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Fuzzy Logic based MRAS Speed Estimator with Rotor Resistance Adaptation Mechanism for Induction Motor Drive

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Abstract

Due to prodigious application of induction motor, heuristic investigation of its control mechanism is must. The main focus of this paper is to investigate the speed of sensorless vector controlled induction motor drive. A rotor flux (RF) based Model Reference Adaptive System (MRAS) with rotor resistance adaptation mechanism is used for speed estimation. Conventional PI controller and fuzzy logic controller in conjunction with MRAS are used for speed estimation and subsequent comparisons of the results. The drive is simulated in MATLAB software and tested for different operating conditions.

Keywords: Induction motor, drive, estimation technique, MRAS, Fuzzy logic controller

NOMENCLATURE

Symbol	Description
v_{ds}, i_{ds}	d- axis stator voltage and current
v_{qs}, i_{qs}	q- axis stator voltage and current
ψ_{dr}, ψ_{qr}	rotor fluxes in d-q frame

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v_{dr}, i_{dr}	d-axis rotor voltage and current
v_{qr}, i_{qr}	q-axis rotor voltage and current
R_s, L_s	stator resistance, stator self-inductance
R_r, L_r	rotor resistance, rotor self-inductance
T_r	rotor time constant
σL_s	leakage inductance

1. INTRODUCTION

Induction motor (IM) drives are indispensable in various industrial applications. They are used in paper mills, pumping, vehicles, fans and others devices. There is a huge expansion in the field of electrical drives with the introduction of microcontrollers. These advancements in technology helped the growth of AC drive control with hardware having lower power dissipation. The most important form of vector control of induction motor is the field oriented control (FOC).

The main purpose here is to deduce a technique that is efficient in estimating the speed sensorless IM problems. As per the hitherto experience of the researchers, RF based MRAS is one of the best technique for speed sensorless estimation of IM drive due to its performance ability and hyper stability in different operating conditions.

There are mainly four types of prevalent MRAS techniques such as - rotor flux oriented MRAS techniques (RF-MRAS), stator current based MRAS, back emf based MRAS (BEMF-MRAS) and instantaneous reactive power based MRAS. There are two models: reference model and adaptive model. The reference model is independent of the rotor speed whereas the adaptive model is dependent on the rotor speed. The rotor flux values are calculated from the IM drive terminal current and voltage values. In the adaptive model, the rotor flux values are estimated. The error is generated between the reference and adaptive model state variables, which is then fed to the IM drive for the adaptation mechanism to estimate the rotor speed. The rotor-flux-based MRAS plan is extremely delicate and vulnerable to parameter variations. Due to low signal to noise ratio, the low speed response of RF based MRAS deals with the problem of inaccuracy. It additionally experiences inverter non-linearity [1]-[2].

In the recent couple of years, speed sensorless drives have been a most talked about topic for researchers and drew their attention as they are proved to be very rugged and economical. Over the last decade, varieties of speed estimation techniques have been developed by many researchers to obviate the necessity of speed sensor. Among all these techniques of estimation, Model Reference Adaptive System (MRAS) has been invariably used with induction motor drives. This scheme is very simple in implementation and gives stable operation over wide range. Rotor and stator are the important part of motor which usually get changed during the operation [2]-[4]. The value of stator resistance can be measured using temperature of stator windings. Rotor resistance may also change upto 100 % and is very difficult to get the same from the temperature sensors [5]. To update the value of rotor resistance in reactive power based MRAS system is also presented [6]. Similarly the estimation of rotor resistance for different speed in transient state is presented in [7]. Also, an adaptive observer is discussed for simultaneous estimation of rotor fluxes and induction motor rotor resistance with voltage source inverters [8]-[9].

In this paper, stability analysis and dynamic performance of a vector control scheme such as the Field Orientated Control (FOC) method is described. The section wise description of the paper is as follows. In Section 1, introduction part is incorporated. Section 2 deals with system description whereas Section 3 presents the concept of designing fuzzy logic based speed estimator. Section 4 gives details of simulation results followed by conclusion in section 5.

