# Model Reference Adaptive System based Speed Sensorless Control of Induction Motor using Fuzzy-PI Controller

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## ABSTRACT

In this paper a Model Reference Adaptive System (MRAS) is presented as the speed estimation technique in which the error speed is estimated by comparing reference model and adaptive model and further the error speed is used to obtain the rotor speed. Proportional Integral (PI) is designed for controlling purpose. A non-linear fuzzy-PI controller is used to optimize the speed error value. The Proposed MRAS based speed sensorless control of Induction Motor (IM) drive will ensure the better dynamic performance and reliability, compared to conventional methods. The proposed scheme is simulated using MATLAB/Simulink software.

## Keywords

Sensorless speed control, Model Reference Adaptive System (MRAS), Induction Motor, stationary reference frame, speed estimation.

## 1. INTRODUCTION

IMs are widely used as variable speed drives in industries due to their advantages like rugged construction, low cost, low maintenance and better performance. In order to get good performance of sensorless vector control different speed estimation methods have been proposed such as Extended kalman filter [1], sliding mode control [2], MRAS [3], [5] and [6], direct calculation method. Among these techniques, MRAS schemes are the most common strategies employed due to their relative simplicity and low computational effort. MRAS –based speed estimators developed so far can be grouped into the following three groups

1. The back Electromotive Force (back EMF)-error-based MRAS scheme, which is proposed by Rashed and A.F.Stronach in which the error vector used for the rotor speed correction is obtained from the comparison of the measured and calculated back EMF of the IM [7].
2. The rotor-flux error based MRAS scheme developed by Schauder [8] and Tamai [10] et al, is one of the most popular methods.The speed is estimated through the closed loop signal from the output of the Proportional Integral (PI) controller operated by the flux –error signal.
3. The stator-current-error-based MRAS schemes, where the stator current is estimated by suitable stator-current model and compared with measured value to obtain the speed-error correction signal [11].

In this paper a Model Reference Adaptive System (MRAS) is used as the speed estimation technique, in which the error speed is estimated by comparing reference model and adaptive model and the error is used to obtain the rotor speed. They have a simple structure and can offer a satisfactory performance over a wide range of operation. Fuzzy logic controller (FLC) is another nonlinear optimizer to minimize the speed tuning signal for rotor speed estimation [13]. The chapter 2 describes about rotor flux MRAS based speed observer, chapter 3 gives the control strategy (fuzzy logic controller) used in the system, chapter 4 presents the simulation of the MRAS based control of IM with detailed analysis of various parameters and chapter 5 concludes the applications of MRAS based controller in various fields with improved performance.

## 2. ROTOR FLUX MRAS BASED SPEED OBSERVER

The block diagram of MRAS based speed estimation and sensor less speed control of IM is shown in figure1.The three phase input supply is given to the rectifier which converts AC to DC and is given to the DC link inductor to smoothen the DC voltage. The DC output voltage fed to the three phase voltage source inverter which converts DC to AC and then given to the IM drive.

The voltage and current signals are sensed from the output of the inverter and is given for three phase to two phase transformation which consist of two transformation such as Clarke transformation (abc to αβ) and park transformation (αβ to dq).The $V_{dq}$ and $I_{dq}$ signals are given to the MRAS controller which optimizes the error speed by using fuzzy-PI controller to get the estimated rotor speed. The estimated speed is compared with reference speed and accordingly the PWM generator which generates the pulses which is given to the gate drivers. When the firing input is given to the voltage source inverter based on turning on and off inverter switches, the induction motor speed is controlled. The speed $\omega_r$ isestimated by the MRAS which consists of two models, namely reference and adaptive model where the output of the reference model compared with the output of the adjustable model until the errors between the two models vanish to zero.

