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Soft Computing Based Speed Control Technique of Induction Motor Drive in Sensorless Operation

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ABSTRACT

Induction motor drives have certain advantages like less cost, ruggedness and required low maintenance. Field oriented control provides good solution for industrial applications. Normally in order to implement a vector control operation we generally require number of position sensors like speed, voltage, current sensors. But if we use the position sensors then the cost and size will be increased. So, to overcome this we need to use limited number of sensors. Reducing the number of sensors will increase the reliability of the system. So, if we eliminate the number of sensors we need to estimate the required quantity. The estimation can be done by using different strategies like model based and signal based. Out of this, model based estimation is the best method to estimate the speed by using Model Reference Adaptive System (MRAS).

KEYWORDS: *Induction Motor, Vector Control, Model Reference Adaptive System (MRAS)*

I. INTRODUCTION

There are different MRAS methods available like flux based MRAS, reactive power based MRAS etc. [1-4] flux based MRAS has certain disadvantages like consisting of a pure integrator and the effect of stator resistance [2]. The back emf based MRAS does have problem of pure integrator but it has disadvantage of derivative terms [2]. If we go for a reactive power based MRAS it has advantages like absence of pure integrator and it also doesn't have effect of stator resistance but the problem with this kind of MRAS is that it is unstable in regenerative mode of operation [3]. A vector controlled induction motor offers a exact control of induction motor over a scalar control, because a scalar control although provides good steady state response but it posses very poor performance during dynamic situation [3] . In order to achieve field oriented control the entire flux should be aligned on the direct axis [1]. To convert the three phase machine variables into two phase variables we have to perform Clarks transformation [4]. Different reference frames are discussed [4]. The machine modeling equations are considered in synchronous reference frame where all the variables appear as DC quantities. [3]

II. MODELLING OF INDUCTION MOTOR

Induction motor and Asynchronous motor are the two different names of the same motor which describe the two characteristics in which this type of motor differs from synchronous motors and DC motors. Induction describes that the field in the rotor is induced by the stator currents, and similarly asynchronous describes that the rotor speed and stator frequency are not the same. The absence of permanent magnets and sliding contacts in an induction motor , makes them very easy and cheap to manufacture. As motors But their speeds are not as easily controlled as DC motors.

Following assumptions are made to derive dynamic model of induction machine

- Uniform air gap
- Balanced rotor and stator windings, with sinusoidal distributed emf
- Inductance Vs rotor position is sinusoidal
- Saturation and parameter changes are neglected

Figure 1 shows block diagram of various steps in modeling the induction machine.

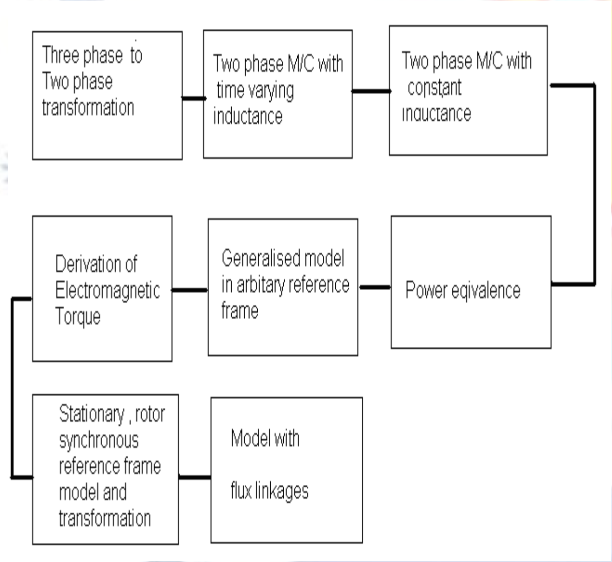


Fig.1 Steps involved in modeling of induction machine

III. DYNAMIC MODEL STATE – SPACE EQUATIONS

The state-space form of an dynamic machine model is important for transient analysis, especially for computer aided simulation . The electrical variables in the Stationary model can be chosen as fluxes, currents or a mixture of both. Here, we will derive the state-space equations of the machine in rotating frame with flux linkages Let's define the flux linkage variables as follows:

$$F_{qs} = w_b \psi_{qs} \quad (1)$$

$$F_{qr} = w_b \psi_{qr} \quad (2)$$

$$F_{ds} = w_b \psi_{ds} \quad (3)$$

$$F_{dr} = w_b \psi_{dr} \quad (4)$$

Where w_b = base frequency of machine

$$V_{qs} = R_s i_{qs} + \frac{1}{w_b}\frac{d(F_{qs})}{dt} + \frac{w_e}{w_b} F_{ds} \quad (5)$$

