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MRAS Based Speed Identification for Sensorless Field Oriented Controlled Induction Motor with online Identification of Stator Resistance

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Abstract**—** This paper presents a new online method of estimating the stator resistance of an induction motor simultaneously with the motor rotor speed for effective implementation of rotor field oriented control technique. Knowledge of stator resistance is required for the correct operation of speed sensorless control of the induction motor in low speed region. Since stator resistance varies with drive operating conditions, stable operation in low speed requires an appropriate on-line estimator for the stator resistance. The paper proposes the stator resistance and rotor speed estimation algorithm based on rotor flux based MRAS in a systematic manner. It enables the correct speed estimation and stable drive operation at low speed. The proposed parallel speed with stator resistance estimator is verified by MATLAB/SIMULINK simulation. A simulation result shows the robustness and accuracy of the proposed method and good speed tracking capability and fast responses have been achieved.

Keywords- *Induction motor, model reference adaptive system (MRAS), stator resistance estimator, sensorless vector controls*

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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 rotor position estimation [1] and require an knowledge of all the machines parameters including stator and rotor resistance, so the interest in stator resistance adaptation appeared recently, with the advances of speed sensorless systems. Any difference 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 unstability [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 area. The most popular methods include different types of estimators which often use an adaptive mechanism to update the value of stator resistance [3]-[15].

Indirect vector or field oriented controlled induction motor drives are increasingly used in high-performance drive systems. Exact knowledge of stator resistance is not required in indirect field oriented control scheme. Speed sensorless control of induction motor drives attracted great attention of researchers to avoid the different problems associated with direct speed sensors. A most of motor speed estimation schemes rely on induction motor model in the process of speed estimation [1] and require an exact 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. An accurate value of the stator resistance has importance to improve the operation of a sensorless drive in the low speed region, since any error between the actual value and the desired value used within the model of speed estimation may cause to a substantial speed estimation error but to instability as well . 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 [5],[7],[9],[15]. In general, all the methods rely on stator current measurement and predominantly require information regarding machine terminals such as stator voltages as well (measured or reconstructed).

A method for stator resistance estimation along with speed estimation using flux on rotor side based model reference following adaptive system (MRAS) is proposed. MRAS is used here because of high speed of adaptation, it is easy to implement and involve less computation. MRAS calculates the one quantity in two different ways, one is independent of the signal and other dependent on it. Stator resistance estimation mechanism is evolved 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 use the idea related to the creation of the error vector for adaptive stator resistance identification. The tuning signal is formed on the basis of differences in rotor flux component, obtained at the output of the reference and the adjustable model. Here, the role of the reference and the adjustable model is interchangeable for the purposes of speed and stator resistance. However, the operation of the speed and stator resistance estimators is in simultaneously occurs rather than sequential. The MRAS speed estimator computes the difference formed by instantaneous phase difference between the two estimates of the flux on rotor side 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 process is provided in the paper and the proposed method is used in IFOC of IM drive verified by MATLAB/ Simulation.

II. SPEED ESTIMATION TECHNIQUE

The speed is calculated by the Model following 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. A block diagram for speed estimation by the MRAS technique is shown in Fig. 1 it relies on the machine stator voltages measured and measured current signals and is composed of the reference (voltage) and the adjustable (current) model. The motor speed estimator operates in the stationary reference frame and it is described with the following equations:

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

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

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

where error vector,

$$\xi = X - Y$$

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

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

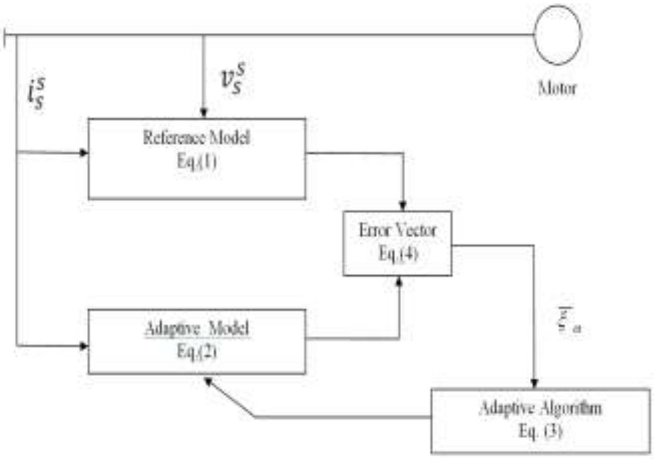

Fig. 1 Structure for speed estimation by model following reference adaptive control (MRAC) principle

