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MRAS Based Speed Sensorless Control of Induction Motor Drives

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Abstract—The recent trend in field oriented control (FOC) is towards the use of sensorless techniques that avoid the use of speed sensor and flux sensor. Sensors are replaced by estimators or observers to minimise the cost and increase the reliability. In this paper an anlyse of perfomance of a MRAS used in sensorless control of induction motors and sensitvity to machine parameters change are studied.

Keywords—Induction motor drive, adaptive observer, MRAS, stability analysis.

I. Introduction

The sensorless control of induction motors knows a real development since the 90's. Adaptive observers introduced by [1] and [2] were a powerful prolongation of initial sensor based observers [3]. However, some limits of operation of conventional observers were quickly highlighted [4]. Model Reference Adaptive System is one of the most popular adaptive control method used in motor control applications for tracking and observing system parameters and states [5]. In this paper rotor flux MRAS based speed estimator is proposed. Simulations are done to analyze dynamic performances and robustness of this approach.

II. Machine modelling

Basic equations of induction motor in a general reference frame in terms of complex space vector quantities are : .

$$\underline{u}_s = R_s \underline{i}_s + \frac{d}{dt}\underline{\psi}_s + j\omega_k \underline{\psi}_s \tag{1a}$$

$$0 = R_r \underline{i}_r + \frac{d}{dt}\underline{\psi}_r + j(\omega_k - \omega)\underline{\psi}_r \tag{1b}$$

where:
$\underline{u}_s = u_{sd} + ju_{sq}$:stator voltage vector,
$\underline{i}_s = i_{sd} + ji_{sq}$:stator current vector,
$\underline{i}_r = i_{rd} + ji_{rq}$:rotor current vector,
$\underline{\psi}_s = \psi_{sd} + j\psi_{sq}$:stator flux vector,
$\underline{\psi}_r = \psi_{rd} + j\psi_{rq}$:rotor flux vector,
R_s, R_r :Stator and rotor resistances,
ω_k, ω: Angular speed of reference frame and of the rotor respectively. The stator and rotor flux linkages are:

$$\underline{\psi}_s = L_s \underline{i}_s + L_m \underline{i}_r \tag{2a}$$

$$\underline{\psi}_r = L_m \underline{i}_s + L_r \underline{i}_r \tag{2b}$$

Where L_m, L_s, L_r are the magnetizing inductance, the stator inductance, and the rotor inductance respectively.

Under the rotor flux orientation conditions (FOC) the rotor flux is aligned on the d-axis. The electromagnetic torque equation is:

$$T_{em} = \frac{3}{2} p \frac{L_m}{L_r} \psi_r I_{sq} \tag{3}$$

The bloc diagrams of sensorless indirect field oriented control induction motor drive are shown in figure (1) and figure (2)

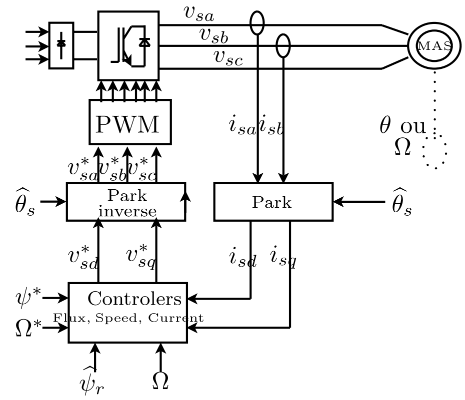

Fig. 1. Block diagram of RFOC IM simulator

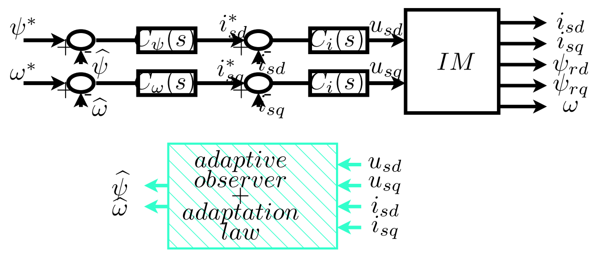

Fig. 2. Block diagram of sensorless IM simulator

III. Model reference adaptive system

The model reference aproach (MRAS) makes use of two machine models of different structures that estimate the same state variable on the basis of different sets of inputs variables [6], [7]. MRAS estimators consist of a reference model (which does not include the speed estimate) and an adjustable model (which include the speed estimate). Figure (3) illustrates the basic structure of MRAS aproach.

