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MRAS based Speed Estimator with Rotor Resistance Adaptation for Vector Controlled Induction Motor Drive

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Abstract—*Presence of a speed encoder in the drive increases its size, cost and decreases the reliability. Alternatively, rotor speed information can be gathered by the help of speed estimators which utilizes the motor terminal voltages/currents. However, the speed estimation is adversely affected by the motor parameter variation. It is well observed that rotor flux MRAS based speed-sensorless drive can suffer from instability problem especially due to the variation in the stator and rotor resistances of the machine. In this paper, effect of rotor resistance variation on the speed estimation is studied. Also, online rotor resistance estimation is incorporated in the conventional Model Reference Adaptive System (MRAS) based speed estimator. For rotor resistance estimation a comparison between the reference rotor flux and the adaptive rotor flux is made as the error in the adaptive system depends directly on the variation of value of rotor resistance. The rotor resistance adaptation loop a proportional-integral controller is used which converges the rotor resistance value exponentially to the true value. In the presented method the rotor resistance is capable of adapting any change in the rotor resistance. The stability of the system is also checked by introducing the error in the rotor resistance without the adaptation method and with the adaptation mechanism. The complete simulation model is developed in MATLAB/SIMULINK environment.*

1. INTRODUCTION

In recent years, speed sensorless drives have gained a lot of attention and popularity as they are proved to be economical, rugged and reliable over drives with speed encoders/sensors [1]. Over a decade various speed estimation techniques have been proposed by various researchers to eliminate the requirement of speed encoder. Among these estimation techniques Model Reference Adaptive System (MRAS) particularly rotor flux based has been extensively used with induction motor drives [2]. This scheme is simple in implementation and provides stable operation over wide range. However, variation in motor parameters due to heating caused by continuous working hours can degrade the performance. Rotor and stator are the motor parameters which usually get varied during the operation [3-5].

Improper value of stator or rotor resistance not only can degrade the performance of the speed estimator but also can made system unstable. Therefore, continuous adaption of their values is essential for high performance. Although it is difficult to simultaneously update the rotor and stator resistance. Stator resistance can be estimated using temperature of stator windings. Rotor resistance may vary upto 100 % and is difficult to get from the thermal models and temperature sensors [6]. Reactive power based MRAS system to estimate the value of rotor resistance incorporating with the rotor speed estimation is presented in [8]. Rotor resistance estimation for low and zero speed and in transient state is done in [7-8]. An adaptive observer is proposed in [9] for concurrent estimation of rotor fluxes, unknown dc-link voltage, and rotor resistance of induction motor with voltage source inverters.

In this paper two motor models (reference and and adaptive models) are used in order to combine the advantages of both at different speed ranges. The reference model is fit to detect flux information at higher speed where the influence of motor parameters is small. The adaptive model has no sensitivity with respect to that of stator resistance variations. However, the detection of detection of stator resistance is not possible but rotor resistance is sensitive to the adaptive model and can be estimated.

2. SYSTEM DESCRIPTION

The complete system consists of a controlled supply, vector control scheme, induction motor and speed estimator. Fig.1 shows the block diagram of the MRAS based speed estimator with rotor resistance adaptation loop.

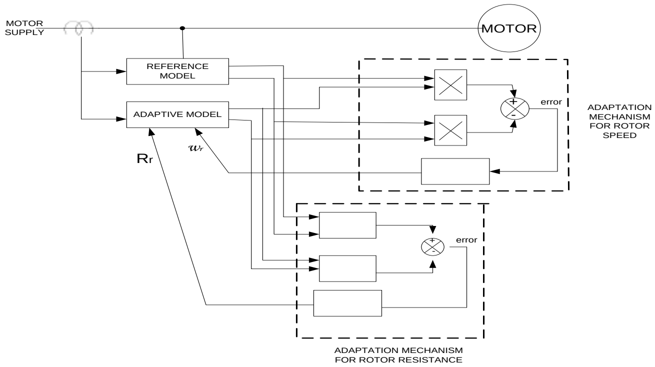


Fig. 1: Block diagram of MRAS based speed sensorless IM drive with rotor resistance adaptation

3. VECTOR CONTROLLED INDUCTION MOTOR

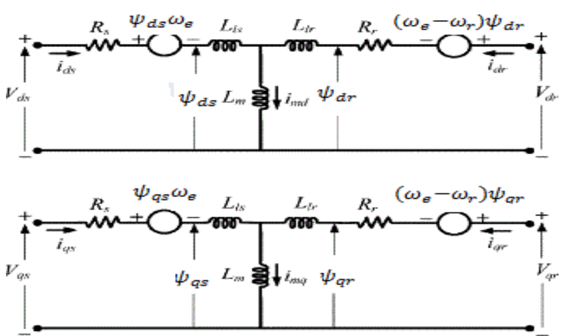


Fig. 2: d-q axis frame model of induction motor.