$$V_{ds} = R_s i_{ds} + \frac{1}{w_b}\frac{d(F_{ds})}{dt} - \frac{w_e}{w_b} F_{qs} \quad (6)$$

$$0 = R_r i_{qr} + \frac{1}{w_b}\frac{d(F_{qr})}{dt} + \frac{w_e - w_r}{w_b} F_{dr} \quad (7)$$

$$0 = R_r i_{dr} + \frac{1}{w_b}\frac{d(F_{dr})}{dt} - \frac{w_e - w_r}{w_b} F_{qr} \quad (8)$$

It is assumed that $V_{qr} = V_{dr} = 0$.

Multiplying the equations by w_b on both sides, the flux linkage expressions will be

$$F_{qs} = w_b \psi_{qs} = X_{ls} i_{qs} + X_m (i_{qs} + i_{qr}) \quad (9)$$

$$F_{qr} = w_b \psi_{qr} = X_{lr} i_{qr} + X_m (i_{qs} + i_{qr}) \quad (10)$$

$$F_{qm} = w_b \psi_{qm} = X_m (i_{qs} + i_{qr}) \quad (11)$$

$$F_{ds} = w_b \psi_{ds} = X_{ls} i_{ds} + X_m (i_{ds} + i_{dr}) \quad (12)$$

$$F_{dr} = w_b \psi_{dr} = X_{lr} i_{dr} + X_m (i_{ds} + i_{dr}) \quad (13)$$

$$F_{dm} = w_b \psi_{dm} = X_m (i_{ds} + i_{dr}) \quad (14)$$

where $X_{ls} = w_b L_{ls}$, $X_{lr} = w_b L_{lr}$ and $X_m = w_b L_m$ or

$$F_{qs} = X_{ls} i_{qs} + F_{qm} \quad (15)$$

$$F_{qr} = X_{lr} i_{qr} + F_{qm} \quad (16)$$

$$F_{ds} = X_{ls} i_{ds} + F_{dm} \quad (17)$$

$$F_{dr} = X_{lr} i_{dr} + F_{dm} \quad (18)$$

From equations (15)-(18), the currents can be expressed in terms of flux linkages as:

$$i_{qs} = \frac{F_{qs} - F_{qm}}{X_{ls}} \quad (19)$$

$$i_{qr} = \frac{F_{qr} - F_{qm}}{X_{lr}} \quad (20)$$

$$i_{ds} = \frac{F_{ds} - F_{qm}}{X_{ls}} \quad (21)$$

$$i_{dr} = \frac{F_{dr} - F_{qm}}{X_{lr}} \quad (22)$$

$$F_{qm} = X_m \left[\frac{F_{qs} - F_{qm}}{X_{ls}} + \frac{F_{qr} - F_{qm}}{X_{lr}} \right] \quad (23)$$

$$F_{qm} = F_{qs}\frac{X_{ml}}{X_{ls}} + F_{qr}\frac{X_{ml}}{X_{lr}} \qquad (24)$$

Where

$$X_{ml} = \frac{1}{\frac{1}{X_m} + \frac{1}{X_{ls}} + \frac{1}{X_{lr}}} \qquad (25)$$

And for F_{dm} as :

$$F_{dm} = F_{ds}\frac{X_{ml}}{X_{ls}} + F_{dr}\frac{X_{ml}}{X_{lr}} \qquad (26)$$

$$V_{qs} = \frac{R_s}{X_{ls}}(F_{qs} - F_{qm}) + \frac{1}{w_b}\frac{d(F_{qs})}{dt} + \frac{w_e}{w_b}F_{ds} \qquad (27)$$

$$V_{ds} = \frac{R_s}{X_{ls}}(F_{ds} - F_{dm}) + \frac{1}{w_b}\frac{d(F_{ds})}{dt} - \frac{w_e}{w_b}F_{qs} \qquad (28)$$

$$0 = \frac{R_r}{X_{lr}}(F_{qr} - F_{qm}) + \frac{1}{w_b}\frac{d(F_{qr})}{dt} + \frac{w_e - w_r}{w_b}F_{dr} \qquad (29)$$

$$0 = \frac{R_r}{X_{lr}}(F_{dr} - F_{dm}) + \frac{1}{w_b}\frac{d(F_{dr})}{dt} + \frac{w_e - w_r}{w_b}F_{qr} \qquad (30)$$