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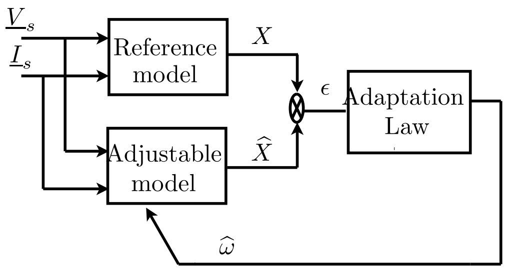

Fig. 3. Block diagram of MRAS

There is three approaches developed in literature of MRAS based speed estimators [8]:

- The rotor flux error based MRAS scheme
- The back EMF error based MRAS scheme
- Stator current error based MRAS scheme

IV. MRAS based on rotor flux estimation

In this approach, reference model is the voltage model its the induction motor model. Its equation is derived from (1) and (2) in the stationary reference frame ($\omega_k = 0$).

$$\underline{\psi}_{rv} = \frac{L_r}{L_m} \int (\underline{u}_s - R_s \underline{i}_s - \sigma L_s \frac{d}{dt} \underline{i}_s) dt \quad (4)$$

where $\sigma = 1 - \frac{L_m^2}{L_s L_r}$

The adjustable model is the current model its equation is obtained from (1b) and (2)

$$\frac{d}{dt}\underline{\psi}_{ri} + \frac{1}{T_r}\underline{\psi}_{ri} = j\widehat{\omega}\underline{\psi}_{ri} + \frac{L_m}{T_r}\underline{i}_s \quad (5)$$

model (5), generates the rotor flux estimate from the measured stator current and from the estimated speed ($\widehat{\omega}$) which is obtained through a PI controller from an error signal ϵ. This error represents difference between the two estimated flux vectors. where $\underline{\psi}_{rv}$ is the rotor flux estimated by the reference model (voltage model), and $\underline{\psi}_{ri}$ is the rotor flux estimated by the adjustable model (current model).

A. Adaptation law

From model (4), rotor flux is

$$\frac{d}{dt}\underline{\psi}_r = (-\frac{1}{T_r} + j\omega)\underline{\psi}_r + \frac{L_m}{T_r}\underline{i}_s \quad (6)$$

From model (5), estimated rotor flux is

$$\frac{d}{dt}\widehat{\underline{\psi}}_r = (-\frac{1}{T_r} + j\widehat{\omega})\widehat{\underline{\psi}}_r + \frac{L_m}{T_r}\underline{i}_s \quad (7)$$

System describing estimation error is

$$\frac{d}{dt}\underline{e}_\psi = (-\frac{1}{T_r} + j\omega)\underline{e}_\psi + j(\omega - \widehat{\omega})\widehat{\underline{\psi}}_r \quad (8)$$

With:
$\underline{\psi}_r = \psi_{rd} + j\psi_{rq}$, $\widehat{\underline{\psi}}_r = \widehat{\psi}_{rd} + j\widehat{\psi}_{rq}$ and $\underline{e}_\psi = \underline{\psi}_r - \widehat{\underline{\psi}}_r$.
Its important to ensure system (8) stability. Its garanteed if error ϵ tend to zero. The adapatation law is obtained from Lyapounov theory using the two following hypothesis [1]

$$\frac{d}{dt}\omega = 0, \quad (9a)$$

$$\widehat{\underline{\psi}}_r \rightarrow \underline{\psi}_r. \quad (9b)$$

Equation (8) is then :

$$\dot{e}_\psi = A e_\psi + W$$

with :
$A = -\frac{1}{T_r} I + \omega J, W = \Delta\omega J \widehat{\underline{\psi}}_r$,
$I = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$ and $J = \begin{bmatrix} 0 & -1 \\ 1 & 0 \end{bmatrix}$.
Lyapounov function is:

$$\nu = \frac{1}{2} e_\psi^t e_\psi + \frac{1}{2}\frac{\Delta\omega^2}{2}$$

Adaptive mecanism is derived from equations above. The estimated speed expression can be writen as :

$$\widehat{\omega} = (K_p + \frac{K_i}{s})\epsilon \quad (10)$$

with: $\epsilon = \Im(\psi_r \widehat{\psi}_r') = \psi_{r\beta}\widehat{\psi}_{r\alpha} - \psi_{r\alpha}\widehat{\psi}_{r\beta}$

V. simulation results

The dynamic behavior of the system was investigated by using computer simulations with Matlab/simulink software.

