IOSR Journal of Electronics and Communication Engineering (IOSR-JECE)
e-ISSN: 2278-2834,p- ISSN: 2278-8735.
PP 63-69
www.iosrjournals.org

MRAS Based Modified Speed Estimator for Speed Sensorless Field Oriented Controlled Induction Motor Drive Using MATLAB

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Abstract: *This paper presents a modified estimator for improving the performance of indirect field oriented control of sensorless induction motor drive. The proposed method estimates the stator resistance of the machine along with speed which is based on knowledge of stator currents and voltages. The proposed scheme takes care of the rotor flux model reference adaptive system (MRAS) based speed estimator which is dependent on the machine stator resistance variation. Stator resistance information is required to improve the accuracy of speed sensorless control of the induction motor especially in low speed region. The paper proposes the stator resistance and rotor speed estimation operation based on rotor flux based MRAS in a systematic manner. The correct speed estimation of the drive operation can be achieved especially at low speed. The proposed parallel speed with stator resistance estimator is verified by MATLAB/SIMULINK software package.*

Keywords: *Induction motor, rotor flux based model reference adaptive system (MRAS), stator resistance, IFOC, speed sensorless.*

I. Introduction

Indirect field oriented controlled induction motor drives are increasingly used in high-performance induction motor(IM) drive systems. A majority of speed estimation schemes rely on utilization of an induction motor model in the process of speed estimation [1] and require an accurate knowledge of all the motor parameters including stator resistance, so the interest in stator resistance adaptation appeared recently, with the advances of speed sensorless systems. Any mismatch between the actual value and the value used within the model of speed estimation may lead not only to a substantial speed estimation error but to instability as well [3]-[5]. Therefore, there is a great interest in the research community to develop online stator resistance identification schemes for accurate speed estimation in the low speed region. The most popular methods include different types of estimators which often use an adaptive mechanism to update the value of stator resistance [3]-[16]. In general, all the methods rely on stator current measurement and predominantly require information regarding machine terminals such as stator voltages as well. The available online stator resistance identification schemes can be classified as, the first group includes all methods which utilize some measured quantities and an appropriate induction motor steady state model to calculate the stator resistance explicitly. The method of [3] calculates stator resistance from the stator voltage model, with the rotor flux space vector value obtained from the rotor current model. The method of [6],[7] is based on the back emf detector and it calculates stator resistance in the reference frame aligned with the stator current space vector. In [8],[9] MRAS based rotor speed and flux estimator is proposed using fuzzy-logic adaptation mechanism which requires lot of memory and computational problem. In [10], the reactive power is evaluated first, stator and rotor flux are calculated and electromagnetic torque is then estimated. An explicit expression for stator resistance calculation is finally derived, as a function of the previously calculated quantities. The method of [11] utilizes the rotor flux reference and only one estimate of the rotor flux d-axis component in formation of the error quantity. The error quantity in [14] is based on active power, the scheme of [15] operates in the rotating reference frame and the error quantity is determined from the difference between the d-axis rotor flux components obtained from the output of voltage and current models. Simultaneous estimation of stator resistance along with speed is estimated [16] using MRAS mechanism where rotor flux is required, estimated using motor voltage and current model.

This paper proposes a method for stator resistance estimation along with speed estimation using rotor flux based model reference adaptive system (MRAS). MRAS is used here because it is easy to implement and involve less computation. MRAS block calculates the same quantity in two different ways, one is independent of the signal and other dependent on it. Stator resistance estimation mechanism is developed for correct implementation of field orientation using the rotor flux based MRAS speed estimator and it operates in the stationary reference frame. It does however utilize the idea related to the creation of the error vector for adaptive stator resistance identification. The error vector is formed on the basis of differences in rotor flux component values, obtained at the output of the reference and the adjustable model. The observation is that the role of the reference and the adjustable model is interchangeable for the purposes of speed and stator resistance estimation. However, the operation of the speed and stator resistance estimators is in parallel rather than sequential. The MRAS speed estimator utilizes an error quantity formed by instantaneous phase difference between the two estimates of the rotor flux while error quantity for stator resistance estimation utilizes the difference in amplitudes of two rotor flux estimates. A detailed derivation of the parallel rotor speed and stator resistance estimation algorithms is provided in the paper and the proposed scheme is verified by MATLAB/Simulation.

