

Estimation Of parameter For Induction Motor Drive

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ABSTRACT

Generally speed measurement is done with sensor, but disadvantage of sensor is difficult to measure speed at low speeds with sensor. These difficulties are eliminated by using sensor less Flux Orientation Controlled (FOC) .

This paper proposes a Model Reference Adaptive System (MRAS) for estimation of rotor speed in FOC. An Induction motor is developed in stationary reference frame and Space Vector Modulation (SVM) is used for inverter design. PID controllers are designed for this FOC. It has good tracking and attains steady state response very quickly which is shown in simulation results.

Keywords – Sensor less field orientation control (FOC), Model Reference Adaptive System (MRAS), Induction motor drive, Speed estimation.

1. 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.

It is well known fact that electric energy consumption of the appliances can be reduced by controlling the speed of the motor. The three phase variable speed IM drives are therefore encouraged to be used in the industry today as an attractive solution forever increasing electricity generation cost.

During the last decade, with the advancement of power electronics technology, a

high speed switching devices such as IGBTs were introduced and more precise motor control strategies, such as vector control techniques, were developed. As a result, today IMs can be used in any kind of variable speed applications, even as a servomechanism, where high-speed response and extreme accuracy is required.

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.

2.DYNAMIC MODELING 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.

From the below figure the terminal voltages are as follows,

$$\begin{aligned} V_{qs} &= R_q i_{qs} + p(L_{qq} i_{qs}) + p(L_{qd} i_{ds}) + p(L_{q\alpha} i_{\alpha}) + p(L_{q\beta} i_{\beta}) \\ V_{ds} &= p(L_{dq} i_{qs}) + R_d i_{ds} + p(L_{dd} i_{ds}) + p(L_{d\alpha} i_{\alpha}) + p(L_{d\beta} i_{\beta}) \\ V_{\alpha} &= p(L_{\alpha q} i_{qs}) + p(L_{\alpha d} i_{ds}) + R_{\alpha} i_{\alpha} + p(L_{\alpha\alpha} i_{\alpha}) + p(L_{\alpha\beta} i_{\beta}) \\ V_{\beta} &= p(L_{\beta q} i_{qs}) + p(L_{\beta d} i_{ds}) + p(L_{\beta\alpha} i_{\alpha}) + R_{\beta} i_{\beta} + p(L_{\beta\beta} i_{\beta}) \end{aligned} \rightarrow (1)$$

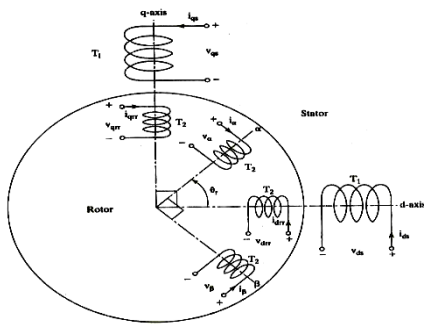


Fig .1 Two-phase equivalent diagram of induction motor

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_s 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

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

The rotor equations are referred 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.

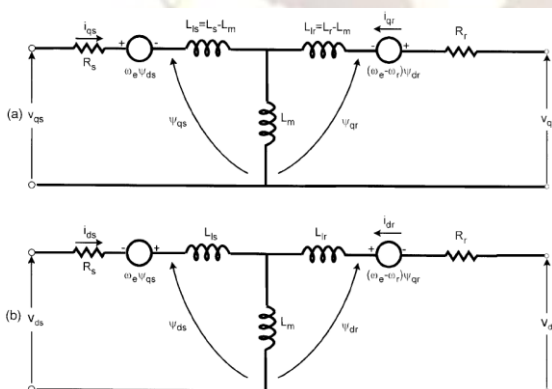


Figure 2 (a) q^e -axis circuit, (b) d^e -axis circuit

Figure 2 shows the d^e - q^e dynamic model equivalent circuit of induction motor under synchronously rotating reference frame, if $v_{qr} = v_{dr} = 0$ and $\omega_e = \omega_r$ then it becomes stationary reference

frame dynamic model.

