Sensorless Control of Two-Phase Induction Machine using MRAS Techniques

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Abstract — **The paper presents most commonly used control techniques based on the Model Reference Adaptive System (MRAS) for the Two-Phase Induction Machine (TPIM). The theoretical and experimental results are obtained using the Rotor Flux, Back EMF, and Reactive power estimators. The main characteristic of this research is their performance during start-up and reverse conditions. The experimental results were obtained at the no load operation. The estimated values of the angular speed are compared with the data from the incremental encoder. The Matlab/Simulink simulation software was utilized to perform the simulation results. The control techniques implementation and data acquisition were done by the technical computing device Dspace DS1103.**

Keywords — Model Reference Adaptive System, Two-Phase Induction Machine, Speed estimation.

I. Introduction

The TPIMs are widely used in industrial, commercial and domestic applications. Their benefits are simple, rugged, low-cost and easy to maintain. The TPIM achieves well control performances as the precise and quick torque and flux response, and the maximum starting torque is its big advantage in comparison with three-phase machine. The wide speed range and the drive control system with the transformation of stator currents into two components (flux and torque producing components) are necessary to provide with the vector control strategy.

In the recent years, the development of sensorless vector-controlled induction motor drives has been receiving much attention due to its low drive cost, high reliability and easy maintenance. The speed estimation is the main parameter which is required in the sensorless techniques for establishing the outer speed loop feedback. A different speed estimation method have been proposed such as Observers (Luenberger, Kalman filter), model reference adaptive system (MRAS) [1], [2], [3], [4], [5].

The MRAS based speed estimator is commonly used in AC speed control systems and also in estimating of the motor parameters such as the stator resistance or mutual inductance due to its easy implementation and good performance.

Firstly, we have to model the two-phase induction motor in order to design the MRAS based sensorless speed control which is considered as a reference model [6]. In the adaptive model, the speed is the adaptive parameter. The purpose of this paper is to examine the operation of the TPIM under different MRAS methods.

II. Induction Motor Model

Eqs. (1) to (9) present the well-known mathematical model of the TPIM. The dynamic model of the two-phase induction machine was implemented considering the *dq* stationary reference frame, since quantities such as voltages and currents are measured on the stator terminals.

$$V_{sd} = R_{sd} i_{sd} + \frac{d\phi_{sd}}{dt} \quad (1)$$

$$V_{sq} = R_{sq} i_{sq} + \frac{d\phi_{sq}}{dt} \quad (2)$$

$$0 = R_{rd} i_{rd} + \frac{d\phi_{rd}}{dt} + \omega\phi_{rq} \quad (3)$$

$$0 = R_{rq} i_{rq} + \frac{d\phi_{rq}}{dt} - \omega\phi_{rq} \quad (4)$$

The stator and rotor flux linkage components are given by:

$$\phi_{sd} = L_{sd} i_{sd} + M_{srd} i_{rd} \quad (5)$$

$$\phi_{sq} = L_{sq} i_{sq} + M_{srq} i_{rq} \quad (6)$$

$$\phi_{rd} = L_{rd} i_{rd} + M_{srd} i_{sd} \quad (7)$$

$$\phi_{rq} = L_{rq} i_{rq} + M_{srq} i_{sq} \quad (8)$$

The electromagnetic torque of the two-phase induction machine in the stator reference frame is given by:

$$T_e = n_p (M_{srq} i_{sq} i_{rd} - M_{srd} i_{sd} i_{rq}), \quad (9)$$

where

$V_s = [V_{sd}, V_{sq}]^T$ is the stator voltage vector,

$i_s = [i_{sd}, i_{sq}]^T$ is the stator current vector,

$i_r = [i_{rd}, i_{rq}]^T$ is the rotor current vector,

R_{sd}, R_{sq} and R_{rd}, R_{rq} are stator and rotor resistances, respectively; L_{sd}, L_{sq}, L_{rd}, L_{rq} and M_{srd}, M_{srq} are stator, rotor and mutual inductances, respectively and ω is the rotor speed.

These dynamic equations are combined in order to achieve speed estimators based on the rotor flux, Back electromotive force and reactive power.

III. MRAS Techniques

The basic idea of the MRAS techniques are two independent models: reference model, where the estimated variable is not present; and adjustable model, where the estimated quantity is adjusted by means of an adaptive mechanism until the error between these models are equal to zero. The adaptation mechanism can be a PI controller or any other tool as the neural network, Kalman filters or other options.