II. Speed and stator resistance Estimation Technique

The speed is calculated by the Model Reference Adaptive System (MRAS), where the output of a reference model is compared with the output of an adjustable model or adaptive model until error between two models is vanish to zero. The estimator operates in the stationary reference frame and it is described with the following equations:

$$\frac{d\Psi_{rU}^{s}}{dt} = \frac{L_r}{L_m}[\bar{u}_s^{s} - (\hat{R}_s + \sigma L_s S)\bar{i}_s^{s}] \qquad (1)$$

$$\frac{d\Psi_{rI}^{s}}{dt} = \frac{L_m}{T_r}\bar{i}_s^{s} - (\frac{1}{T_r} - j\hat{\omega}_r)\hat{\Psi}_{rI}^{s} \qquad (2)$$

$$\hat{\omega}_r = \xi\,(K_{P\omega} + \frac{K_{I\omega}}{s}) \qquad (3)$$

where error vector,

$$\xi = X - Y$$

$$= \hat{\Psi}_{drI}^{s}\ \hat{\Psi}_{qrU}^{s} - \hat{\Psi}_{drU}^{s}\ \hat{\Psi}_{qrI}^{s} \qquad (4)$$

where, $K_{P\omega}$ *and* $K_{I\omega}$ are the gain of PI controller.

The rotor speed and stator resistance estimator is designed based on the concept of Hyperstability [2] in order to make the system asymptotically stable. For designing the an adaptive operation initially rotor speed is consider as a constant parameter, as it changes slowly and the stator resistance of the motor varies with temperature, but variations are slow so that it can be also consider constant.

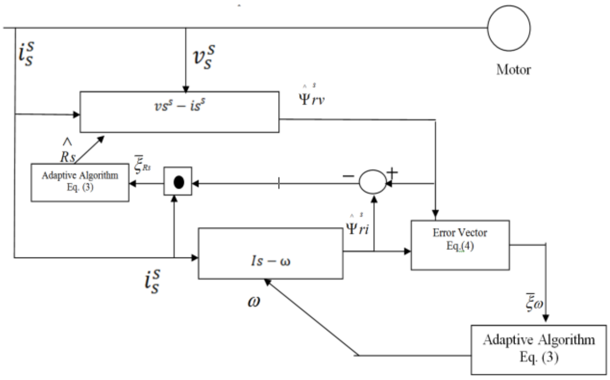

Fig. 1 Model Reference Adaptive System (MRAS) structure for parallel estimation of rotor speed and stator resistance

The structure of the proposed parallel rotor speed and stator resistance is shown in Fig. 1. R_s and ω denote the true values of the stator resistance in the motor and rotor speed, respectively. These are in general different from the estimated values. Consequently, a mismatch between the estimated and true rotor flux space vectors appears as well.

The error equations for the motor voltage model and current model can be written as:

$$\frac{d\xi_U}{dt} = -\frac{L_r}{L_m}[(R_S - \hat{R}_S)\bar{i}_S^{\,s}] \tag{6}$$

$$\overline{\xi_U} = \bar{\Psi}^{s}_{rU} - \overset{\Delta}{\Psi}{}^{s}_{rU} \tag{7}$$

$$\frac{d\xi_I}{dt} = \left[j\omega - \frac{1}{T_r}\right]\bar{\xi}_I + j(\omega - \hat{\omega})\overset{\Delta}{\Psi}{}^{s}_{rI} \tag{8}$$

$$\xi_I = \bar{\Psi}^{s}_{rI} - \overset{\Delta}{\Psi}{}^{s}_{rI} \tag{9}$$

Equations (6)-(9) in matrix form can be written as

$$\frac{d}{dt}\begin{pmatrix}\xi_{dI}\\ \xi_{qI}\\ \xi_{dU}\\ \xi_{qU}\end{pmatrix} = \begin{pmatrix}-\frac{1}{T_r} & -\omega & 0 & 0\\ \omega & -\frac{1}{T_r} & 0 & 0\\ 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0\end{pmatrix}\begin{pmatrix}\xi_{dI}\\ \xi_{qI}\\ \xi_{dU}\\ \xi_{qU}\end{pmatrix} - w = A\bar{\xi} - w \tag{10}$$