The 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

$$\left. \begin{aligned} \psi_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \psi_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \psi_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \psi_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned} \right\} \text{----- (2)}$$

$$\left. \begin{aligned} \psi_{qm} &= L_m (i_{qs} + i_{qr}) \\ \psi_{dm} &= L_m (i_{ds} + i_{dr}) \end{aligned} \right\} \text{----- (3)}$$

Stator and rotor voltage and current equations are as follows

$$\left. \begin{aligned} v_{ds} &= R_s i_{ds} + p \psi_{ds} \\ v_{qs} &= R_s i_{qs} + p \psi_{qs} \\ v_{dr} &= R_r i_{dr} + \omega_r \psi_{qr} + p \psi_{dr} \\ v_{qr} &= R_r i_{qr} - \omega_r \psi_{dr} + p \psi_{qr} \end{aligned} \right\} \text{----- (4)}$$

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

$$\left. \begin{aligned} R_r i_{dr} + \omega_r \psi_{qr} + p \psi_{dr} &= 0 \\ R_r i_{qr} - \omega_r \psi_{dr} + p \psi_{qr} &= 0 \end{aligned} \right\} \text{----- (5)}$$

From (5), we have

$$\left. \begin{aligned} i_{dr} &= \frac{-p \psi_{dr} - \omega_r \psi_{qr}}{R_r} \\ i_{qr} &= \frac{-p \psi_{qr} + \omega_r \psi_{dr}}{R_r} \end{aligned} \right\} \text{----- (6)}$$

By solving the equations (4)-(6) we get the following equations

$$\psi_{ds} = \int (v_{ds} - R_s i_{ds}) dt \text{----- (7)}$$

$$\psi_{qs} = \int (v_{qs} - R_s i_{qs}) dt \text{----- (8)}$$

$$\psi_{dr} = \frac{-L_r \omega_r \psi_{qr} + L_m i_{ds} R_r}{R_r + s L_r} \text{----- (9)}$$

$$\psi_{qr} = \frac{L_r \omega_r \psi_{dr} + L_m R_r i_{qs}}{R_r + s L_r} \text{----- (10)}$$

$$i_{ds} = \frac{v_{ds}}{R_s + sL_s} - \left[\frac{\psi_{dr} \cdot sL_m}{L_r \cdot (R_s + sL_s)} \right] \dots\dots\dots (11)$$

$$i_{qs} = \frac{v_{qs}}{R_s + sL_s} - \left[\frac{\psi_{qr} \cdot sL_m}{L_r \cdot (R_s + sL_s)} \right] \dots\dots\dots (12)$$

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

$$T_e = \frac{3}{2} \frac{P}{2} L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \dots\dots\dots (13)$$

$$\text{or } T_e = \frac{3}{2} \frac{P}{2} \frac{L_m}{L_r} (i_{qs} \psi_{dr} - i_{ds} \psi_{qr}) \dots\dots\dots (14)$$

3. PRINCIPLE OF VECTOR CONTROL

The fundamentals of vector control can be explained with the help of figure 3, where the machine model is represented in a synchronously rotating reference frame.

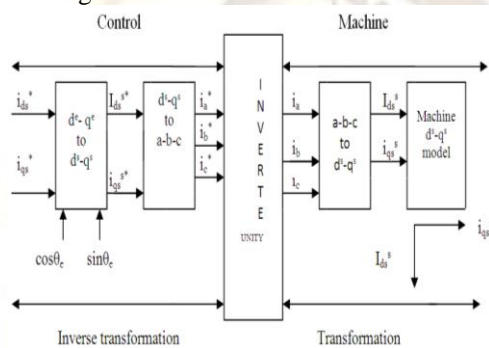


Fig 3 Basic block diagram of vector control

Vector control implementation principle with machine d^s-q^s model as shown. The controller makes two stages of inverse transformation, as shown, so that the control currents and i_{qs}^{*} correspond to the machine currents i_{ds} and i_{qs}, respectively. In addition, the unit vector assures correct alignment of i_{ds} current with the flux vector Ψ_r and i_{qs} perpendicular to it, as shown. It can be noted that the transformation and inverse transformation including the inverter ideally do not incorporate any dynamics, and therefore, the response to i_{ds} and i_{qs} is instantaneous (neglecting computational and sampling delays).