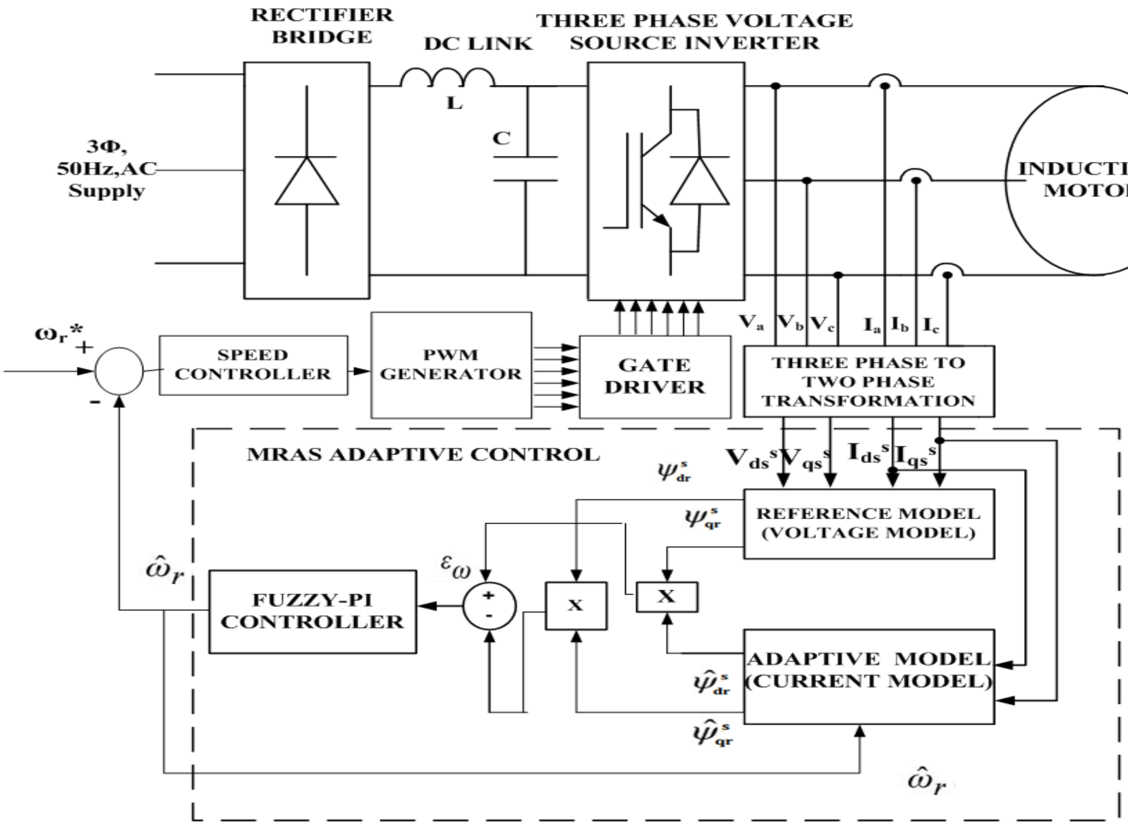


**Figure 1.Proposed Block Diagram of MRAS based induction motor drive using Fuzzy-PI controller.**

## 2.1. Reference Model (Voltage Model)

Consider the voltage model stator equation which is defined as a reference model. It generates the reference value of the rotor flux components in the stationary reference frame ($d^s$-$q^s$).The $d^s$-$q^s$ equivalent circuits are shown in figures 2(a) &2(b) respectively.

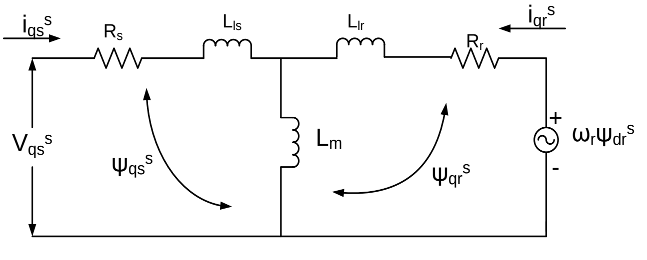


**Figure 2(a). $d^s$ -equivalent circuit**

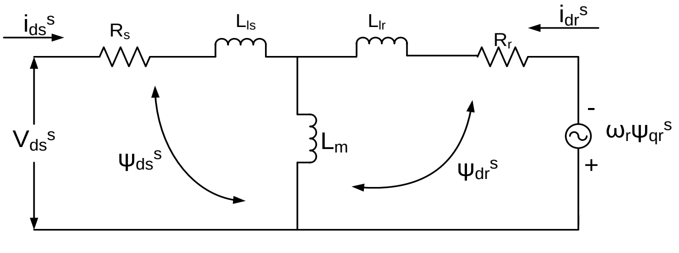


**Figure 2(b).$q^s$-equivalent circuit**

The reference model equations for the rotor flux in stationary reference frame are obtained from the equivalent circuits and shown in equations (1) & (2).

$$\frac{d}{dt}\left(\varphi^s_{dr}\right) = \frac{L_r}{L_m}\left(V^s_{ds} - [R_s + \sigma s L_s] i^s_{ds}\right) \quad (1)$$

$$\frac{d}{dt}\left(\varphi^s_{qr}\right) = \frac{L_r}{L_m}\left(V^s_{qs} - [R_s + \sigma s L_s] i^s_{qs}\right) \quad (2)$$

## 2.2. Adaptive Model (Current Model)

The current model flux equations are defined as an adaptive model. This model calculates the flux from the input stator current only if the speed signal $\omega_r$ is known. The rotor flux components are obtained with the help of speed and current signals. The $d^s$-$q^s$ equivalent circuits are shown in figures3 (a) &3(b).

