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A Comparative Analysis of Different MRAS Schemes for Speed Sensorless Induction Motor Drives Employing PI and Fuzzy Controllers

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Abstract

MRAS speed estimators are becoming more popular over the years because of their high accuracy and flexibility in estimating speed of Induction motor drive without speed sensors to be mounted on the shaft. This paper considers three MRAS configurations they are Rotor flux, Back-Emf and Reactive power based methods. The performance of these MRAS schemes is analyzed for variations in torque .The effectiveness of MRAS is analyzed for various speed ranges. Reactive power based MRAS is proven to have the fastest response of the remaining two MRAS schemes interms of fast settling time and it has very good response at high speeds as well. These estimators are then merged with an Indirect field oriented control and carefully tested on simulation. Also a comparison is carried out between the three MRAS schemes using both PI and FUZZY logic controller.

Keywords: Induction motor drives (IMD), Indirect field oriented control(IFOC),Sensorless speed control, Speed estimators, MRAS, Rotor Flux, Instantaneous Reactive Power, Back EMF, Fuzzy Logic Control(FLC)

INTRODUCTION

The adjustable speed drives (ASDs) withIMDs are making significant effects in loadsbecause of robustness, effective performance and rugged structure. Theyare globally used in various industrial applications as traction locomotives,electric vehicles, and electric propulsionships. The vector control or FOC of an IMD workslike a separately excited DC motor [2].The FOC method sufferswith few drawbacks, such as; it requires,current controllers,co-ordinate transformations, andissensitive to variations in parameters. These FOC schemedrawbacks are reducedwith a new control strategy introduced by Toshihiko andIsao Takahashi which is named as IFOC scheme [3]. The DFOC of an IMD require the rotor shaft angular position information which is measured using speed sensors mounted on rotor shaft. The speed sensorusage is encountered with fewdrawbacks. Those drawbacks have made speed sensor less IFOC drive very attractive over theDFOC drive. The popular MRAS techniques are: Back-emf [7], rotor-flux [8], reactivepower [9]. OF all the three MRAS schemes Reactive power gives fast response and good performance at all speeds.

MRAS BASED SPEED ESTIMATORS

The basic MRAS structure is shown in the fig 2.1.the structure has two models one is reference model (RM) and the other is adjustable model (AM). An adaptive mechanism is present. The error from RM and AM is fed to the adaptive mechanism.The parameters in the RM are fixed and the parameter values in AM are varied based on error between reference and adjustable model values so that the error between two models becomes zero. The three MRAS schemes are explained as follows.

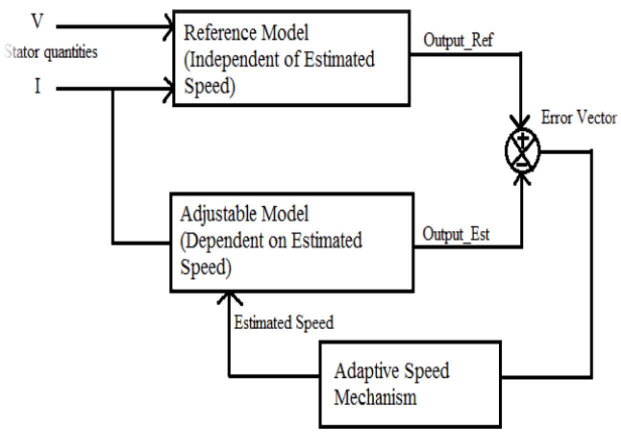


Figure 2.1. Basic structure of MRAS

A)Rotor flux based MRAS speed estimation:

Here in this scheme the output of both AM and RM is interms of rotor flux.