4. INVERTER

Processing of the torque status output and the flux status output is handled by the optimal switching logic. Fig (4) shows the schematic diagram of voltage source 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.

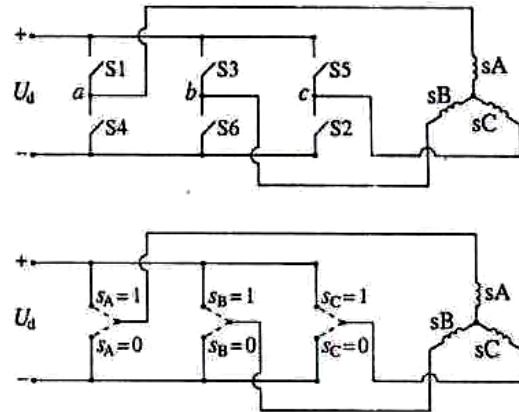
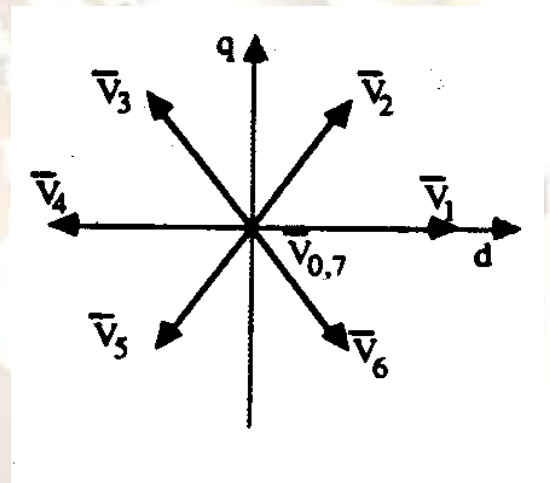
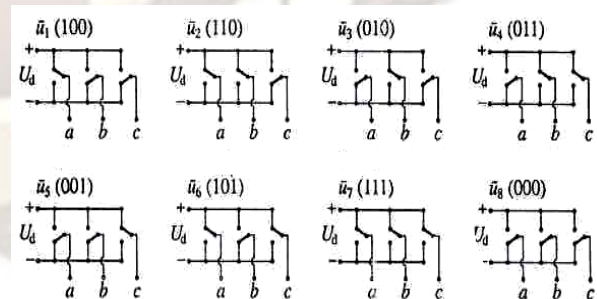


Fig 4: Schematic diagram of voltage source inverter

In reality, there are only six nonzero voltage vectors and two zero voltage vectors as shown in Fig 5(a) & (b).



(a)



(b)

Fig 5(a) Inverter Switching Stages, (b) Switching – voltage space vectors

The machine voltages corresponding to the switching states can be calculated by using the following relations.

$$\left. \begin{aligned} v_{ab} &= v_a - v_b \\ v_{bc} &= v_b - v_c \\ v_{ca} &= v_c - v_a \end{aligned} \right\} \text{----- (15)}$$

Sensor less vector control induction motor drive essentially means vector control without any speed sensor. An incremental shaft mounted speed encoder, usually an optical type is required for closed loop speed or position control in both vector control and scalar controlled drives. A speed signal is also required in indirect vector control in the whole speed range and in direct vector control for the low speed range, including the zero speed start up operation. Speed encoders undesirable in a drive because it adds cost and reliability problems, besides the need for a shaft extension and mounting arrangement.