Fig.1 shows the basic scheme of the MRAS technique applied in this paper in order to estimate the rotor speed of the TPIM. The outputs of the reference and adaptive models can be rotor fluxes, Back EMFs and reactive powers based on the different equations.

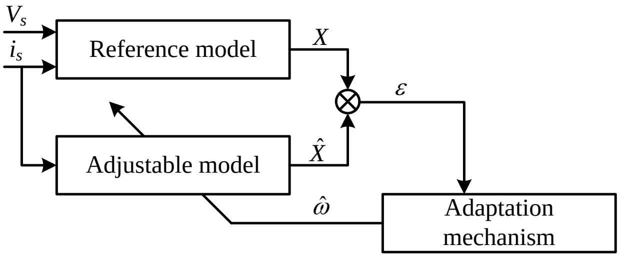

Fig. 1. MRAS scheme for speed estimation.

A. Rotor Flux Estimator

Rewriting of Eqs. (1) to (8) to form (10), (11) and (12), (13) yields the reference and adjustable models based on the rotor flux observer, respectively. The reference rotor flux components obtained from the reference model are given by

$$s\phi_{rd} = \frac{M_{srd}}{L_r}(V_{sd} - (R_{sd} - \sigma L_{sd}s)i_{sd}) \quad (10)$$

$$s\phi_{rq} = \frac{M_{srq}}{L_r}(V_{sq} - (R_{sq} - \sigma L_{sq}s)i_{sq}) \quad (11)$$

The rotor flux components obtained from the adaptive model are given by

$$s\hat{\phi}_{rd} = \frac{M_{srd}}{T_r}i_{sd} - \frac{1}{T_r}\hat{\phi}_{rd} - \omega\hat{\phi}_{rq} \quad (12)$$

$$s\hat{\phi}_{rq} = \frac{M_{srq}}{T_r}i_{sq} - \frac{1}{T_r}\hat{\phi}_{rq} - \omega\hat{\phi}_{rd} \quad (13)$$

The adaptation mechanism (14), (15) is designed to generate the value of the estimated speed by means of minimizing the error between the reference and estimated fluxes using the PI controller [7].

$$\varepsilon = \phi_{rq}\hat{\phi}_{rd} - \phi_{rd}\hat{\phi}_{rq} \quad (14)$$

$$\hat{\omega} = (K_p + \frac{K_i}{s})\varepsilon \quad (15)$$

B. Back EMF Estimator

The equations for the reference model expressed in (16) and (17) were developed in order to eliminate the need for integration in the reference model of the rotor flux observer, defining e_m as the Back EMF [8].

$$e_{md} = V_{sd} - (R_{sd} - \sigma L_{sd}s)i_{sd} \quad (16)$$

$$e_{mq} = V_{sq} - (R_{sq} - \sigma L_{sq}s)i_{sq}) \quad (17)$$

The adjustable model is derived from the equation for the magnetizing current vector $i_m = {M^2}/{L_r}\, s\phi_r$, where M'= M^2/L_r is the equivalent mutual inductance.

$$\hat{e}_{md} = M'(\omega i_{mq} - \frac{1}{T_r}i_{md} + \frac{1}{T_r}i_{sd}) \quad (18)$$

$$\hat{e}_{mq} = M'(\omega i_{md} - \frac{1}{T_r}i_{mq} + \frac{1}{T_r}i_{sq}) \quad (19)$$

The rotor speed adaptation mechanism is done similarly to the previous method and it is:

$$\hat{\omega} = (K_p + \frac{K_i}{s})(e_{mq}\hat{e}_{md} - e_{md}\hat{e}_{mq}) \quad (20)$$

The inductance *M'* can be conveniently incorporated into the adaptation gain constants K_p and K_i. The inductance *M'* has no influence on the estimation if the gains are high enough.