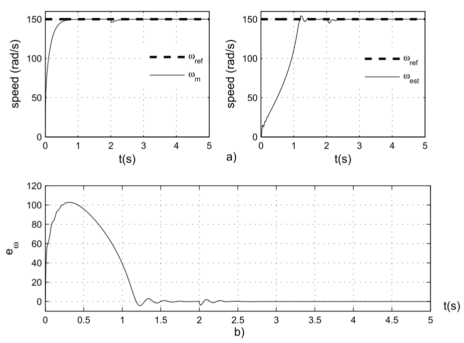

Fig. 4. a):reference, rotor speed and estimated speed, b):error speed for $K_p = 1, K_i = 1000$

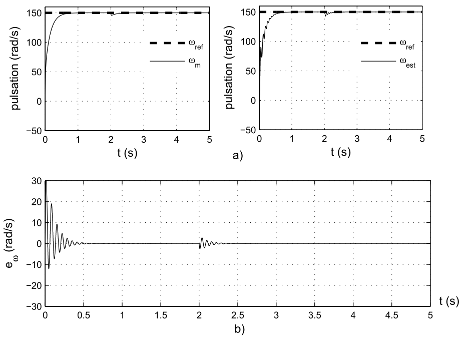

Fig. 5. a):reference, rotor speed and estimated speed, b):error speed, for $K_p = 10, K_i = 10000$

Figures (4) and (5) shows simulation results of the speed sensorless vector control using the flux based MRAS speed estimator for tow different observer gains. Analysing speed error, $e_\omega = \omega_m - \omega_{est}$, it can be seen that better performance tracking capability are obtained for propotional gain $K_p = 10$ and integral gain $K_i = 10000$.
Figures (6), (7) are obtained with nominal torque $T_{Lo} = 7N.m$ applied at $t = 2s$. Figure (6) shows system behavior during steady state condition at high speed (150 rad/s) and during transient with speed inversion. Figure (7) shows system performance in the low speed region (10 rad/s). A negligible speed and flux error are obtained either at high or low speed.

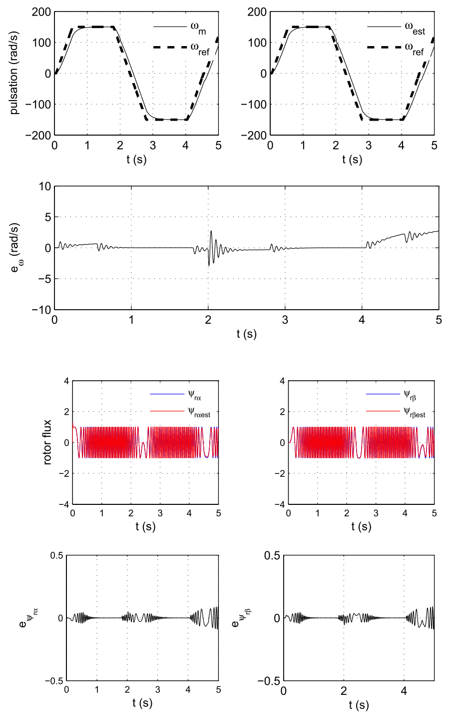

Fig. 6. Four quadrant operation at high speed for $K_p = 10, K_i = 10000$

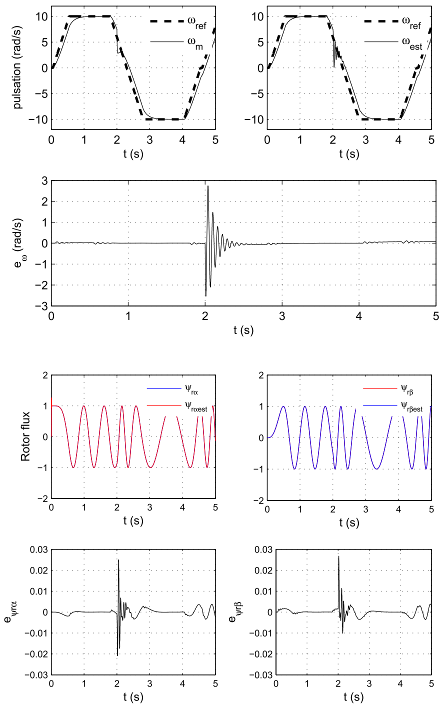

Fig. 7. Four quadrant operation at low speed for $K_p = 10, K_i = 10000$

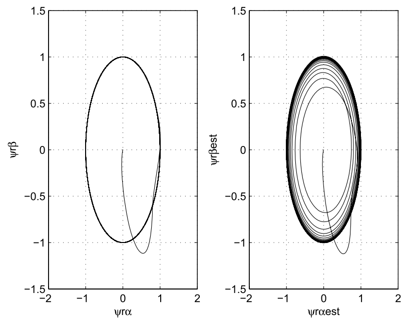

Fig. 8. rotor flux linkage trajectories during motoring operation

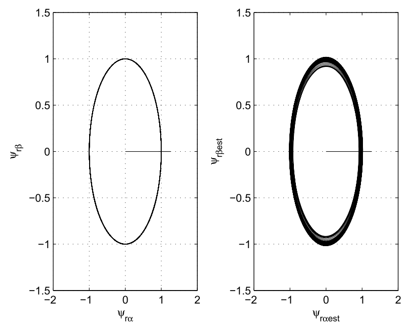

Fig. 9. rotor flux linkage trajectories during four quadrant operation

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Figures (8) and (9) show rotor flux linkage trajectories during motoring and four quadrant operation.