It can be expressed in state-space form as

$$\frac{d(F_{qs})}{dt} = w_b\left[V_{qs} - \frac{w_e}{w_b}F_{ds} - \frac{R_s}{X_{ls}}(F_{qs} - F_{qm})\right] \qquad (31)$$

$$\frac{d(F_{ds})}{dt} = w_b\left[V_{ds} - \frac{w_e}{w_b}F_{qs} - \frac{R_s}{X_{ls}}(F_{ds} - F_{qm})\right] \qquad (32)$$

$$\frac{d(F_{qr})}{dt} = -w_b\left[\frac{w_e}{w_b}F_{dr} + \frac{R_r}{X_{lr}}(F_{qr} - F_{qm})\right] \qquad (33)$$

$$\frac{d(F_{qs})}{dt} = -w_b\left[\frac{w_e}{w_b}F_{qr} + \frac{R_r}{X_{lr}}(F_{dr} - F_{dm})\right] \qquad (34)$$

$$F_{qs} = \int\left\{w_b\left[V_{qs} - \frac{w_e}{w_b}F_{ds} - \frac{R_s}{X_{ls}}(F_{qs} - F_{qm})\right]\right\} \qquad (35)$$

$$F_{ds} = \int\left\{w_b\left[V_{ds} - \frac{w_e}{w_b}F_{qs} - \frac{R_s}{X_{ls}}(F_{ds} - F_{dm})\right]\right\} \qquad (36)$$

$$F_{qr} = \int\left\{w_b\left[\frac{w_e}{w_b}F_{dr} + \frac{R_r}{X_{lr}}(F_{qr} - F_{qr})\right]\right\} \qquad (37)$$

$$F_{dr} = \int\left\{w_b\left[\frac{w_e}{w_b}F_{qr} + \frac{R_r}{X_{lr}}(F_{dr} - F_{dm})\right]\right\} \qquad (38)$$

Finally, from equation (6)

$$T_e = (3/2)(p/2)(1/w_b)(F_{ds}i_{qs} - F_{qs}i_{ds}) \qquad (39)$$

Equations (35)-(39) describe the complete model in state-space form where F_{qs}, F_{qr}, F_{ds},F_{dr} are the state variables.

$$T_e = T_L + J\frac{dw_m}{dt} + BW_m$$

(or) $$W_m = \frac{1}{J}\int(T_e - T_1)$$

IV. SENSORLESS VECTOR CONTROL

Normally in order to achieve accurate control we generally use closed loop control. To achieve closed loop operation we require feedback signal, to get this signal we generally use sensors, but use of sensors not only increase the cost of the system but also the size of the system will increases. These sensors are very sensitive to damage. So, removing these sensors from the system will not only reduces the cost but also reduces the size of the system.

So, we are choosing to control our motor without a sensor. But now the question is how can I get a feedback signal to control our motor. Instead of measuring it with sensors we can also get the information through estimation.

There are mainly two types of control techniques:

1. Open loop estimator
2. Close loop estimator

These estimated values are often used by the FOC to adjust the PWM waveform similar to that of the actually measured values.

Generally sensorless control can be defined as a control in which we won't measure some of the parameters like speed, torque etc. In normal vector control systems slip and flux estimation based on some measurements like DC voltage of the inverter and phase currents the disadvantage with this type is that a low speeds these will give large error in speed.

Closed Loop Observers

In closed loop observer we generally use a feedback which will produce more vigorous structures to variations in parameters. In time-varying system model problems, closed-loop observers are required. The complexity will be increased drastically when compared with the earlier open loop observer but advanced processors are good enough to give faster response in solving these algorithms. In many closed-loop observers Extended Kalman Filter (EKF) was developed to estimate rotor currents which require a speed transducer. This can also be used for estimating the rotor flux and the rotor speed. But the problem with this EKF is that, it is very computationally intensive.

So, among all the closed loop observers a Model Reference Adaptive Reference System(MRAS) attracts more attention. In this MRAS observer the output is generated from comparison between two estimators.

A. Adaptive Control

Adaptive control can be explained in many ways. The best way to explain is "a system which adapts itself accordingly with the changes in the system" .