2. SYSTEM DESCRIPTION

2.1. Field oriented control

The Field Orientated Control (FOC) mainly uses the stator current vectors for controlling the speed of ac machines as shown in figure 1. This control methodology is dependent upon the projections in which transformation of a three phase system into a two coordinate system (d and q coordinates) is done. This method offers a good control performance in steady state as well as transient states with ac motors, like to DC machine control. Two components of the stator current namely torque component and flux component are considered for FOC.

FOC was discovered as a solution to the coupling between the variables in induction motors. It uses hypothetical reference frames to get a linear relationship between the torque development and torque producing component of current while keeping the flux constant. It implies that the motor torque can be easily controlled by only controlling the stator current component responsible for torque generation.

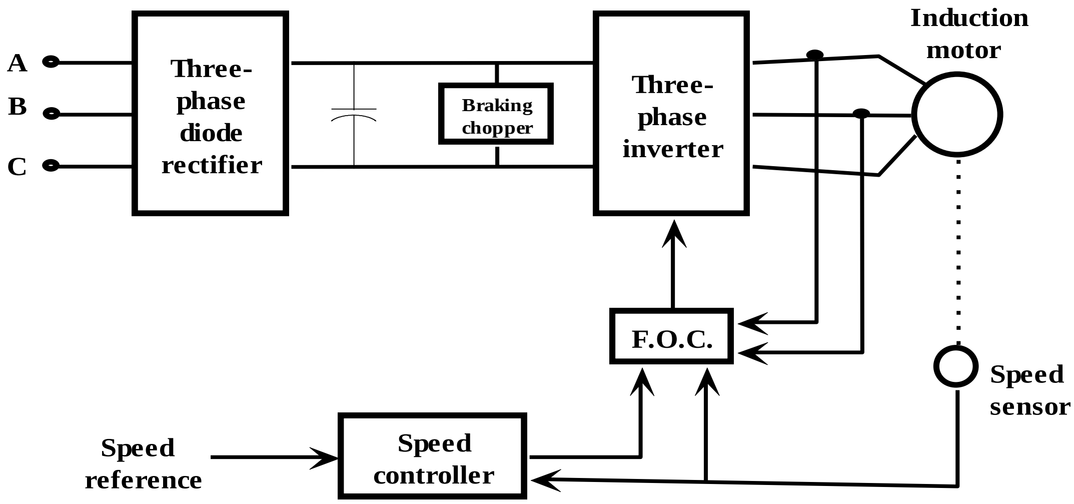

Fig 1: Block Diagram of FOC

2.2. Mathematical model of RF-MRAS

In state space, the equations for the reference and the adaptive model of MRAS speed estimator can be expressed as:

$$p\begin{bmatrix}\psi_{dr}\\ \psi_{qr}\end{bmatrix}=\frac{L_r}{L_m}\left(\begin{bmatrix}v_{ds}\\ v_{qs}\end{bmatrix}-\begin{bmatrix}R_s+p\sigma L_s & 0\\ 0 & R_s+p\sigma L_s\end{bmatrix}\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix}\right) \tag{1}$$

$$p\begin{bmatrix}\psi^e_{dr}\\ \psi^e_{qr}\end{bmatrix}=\begin{bmatrix}-\frac{1}{T_r} & -\omega_r\\ \omega_r & -\frac{1}{T_r}\end{bmatrix}\begin{bmatrix}\psi_{dr}\\ \psi_{qr}\end{bmatrix}+\frac{L_m}{T_r}\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix} \tag{2}$$

2.3. Speed adaptation Mechanism

Speed adaptation mechanism in MRAS based speed estimator is very generally designed in line with a concept of hyper stability. It guarantees the stability of estimator over wide range of operation. However, the convergence to the final speed depends upon the performance of controller used in the adaptation mechanism. In this work, the speed tuning signal is derived by using Popov’s criterion of hyper-stability for a globally asymptotically stable expressed as:

$$\xi_{\omega}=\psi_{qr}\psi^e_{dr}-\psi_{dr}\psi^e_{qr} \tag{3}$$

This speed tuning signal which is basically an error represents the difference between the reference model and the adaptive model. This error is passed on to a controller and forced to zero value. The speed estimated by minimizing the error is used for speed control as well as used for updating the adaptation model continuously.