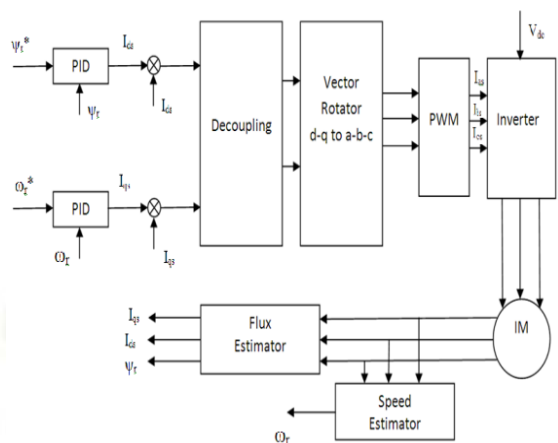


Fig 6:Block Diagram of Sensor less Control of Induction Motor

The schematic diagram of control strategy of induction motor with sensor less control is shown in Fig 4.. Sensor less control induction motor drive essentially means vector control without any speed sensor [5]. 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.

5. 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, ω_r) 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.

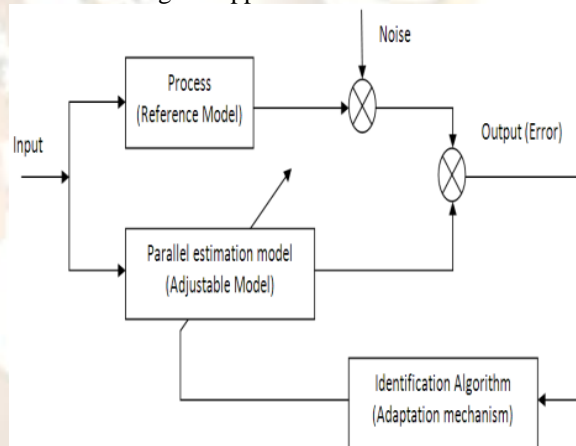


Fig 7: basic identification structures and their correspondence with MRAS

The basic scheme of the MRAS given in Fig. 7 is called a parallel (output error method) MRAS in order to differentiate it from other MRAS configurations where the relative placement of the reference model and of a adjustable system is not the same. The MRAS scheme presented above are characterized by the fact that the reference model was disposed in parallel with the adjustable system. In this scheme the reference and adjustable models are located in series [6]. The use of parallel MRAS is determined by its excellent noise-rejection properties that allow obtaining unbiased parameter estimates. By contrast, “series-parallel” MRAS configurations always lead to biased parameter estimations in presence of measurement noise [8]. Reference model equations:

$$\Psi_{r\alpha} = \frac{L_r}{L_m} \left(\int (U_{s\alpha} - R_s i_{s\alpha}) dt - (L_s - \frac{L_m^2}{L_r}) i_{s\alpha} \right) \text{----- (16)}$$

$$\Psi_{r\alpha} = \frac{L_r}{L_m} \left(\int (U_{s\beta} - R_s i_{s\beta}) dt - (L_s - \frac{L_m^2}{L_r}) i_{s\beta} \right) \text{---- (17)}$$

Adjustable model equations

$$\frac{d\Psi_{\alpha r}}{dt} = \frac{L_m}{T_r} i_{\alpha s} - \omega_r \Psi_{\beta r} - \frac{\Psi_{\alpha r}}{T_r} \text{----- (18)}$$

$$\frac{d\Psi_{\beta r}}{dt} = \frac{L_m}{T_r} i_{\beta s} + \omega_r \Psi_{\alpha r} - \frac{\Psi_{\beta r}}{T_r} \text{----- (19)}$$

Error between reference and adjustable models:

$$\varepsilon_\omega = \Psi_{r\beta} \hat{\Psi}_{r\alpha} - \Psi_{r\alpha} \hat{\Psi}_{r\beta} \text{----- (20)}$$

Estimated speed from PI controller is

$$\hat{\omega}_r = K_p \varepsilon_\omega + K_i \int \varepsilon_\omega dt \text{----- (21)}$$

6. VECTOR CONTROL OF INDUCTION MOTOR DRIVE:

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. It provides a user interactive platform and a wide variety of numerical algorithms. This chapter discusses the realization of vector control of induction motor using Simulink blocks.

Fig.8 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.