VI. Parameter variation effect

In order to test sensitiviy of the MRAS technique to parameter variations, simulations are done for rotor resistance variation, stator resistance variation.

A. R_r variation

For rotor resistance variation from R_r to $2 * R_r$ at $t = 3s$, response of the machine is presented on figure (10). High and low speed four quadrant operation with rotor resistance variation simulations are presented on figures (11) and (12). It show that divergence is highlighted between rotor speed and estimated speed.

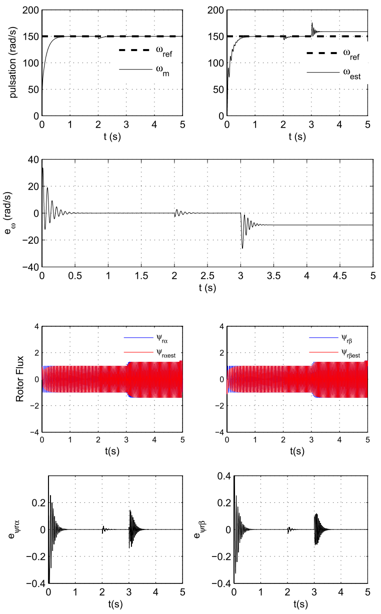

Fig. 10. Rotor speed, speed error and rotor flux for rotor resistance variation at t=3s

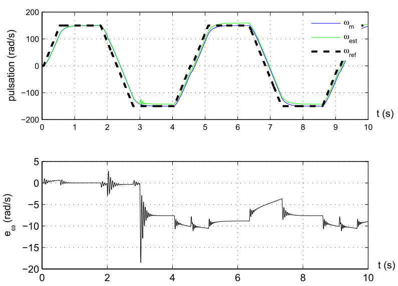

Fig. 11. High speed,four quadrant operation with rotor resistance variation at t=3s

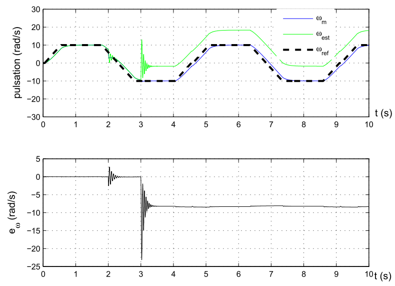

Fig. 12. Low speed,four quadrant operation with rotor resistance variation at t=3s

B. R_s variation

Dynamic performance of this technique are tested for 50% of stator resistance variation at $t = 3s$. Simulation results for high and low speed operation (figures 13,14) show that any variation of stator resitance does'nt affect robustness of the estimator.

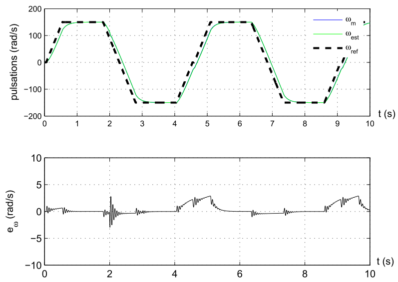

Fig. 13. High speed,four quadrant operation with stator resistance variation at t=3s

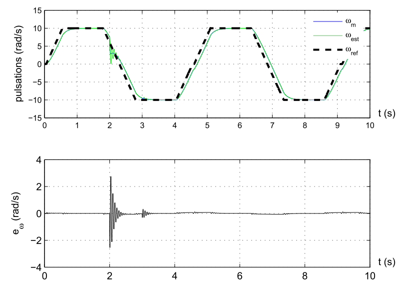

Fig. 14. low speed,four quadrant operation with stator resistance variation at t=3s

VII. conclusion

MRAS based on rotor flux estimation had good tracking performances at high speed and even at low speed operation. Estimated and measured speeds , are equal each other not only for the steady-state operation but also under speed reference and load torque changes. The transient errors between measured and estimated speeds for relatively parameter mismatch show that tracking capability are better for stator resistance variation than for rotor resistance variation. The proposed speed estimator can be easily implemented but pure integration process causes drift problems. So this approach must be replaced by MRAS based on back EMF estimation or on reactive power estimation.

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