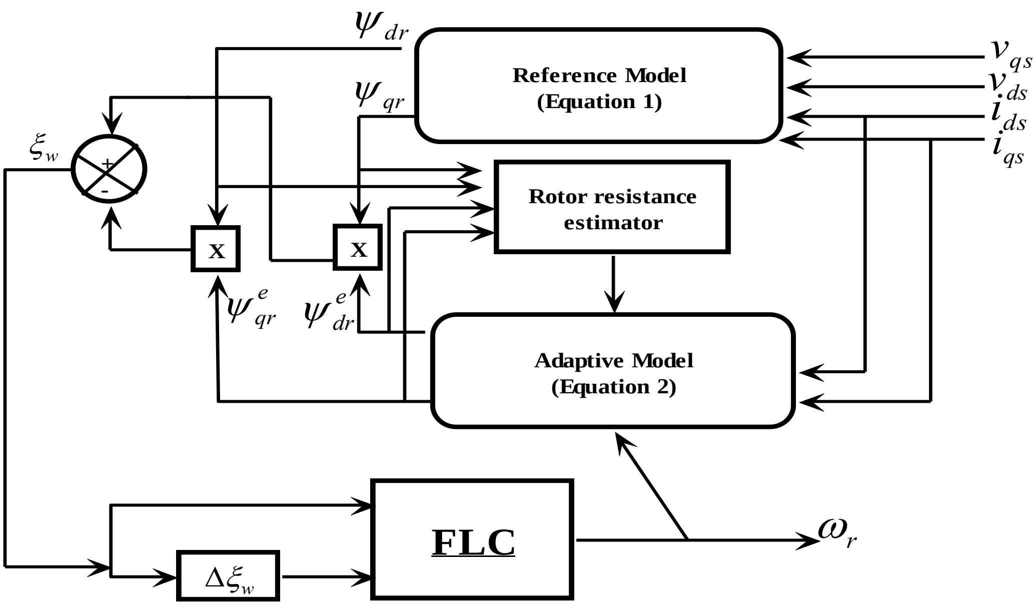

Fig 2: RF-MRAS with FLC and rotor resistance adaptation

Table 1: Fuzzy logic controller rule base

ξ_ω / $\Delta\xi_\omega$		Error				
		PL	**PS**	**ZE**	**NS**	**NL**
Change in error	**PL**	**PL**	**PL**	**PS**	**PS**	**ZE**
	PS	**PL**	**PS**	**PS**	**ZE**	**NS**
	ZE	**PL**	**PS**	**ZE**	**NS**	**NL**
	NS	**PS**	**ZE**	**NS**	**NS**	**NL**
	NL	**ZE**	**NS**	**NL**	**NL**	**NL**

Usually, deviation in the value of rotor resistance of the motor due to thermal loading degrades the performance of the speed estimator designed with constant value of rotor resistance. In this paper an additional loop for updating the value of rotor resistance is also added.

3. FUZZY LOGIC BASED SPEED ADAPTATION

Fuzzy logic has been extensively applied in developing the controllers for speed control actions. The fuzzy logic controller (FLC) can deal with different types of uncertainties and furthermore does not require exact mathematical expressions, making it appropriate for complex systems. The schematic diagram of the RF- MRAS with FLC and rotor resistance adaptation mechanism is shown in figure 2.

The FLC interchanges the crisp values of the inputs into the linguistic words and finally again into crisp value for control action. It takes on the control action based on the rules formulated by the experts of the system. Rules are made available in the rule base for conclusion. FLC rule base designing is an extremely important task involves defining rules that exhibits the relationship in between the inputs and the output.

