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Speed Estimation of Sensorless Induction Motor through Vector Control Using MRAS and Direct Synthesis Test

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ABSTRACT

The objective of this project 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 using MRAS and also with direct synthesis test. 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. Second, with the help of synchronous reference frame model the indirect field oriented vector control was developed. Third, Model Reference Adaptive System is studied as a state estimator. Rotor flux estimation scheme is applied to MRAS to estimate rotor speed. . By using the Direct Synthesis test, we can estimate the speed directly without feedback and control algorithm. This test can reduce the total cost.

KEYWORDS: *Induction motor, Sensorless vector control, MRAS, Direct Synthesis test, MATLAB/SIMULINK.*

I. INTRODUCTION

In this thesis, the speed sensorless estimation concept via implementation of Model Reference Adaptive System (MRAS) schemes was studied[1]. It is a well-known fact that the performance of MRAS based speed estimators is beyond par from other speed estimators with regards to its stability approach and design complexity. Although this thesis is all about MRAS based speed estimators, but it is also the aim of this project to investigate several speed sensorless estimation strategies for IMs. Explanations on the type of control strategies also were briefly discussed. As far as simulation works is concerned, the MRAS based speed sensorless estimation schemes chosen in this thesis have been implemented in the Field oriented control (FOC) to evaluate the estimators' performance [2-4].

Operation at low and zero speed is still a problem to overcome, though the performance of MRAS based estimators is considerably good at high speed. To make the system sensorless, we go for rotor speed estimation using direct synthesis of state equation, as the closed loop control requires the speed sensor[5]. By using speed sensor, the IM becomes more costly and less reliable and increased maintenance cost. The different simulation results are observed and studied and the analysis of the different simulated results are presented.

II. MODELLING OF INDUCTION MOTOR

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 whereas asynchronous refers to the fact that the rotor speed is not equal to the stator frequency. To make an IM work, No sliding contacts and permanent magnets are needed which makes it work very simple and cheap to manufacture. As they are motors, they are rugged and don't need much maintenance. However, their speeds are not as easily controlled as with DC motors. They draw large starting currents but when lightly loaded, they operate with a poor lagging factor.

The IM can be operated directly from the mains, but variable speed and often better energy efficiency are achieved by means of a frequency converter between the mains and the motor. A typical frequency converter circuit includes a pulse-width modulated (PWM) inverter, a rectifier and a voltage-stiff DC link. A digital signal processor (DSP) is used to control the inverter.

Its main advantages are the electrical simplicity, mechanical and ruggedness, the lack of rotating contacts (brushes) and its capability to produce torque over the entire speed range.

The assumptions made are:

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

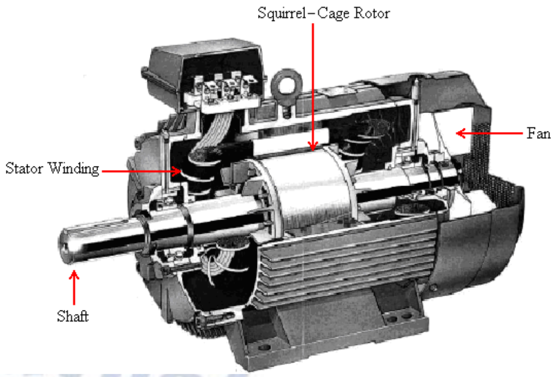


Fig1: A cut-away view of a squirrel cage IM

III. DYNAMIC MODEL STATE – SPACE EQUATIONS

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.

The terminal voltages are as follows,

$$V_{qs} = R_q i_{qs} + p\,(L_{qq} i_{qs}) + p\,(L_{qd} i_{ds}) + p\,(L_{q\alpha} i_\alpha) + p\,(L_{q\beta} i_\beta)$$
$$V_{ds} = p\,(L_{dq} i_{qs}) + R_d i_{ds} + p\,(L_{dd} i_{ds}) + p\,(L_{d\alpha} i_\alpha) + p\,(L_{d\beta} i_\beta)$$
$$V_\alpha = p\,(L_{\alpha q} i_{qs}) + p\,(L_{\alpha d} i_{ds}) + R_\alpha i_\alpha + p\,(L_{\alpha\alpha} i_\alpha) + p\,(L_{\alpha\beta} i_\beta)$$
$$V_\beta = p\,(L_{\beta q} i_{qs}) + p\,(L_{\beta d} i_{ds}) + p\,(L_{\beta\alpha} i_\alpha) + R_\beta i_\beta + p\,(L_{\beta\beta} i_\beta)$$