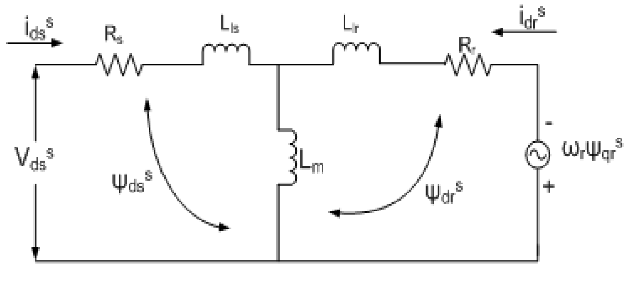


**Figure 3(a). $d^s$- equivalent circuit**

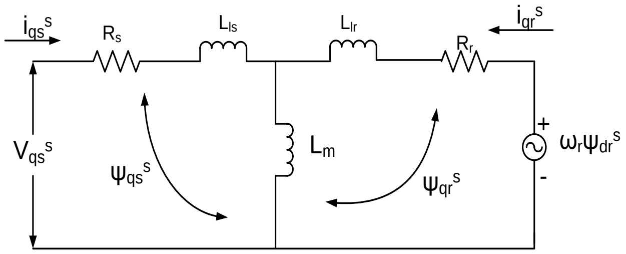


**Figure 3(b).$q^s$- equivalent circuit**

The adaptive model equations are obtained from the equivalent circuits and shown in equations (3) & (4)

$$\frac{d\varphi^s_{dr}}{dt} = \frac{L_m}{T_r} i^s_{ds} - \omega_r \varphi^s_{qr} - \frac{\varphi^s_{dr}}{T_r} \qquad (3)$$

$$\frac{d\varphi^s_{qr}}{dt} = \frac{L_m}{T_r} i^s_{qs} + \omega_r \varphi^s_{dr} - \frac{\varphi^s_{qr}}{T_r} \qquad (4)$$

With the correct speed signal, ideally the fluxes are calculated from the reference model and those calculated from the adaptive model will match that is$\varphi_{rd} = \widehat{\varphi_{rq}}$ and $\varphi_{rq} = \widehat{\varphi_{rd}}$ where the $\widehat{\varphi_{rd}}$ and $\widehat{\varphi_{rq}}$ are the adaptive model outputs.

The rotor flux MRAS scheme, this is performed by defining a speed tuning signal $\varepsilon_\omega$ to be minimized by PI-Fuzzy controller which is generates the estimated speed that is fed back to the adaptive model.

The error speed is the difference between the product of rotor flux of reference and adaptive model [9] of corresponding dq axis. The expressions for the speed tuning signal and the estimated speed is given by equation (5) & (6) respectively.

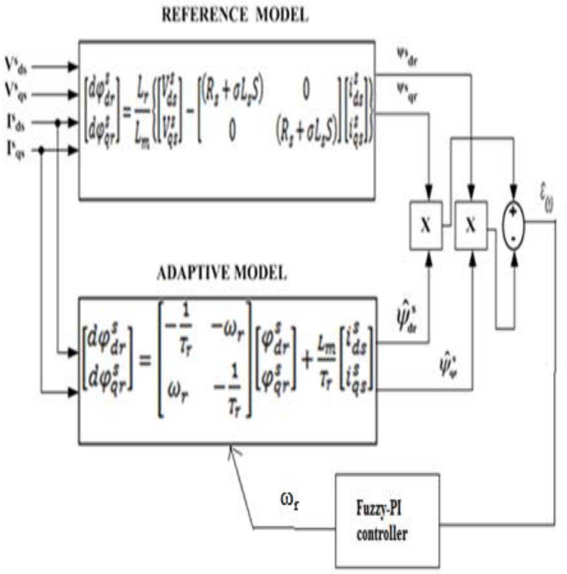


Figure 4. MRAS block diagram

$$\varepsilon_\omega = \varphi_{rq}\widehat{\varphi_{rd}} - \varphi_{rd}\widehat{\varphi_{rq}} \qquad (5)$$