In this work, the FLC is used in the speed adaptation loop of RF-MRAS based speed estimator. The difference in the outputs of the adaptive model and the reference model is minimized for determination of the motor speed. The input variables before fuzzification stage for the rotor speed estimations are error signal 'ξ_ω' and it's change '$\Delta\xi_\omega$' whereas the rotor speed estimated is the output. The five fuzzy sets are used to convert the numerical variables into linguistic variables, such as; Positive Large (PL), Positive Small (PS), Zero (ZE), Negative Small (NS), and Negative Large (NL), which are summarized in Table 1. The Member functions (MF) are same for the two input variables and one output variable with triangular shapes. The FLC universe of discourse is -1 to 1 is decided for the input and output variables and so inputs and the output are scaled by appropriate gains.

4. SIMULATION RESULTS

In order to verify the performance and effectiveness of the RF-MRAS speed sensorless drive with rotor resistance adaption scheme, it has been simulated using MATLAB/Simulink environment with different operating conditions especially at low speed.

4.1. Speed Tracking at low speed

The simulation performance of RF-MRAS speed sensorless drive with rotor resistance adaptation is tested under no load torque with reference speed, $\omega = 100rpm$. The steady state error in case of Fuzzy MRAS is less as compared to conventional MRAS when there is no mismatch in rotor resistance value as shown in figure 3 and figure 4. Rotor resistance adaptation is incorporated after1.2 sec when rotor resistance is varied

100% and its performance is tested for both ie conventional and Fuzzy based MRAS. There is fast response to rotor resistance adaptation in case of Fuzzy MRAS than conventional MRAS estimator as shown in figure 5 and figure 6.

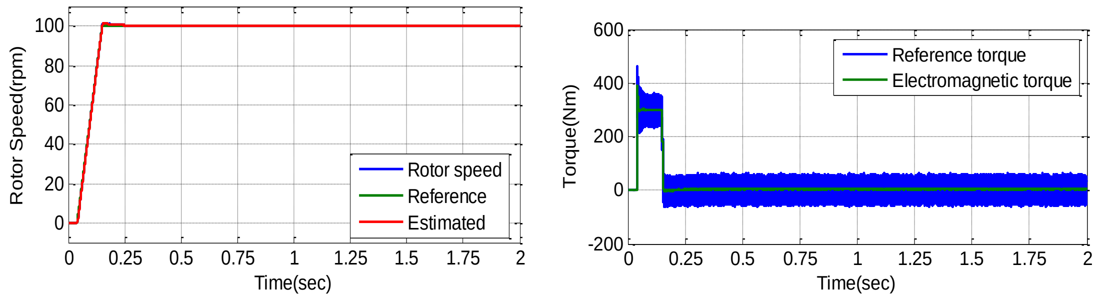

Fig.3. Response of conventional MRAS estimator drive without rotor resistance mismatch