Model Reference Adaptive System (MRAS)

Basically it has two models one is reference model and the other one is adjustable model. The model which does not depends on which quantity it has to be measured is known as reference model and the model which depends on which quantity it has to be measured is known as adaptive model. The error generated from these two models is used as an input for the adaptive mechanism. In sensorless controls most of the times the quantity which defers the two models is rotor speed.

It consists of reference model and adaptable model as shown in the figure 5.1. The Speed adaption mechanism will adjust its output based upon the outputs of reference and adaptive models.

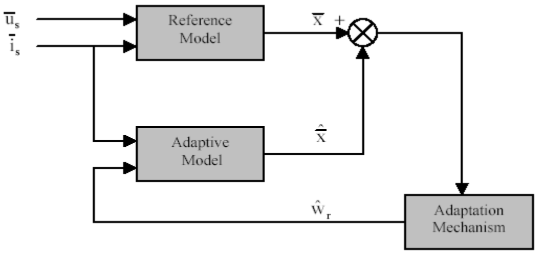


Fig.3.1 Model reference adaptive system

MRAS Based on Rotor Flux Estimation

In this MRAS observer rotor flux linkage (Ψ_r) is used as a speed correction signal. The motor currents and voltages are in a stationary frame of reference. Speed calculation can be done with the help of MRAS were the difference between the two adaptable and reference model vanishes to zero. By using the stator voltage equations in stationary reference frame, the reference model equations can be expressed as:

Reference model equations:

$$\dot{\psi}_{dr} = \frac{L_r}{L_m} v_{ds} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right) i_{ds}$$

$$\dot{\psi}_{qr} = \frac{L_r}{L_m} v_{qs} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right) i_{qs} \quad (40)$$

where Ψ is flux linkage,

L_r , L_m are inductances,

R_s is resistance and

σ is the leakage coefficient of the motor.

$$\sigma = 1 - L_m^2/(L_r L_s)$$

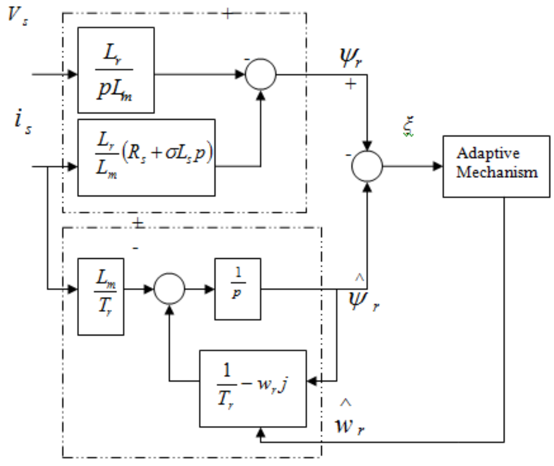


Fig 3.2 MRAS based on rotor flux estimation

Adaptive Model equations:

$$\hat{\psi}^s_{dr} = \int\left(\frac{L_m}{T_r} i_{ds} - w_r \hat{\psi}^s_{qr} - \frac{1}{T_r}\hat{\psi}^s_{dr}\right)$$

$$\hat{\psi}^s_{qr} = \int\left(\frac{L_m}{T_r} i_{qs} + w_r \hat{\psi}^s_{dr} - \frac{1}{T_r}\hat{\psi}^s_{qr}\right) \quad (41)$$

where ω_r is rotor electrical speed and Tr = Lr/Rr is rotor time constant.

V. BLOCK DIAGRAM OF SENSORLESS VECTOR CONTROL

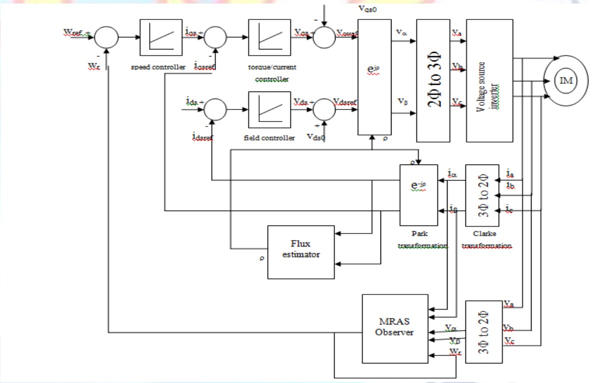


Fig 3.3 Block diagram for Sensor-less vector control

A. Simulink Implementation of MRAS

V_{ds} , V_{qs} , i_{ds} , i_{qs} inputs are derived from the IM and there stationary values are calculated in stationary reference frame.