The following equations from Eq. no (1) to (5) are used in the modeling of rotor flux based MRAS speed estimation.

a) Reference model:

$$\Psi_{qr}^{s} = \frac{L_r}{L_m}\left[\int\left(V_{qs}^{s} - R_s i_{qs}^{s} - \sigma L_s i_{qs}^{s}\right) dt\right](1)$$

$$\Psi_{dr}^{s} = \frac{L_r}{L_m}\left[\int\left(V_{ds}^{s} - R_s i_{ds}^{s} - \sigma L_s i_{ds}^{s}\right) dt\right](2)$$

Where$\sigma = 1 - {L_m^2}\big/{L_s L_r}$

b) Adjustable model:

$$^{d\Psi^s_{qr}}/_{dt} = -{}^1/_{T_r}\,\Psi^s_{qr} + \omega_r\Psi^s_{dr} + {}^1/_{T_r}\,i^s_{qs} \quad (3)$$

$$^{d\Psi^s_{dr}}/_{dt} = -{}^1/_{T_r}\,\Psi^s_{dr} - \omega_r\Psi^s_{qr} + {}^1/_{T_r}\,i^s_{ds} \quad (4)$$

c) Adaptive mechanism:

$$\widehat{\omega}_r = \left\{K_P + \frac{K_I}{P}\right\}\left(\Phi_q\widehat{\varphi}_d - \Phi_d\widehat{\varphi}_q\right)(5)$$

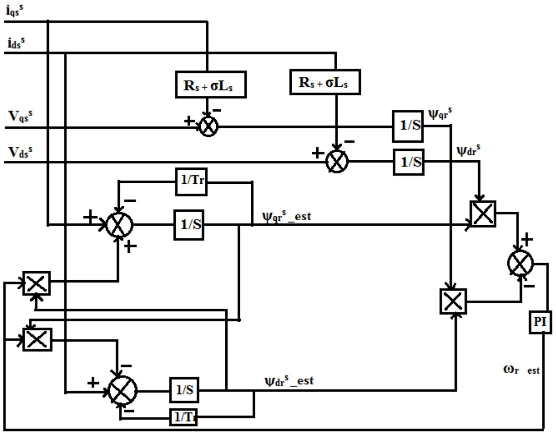


Figure 2.2 Structure of Rotor flux MRAS based Speed estimator

B) Back Emf based MRAS speed estimation:

Here in this scheme output of both AM and RM is induced Emf.

The following equations from eq.no(6) to (12) are used in the modeling of Emf based MRAS speed estimation.

a) Reference model:

$$e_{md} = V^s_{ds} - \{R_s i^s_{ds} + \sigma L_s i^s_{ds}\}(6)$$

$$e_{mq} = V^s_{qs} - \{R_s i^s_{qs} + \sigma L_s i^s_{qs}\}\ (7)$$

b)Adjustable model:

$$\hat{e}_{md} = \left({}^{L_m^2}/_{L_r}\right)\left({}^{di_{md}}/_{dt}\right)(8)$$

$$\hat{e}_{mq} = \left({}^{L_m^2}/_{L_r}\right)\left({}^{di_{mq}}/_{dt}\right)\ (9)$$

Where

$$\frac{di_{md}}{dt} = -\widehat{\omega}_r i_{mq} - {}^1/_{T_r}\,i_{md} + {}^1/_{T_r}\,i^s_{ds} \qquad (10)$$

$$\frac{di_{mq}}{dt} = \widehat{\omega}_r i_{mq} - {}^1/_{T_r}\,i_{md} + {}^1/_{T_r}\,i^s_{ds} \qquad (11)$$

c) Adaptive mechanism:

$$\widehat{\omega}_r = \left\{K_P + \frac{K_I}{P}\right\}(\hat{e}_m - e_m) \qquad (12)$$

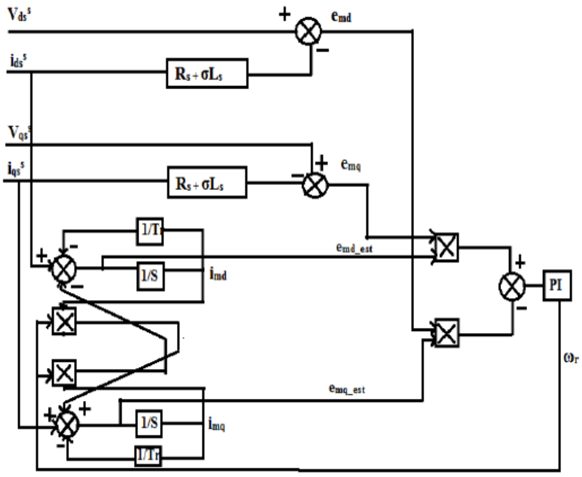


Figure 2.3 Structure of Back emf base MRAS Speed estimator

C)Reactive power based MRAS speed estimation:

Here in this scheme output of RM is instantaneous reactive power and output of AM is steady state reactive power. Error between the two reactive powers is fed to the pi integral control and the rotor speed is estimated.