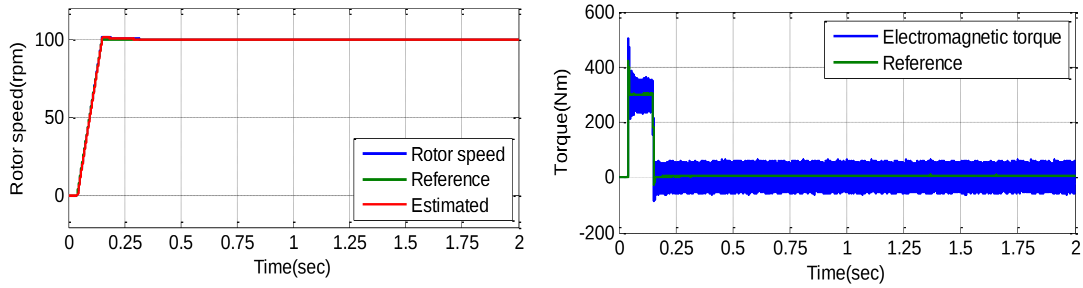

Fig.4. Response of Fuzzy MRAS estimator drive without rotor resistance mismatch

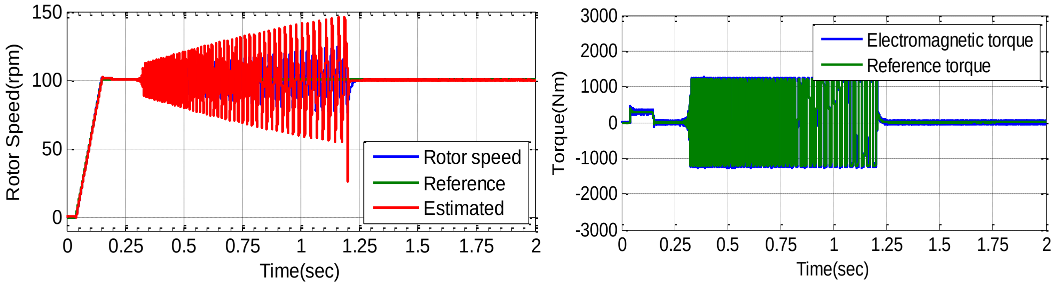

Fig.5. Response of conventional MRAS estimator drive with rotor resistance mismatch

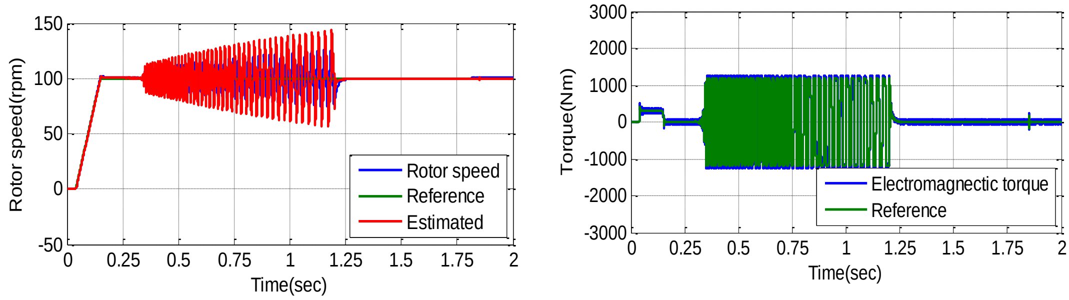

Fig.6. Response of Fuzzy MRAS estimator drive with rotor resistance mismatch

4.2. Speed reversal

The performance of RF-MRAS speed sensorless drive with rotor resistance adaptation is tested under no load torque with reference speed $\omega = 500rpm$ to -500 rpm. The sudden change in speed is applied at a time interval of 0.8 sec. Rotor resistance adaptation is incorporated after 1.2 sec when rotor resistance is varied 100% and its performance is tested for both estimators. Fuzzy MRAS based drive shows satisfactory performance as shown in figure 7 and figure 8.

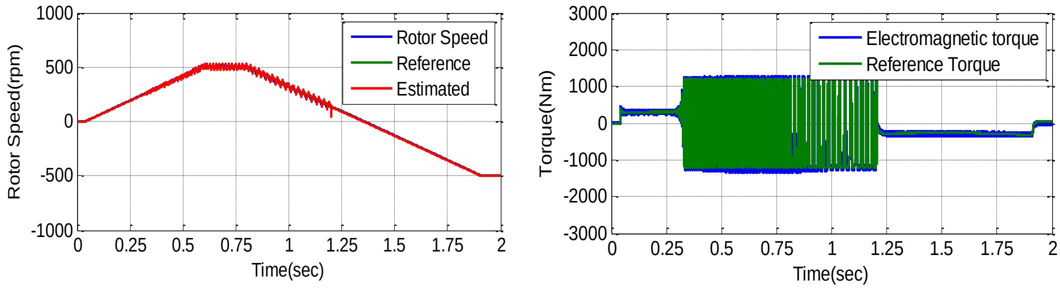

Fig.7. Response of conventional MRAS estimator drive with rotor resistance mismatch