Fig. 2 shows the dynamic d-q model of the induction motor. From the Fig. we can deduce the following equations:

$$V_{qs} = R_s i_{qs} + p\psi_{qs} + \psi_{ds}\omega_e \quad (1)$$

$$V_{qr} = R_r i_{qr} + p\psi_{qr} + (\omega_e - \omega_r)\psi_{dr} \quad (2)$$

$$V_{ds} = R_s i_{ds} + p\psi_{ds} + \psi_{qs}\omega_e \quad (3)$$

$$V_{dr} = R_r i_{dr} + p\psi_{dr} - (\omega_e - \omega_r)\psi_{qr} \quad (4)$$

Where;

$$\psi_{qs} = L_s i_{qs} + L_m i_{qr} \quad (5)$$

$$\psi_{qr} = L_r i_{qr} + L_m i_{qs} \quad (6)$$

$$\psi_{ds} = L_s i_{ds} + L_m i_{dr} \quad (7)$$

$$\psi_{dr} = L_r i_{dr} + L_m i_{ds} \quad (8)$$

In stationary frame rotor voltage is assumed to zero and ω_e is also zero.

4. MRAS BASED SPEED ESTIMATOR

From above model of induction motor we can drive the equations for the reference and adaptive model for the MRAS system based on the rotor resistance. And It is convenient to express the motor voltages and currents in a stator frame of reference.

Reference model

$$p\begin{bmatrix}\Psi_{dr}\\ \Psi_{qr}\end{bmatrix} = \frac{L_r}{L_m}\left(\begin{bmatrix}V_{ds}\\ V_{qs}\end{bmatrix} - \begin{bmatrix}R_s + pL_s\sigma & 0\\ 0 & R_s + pL_s\sigma\end{bmatrix}\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix}\right) \quad (9)$$

Adaptive model

$$p\begin{bmatrix}\Psi_{dr}^{e}\\ \Psi_{qr}^{e}\end{bmatrix} = \begin{bmatrix}\left(-\frac{1}{T_r}\right) & (-\omega_r)\\ \omega_r & \left(-\frac{1}{T_r}\right)\end{bmatrix}\begin{bmatrix}\Psi_{dr}\\ \Psi_{qr}\end{bmatrix} + \frac{L_m}{T_R}\begin{bmatrix}i_{ds}\\ i_{qs}\end{bmatrix} \quad (10)$$

Where, $T_r = \frac{L_r}{R_r}$ and $\sigma = 1 - \frac{{L_m}^2}{L_r L_s}$

The equation (9) & (10) are used for calculating rotor flux, which later can be used for estimating the rotor speed and rotor resistance.

It is important to design the adaptation mechanism of the MRAS according to the hyper-stability concept. This will result in a stable and quick response system where the convergence of the estimated value to the actual value can be assured with suitable dynamic characteristics. Popov's criterion of hyper-stability for a globally asymptotically stable system is used in deriving the speed estimation relation. It gives the below objective function:

$$e = \psi_{qr}\psi_{dr}^{e} - \psi_{qr}^{e}\psi_{dr} \quad (11)$$

which represents the difference between the reference model and the adjustable model. The parameter E: should be passed through a PI block that is found to be satisfactory for the adaptive scheme. Rotor speed is estimated by forcing the objective function to zero. The speed estimated from MRAS is fed back to a speed controller in a sensorless drive and is compared with the reference speed to get the command output.

5. ROTOR RESISTANCE ADAPTATION

The rotor resistance is estimated by calculating the error between the amplitudes of flux of reference and the adaptive model. From the equation (10) it can be seen that the error in the estimated value of fluxes is greatly affected because of the error in the rotor resistance. The reference and the adaptive models are given by equations (9) & (10).

The rotor flux ψ_r acts as the reference output given by:-

$$\Psi_r = \sqrt{{\Psi_{dr}}^2 + {\Psi_{qr}}^2} \quad (12)$$

Where, ψ_{dr} and ψ_{qr} are the d-axis and q-axis rotor flux in the stationary reference frame.

Similarly, ψ_r^e acts as the adaptive or estimated output given by :-

$$\psi_r^e = \sqrt{{\psi_{dr}^e}^2 + {\psi_{qr}^e}^2} \qquad (13)$$

Where, ψ_{dr}^e & ψ_{qr}^e are the estimated d-axis & q-axis rotor fluxes in the stationary adaptive frame.