The following equations from Eq. no (13) to (16) are used in the modeling of reactive power based MRAS speed estimation.

a) Reference model:

The direct measurement of per phase reactive power can be done by using park's transformation from the terminals of the motor.

$$Q^* = {}^1/_{\sqrt{3}}(V_{as}i_{cs} - V_{cs}i_{as})(13)$$

b) Adjustable model:

The equation for steady state reactive power is given by the following equation.

$$Q^* = {}^1/_{\sqrt{3}}(V_{as}i_{cs} - V_{cs}i_{as})\ (14)$$

The right hand side solution of the above equation is expressed in the stationary reference frame as follows:

$$Q^* = \left({}^1/_{T_r}\right)\left({}^{L_m}/_{L_r}\right)\left(\Psi^s_{dr}i^s_{qs} - \Psi^s_{qr}i^s_{ds}\right) + {}^{\omega_r L_m}/_{L_r}\left(\Psi^s_{dr}i^s_{qs} + \Psi^s_{qr}i^s_{ds}\right) + \sigma L_s\left(i^s_{ds}i^s_{qs} - i^s_{qs}i^s_{ds}\right)(15)$$

c) Adaptive mechanism:

$$\widehat{\omega}_r = \left\{K_P + \frac{K_I}{P}\right\}\left(\hat{Q}^* - Q\right) \qquad (16)$$

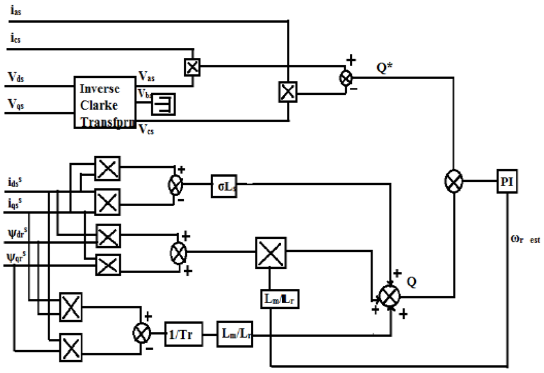


Figure 2.4. Structure of Reactive power based MRAS Speed estimator

MRAS BASED SPEED OBSERVER USING FUZZYLOGIC ADAPTATION MECHANISM

The FLC is a nonlinear, adaptive control approach and itoffers rugged performance under sudden change in speed andload disturbances.FLC has several advantages over other controllers they are it is very robust and can be easily modified and it can use for multiple inputs and multiple outputs finally it is very cheaper and quick to implement. The FLC can handle complicated nonlinear system which has a degree of uncertainty and also does notrequire precise mathematical modeling and parameters unlike constant gain in PI controller, which makes the controller suitable for theIMD [10].

a.Design of Fuzzy Rule Base

The FLC transfers a linguistic control approach into anautomatic control approach, and fuzzy rule bases are designedby an experienced knowledge. The FLC rule base designinvolves designing rules which relates the input variables to the output model properties [8, 10]. The proposed FLC adaptation mechanism, which is designed to estimate the rotorspeed while the IMD is in operating condition. The errorsignal between the RM and the AM is used to determine therotor speed estimation through a FLC adaptationmechanism.

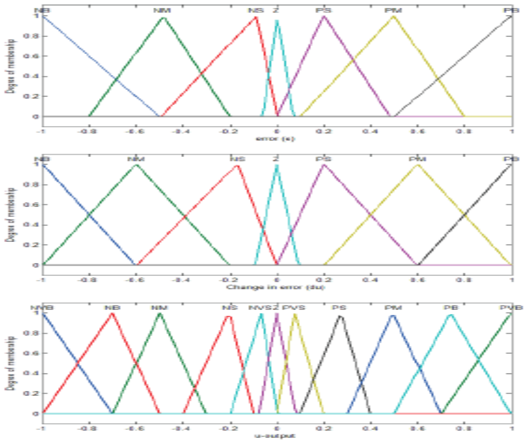


Figure 3.1 The fuzzy input and output variables with normalized triangular wave forms.