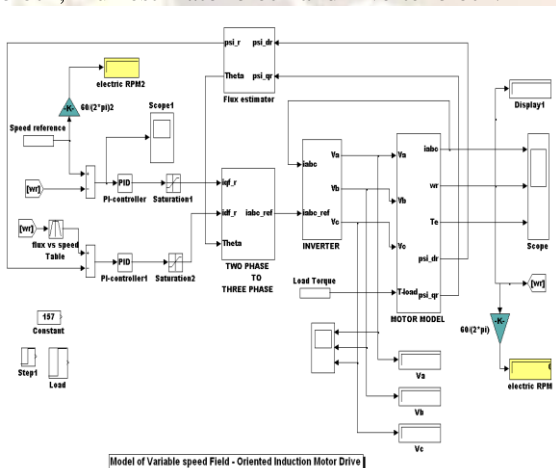


Fig 8: Simulink Model of Vector Controlled Induction motor

6.1 Induction Motor Model:

The motor is modeled in stator reference frame. The dynamic equations are given by (1) to (14). By using these equations we can develop the induction motor model in stator reference frame. Fig.9 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 quadrature axis rotor fluxes, direct and quadrature axes stator currents, electrical torque developed and rotor speed.

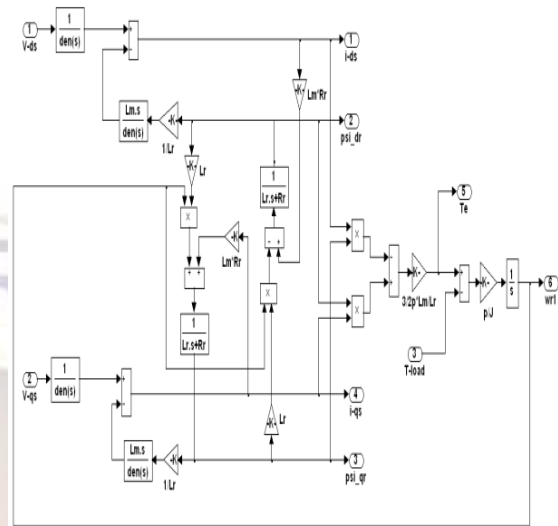


Fig.9: Simulink block diagram for induction motor model

6.2 INVERTER

Fig 4 shows the Voltage Source Inverter (VSI), it consists of an Optimal Switching Logic which is shown in Fig 10. 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.

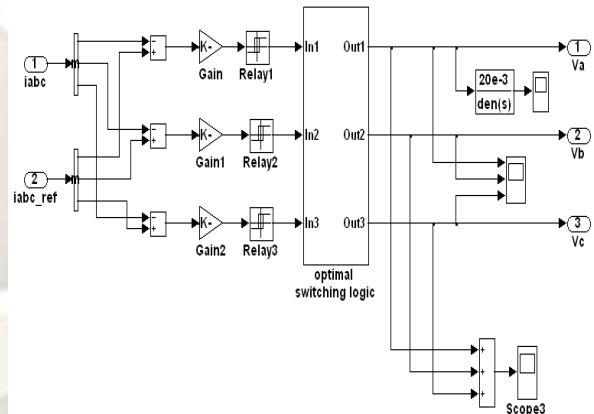


Fig 10 Voltage Source Inverter

6.3 Model Reference Adaptive System (MRAS)

Fig 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, (16) & (17) are defined as a Reference Model and the simulink block diagram of Reference Model is shown in Fig11. The Adaptive Model receives the machine stator voltage and current signals and calculates the

rotor flux vector signals, as indicated by equations, (18) and (19) which is shown in Fig 11. By using suitable adaptive mechanism the speed ω_r , can be estimated and taken as feedback.

