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Field Oriented Controlled Speed Sensorless Control of Induction Motors

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Abstract—In this paper, a special class of adaptive control system, model reference adaptive controller (MRAC) for the speed estimation of the field oriented controlled (FOC) induction motor drive is presented. The proposed MRAC is formed using instantaneous and steady-state values of tuning signal insynchronously rotating reference frame, which is a fictitious quantity and has no physical significance. Requirement of no additional sensors makes the drive suitable for retrofit applications. The proposed MRAC-based speed sensorless field oriented controlled induction motor drive estimation technique has been simulated in MATLAB/SIMULINK

Keywords-*field oriented controlled**,** induction motor, MRAC*

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I. INTRODUCTION

Induction machines (IM) are favorite in the industry, serving as one of the most important roles during the energy conversion between electrical power and mechanical power.Vector-controlled induction motor drive has been widely used for high performance drive of the induction motor. Though most of the vector control drives are based on the feedforward adaptation of slip frequency which is well known as indirect field or vector control method, this control is strongly influenced by the machine parameters variation. In these schemes both torque and rotor flux, are controlled by decomposing the stator current. However, implementation of the vector control scheme requires the knowledge of the rotor speed and other parameters. Thus, field oriented control of IM drive can be achieved at the cost of using additional shaft sensor normally tachogenerator/encoder are used for sensing the rotor speed, thereby increasing the size and reducing the reliability of the whole drive. To overcome these problems, recently the rotor shaft sensorless field oriented control is much more focused and has progressed [1]. Thus the research on the speed control of induction machines has moved to the sensorless speed control, which increases the overall reliability of the electricdrive.Therefore speed estimation algorithm is preferred over the speed sensing. A variety of methods are available for the speed identification in sensorless control of induction motor in the last two decade [2].However, these methods heavily rely upon the machine parameters, reducing the accuracy of speed estimation.In medium and high speed regions,sensorless IM drives gives good dynamic performance, but low and zero speed operation is problematic and still remains a challenge.

The simplest method for speed identification is based on the angular velocity of rotor-flux vector and slip calculation, based on the rotor-flux-vector coordinates obtained using the IM model [2]. This method is quite popular and simple to implement, but the obtained accuracy is not very good due to the great sensitivity to motor-parameter uncertainties. Other methods are based on adaptive Luenberger observers or extended Kalman filters (EKFs) [3]–[7], which are more robust to the IM parameter changes or identification errors but involve lots of computational complexity and the difficulty in tuning criterion. Another solution for speed identification based upon the theory of model reference adaptive system (MRAS) principle [8], a classical adaptive control system propose by Landau, in which an error vector is formed from the outputs of two models, both dependent on different motor parameters. The error is driven to zero through adjustment of the parameter that influences one of the model. The MRAS approach has the advantage in the simplicity of used models, easy in implementation and has direct physical interpretation.

In thispaper, tuning signal for speed estimation is is defined by the outer product of v^* and i(i.e.,$v^* \times i$). The instantaneous value of $v^* \times I$ is used in the reference model and steady-state value of the same is considered for the adjustable model. The structure of such MRAC for speed estimation is shown in Fig.1. The estimator performs very well at low speed including zero speed and does not require flux computation. These make the drive easy for implementation.

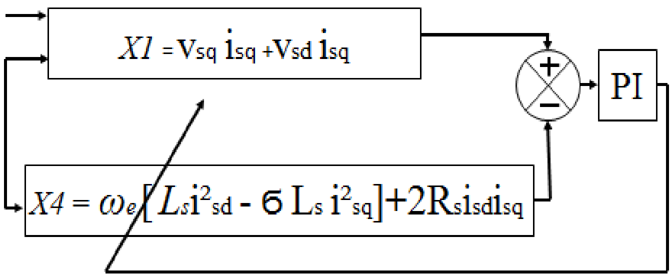

Figure 1. Model Reference Adaptive Control (MRAC) speed estimation

II. SPEED IDENTIFICATION TECHNIQUE

To improve the performance of the speed observer, various practical techniques are available in the literature also discussed which avoids the use of pure integrator. Pure integrator leads to drift and initial condition problem in digital applications, so recent speed sensorless algorithms tend to avoid pure integrators. Most of the traditional vector control algorithms use low-pass filters instead of pure integrators, although they also cause serious problems at low speed range affecting the speed estimation accuracy. Proposed MRAS algorithms avoid both pure integrators and low-pass filters. Reactive power quantity is used as tuning signal for MRASbased speed identification under steady state is robust to both stator and rotor resistance temperature variations.