$$where\ \ \bar{\xi} = (\xi_{dI}\ \ \xi_{qI}\ \ \xi_{dU}\ \ \xi_{qU})^T = (\overline{\xi_I}\ \ \overline{\xi_U})^T \tag{11}$$

and W is the non-linear block which is defined as

$$W = \left(\begin{array}{cc} -\Delta\omega\begin{bmatrix}0 & -1\\ 1 & 0\end{bmatrix} \ \vdots & \begin{matrix}0 & 0\\ 0 & 0\end{matrix}\\ \cdots\cdots\cdots\cdots & \\ \begin{matrix}0 & 0\\ 0 & 0\end{matrix} & \frac{L_r}{L_m}\Delta R_s\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix}\end{array}\right)\begin{pmatrix}\hat{\Psi}^{s}_{drI}\\ \hat{\Psi}^{s}_{qrI}\\ i_{ds}\\ i_{qs}\end{pmatrix}$$

$$J = \begin{pmatrix}0 & -1\\ 1 & 0\end{pmatrix} \quad \text{and} \quad I = \begin{pmatrix}1 & 0\\ 0 & 1\end{pmatrix}$$

The system is hyperstable if the input and output of the block W satisfy the Popov's criterion. The adaptation mechanism for rotor speed estimator is given by

$$\hat{\omega}r = \left(\overline{\xi_I^T} \times J \times \hat{\Psi}^{s}_{rI}\right)\left(K_{P\omega} + \frac{K_{I\omega}}{s}\right) \tag{12}$$

and the adaptation mechanism for stator resistance estimator is given by

$$\hat{R}_S = \left(-\overline{\xi^T_U} \cdot i_S\right)\left(K_P + \frac{K_I}{s}\right) \tag{13}$$

where $K_{P\omega}$, $K_{P\omega}$, K_P and K_I are the PI controller gain of the rotor speed and stator resistance adaptation mechanisms respectively. The value of $(\overline{\xi^T_I} \cdot J \cdot \hat{\Psi}^{s}_{rI})$ in (12) is calculated as by taking into account that for speed estimation the output of the reference model (1) is taken equal to the true value of rotor flux space vector.

Hence, $\overline{\xi_I} = \overline{\Psi^{s}_{rI}} - \overline{\hat{\Psi}^{s}_{rI}} = \overline{\hat{\Psi}^{s}_{rU}} - \overline{\hat{\Psi}^{s}_{rI}}$ *as* $\overline{\Psi^{s}_{rI}} \equiv \overline{\hat{\Psi}^{s}_{rU}}$

Thus, $\overline{\xi_I^T}\cdot J\cdot\hat{\Psi}^s_{rI}$

$$=\begin{bmatrix}\hat{\Psi}^s_{drU}-\hat{\Psi}^s_{drI} & \hat{\Psi}^s_{qrU}-\hat{\Psi}^s_{qrI}\end{bmatrix}\cdot\begin{pmatrix}0 & -1\\ 1 & 0\end{pmatrix}\cdot\begin{bmatrix}\hat{\Psi}^s_{drI}\\ \hat{\Psi}^s_{qrI}\end{bmatrix}$$

$$\overline{\xi_I^T}\cdot J\cdot\hat{\Psi}^s_{rI}= =\begin{bmatrix}\hat{\Psi}^s_{drU}-\hat{\Psi}^s_{drI} & \hat{\Psi}^s_{qrU}-\hat{\Psi}^s_{qrI}\end{bmatrix}\cdot\begin{bmatrix}-\hat{\Psi}^s_{qrI}\\ \hat{\Psi}^s_{drI}\end{bmatrix} \qquad (14)$$

$$=\hat{\Psi}^s_{rI}\times\hat{\Psi}^s_{rU}=\bar{\xi}_{\omega}$$

i.e. error vector for speed estimation.