Table I: Rule Matrix for FLC

e ce	NB	NM	NS	Z	PS	PM	PB
NB	NVB	NVB	NB	NB	NM	NS	Z
NM	NVB	NB	NB	NM	NS	Z	PS
NS	NB	NB	NM	NS	Z	PS	PM
Z	NB	NM	NS	Z	PS	PM	PB
PS	NM	NS	Z	PS	PM	PB	PB
PM	NS	Z	PS	PM	PB	PB	PVB
PB	Z	PS	PM	PB	PB	PVB	PVB

The fuzzification stage input variables for the rotor speed estimations are error signal ‘ξ_ω ’ and rate of change in error signal ‘ $\omega\ \Delta\xi$ ’ and the output variable is the estimated rotor speed ‘$\hat{\omega}_r$’. The five fuzzy sets are selected to convert the numerical variables into linguistic variables, which are reviewed in Table 1. This membership functions(M.F) are samefor the two input variables and one output variable, which are characterized using Mamdani max-min operation type triangular M.Fs is shown in Fig. 3.1. The FLC universe of discourse in between -1 to 1 is chosen for the input and for output variables.

SIMULATION RESULTS

An equivalent simulation model of each of the above speed observers is built in Simulink and the dynamic performanceis observed for speed change and torque perturbations.The simulation results of the estimator models are analyzed and compared.

(a) Rotor Flux based MRAS estimator:

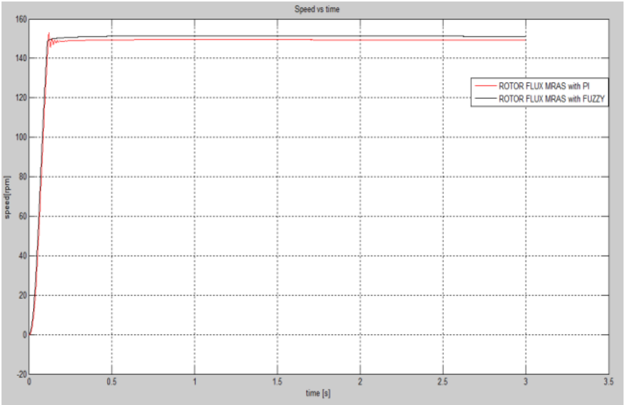


Figure4.1. Comparison of estimated speed with PI and FLC

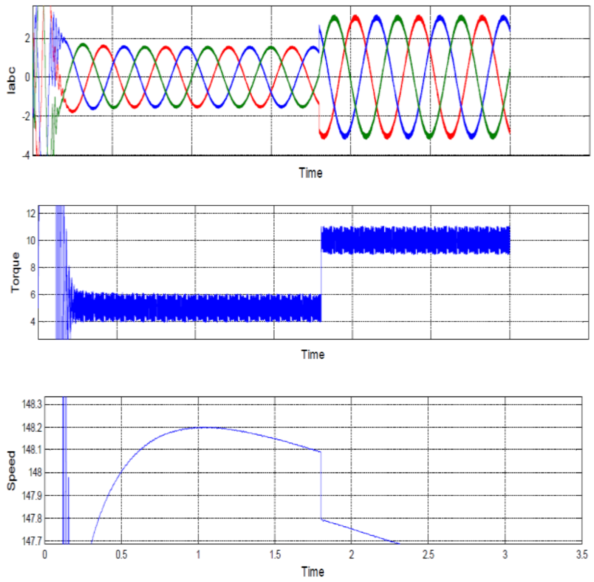


Figure 4.2. Iabc, Torque and Speed during application of step torque of 10 Nm at 1.8 sec, Nr=150 rpm

High speed performance (Nr=900 rpm):