Hence, the rotor resistance can be calculated as the error between the ψ_r & ψ_r^e which is fed to the adaptive system by the help of an adaptive mechanism that may be PI, Fuzzy, or Neural controller.

Equation to calculate rotor resistance with PI controller as adaptive mechanism is given below.

$$e = \psi_r - \psi_r^e \qquad (14)$$

$$R_r = e\left(K_p + \frac{K_i}{s}\right) \qquad (15$$

Where, e is the error, R_r is the rotor resistance, and K_p & K_i are the proportional and integral gains of the PI controller.

Following Fig. shows the adaptation of rotor speed with that of the rotor resistance.

6. RESULTS & DISCUSSION

A three phase 3HP, 4 pole, 220 V cage type induction motor with parameters given in Appendix has been used for the simulation study. For testing the drive performance the rotor resistance is changed in steps of 10%, 25% & 50%.

Fig. 3 shows the response of rotor resistance adaptation loop for the mentioned changes. It is evident from the Fig. 3 that estimated value closely follows the true value.

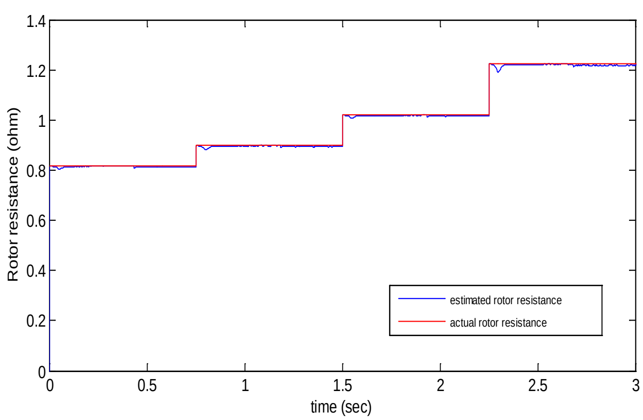


Fig. 3: True value and estimated value of rotor resistance with 10, 25, & 50 percentage change in the rotor resistance.

Fig. 4 shows the rotor speed response of the drive with 10% higher value of rotor resistance. Oscillations in speed response are observed which dies after 1.2 sec when rotor resistance adaption loop is activated.

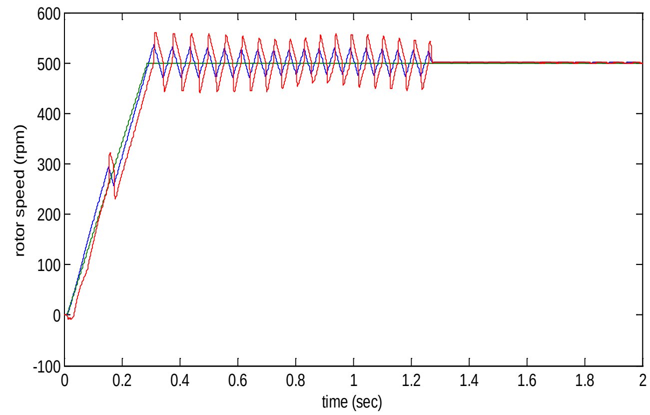


Fig. 4: Rotor speed with 10% change in the rotor speed.

Fig. 5 shows the rotor speed response with 25 % higher value of rotor resistance. In comparison to 10% change higher oscillations are observed without resistance adaptation loop.

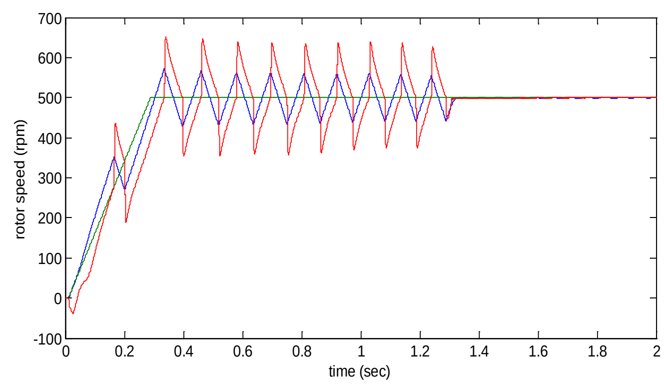


Fig. 5: Rotor speed with the 25% error in the rotor resistance.

Fig. 6 shows the rotor speed response with 50% change in rotor resistance. Oscillations in the rotor speed are observed without adaptation loop.