From the assumptions made in the modelling of the Induction Motor, the equation is modified as

$$vqs = (R_s + L_s\,p)\,iqs + L_{sr} p(i_\alpha \sin\theta_r) - L_{sr}\,p(i_\beta \cos\theta_r)$$

$$v_{ds} = (R_s + L_s\,p)\,ids + L_{sr} p(i_\alpha \cos\theta_r) + L_{sr}\,p(i_\beta \sin\theta_r)$$

$$v_\alpha = Lsr\,p\,(i_{qs} \sin\theta_r) + L_{sr}\,p\,(i_{ds} \cos\theta_r) + (R_{rr} + L_{rr} p)\,i_\alpha$$
$$v_\beta = -\,L_{sr} p\,(i_{qs} \cos\theta_r) + L_{sr}\,p\,(i_{ds} \sin\theta_r) + (R_{rr} + L_{rr} p)\,i_\beta$$

Where $R_s = R_q = R_d\,;\, R_{rr} = R_\alpha = R_\beta$

$$\begin{bmatrix} i_{drr} \\ i_{qrr} \end{bmatrix} = \begin{bmatrix} \cos\theta_r & \sin\theta_r \\ \sin\theta_r & -\cos\theta_r \end{bmatrix} = \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \qquad \ldots\ldots.(1)$$

By applying Transformation to the α and β rotor winding currents and voltages the equation will be written as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qrr} \\ V_{drr} \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_{sr}p & 0 \\ 0 & R_s + L_s p & 0 & L_{sr}p \\ L_{sr}p & -L_{sr}\theta^o{}_r & R_{rr} + L_{rr}p & -L_{rr}\theta^o{}_r \\ L_{sr}\theta^o{}_r & L_{sr}p & L_{rr}\theta^o{}_r & R_{rr} + L_{rr}p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qrr} \\ i_{drr} \end{bmatrix}$$

$$R_r = a^2 R_{rr} \; ; L_r = a^2 L_{rr} \qquad ....(2)$$

$$i_{qr} = \frac{i_{qrr}}{a} ; i_{dr} = \frac{i_{drr}}{a} \qquad ....(3)$$

V_{qr}=av_{qrr}; v_{dr} = av_{drr}

$$L_m \,\alpha\, T_1{}^2 \quad L_{sr} \,\alpha\, T_1 T_2 \qquad ....(4)$$

$$L_m = aL_{sr} \qquad ....(5)$$

From equations 3,4&5 the equation is modified as

$$\begin{bmatrix} V_{qs} \\ V_{ds} \\ V_{qr} \\ V_{dr} \end{bmatrix} = \begin{bmatrix} R_s + L_s p & 0 & L_m p & 0 \\ 0 & R_s + L_s p & 0 & L_m p \\ L_m p & -L_m\theta^o{}_r & R_r + L_r p & -L_r\theta^o{}_r \\ L_m\theta^o{}_r & L_m p & L_r\theta^o{}_r & R_r + L_r p \end{bmatrix} \begin{bmatrix} i_{qs} \\ i_{ds} \\ i_{qr} \\ i_{dr} \end{bmatrix}$$

Where $\theta^o{}_r = \omega_r = d\theta/dt$ and $p = d/dt$

The stator and rotor flux linkages in the stator reference frame are defined as

$$\left.\begin{aligned} \psi_{qs} &= L_s i_{qs} + L_m i_{qr} \\ \psi_{ds} &= L_s i_{ds} + L_m i_{dr} \\ \psi_{qr} &= L_r i_{qr} + L_m i_{qs} \\ \psi_{dr} &= L_r i_{dr} + L_m i_{ds} \end{aligned}\right\} \qquad ....(6)$$

$$\left.\begin{aligned} v_{ds} &= R_s i_{ds} + p\psi_{ds} \\ v_{qs} &= R_s i_{qs} + p\psi_{qs} \\ v_{dr} &= R_r i_{dr} + \omega_r\psi_{qr} + p\psi_{dr} \\ v_{qr} &= R_r i_{qr} - \omega_r\psi_{dr} + p\psi_{qr} \end{aligned}\right\} \qquad ....(7)$$