Using $V_{ds}{}^s$, $V_{qs}{}^s$, $i_{ds}{}^s$, $i_{qs}{}^s$ values $\Psi_{dr}{}^s$,$\Psi_{qr}{}^s$ are calculated from reference model equations.

$$\dot{\psi}_{dr} = \frac{L_r}{L_m} v_{ds} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right) i_{ds}$$

$$\dot{\psi}_{qr} = \frac{L_r}{L_m} v_{qs} - \frac{L_r}{L_m}\left(R_s + \sigma L_s \frac{d}{dt}\right) i_{qs}$$

Similarly by using i_{ds}, i_{qs} and $\hat{\psi}^s_{dr}$, $\hat{\psi}^s_{qr}$ values $\hat{\psi}^s_{dr}$, $\hat{\psi}^s_{qr}$ are calculated from the equations, these are the actual estimated values.

$$\hat{\psi}^{s}_{dr} = \int\left(\frac{L_m}{T_r} i_{ds} - w_r \hat{\psi}^{s}_{qr} - \frac{1}{T_r}\hat{\psi}^{s}_{dr}\right)$$

$$\hat{\psi}^{s}_{qr} = \int\left(\frac{L_m}{T_r} i_{qs} + w_r \hat{\psi}^{s}_{dr} - \frac{1}{T_r}\hat{\psi}^{s}_{qr}\right)$$

using these values the error can be calculated as

i.e $\xi = X - Y = \hat{\psi}^{s}_{dr}\psi^{s}_{qr} - \hat{\psi}^{s}_{qr}\psi^{s}_{dr}$

Equation for speed estimation

$\omega_r = \xi(k_p + k_i/s)$

B. Simulation of Proposed System

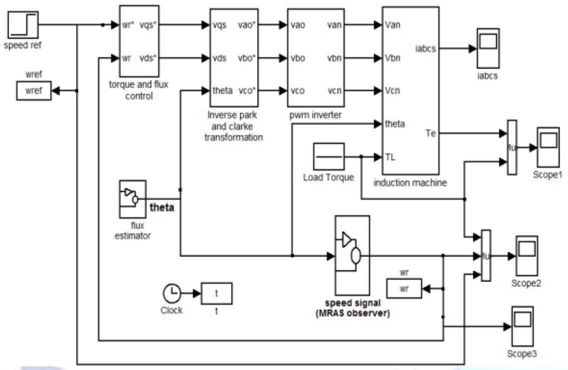


Fig 3.4 Simulink model of sensorless vector controlled induction motor drive

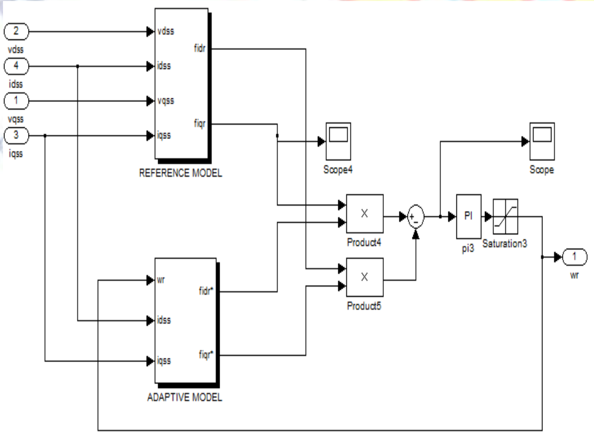


Fig 3.5 Simulink model of MRAS Observer

VI. FUZZY LOGIC CONTROLLERS

Boolean logic was developed based on the thinking of human. It states that the human takes decisions based on yes or no analysis, or simply '1' / '0'. By using this logic a traditional Expert system model was formulated. But in practical human decisions are not always based on yes or no analysis they are normally fuzzy in nature. By considering the above drawback a fuzzy logic was developed. If we consider a situation in normal Boolean logic the output will be logic 1 if it is true and if it is false the output will be logic 0. Unlike this a fuzzy offers more crystal clear output of a given situation, here the output will have degree of membership and output may be anywhere between 0 and 1. With all these advantages fuzzy logic controllers have been used in many applications like refrigerators, washing machines etc.