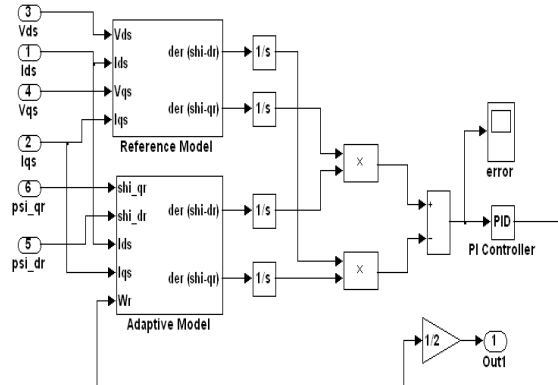


Fig 11: Simulink block diagram for Model Referencing Adaptive System

6.4 Sensor less control of induction motor

The Sensor less control of induction motor using Model Reference Adaptive System (MRAS) 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. It provides a user interactive platform and a wide variety of numerical algorithms. Here we are going to discuss the realization of Sensor less control of induction motor using MRAS for simulink blocks. Fig. 12 shows the root-block simulink diagram for simulation. 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.

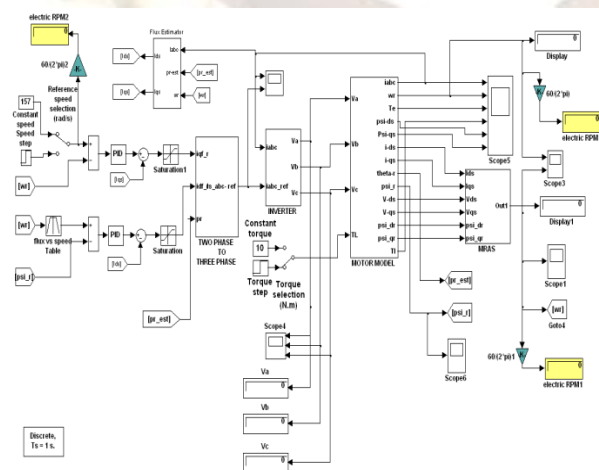


Fig 12: Simulink root block diagram of Sensorless control of induction motor using MRAS

7. SIMULATION RESULTS

The simulation of Vector Control of Induction Motor is done by using

MATLAB®/SIMULINK. The results for different cases are given below.

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

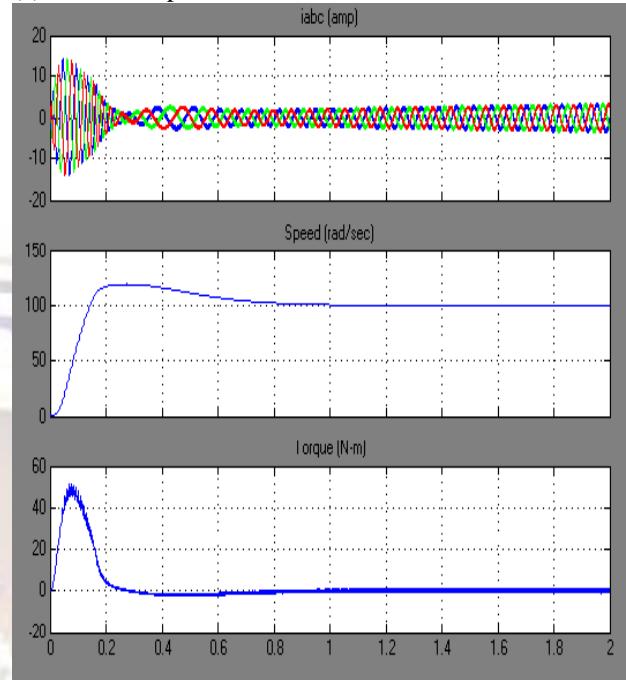


Fig 13: 3-φ currents, Speed, and Torque for no-load reference speed of 100 rad/sec