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

$$\left.\begin{aligned} R_r i_{dr} + \omega_r\psi_{qr} + p\psi_{dr} &= 0 \\ R_r i_{qr} - \omega_r\psi_{dr} + p\psi_{qr} &= 0 \end{aligned}\right\} \qquad ....(8)$$

$$\left.\begin{aligned} i_{dr} &= \frac{-p\psi_{dr} - \omega_r\psi_{qr}}{R_r} \\ i_{qr} &= \frac{-p\psi_{qr} + \omega_r\psi_{dr}}{R_r} \end{aligned}\right\} \qquad ....(9)$$

By solving the equations 7,8 and 9,we get the following equations

$$\psi_{ds} = \int (v_{ds} - R_s i_{ds})dt \qquad ....(10)$$

$$\psi_{qs} = \int (v_{qs} - R_s i_{qs})dt \qquad ....(11)$$

$$\psi_{dr} = \frac{-L_r\omega_r\psi_{qr} + L_m i_{ds} R_r}{R_r} \qquad ......(12)$$

$$\psi_{qr} = \frac{L_r\omega_r\psi_{dr} + L_m R_r i_{qs}}{R_r + sL_r} \qquad ......(13)$$

$$i_{ds} = \frac{v_{ds}}{R_s + sL_s} - \left[\frac{\psi_{dr}.sL_m}{L_r.(R_s + sL_s)}\right] \qquad ......(14)$$

$$i_{qs} = \frac{v_{qs}}{R_s + sL_s} - \left[\frac{\psi_{qr}.sL_m}{L_r.(R_s + sL_s)}\right] \qquad ....(15)$$

$$T_e = \frac{3}{2}\frac{p}{2} L_m (i_{qs} i_{dr} - i_{ds} i_{qr}) \qquad ....(16)$$

$$\text{Or } T_e = \frac{3}{2}\frac{p}{2}\frac{L_m}{L_r}(i_{qs}\psi_{dr} - i_{ds}\lambda_{qr}) \qquad ....(17)$$

The electro-mechanical equation of the induction motor drive is given by

$$\boxed{T_e - T_L = \frac{2}{p} J \frac{d\omega_r}{dt}} \qquad ....(18)$$

IV. SENSORLESS VECTOR CONTROL

Vector control implements the principle with machine d^s-q^s model. The controller makes two stages of inverse transformation, as shown, so that the control currents i^*_{ds} 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 $\hat{\Psi}_r$ 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).

Types of Vector Control

In general, there are essentially two methods for the vector control. They are namely:

(1) Direct vector control, which was developed by F.Blaschke and

(2) Indirect vector control, developed by K.Hasse.

SENSOR INDUCTION MOTOR:	SENSORLESS INDUCTION MOTOR:
This vector control using sensors is known as direct vector control.	This vector control without sensors is known as indirect vector control.

Fixing of number of sensors is a tedious job.	The sensors are eliminated.
The sensors increase the cost of the machine.	The cost factor is decreased.
Drift problem exist because of temperature.	There is no drift problem as in direct vector control.
Poor flux sensing at lower temperatures	The dynamic performance of the indirect vector control s better than the direct vector control

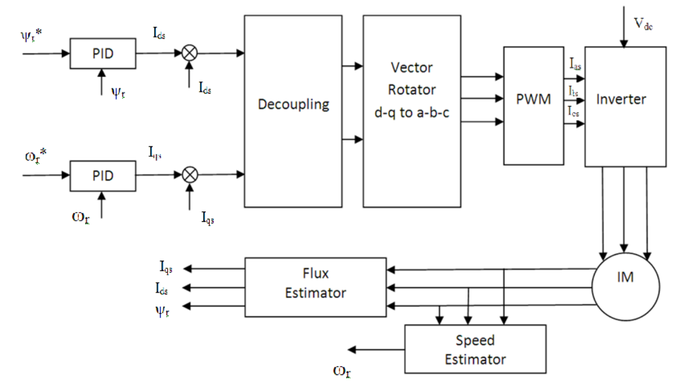


Fig 2: Block Diagram of Sensorless Control of Induction Motor

Speed sensorless estimation strategies:

The concept of sensorless control is to use estimation techniques to estimate the position of the rotor from motor terminal voltage and current signals. These signal processing methods are then implemented into ac motor drives using DSP chips.