The current model flux equations (2) are defined as adaptive model. This model calculates the fluxes from the stator current only if the speed is known. With the correct speed signal fluxes calculated from the reference model and adjustable model matches i.e. $\hat{\Psi}_{drV}^{s} = \hat{\Psi}_{drI}^{s}$ and $\hat{\Psi}_{qrV}^{s} = \hat{\Psi}_{qrI}^{s}$, where $\hat{\Psi}_{drI}^{s}$ and $\hat{\Psi}_{qrI}^{s}$ are the adaptive model output. An adaptation algorithm with P-I control, as indicated can be used to tune the speed $\hat{\omega}_r$ so that error $\xi = 0$. In designing the adaptation algorithm for MRAS, overall stability of the system is considered and speed converges to the desired value with satisfactory dynamics characteristics. Parameters with sub-scripts used for the outputs of the voltage (reference) and current (adjustable) models, respectively whereas subscripts s and r used for stator and rotor circuits, respectively in stationary reference frame. From (1)-(4) and Fig.1, the adaptive mechanism is based on the error vector between the instantaneous position of two rotor flux estimator but the difference in the magnitude of two rotor flux is not utilized. The simultaneous estimation of rotor speed and stator resistance based on MRAS scheme is proposed in next section will make use of this difference in the magnitude of two rotor flux to achieve simultaneous estimation of the two quantities. The reference and the adjustable model will switch their role for this purpose, since the rotor flux estimate of (2) is independent of stator resistance.

III. Stator Resistance AND Motor Speed Estimation

The speed is calculated by the Model Following Reference Adaptive System (MRAS), where the output of one model called as reference model is compared with the output of other model called as an adjustable model or adaptive model. The output of two models then compared until error 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 motor speed and stator resistance estimator is designed based on the theory of Hyperstability [2] to make the system globally stable. For designing an adaptive mechanism initially rotor speed is consider as a constant , as it varies slowly and the stator resistance of the motor varies with temperature, but variations are slow so that it can be also consider constant.

The structure of the parallel machines rotor speed and stator resistance is shown in Fig. 2. 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. Also, any 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:

$$\frac{d\xi_U}{dt} = -\frac{L_r}{L_m}[(R_s - \hat{R}_s)\bar{i}_s^{s}] \qquad (5)$$

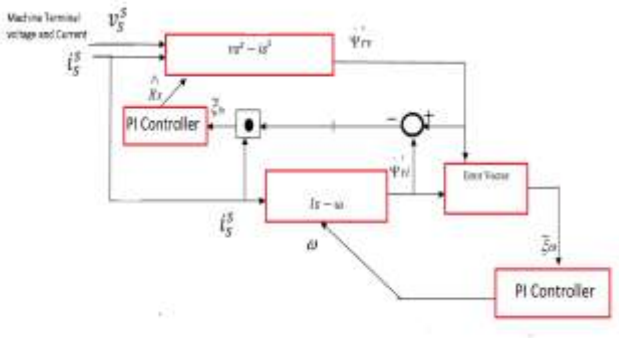

Fig. 2 Model Reference Adaptive System (MRAS) structure for parallel estimation of rotor speed and stator resistance

$$\overline{\xi_U} = \overline{\Psi}{}^s_{rU} - \overset{\Delta}{\Psi}{}^s_{rU} \qquad (6)$$

$$\frac{d\xi_I}{dt} = \left[j\omega - \frac{1}{T_r} \right] \overline{\xi}_I + j(\omega - \hat{\omega})\overset{\Delta}{\Psi}{}^s_{rI} \qquad (7)$$

$$\xi_I = \overline{\Psi}{}^s_{rI} - \overset{\Delta}{\Psi}{}^s_{rI} \qquad (8)$$

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

$$\hat{\omega} r = \left(\overline{\xi_I^T} \times J \times \hat{\Psi}{}^s_{rI} \right)\left(K_{P\omega} + \frac{K_{I\omega}}{s}\right) \qquad (9)$$

and the adaptation mechanism for stator resistance estimator is given by

$$\hat{R}_S = \left(-\overline{\xi^T_U} \cdot i_S \right)\left(K_P + \frac{K_I}{s}\right) \qquad (10)$$

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.