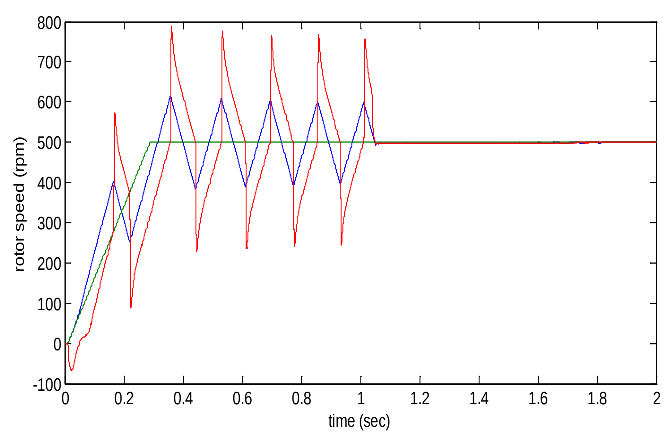
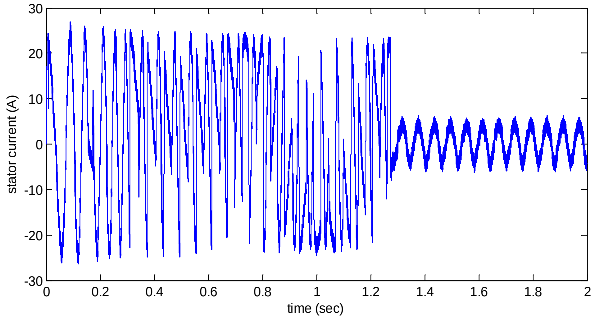
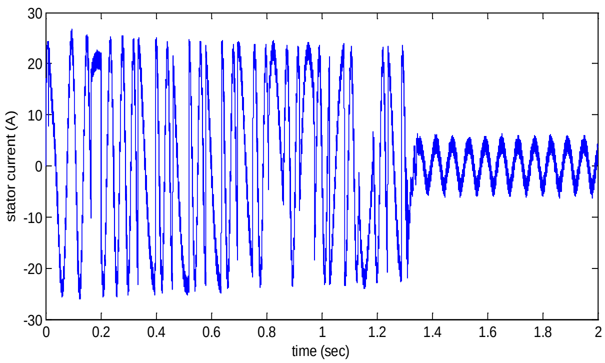


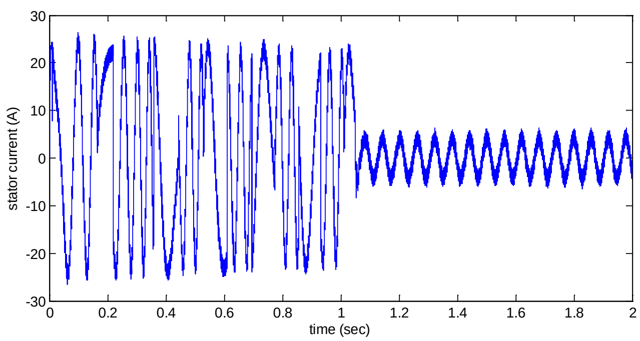
Fig. 6: Rotor speed with 50 % error in the rotor resistance.



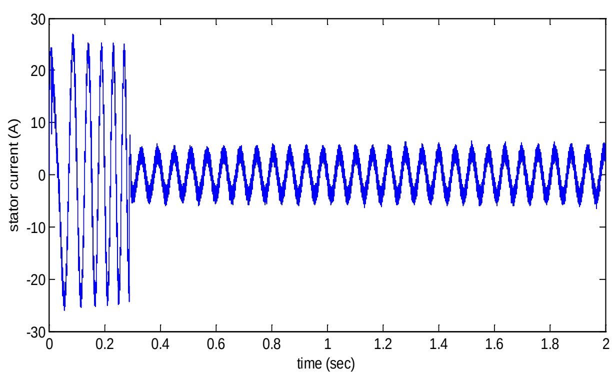
(a)



(b)



(c)



(d)

Fig.7: (a) Stator current with the 10% change in the rotor resistance (b)Stator current with 25% of the error in the rotor resistance (c) Stator current with 50% change in the rotor resistance (d) Stator current under normal condition.

Fig. 7 shows the effect of rotor resistance variation on the motor stator current. When there is mismatch in the rotor resistance there is disturbances observed in the stator current.

7. CONCLUSION

In this paper, online rotor resistance adaptation technique incorporated with a rotor flux oriented MRAS speed estimator for vector controlled induction motor drive is presented. The speed estimator with rotor resistance adaption technique gives better performance. Complete model is developed and analyzed in MATLAB/Simulink software.

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APPENDIX

Table 1: Induction motor parameters

Parameter	Value
Stator resistance	0.435 Ω
Rotor resistance	0.816 Ω.
Mutual inductance	0.06931 H
Stator inductance	0.002 H
Rotor inductance	0.002 H
Inertia	0.089 kg.m2
Friction coefficient	0.005 N-m