The value of $-\overline{\xi_U^T}\cdot i_S$ in (15) needs to be evaluated now, in order to do this, it is necessary to take into account that, for stator resistance estimation, reference and adjustable model (1), (2) interchange their roles. The true value of the rotor flux space vector is now taken to be the output of (2). Hence

$$\overline{\xi_U}=\overline{\Psi^s_{rU}}-\overline{\hat{\Psi}^s_{rU}}=\overline{\hat{\Psi}^s_{rI}}-\overline{\hat{\Psi}^s_{rU}} \qquad as\ \overline{\Psi^s_{rU}}=\overline{\hat{\Psi}^s_{rI}}$$

so, we can have $-\overline{\xi^T_U}\cdot i_S=\begin{bmatrix}\hat{\Psi}^s_{drU}-\hat{\Psi}^s_{drI} & \hat{\Psi}^s_{qrU}-\hat{\Psi}^s_{qrI}\end{bmatrix}\cdot\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix}$

$$=i^s_s\cdot\left[\overline{\hat{\Psi}_{rU}}-\overline{\hat{\Psi}_{rI}}\right]=\xi_{Rs} \qquad (15)$$

The error vector for stator resistance estimation can be written as

$$\xi_{Rs}=i_{ds}\left[\hat{\Psi}_{drU}-\hat{\Psi}_{drI}\right]+i_{qs}\left[\hat{\Psi}_{qrU}-\hat{\Psi}_{qrI}\right] \qquad (16)$$

Stator resistance is here estimated in the stationary reference frame and error quantity is obtained using two rotor flux space vector estimates (rather than the reference and a single estimated value. Further, stator resistance and rotor speed estimation operate simultaneously, rather than sequentially. This is possible by utilizing the difference in rotor flux amplitudes in the process of stator resistance.

III. MATLAB Based Verification of Speed and Stator Resistance Estimator

The block diagram of a field oriented sensorless control of induction motor drive together with both rotor speed and stator resistance estimator is shown in Fig. 2. Simulation using MATLAB Software package, have been carried out to verify the speed and resistance estimation operation. The parameters of the induction motor used are given in Table I.

The field oriented control algorithm consist of speed and torque control loop usually a PI controller is used, motor voltage and current measured which is used as input to MRAS based speed and resistance estimator, 3phase to 2-phase, 2-phase stationary to 2-phase synchronously rotating transformation block and sinusoidal pulse width modulation block whose switching frequency is chosen as 10Khz which produces the correct switching signal pulse for the inverter to achieve the desired performance of the motor.

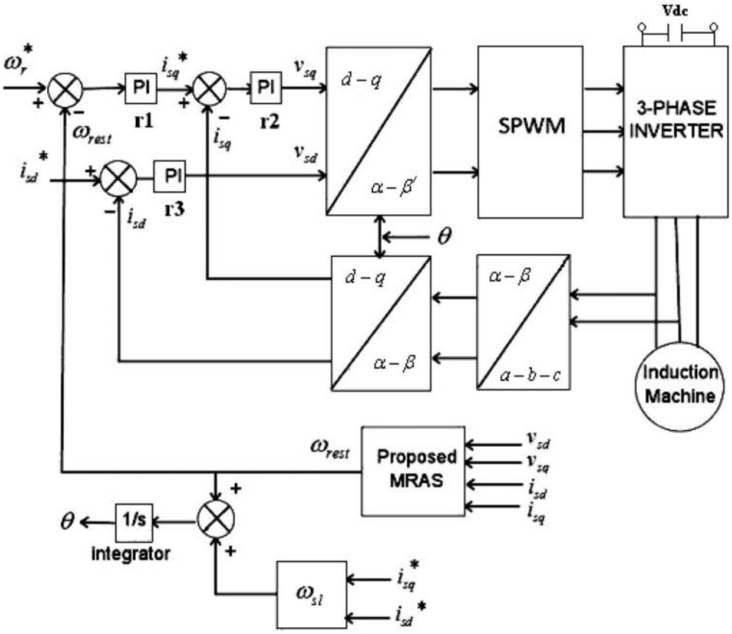

Fig. 2 Indirect field oriented control structure of IM for parallel estimation of rotor speed and stator resistance

