Model Reference Adaptive System (MRAS) is simulated on MATLAB/SIMULINK - platform to study the various aspects of the controller.. Here we are going to discuss the realization of Sensorless control of induction motor using MRAS for simulink blocks.. Main subsystems are the 3-phase to 2-phase transformation, 2-phase to 3-phase transformation, induction motor model, Model Reference Adaptive System (MRAS) and optimal switching logic & inverter.

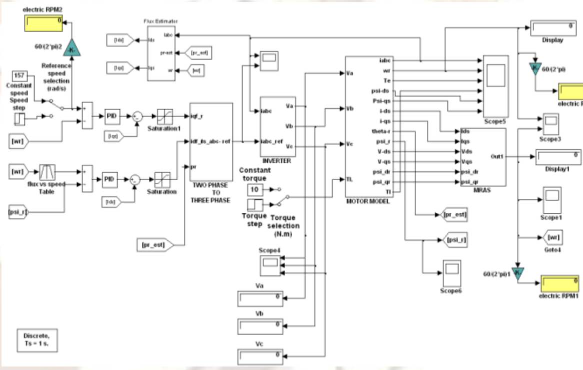

Fig 5.4 Simulink root block diagram of Sensorless control of induction motor using MRAS

5.4 Model Refernce Adaptive System (MRAS)

Fig 5.11 shows the simulink block diagram Model Referencing Adaptive System (MRAS). Which is consists Two blocks one is called Reference Model and other is Adaptive Model. The voltage model's stator-side equations, are defined as a Reference Model and the simulink block diagram of Reference Model is shown in Fig5.4. The Adaptive Model receives the machine stator voltage and current signals and calculates the rotor flux vector signals, as indicated by equations, which is shown in Fig 5.5. By using suitable adaptive mechanism the speed ω_r, can be estimated and taken as feedback.

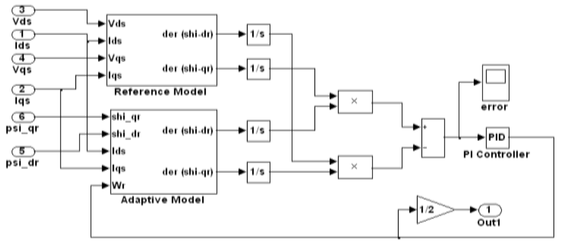

Fig 5.5 Simulink block diagram for Model Referencing Adaptive System

VI. Simulation Results

The simulation of Vector Control of Induction Motor is done by using MATLAB®/SIMULINK. The results for different cases are given below.

Reference speed = 100 rad/sec and on no-load

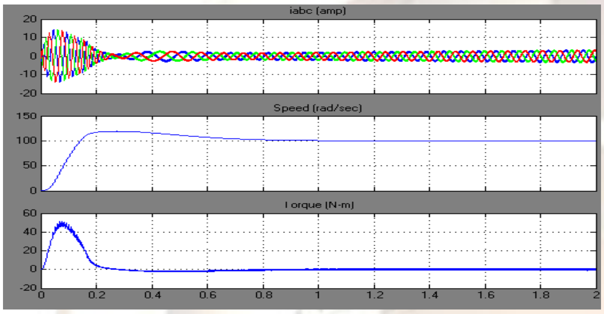

Fig 6.1: 3-ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec

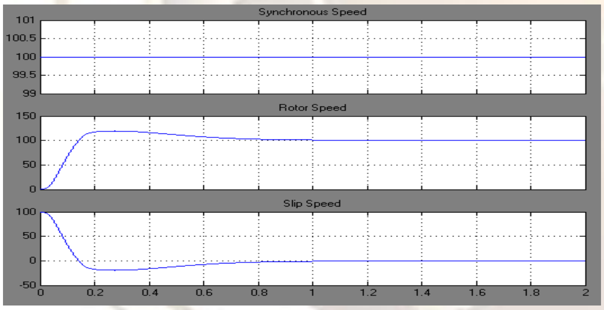

Fig 6.2: Reference speed, Rotor Speed, Slip Speed Respectively

Reference speed = 100 rad/sec; Load torque of 15 N-m is applied at t = 1.5 sec

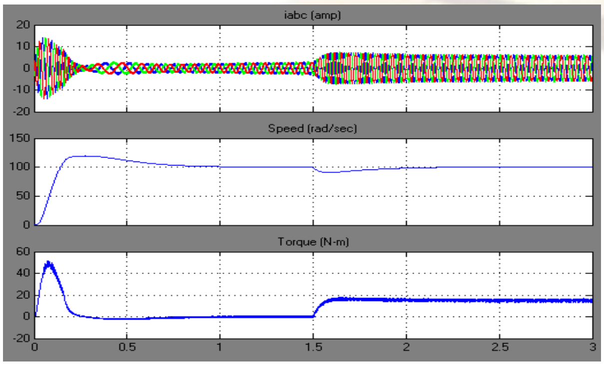

Fig 6.3: 3-ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec

VII. Conclusion

In this paper, Sensorless control of induction motor using Model Reference Adaptive System (MRAS) technique has been proposed. Sensorless control gives the benefits of Vector control without using any shaft encoder. In this thesis the principle of vector control and Sensorless control of induction motor is given elaborately. The mathematical model of the drive system has been developed and results have been simulated. Simulation results of Vector Control and Sensorless Control of induction motor using MRAS technique were carried out by using Matlab/Simulink and from the analysis of the simulation results, the transient and steady state performance of the drive have been presented and analyzed.

From the simulation results, it can be observed that, in steady state there are ripples in torque wave and also the starting current is high. We can also increase the ruggedness of the motor as well as fast dynamic response can be achieved.

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