IV. SOFTWARE SIMULATION RESULTS OF SPEED AND STATOR RESISTANCE ESTIMATOR

The block diagram of a field oriented rotor speed sensorless control of induction motor drive together with both rotor speed and stator resistance estimator is shown in Fig. 3. Software Simulation using MATLAB, 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 process consist of speed and torque control loop is used, motor voltage and current measured which is used as input to MRAS based speed and resistance estimator, rotating transformation block and sinusoidal pulse width modulation block which produces the correct switching signal pulse for the inverter to achieve the desired performance of the motor.

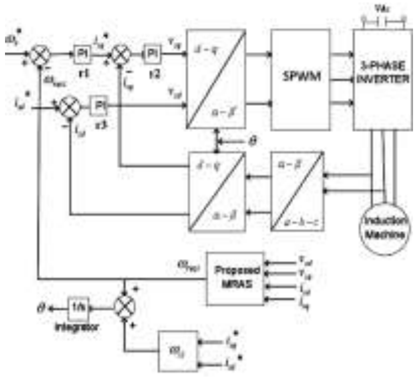

Fig. 3 Indirect field oriented control structure of IM for parallel estimation of rotor speed and stator resistance

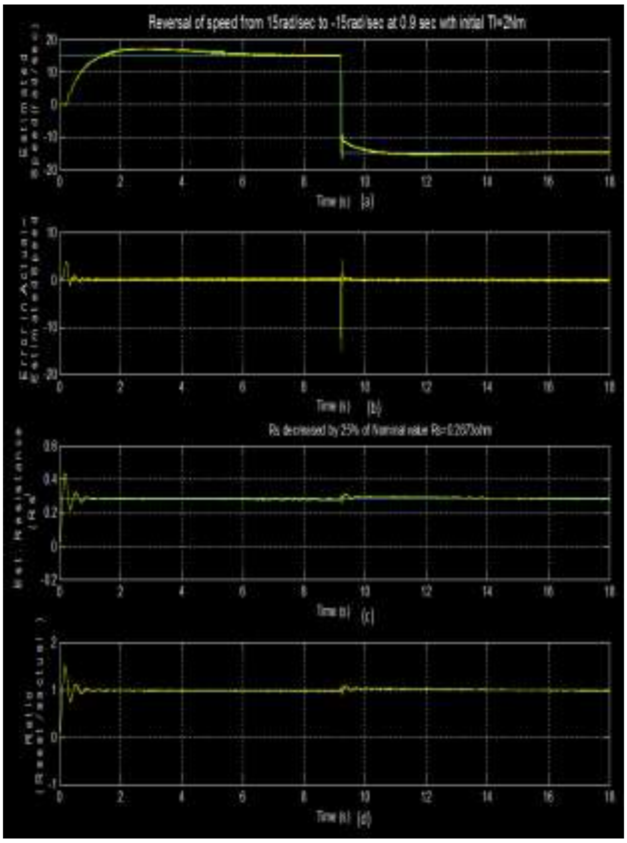

Fig.4. Step change in reference speed from 15rad/sec to -15rad/sec at 0.9 seconds and initial load torque of 2 Nm with 25% decrease in nominal value of stator resistance (Rs=0.2873ohm).(a) Estimated speed tracking the speed reference (b) Difference between actual and estimated speed .(c) Estimated stator resistance. (d) Ratio of Estimated stator resistance to its nominal value.

TABLE I
INDUCTION MOTOR DATA

Rated power	3.7 KW
Rated voltage	160 V
Base frequency	60 Hz
No. of Poles	4
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

V. CONCLUSION

A method of estimating motor speed and the stator resistance in speed sensorless field oriented control of induction motor using the 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.

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