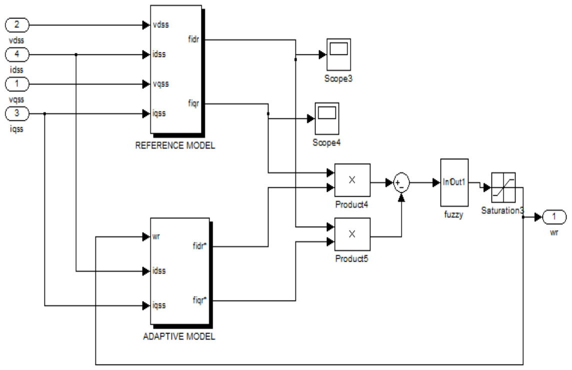
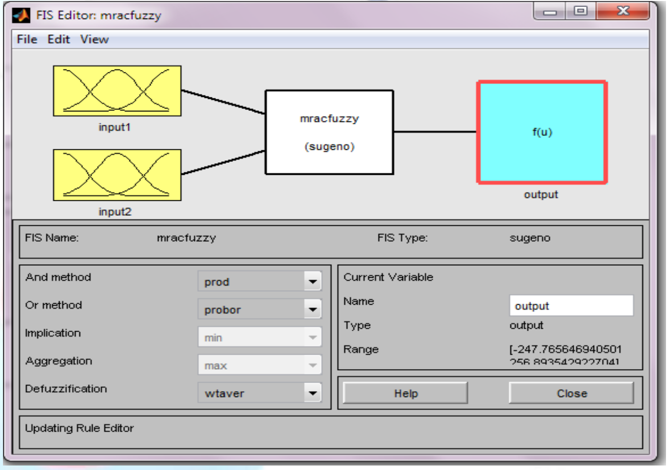


Fig 3.6 : Simulink Block Diagram of MRAS observer with fuzzy controller



FIS Name: mracfuzzy

FIS Type: sugeno

And method: prod

Or method: probor

Implication: min

Aggregation: max

Defuzzification: wtaver

Current Variable

Name: output

Type: output

Range: [-247.765646940501 256.8935429227041

Updating Rule Editor

Fig 3.7 Editor view of fuzzy controller in MATLAB/SIMULINK

VII. SIMULATION RESULTS OF INDUCTION MOTOR ARE GIVEN MAINTAINING THE LOAD TORQUE AS ZERO

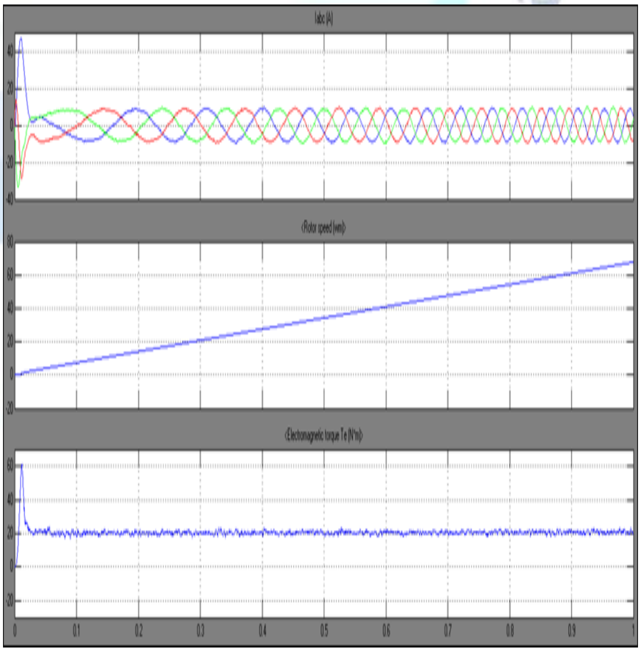


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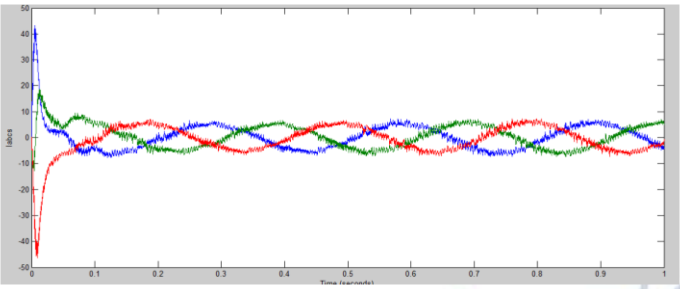
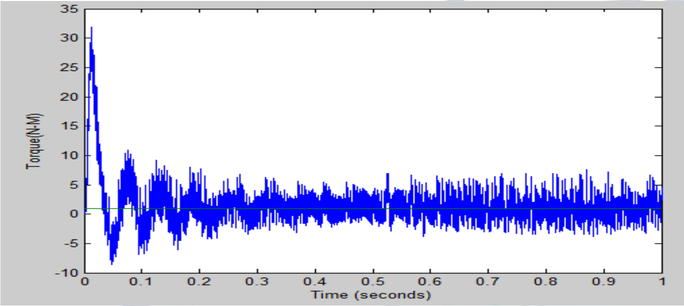
Fig 3.8: Simulation Results Of Induction Motor Are Given Maintaining The Load Torque As Zero