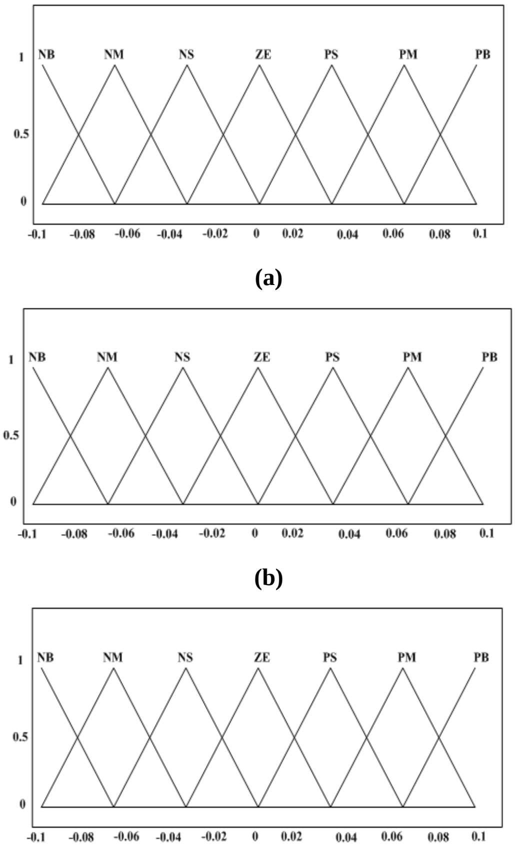
The rotor speed is given by

$$\omega_r = \left(K_p + \frac{K_i}{s}\right) * \varepsilon_\omega \qquad (6)$$

## 3. FUZZY LOGIC CONTROLLER

Fuzzy Logic Controller (FLC) has become popular in several industrial control applications are solving control, estimation and optimization problem, ease of understanding and implementations, ability to handle uncertainty and imprecision [13].In this section, FLC is used for error minimization in the conventional MRAS speed observer.

The proposed FLC is a Mamdani-type rule base where the inputs are the speed tuning signal $\varepsilon_\omega$ and its change in error speed $d\varepsilon_\omega/dt$, which can be defined as,



(a)

(b)

(c)

Figure5. Fuzzy controller input and output functions (a) error (b) change in error (c) change in estimated speed.

Each variable of the FLC has seven membership functions. The following fuzzy sets are used: NB=negative big, NM=Negative Small, ZE= Zero, PS=Positive Small, PM=Positive Medium and PB= Positive Big. The universe of discourse of the inputs and outputs of the FLC are chosen between -0.1 to 0.1with triangular membership functions as shown in Figure.5. Table I shows the fuzzy rule base with 49 rules [14]. FLC is modeled using the MATLAB fuzzy-logic toolbox GUI.

Table I-Linguistic Rule Base

| $\varepsilon_\omega$<br>$d\varepsilon_\omega/dt$ | NB | NM | NS | ZE | PS | PM | PB |
|---|---|---|---|---|---|---|---|
| NB | NB | NM | NM | NS | NS | NS | ZE |
| NM | NM | NM | NS | NS | NS | ZE | PS |
| NS | NM | NM | NS | NS | ZE | PS | PM |
| ZE | NB | NM | NS | ZE | PS | PM | PM |
| PS | NS | NS | ZE | PS | PS | PM | PM |
| PM | NS | ZE | PS | PS | PS | PM | PM |
| PB | ZE | PS | PS | PM | PM | PB | PB |

## 4. SIMULATION RESULTS

Here, a squirrel cage type IM of three phases, 2 poles, 565 V is used in simulation. The figure6show the overall Simulink model of IM drive system. It consists of inverter, induction motor, 3 phase to 2 phase transformation and model of subsystem which consists of MRAS and Fuzzy-PI controller.