Three types of open loop control approaches may be used for drives where only moderate dynamic performance is required:

- Back emf-based estimation.
- Constant V/Hz control.
- Space harmonics-based speed estimation.

Vector control based systems can be used for high performance drives. These methods include:

- Rotor field orientation
- Model reference adaptive systems
- Feedforward control of stator voltages
- Stator flux orientation
- Estimation of rotor flux and torque current

As the rotor speed drops, the open loop estimation models lose accuracy. Closed loop approaches provide improved performance at lower speeds. In addition adaptive/self-tuning approaches are useful when machine parameters are not fully known. We will consider various adaptive approaches in this discussion. Finally, rotor speed estimation is not possible at motor start up and so special techniques to start the motor must be used.

Speed estimation techniques are used to extract the information of speed at shaft by using the motor terminal voltages and currents. The speed estimation techniques are generally classified as follows:

- Slip calculation
- Direct synthesis from state equations
- Model Referencing Adaptive System (MRAS)
- Speed adaptive flux observer
- Extended Kalman filter (EKF)
- Slot harmonics
- Injection of auxiliary signal on salient rotor

In this project, we mainly concentrate on Model Referencing Adaptive System (MRAS) and Direct Synthesis Method which will be discussed briefly in the next chapter.

V. MODEL REFERENCE ADAPTIVE SYSTEM(MRAS)

A. 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.The MRAS identification structures are

- Output Error Method (Parallel MRAS)
- Equation Error Method (Series – Parallel MRAS)
- Input Error Method (Series MRAS)

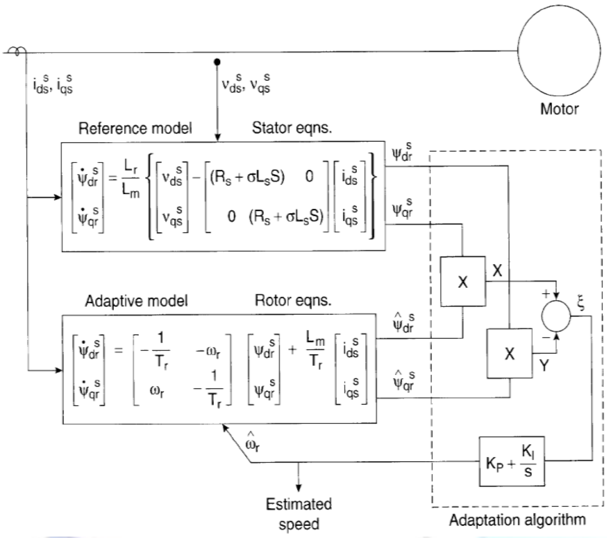


Fig 3: Basic Block Diagram of MRAS speed estimation

B Reference Model

From stator voltage equation

$$v_{ds} = R_s i_{ds} + p\psi_{ds} \qquad \ldots\ldots(19)$$

$$v_{ds} = R_s i_{ds} + L_{ls}\frac{d}{dt}(i_{ds}) + \frac{d}{dt}\psi_{dm} \qquad \ldots\ldots(20)$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \qquad \ldots\ldots.(21)$$

$$\psi_{dr} = \frac{L_r}{L_m}\psi_{dm} - L_{lr} i_{ds} \qquad \ldots\ldots.(22)$$