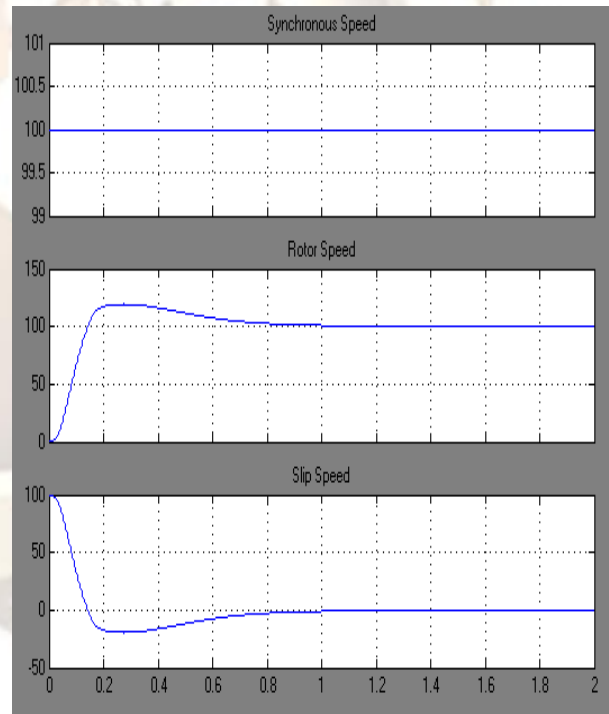


Fig 14: Reference speed, Rotor Speed, Slip Speed Respectively

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

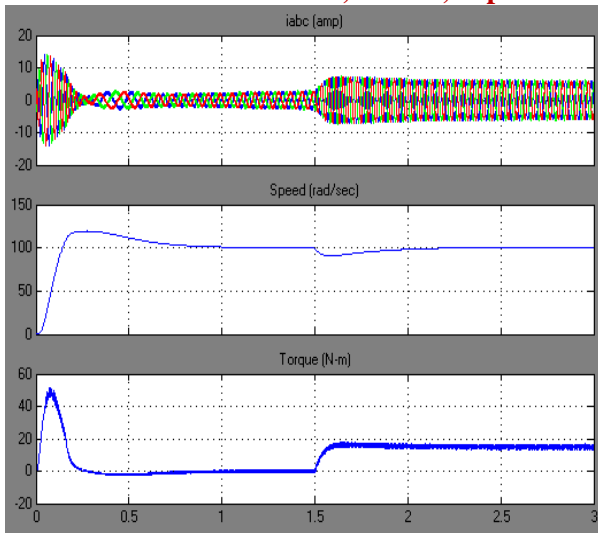


Fig 15: 3- ϕ currents, Speed, and Torque for no-load reference speed of 100 rad/sec

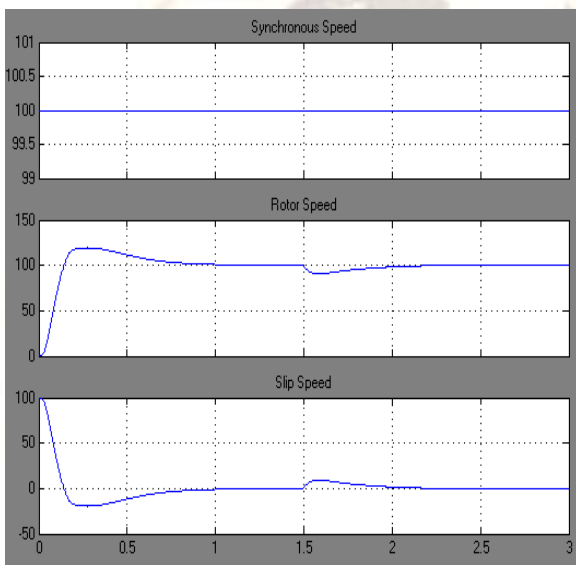


Fig 16: Reference speed, Rotor Speed, Slip Speed Respectively

7.1. Conclusion

In this thesis, 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. The main results obtained from the Simulation, the following observations are made.

- i) The transient response of the drive is fast, i.e. we are attaining steady state very quickly.
- ii) The speed response is same for both vector control and Sensor less control.
- iii) By using MRAS we are estimating the speed, which is same as that of actual speed of induction motor.

Thus by using sensor less control we can get the same results as that of vector control without shaft encoder. Hence by using this proposed technique, we can reduce the cost of drive i.e. shaft encoder's cost, we can also increase the ruggedness of the motor as well as fast dynamic response can be achieved.

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