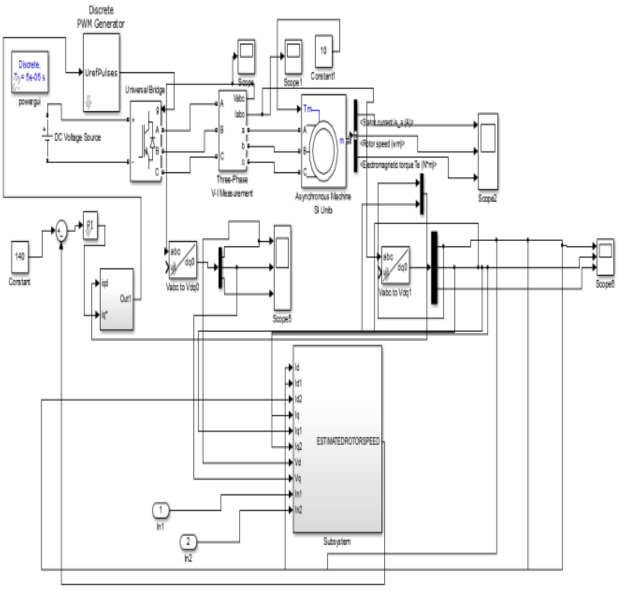


**Figure 6. Overall Simulink model of sensorless control of induction motor using MRAS with fuzzy-PI controller**

The sensorless control of induction motor using MRAS is simulated on MATLAB/SIMULINK-platform to study the various aspects of the controller. Figure 7 shows the simulink block of MRAS with Fuzzy-PI controller.

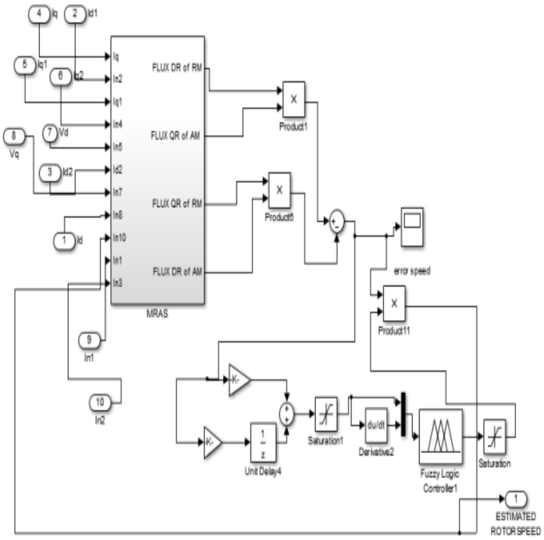


**Figure7. Simulink block diagram of MRAS with fuzzy-PI Controller**

The MRAS consist of two blocks, the reference model and adaptive model. By using suitable adaptive mechanism the speed $\omega_r$ can be estimated and taken as feedback. Fuzzy-PI controller is used to optimize the error speed.

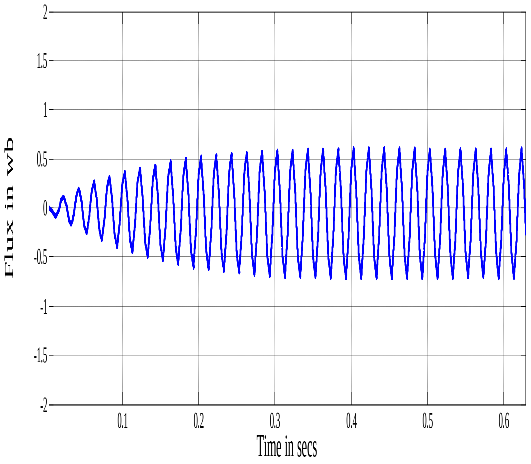


**Figure8(a). Direct rotor flux of reference model**

Figure 8(a) indicates that both the direct and quadrature rotor fluxes of reference model with 90 phase shift.

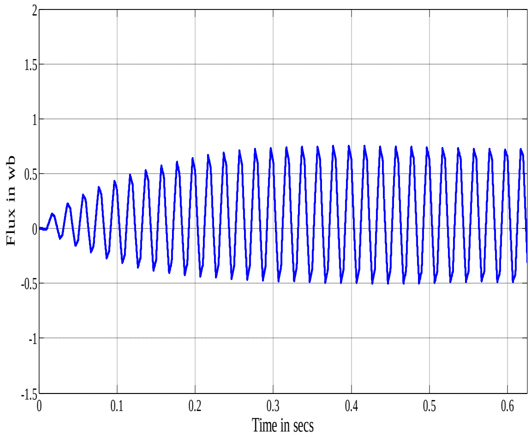


**Figure 8(b). Quadrature rotor flux of reference model**

Figure 8(b) indicates that both the direct and quadrature rotor fluxes of adaptive model with 90 phase shift.