Rearranging the equation

$$\psi_{dm} = \frac{L_m\psi_{dr} + L_{lr}L_m i_{ds}}{L_r} \qquad \ldots\ldots(23)$$

$$v_{ds} = \frac{L_m}{L_r}\frac{d}{dt}\psi_{dr} + (R_s + \sigma\, SL_s)i_{ds} \qquad \ldots\ldots(24)$$

$$where\ \sigma = 1 - \frac{L_m^{\ 2}}{L_r L_s};\ L_{ls} = L_s - L_m\ \&\ L_{lr} = L_r - L_m$$

Rearranging the above equation

$$\frac{d}{dt}\psi_{dr} = \frac{L_r}{L_m}\left[v_{ds} - (R_s + \sigma\, SL_s)i_{ds}\right] \qquad \ldots\ldots(25)$$

Similarly

$$\frac{d}{dt}\psi_{qr} = \frac{L_r}{L_m}\left[v_{qs} - (R_s + \sigma\, SL_s)i_{qs}\right] \qquad \ldots\ldots(26)$$

C. Adaptive Model

From rotor circuit equations

$$\left.\begin{array}{l} R_r i_{dr} + \omega_r\psi_{qr} + p\psi_{dr} = 0 \\ R_r i_{qr} - \omega_r\psi_{dr} + p\psi_{qr} = 0 \end{array}\right\} \qquad \ldots\ldots(27)$$

$$\frac{L_m R_r}{L_r} i_{qs} = \frac{d}{dt}\psi_{qr} - \omega_r\psi_{dr} + \frac{R_r}{L_r}\left(L_r i_{qr} + L_m i_{qs}\right)$$

$$\frac{L_m R_r}{L_r} i_{qs} = \frac{d}{dt}\psi_{qr} - \omega_r\psi_{dr} + \frac{R_r}{L_r}\psi_{qr}$$

Rearranging the above equation

$$\frac{d}{dt}\psi_{qr} = \frac{L_m}{T_r} i_{qs} + \omega_r\psi_{dr} + \frac{1}{T_r}\psi_{qr} \ldots.(28)$$

The rotor circuit equation in direct axis is modified as

$$\frac{L_m R_r}{L_r} i_{ds} = \frac{d}{dt}\psi_{dr} + \omega_r\psi_{qr} + \frac{R_r}{L_r}\left(L_r i_{dr} + L_m i_{ds}\right)$$

12 5.1

$$\frac{L_m R_r}{L_r} i_{ds} = \frac{d}{dt}\psi_{dr} + \omega_r\psi_{qr} + \frac{R_r}{L_r}\psi_{dr}$$

5.2

Rearranging the equation ,we grt

5.3

$$\frac{d}{dt}\psi_{dr} = \frac{L_m}{T_r} i_{ds} - \omega_r\psi_{qr} - \frac{1}{T_r}\psi_{dr}$$

5.4

Similarly

$$\frac{d}{dt}\psi_{qr} = \frac{L_m}{T_r} i_{qs} - \omega_r\,\psi_{dr} - \frac{1}{T_r}\psi_{qr} \qquad \ldots..(29)$$

5.5

Where $T_r = \frac{L_r}{R_r}$

5.6

The voltage model's stator-side equations are defined as a reference model. The model receives the machine stator voltage and current signals and calculates the rotor flux vector signals, as indicated. The current model flux equations and are defined as an adaptive model in Figure.This model calculates fluxes from the input stator currents only if the speed signal ω_r is known.With the correct spee5.7signal, ideally, the fluxes calculated from the adaptive model will match, that is $\Psi_{dr}^{s} = \hat{\Psi}_{dr}^{s}$ and $\Psi_{qr}^{s} = \hat{\Psi}_{qr}^{s}$, where $\hat{\Psi}_{dr}^{s}$ *and* $\hat{\Psi}_{qr}^{s}$ are the adaptive model outputs.An adaptation algorithm with P-I control, as indicated, can be used to tune the speed ω_r so that the error $\zeta = 0$.