C. Reactive Power Estimator

In [9], the reference model (21) calculates the instantaneous reactive power and it is independent on the slip speed ω_{sl}. The adjustable model calculates the steady state reactive power and depends on ω_{sl}. The instantaneous reactive power is given as:

$$Q_{ref} = V_{sq}i_{sd} - V_{sd}i_{sq} \quad (21)$$

The adjustable model (22) can be derived also from the equations of the mathematical model (1) to (8) and it is as follows:

$$Q_{ad} = \omega_s\sigma L_s(i_{sd}^2 + i_{sq}^2) + \omega_s\frac{M}{L_r}(\phi_{rq}i_{sq} + \phi_{rd}i_{sd}) \quad (22)$$

The two-phase induction machine is driven by the indirect rotor field oriented control (IRFOC) [10], Fig. 2. Therefore, substituting the condition $\phi_{rd} = Mi_{sd}$ and $\phi_{rq} = 0$, the more simplified equation (23) of Q_{ad} is

$$Q_{ad} = \omega_s\sigma L_s(i_{sd}^2 + i_{sq}^2) + \omega_s\frac{M^2}{L_r}i_{sd}^2\ , \quad (23)$$

where $\omega_s = \omega_{r} + \omega_{sl}$.

The adaptation mechanism is:

$$\hat{\omega} = (K_p + \frac{K_i}{s})(Q_{ref} - Q_{ad})\ . \quad (24)$$

The diagram of the IRFOC (Fig. 2) consists of the TPIM, PWM half/bridge inverters, indirect field orientation algorithm and MRAS techniques.

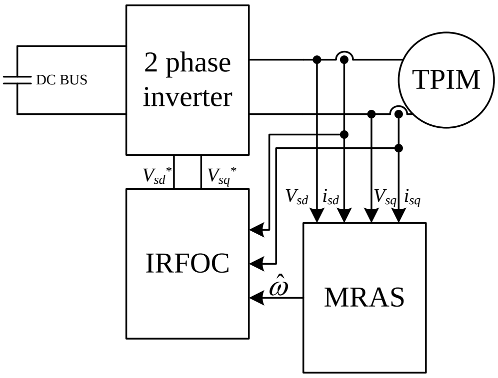

Fig. 2. Diagram of the IRFOC control strategy.

IV. Simulation Results

The parameters of the TPIM obtained through the locked rotor and no load tests are used during the simulation and experimental implementation.

TABLE I.
TPIM Parameters

Stator resistance in d axis R_{sd}	58.85 Ω
Stator resistance in q axis R_{sd}	66.11 Ω
Rotor resistance R_r	87.3 Ω
Stator inductance in d axis L_{sd}	1.5 H
Stator inductance in d axis L_{sq}	1.68 H
Rotor inductance L_r	1,56 H
Mutual Inductance M_{srd}	1.41 H
Mutual Inductance M_{srq}	1.6 H
Moment of inertia	$4.888\text{x}10^{-4}$ kgm^2
Number of pole-pairs	1
Rated voltage	230 V
Frequency	50 Hz

Figs. 3 to 5 represent simulation results of the indirect vector controlled TPIM during the start-up and describe the estimated rotor angular speed using the Rotor Flux observer, Back EMF observer and Reactive Power observer, respectively. In this test, the reference speed was always set to 100 rad/s and the drive was operated at no load.

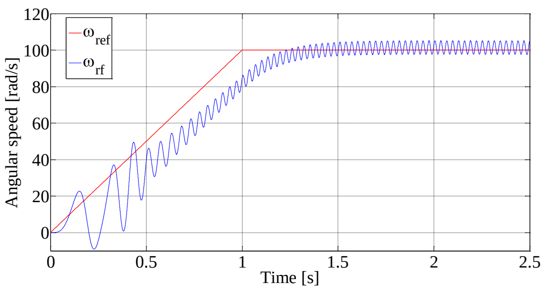

Fig. 3. Simulation of the angular speed ω_{rf} using the Rotor Flux based MRAS observer.

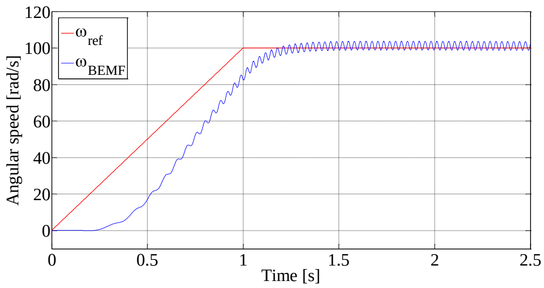

Fig. 4. Simulation of the angular speed ω_{BEMF} using the Back EMF based MRAS observer.

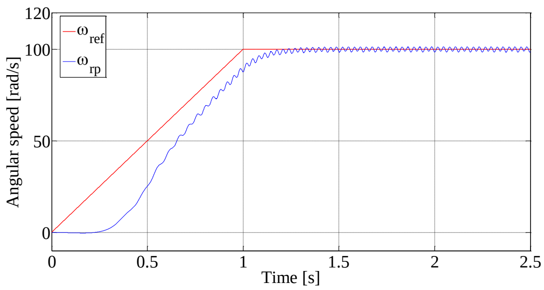

Fig. 5. Simulation of the angular speed ω_{rp} using the Reactive Power based MRAS observer.