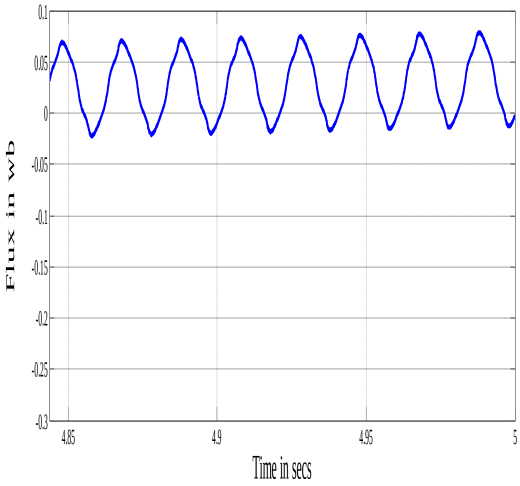


**Figure8(c). Direct rotor flux of adaptive model**

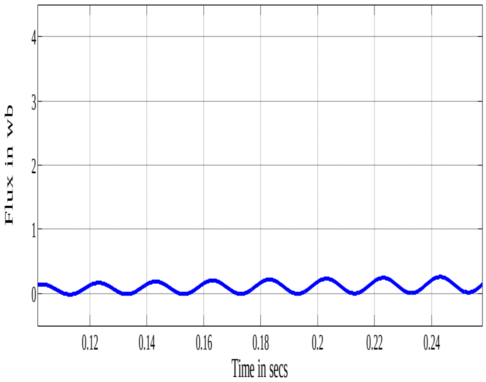


**Figure8(d). Quadrature rotor flux of adaptive model**

The reference model is compared with the adaptive model and the error speed is obtained and shown in figure 9.

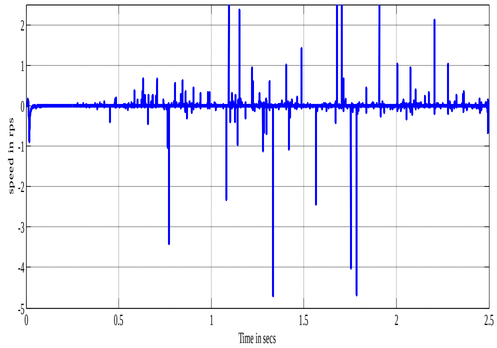


**Figure9. Error speed**

The simulation results of stator current, rotor speed and electromagnetic torque are shown in figure 10.

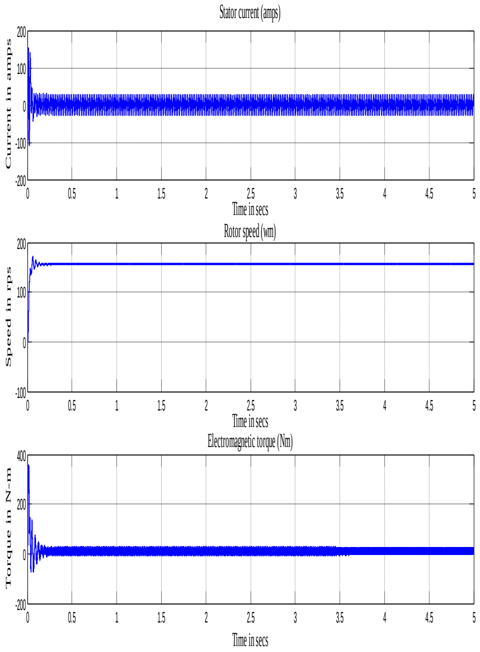


**Figure10. Stator current, rotor speed and electromagnetic torque**

## 5. CONCLUSION

In this paper, a MRAS based speed estimator is proposed for estimating the rotor flux and speed of an IM. The proposed method has better performance under both steady and transient state conditions. The simulation results of speed sensorless control of IM using MRAS technique using Fuzzy-PI controller were carried out by using Matlab/Simulink and simulation results are presented and analyzed. This MRAS based estimator can be used for high performance IM especially at very low speeds. In this paper MRAS based speed sensorless control of induction motor is proposed which can be widely used for textile mills and electrical vehicle applications.

### Appendix

**Table II-Motor Parameters**

| | |
|---|---|
| Power | 10Hp |
| DC Voltage | 565V |
| Stator Resistance($R_s$) | 0.7384Ω |
| Stator Inductance($L_{ls}$) | 0.003045H |
| Rotor Resistance ($R_r$) | 0.7042 Ω |
| Rotor Inductance ($L_{lr}$) | 0.003045H |
| Mutual Inductance($L_{m)}$ | 0.1241H |
| Inertia | 0.0343 J(kg.m$^2$) |
| Pole | 2 |
| Friction factor | 000503F(N.m.s) |

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