In designing the adaptation algorithm for the MRAS, it is important to take account of the overall stability of the system and to ensure that the estimated speed will converge to the desired value with satisfactory dynamic characteristics. Using Popov's criteria estimated speed is derived as follows:

$$\omega_r = \varsigma\left(k_p + \frac{k_i}{s}\right) \qquad ....(30)$$

Where

$$\varsigma = A - B = \hat{\psi}_{dr}^{s}\psi_{qr}^{s} - \hat{\psi}_{qr}^{s}\psi_{dr}^{s}$$

In steady state, $\zeta=0$, balancing the fluxes; in other words, $\Psi_{dr}^{s} = \hat{\Psi}_{dr}^{s}$ and $\Psi_{qr}^{s} = \hat{\Psi}_{qr}^{s}$. The MRAS in Figure 5.3 can be interpreted as a vector Phase Locked Loop (PLL) in which the output flux vector from the reference model is the reference vector and the adjustable model is a vector phase shifter controlled by ω_r.

In practice, the rotor flux synthesis based on the reference model is difficult to implement, particularly at low speeds, because of the pure integration of the voltage signals. The MRAS speed estimation algorithm remains and valid if, instead of integration, the corresponding CEMF signals are compared directly through some low-pass filters. Estimation accuracy can be good if machine parameters are considered as constant. However, accuracy, particularly at low speeds, deteriorates due to parameter variation.

VI. DIRECT SYNTHESIS TEST

The state equations in the d^s-q^s reference frame can be manipulated to yield the rotor speed.

The stator voltage in the d^s-q^s reference frame is given by:

$$v_{ds} = i_{ds}^{s}R_s + L_{ls}\frac{di_{ds}^{s}}{dt} + \frac{d\psi_{dm}^{s}}{dt}$$

But

$$\psi_{dr}^{s} = \frac{L_r}{L_m}\psi_{dm}^{s} - L_{lr}i_{ds}^{s}$$

........(31)

$$v_{ds}^{s} = \frac{L_m}{L_r}\frac{d\psi_{dr}^{s}}{dt} + (R_s + \sigma L_s s)i_{ds}^{s}$$

$$\sigma = 1 - \frac{L_m^2}{L_r L_s}$$

This equation can be rewritten as:

$$\frac{d\psi_{dr}^{s}}{dt} = \frac{L_r}{L_m}v_{ds}^{s} - \frac{L_r}{L_m}(R_s + \sigma L_s s)i_{ds}^{s} \qquad ....(32)$$

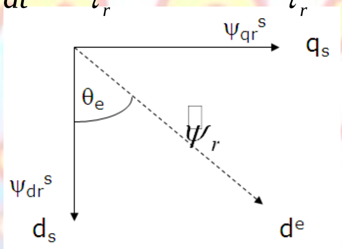
A similar expression can be derived for ψ_{qr}^{s} as:

$$\frac{d\psi_{qr}^{s}}{dt} = \frac{L_r}{L_m}v_{qs}^{s} - \frac{L_r}{L_m}(R_s + \sigma L_s s)i_{qs}^{s}$$

The rotor flux equations in a stationary d^s-q^s reference frame can be written as:

$$\frac{d\psi_{dr}^{s}}{dt} = \frac{L_m}{\tau_r}i_{ds}^{s} - \omega_r\psi_{qr}^{s} - \frac{1}{\tau_r}\psi_{dr}^{s} \quad \text{and}$$

$$\frac{d\psi_{qr}^{s}}{dt} = \frac{L_m}{\tau_r}i_{qs}^{s} + \omega_r\psi_{dr}^{s} - \frac{1}{\tau_r}\psi_{qr}^{s}$$



The angle θ_e between d^e and d^s is given by:

$$\theta_e = \arctan\left(\frac{\psi_{qr}^{s}}{\psi_{dr}^{s}}\right)$$

But

$$\arctan(x) = x - \frac{x^3}{3} + \frac{x^5}{5} - \ldots$$

Ignoring higher order terms, we can write

$$\theta_e \approx \left(\frac{\psi_{qr}^{s}}{\psi_{dr}^{s}}\right)$$

$$\therefore \quad \omega_r = \frac{d\theta_e}{dt} - \frac{L_m}{\tau_r}\left[\frac{\psi_{dr}^{s}i_{qs}^{s} - \psi_{qr}^{s}i_{ds}^{s}}{\psi_{dr}^{s2}}\right]$$