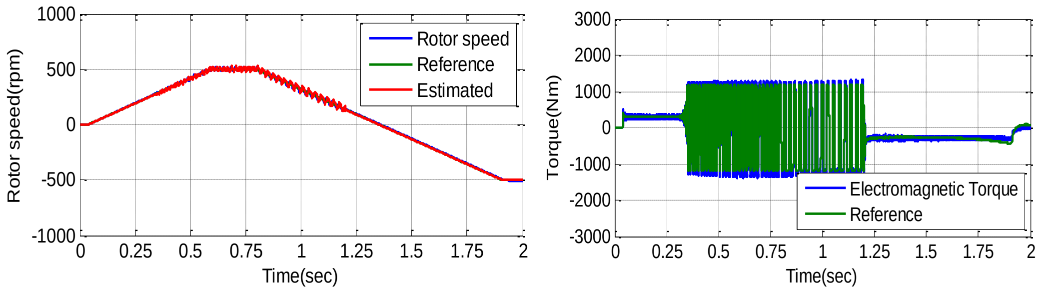

Fig.8. Response of fuzzy MRAS estimator drive with rotor resistance mismatch

4.3. Speed Tracking with load 25% of rated torque

In this case performance of RF-MRAS speed sensorless drive with rotor resistance adaptation is tested under load equals to 25% of rated torque with reference speed $\omega = 500rpm$. Rotor resistance adaptation is incorporated after 1.2 sec when rotor resistance is varied 100% and its performance is tested for both PI and FLC. There is fast response to rotor resistance adaptation in case of Fuzzy MRAS than conventional MRAS speed estimator as shown in figure 9 and figure 10. Initially there are more ripples in case of PI controller but with FLC, it is more prone to unstable condition.

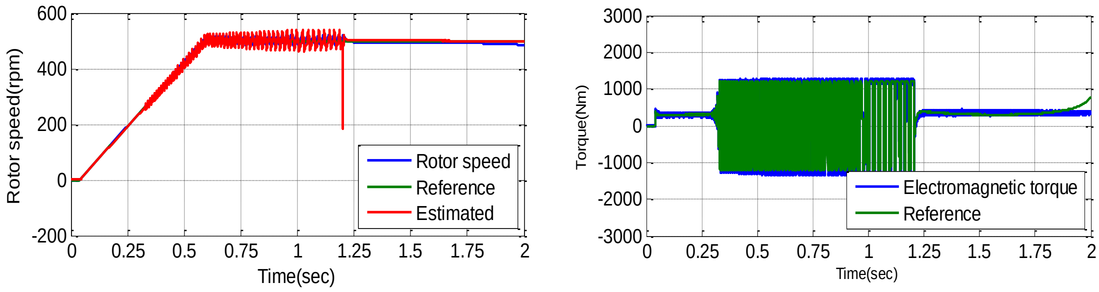

Fig.9. Response of conventional MRAS estimator drive with rotor resistance mismatch

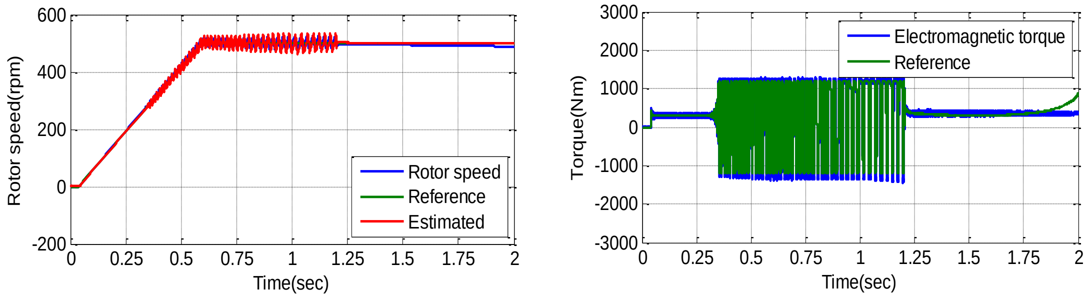

Fig.10. Response of fuzzy MRAS estimator drive with rotor resistance mismatch

5. CONCLUSION

In this paper, a rotor flux based MRAS speed sensorless drive is analyzed with a conventional MRAS and Fuzzy MRAS for rotor resistance estimation and adaptation. The drive is developed and analyzed in MATLAB/Simulink software. The fuzzy MRAS shows better performance than conventional MRAS in terms of transient as well as steady state response. The drive is less prone to the rotor resistance variation with Fuzzy based MRAS than conventional.

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