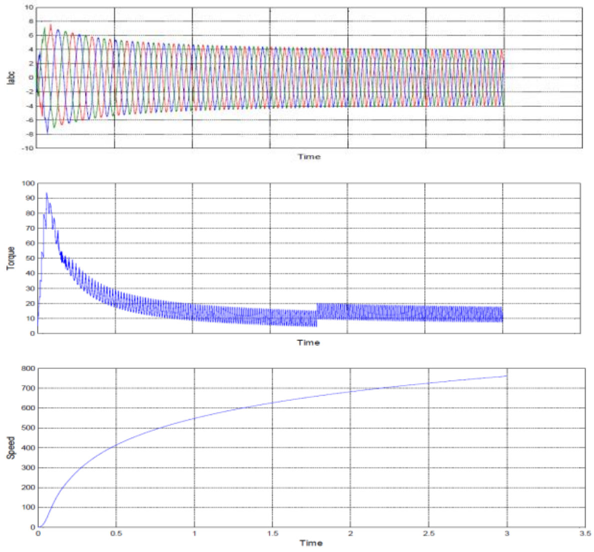


Figure 4.3. Iabc, Torque and Speed at Nr= 900 rpm

(b) Back EMF based MRAS Estimator:

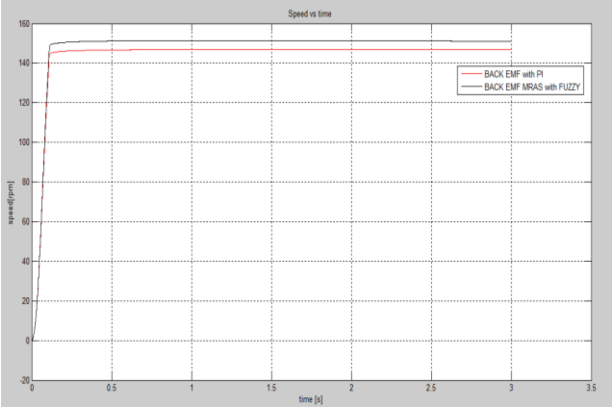


Figure4.4. comparision of estimated speed with PI and FLC

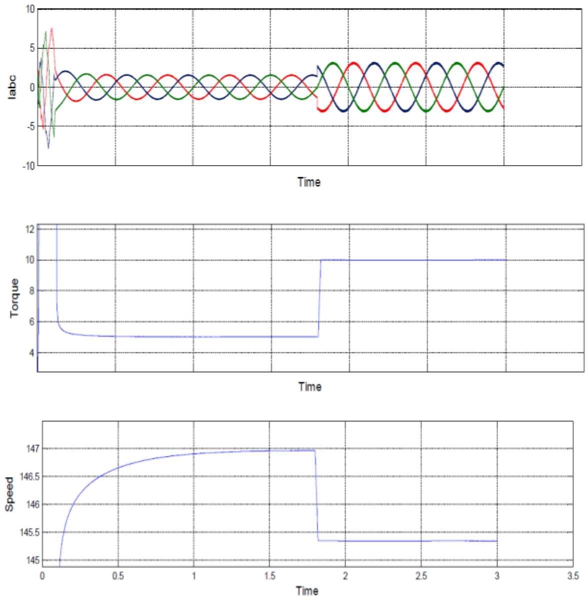


Figure 4.5. Iabc, Torque and Speed during application of step torque of 10 Nm at 1.8 sec, Nr=150 rpm

High speed performance (Nr=900):

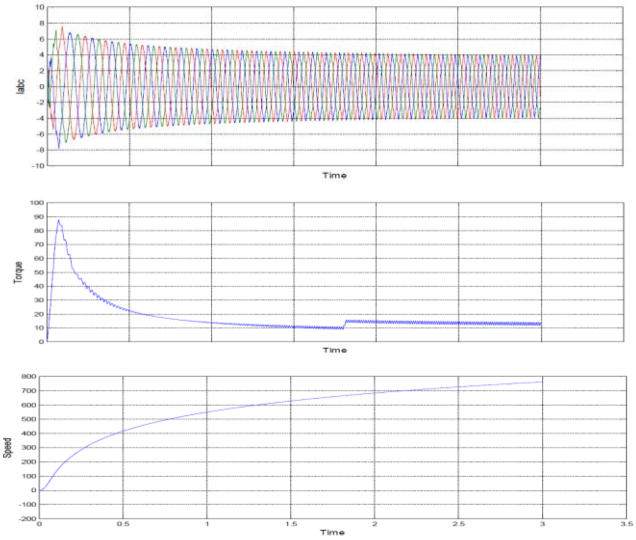


Figure 4.6. Iabc, Torque and Speed at Nr=900 rpm

(C)Reactive Power Based MRAS estimator:

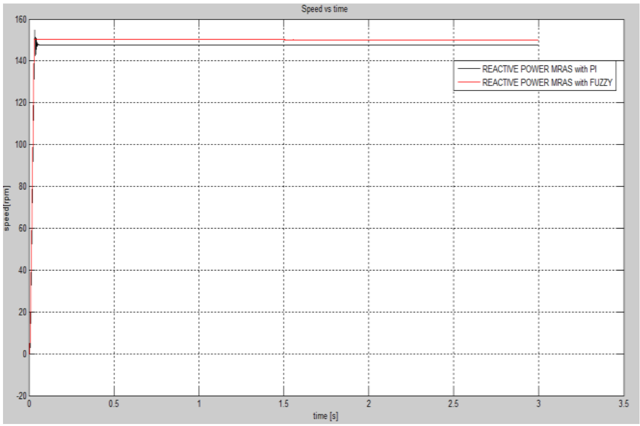


Figure4.7 Comparison of estimated speed with PI and FLC

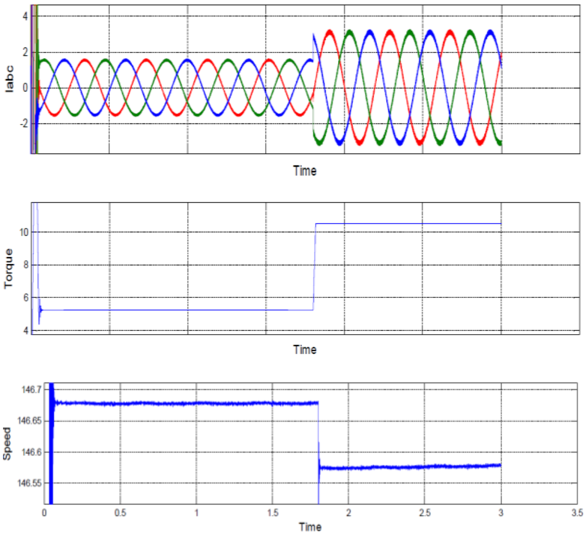


Figure4.8. Iabc, Torque and Speed during application of step torqueof 10 Nm at 1.8 sec, Nr=150 rpm

High speed performance (Nr=900):