Combining these equations and some algebra gives:

$$\frac{d\theta_e}{dt} = \frac{\psi_{dr}^{s}\dot{\psi}_{qr}^{s} - \psi_{qr}^{s}\dot{\psi}_{dr}^{s}}{\left(\psi_{dr}^{s}\right)^2}$$

$$= \frac{1}{\psi_{dr}^{s2}}\left[\left(\psi_{dr}^{s}\dot{\psi}_{qr}^{s} - \psi_{qr}^{s}\dot{\psi}_{dr}^{s}\right) - \frac{L_m}{\tau_r}\left(\psi_{dr}^{s}i_{qs}^{s} - \psi_{qr}^{s}i_{ds}^{s}\right)\right]$$

...............(33)

A block diagram of this method is shown below:

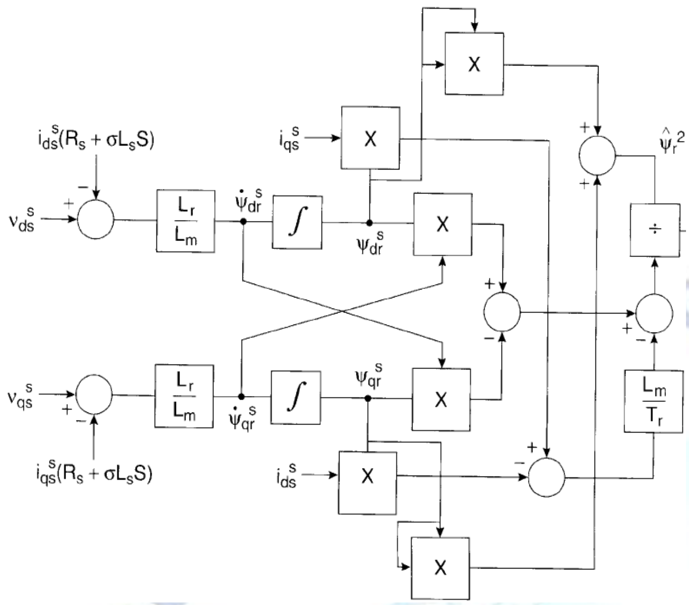


Fig 4 Speed estimation by direct synthesis from state equations

VII. SIMULATION BLOCK DIAGRAM AND SIMULATTION RESULTS OF MRAS:

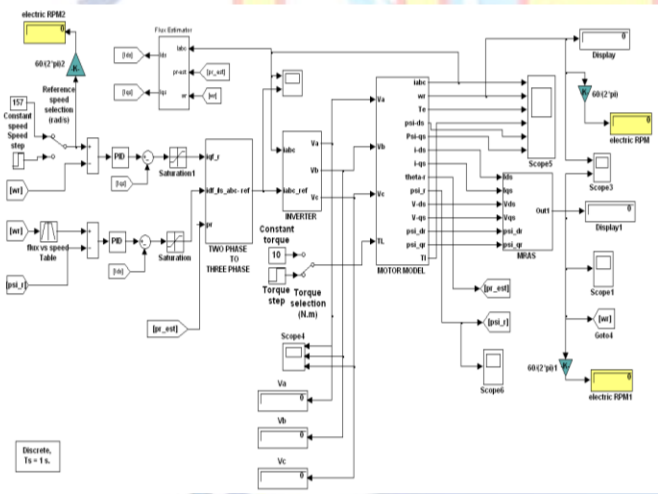


Fig 5: Simulink root block diagram of Senso rless control of induction motor using MRAS

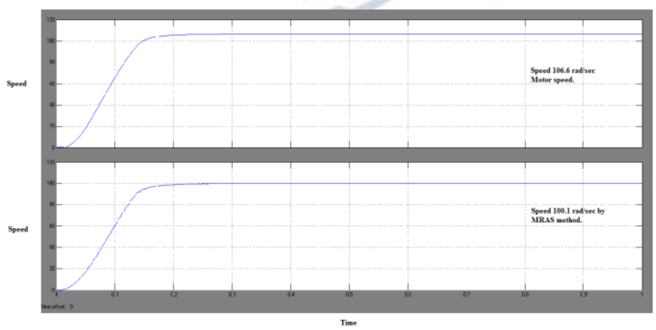


Fig 6: Simulation result of sensorless induction motor using MRAS.