From the simulation results (Fig. 3) we can see the visible transients during the start-up of the rotor flux estimated angular speed and some oscillation remains also in the steady-state operation. Fig. 4 shows the lower ripple of the estimated angular speed using the Back EMF observer and the angular speed in Fig. 5 exhibit the lowest ripple using the Reactive Power observer. The dynamic response on the reference angular speed is very similar and the worst behaviour of the TPIM at the low speed operation is under the rotor flux estimation technique.

V. Experimental Results

To confirm the use of the proposed procedure for two-phase induction motor, the simulation results have to be compared with those given by experimental tests. Experimental measurements were verified using the control device dSpace DS1103, squirrel cage motor, incremental encoder and full-bridge inverters for each phase. The advantage of using two full bridge inverters is that each phase of the machine is connected and controlled independently, so the d component of the stator current is controlled by one full-bridge inverter and the q component of the stator current by the other one. The incremental encoder was used to compare the estimated and real angular speeds. The applied software was the Matlab/Simulink and Control Desk. Functions of the particular library give a direct access from the MATLAB model to the variables of the application program running on the dSpace board.

Same as in the simulation the experimental measurement confirm the transients during the start-up using the Rotor Flux observer (Fig. 6) and also the ripple of the angular speed in the steady-state operation. Fig. 7 shows a better response during the start-up and smaller ripple of the angular speed, that is the same result as in the simulation (Fig. 4). The Reactive power based MRAS observer exhibits different behaviour during measurement test (Fig. 8). The ripple of the angular speed in the steady-state is bigger, but the response on the desired angular speed is faster.

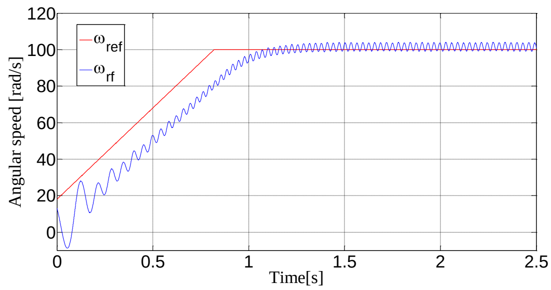

Fig. 6. Measurement of the angular speed ω_{rf} using the Rotor Flux based MRAS observer.

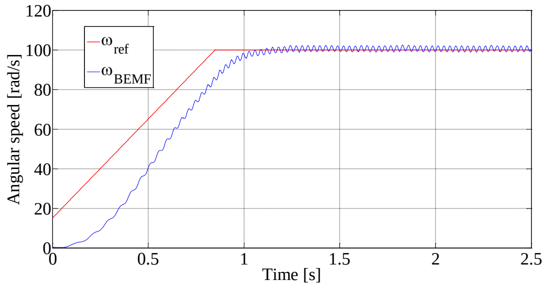

Fig. 7. Measurement of the angular speed ω_{BEMF} using the Back EMF based MRAS observer.

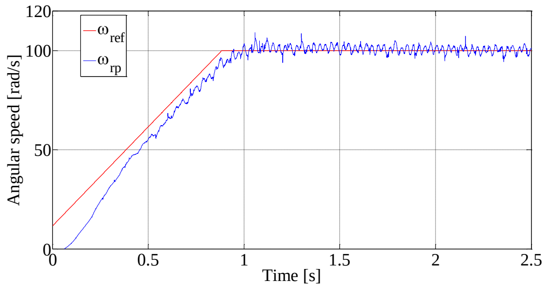

Fig. 8. Measurement of the angular speed ω_{rp} using the Reactive Power based MRAS observer.

The difference between simulation and measurement, where the Reactive power observer was used, can be in motor parameter changes.

VI. Conclusion

In the paper we have validated the MRAS based rotor flux, Back EMF and Reactive power observers under the IRFOC control strategy.

The validity of the proposed Sensorless Speed Control for the TPIM was also proven by simulation and experiment results that confirm effectiveness and good dynamic performances of the shown method.

In the future work we want to do some experiments at the load condition. Because of the difference in the test experiments also the parameter estimation of the TPIM will be done.

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