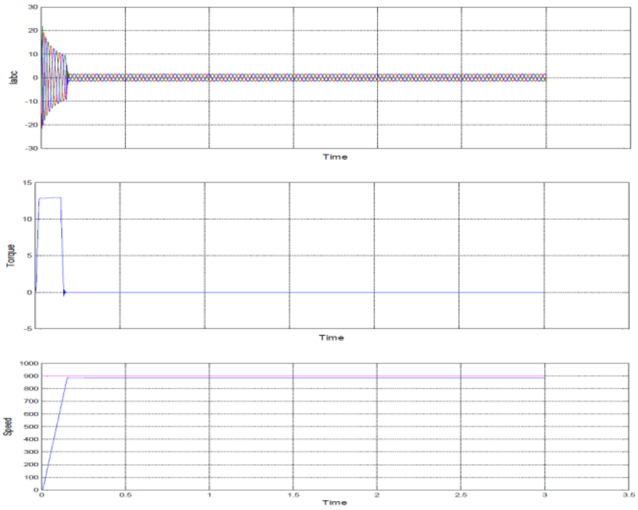


Figure 4.9. Iabc, Torque and Speed at Nr=900 rpm

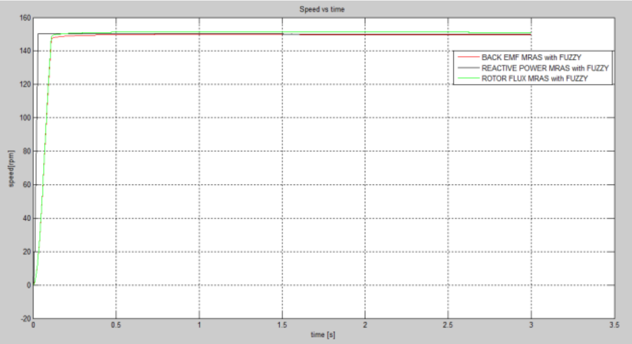


Figure 4.10. FLC based Reactive Power-MRAS, Back -Emf MRAS, Rotor Flux-MRAS

Rotor resistance and stator resistance of IMD

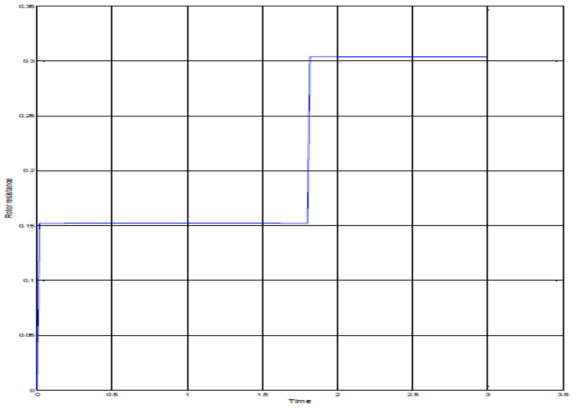


Figure 4.11 Rotor resistance of IMD during application of step torque

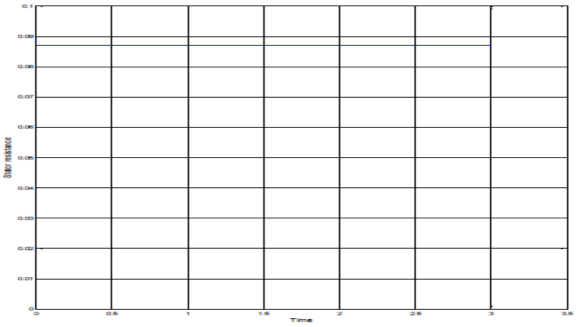
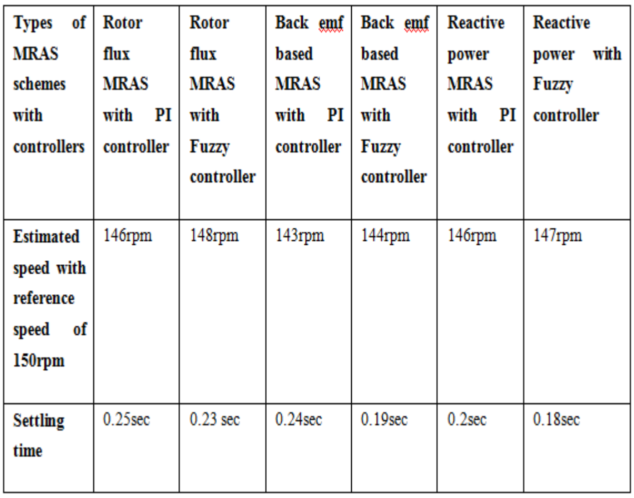


Figure 4.12 Stator resistance of IMD

CONCLUSION

A method of estimating speed of the IMD with various MRAS schemes has been proposed and the variation in the parameters such as speed, current and rotor resistance has been tracked with application of step torque.In view of speed estimation rotor flux scheme reaches the highest estimated speed of148 rpm which is nearest to the reference speed 150 rpm.Even though rotor flux has reached highest estimated speed but it has poor performance in view of rise time and settling time when compared to reactive power method.The analysis has proved the superiority of the Reactive power based MRAS speed estimator over the other two configurations interms of the tracking capability and parameter variations.A comparison table has made between three MRAS schemes with both PI and FLC in terms of their estimated speeds and settling times which is shown in the table below.

Table 2. Comparison between three MRAS schemes with PI and FLC.



Types of MRAS schemes with controllers	Rotor flux MRAS with PI controller	Rotor flux MRAS with Fuzzy controller	Back emf based MRAS with PI controller	Back emf based MRAS with Fuzzy controller	Reactive power MRAS with PI controller	Reactive power with Fuzzy controller
Estimated speed with reference speed of 150rpm	146rpm	148rpm	143rpm	144rpm	146rpm	147rpm
Settling time	0.25sec	0.23 sec	0.24sec	0.19sec	0.2sec	0.18sec

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