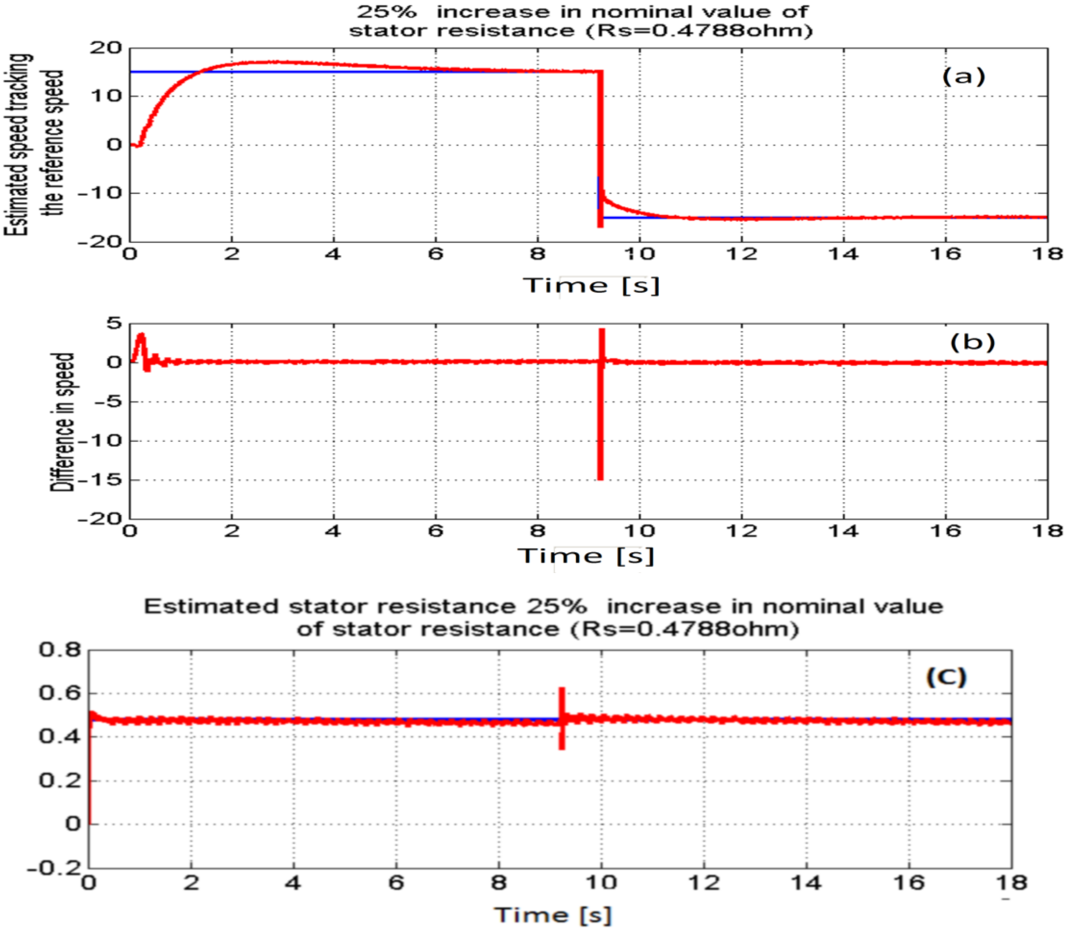

Fig.3. Simulation results for parallel estimation of rotor speed and stator resistance for step change in reference speed from 15rad/s to

-15rad/s and initial load torque of 2 N-m with increase in nominal value of stator resistance (Rs=0.4788ohm).(a) Estimated speed tracking the speed reference (b) Error between actual and estimated speed. (c) Stator resistance estimated value