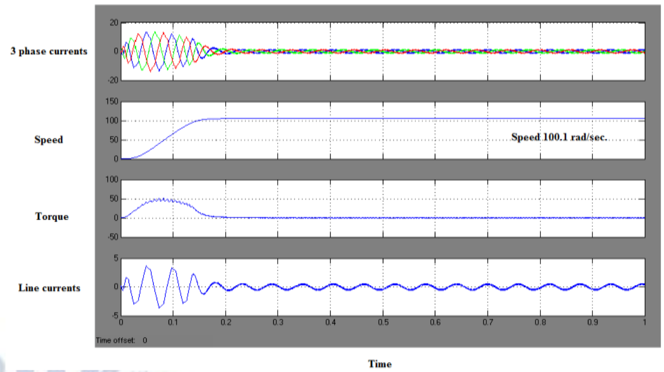


Fig7: Motor speed and torque variations using MRAS at 100 rad/sec.

VIII. SIMULATION BLOCK DIAGRAM AND SIMULATION RESULTS OF DIRECT SYNTHESIS TEST:

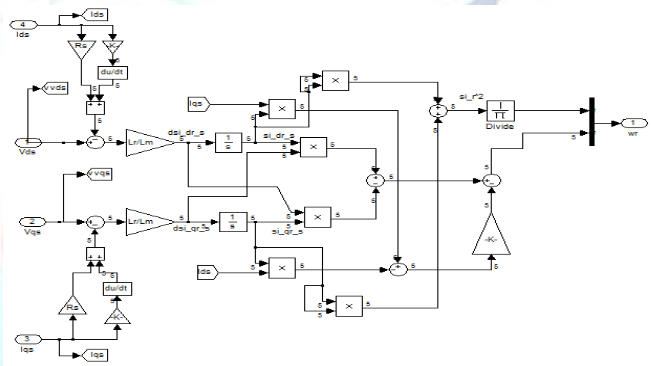


Fig 7: Simulation diagram using Speed estimation by direct synthesis from state equations

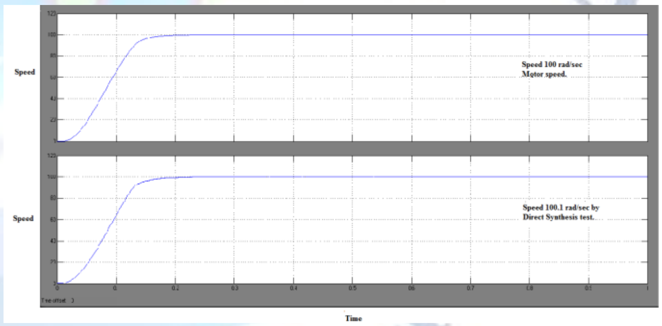


Fig 8: For reference speed 100 rad/sec the motor speed estimation by Induction motor and using Direct Synthesis test.

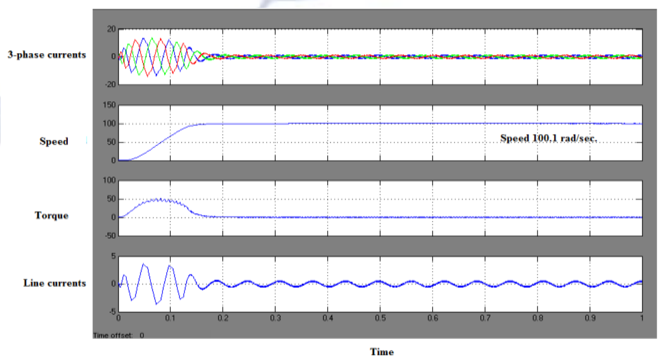


Fig 9: Motor speed and torque variations using Direct Synthesis test at 100 rad/sec.

IX. Conclusion

In this paper, Sensorless control of induction motor using Model Reference Adaptive System (MRAS) technique has been proposed and the results are compared with direct synthesis test. 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.

By using direct synthesis test there is no requirement of addition control algorithm and the speed can be estimated directly by the method.

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