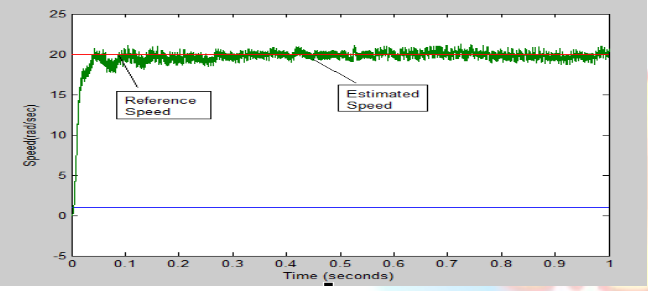
VIII. SIMULATION RESULTS OF MRAS WITH PI CONTROLLER



Iabcs(vs)Time



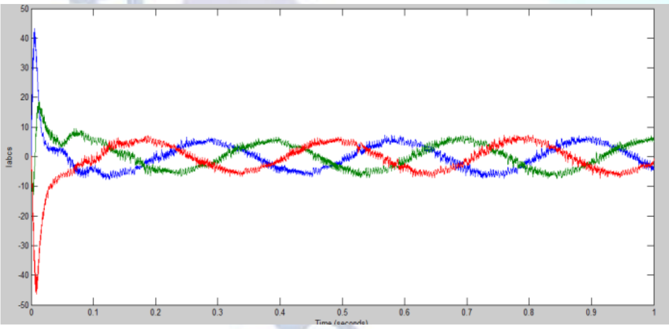
Torque(vs)Time



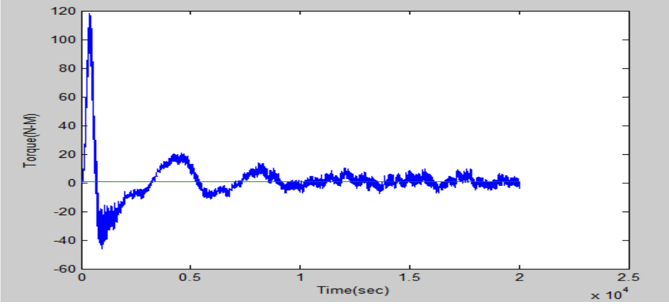
Speed(vs)Time

Fig 3.9: Simulation Results Of MRAS with PI controller

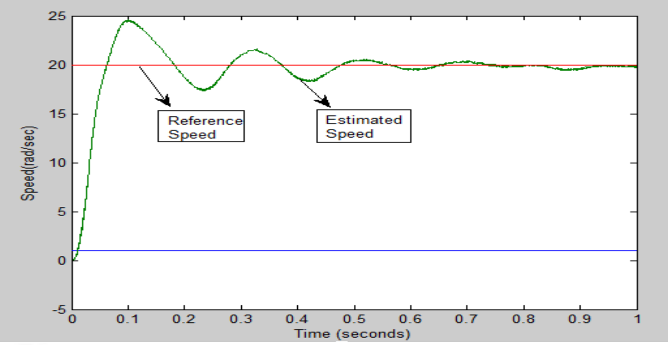
IX. SIMULATION RESULTS OF MRAS WITH FUZZY CONTROLLER



Iabcs(vs)Time



Torque(vs)Time



Speed(vs)Time

Fig 3.10: Simulation Results Of MRAS with Fuzzy controller

X. CONCLUSION

This work presented a speed sensorless vector controlled Induction motor Drive which provides same dynamic and satisfactory performance as that of a vector controlled Induction motor drive using a sensor. The dynamic performance of the proposed system is tested under many cases. This work also presented a fuzzy controller based Model Reference Adaptive System which will give better results than a PI controller based MRAS.

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