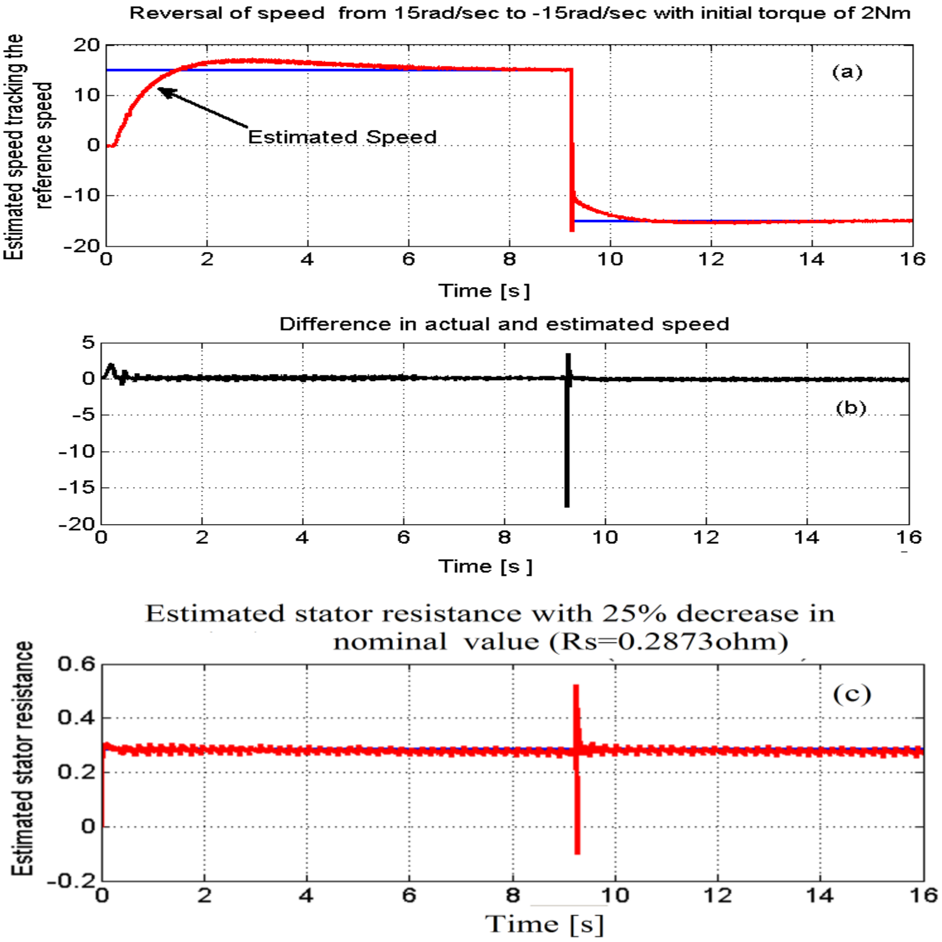

Fig.4. Simulation results for simultaneous estimation of rotor speed and stator resistance for step change in reference speed from 15rad/s to -15rad/s with initial load torque of 2 Nm with decrease in nominal value of stator resistance (Rs=0.2873ohm).
(a) Estimated speed tracking the speed reference (b) Error between actual and estimated speed .(c) Stator resistance estimated value.

Fig. 3 shows the estimation of motor speed and stator resistance for step change in the speed command from 15rad/s to -15rad/s. Figure (a) shows estimated speed tacks the command speed with good accuracy as shown in Fig. (b) error between actual and estimated speed is very small. Fig. (c) shows the MRAS mechanism estimate the stator resistance for 25% increase in the nominal value.

Fig.4 shows the estimation of motor speed and stator resistance for step change in the speed command from 15rad/s to -15rad/s. Figure (a) shows estimated speed tacks the command speed with good accuracy as shown in Fig. (b) error between actual and estimated speed is very small even when the speed goes through the zero for a while for reversal in speed. Fig. (c) shows the MRAS mechanism estimate the stator resistance for 25% decrease in the nominal value.

IV. Conclusion

A method of estimating motor speed and the stator resistance in conjunction with sensorless indirect field oriented control of induction motor using the rotor flux based MRAS has been proposed. The proposed MRAS system is simple in nature than its counterpart with speed estimation only and enables very good speed estimation accuracy for step change in the speed command. The proposed stator resistance estimation mechanism output is taken as input for speed estimation improves the speed accuracy and reduces sensitivity with the error in machine stator resistance. The effectiveness of the proposed method verified under various operating condition and in tracking application was verified especially for reversal of speed and gives the good performance.

Table I Induction Motor Parameters

Pole pair	2
Rated frequency	60 Hz
Rated voltage	160 V
Stator resistance	0.3831 Ω
Stator Inductance	33.34 mH
Rotor resistance	0.2367 Ω
Rotor Inductance	33.34 mH
Mutual inductance	42.08 mH
Rated power	3.7 KW

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