The induction motor stator voltages in the synchronously rotating reference frame may be expressed as

$$V_{sq} = R_s i_{sq} + \omega_e L_s i_{sd} + p_\sigma L_s i_{sd} + L_m L_r(\omega_e \psi_{rd} + p\psi_{rq}) \quad (1)$$

$$V_{sd} = R_s i_{sd} - \omega_{e\sigma} L_s i_{sq} + p_\sigma L_s i_{sd} - L_m L_r(\omega_e \psi_{rq} - p\psi_{rd}) \quad (2)$$

Instantaneous value of X (i.e.$v^* \times$i) is defined as

$$X_1 = v_{sq} i_{sd} + v_{sq} i_{sq} \quad (3)$$

Substituting the values of v_{sq} and v_{sd} from (1) and (2) in (3),the instantaneous value of X becomes

$$X_2 = \left[R_s i_{sq} + \omega_e \sigma L_s + \rho\sigma L_s i_{sq} + \frac{L_m}{L_r}(\omega_e \psi_{rd} + p\psi_{rq})\right] i_{sd} + \left[R_s i_{sd} - \omega_e \sigma L_s i_{sq} + \rho\sigma L_s i_{sd} - \frac{L_m}{L_r}(\omega_e \psi_{rq} - p\psi_{rd})\right] i_{sq} \quad (4)$$

At steady state, the expression of X is

$$X_3 = \left[R_s i_{sq} + \omega_e \sigma L_s + \rho\sigma L_s i_{sq} + \frac{L_m}{L_r}(\omega_e \psi_{rd})\right] i_{sd} + \left[R_s i_{sd} - \omega_e \sigma L_s i_{sq} - \frac{L_m}{L_r}(\omega_e \psi_{rq})\right] i_{sq} \quad (5)$$

For a rotor flux-oriented drive, substituting $\psi_{rd} = Lmisd$ and ψrq= 0, the simplified expression of X becomes

$$X_4 = \omega_e \left[L_s i_{sd}^2 - \sigma L_s i_{sq}^2 + R_s i_{sd} i_{sq}\right] \quad (6)$$

The expression of X_1 is independent of rotor speed. Hence,it is selected for the reference model. X_2, X_3 or X_4 may bechosen as the adjustable model as they are dependent on therotor speed (ω_r). However, X_4 is selected in the adjustablemodel, as this quantity does not involve flux estimation and any derivative operations.

III. PROPOSED SPEED IDENTIFICATION SCHEME MATLAB SIMULATION

To verify the performance, proposed MRAC based speed identification scheme estimation implemented in indirect field oriented control of IM drive and has been simulated using MATLAB/ SIMULINK. The block diagram of a field oriented sensorless control of induction motor drive as shown in Fig. 2.The block diagram consist of MRAC based speed estimation scheme to which machine terminal voltage and currents are the input for the calculation of X_1 and X_4, speed control loop and flux control loop normally PI controller which produces the reference value of torque and flux producing stator current components, inverse Park's and Clark's transformation block , SPWM block which produces the switching pulses for the three phase inverter as shown in figure. Simulation using MATLAB Software package, is carried out in sensorless environment.

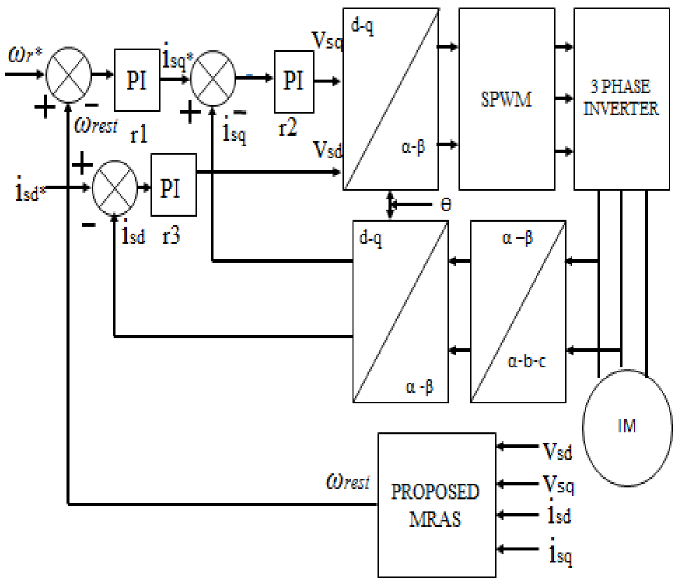

Figure 2.Sensorless indirect field oriented control with proposed speed identification block

IV. SIMULATION RESULTS

The complete system is extensively simulated inMATLAB/ SIMULINK, and this section presents some of the simulation results. The parameters of the machine are given in Table I.

TABLE I. INDUCTION MACHINE PARAMETERS

Symbol	Meaning	Value
P	No. of Pole	2
L_s	Stator self inductance	0.6848H
L_r	Rotor self inductance	0.6848H
L_m	Mutual inductance	0.6705H
R_s	Stator Resistance	5.71ohm
R_r	Rotor Resistance	4.0859ohm
J	Machine Inertia	0.011Kg-m^2
--	Rated Power	1.3KW
--	Line voltage	400V
--	Rated speed	1430rpm

A. Step Change of Rotor Speed and Zero-Speed Operation

The response of the induction motor for a step change in reference speed and zero-speed operation can be seen in Fig.3. A step change in speed of 5rad/s is applied every 4s, and the actual speed is found to track the reference speed satisfactorily [videFig.3(a)].The estimated speed is available in Fig.3(b), which shows that the same is very close to the actual rotor speed. Flux orientation is well maintained, as depicted in Fig.3(c). The load applied to the motor is through a DC generator which offers 0.5 putorque.

B.Ramp Response

The tracking performance of the algorithm at low speeds (near zero speed) is tested by applying a triangular wave input as in Fig.4.The estimated speed is following the actual speed which in turn is matching with the reference speed, as shown in Fig.4(a). In all these operations, the flux orientation is not disturbed as observed in Fig.4(b). Load arrangement is kept same. The results have also confirmed stable operation in forward and reverse-motoring modes.

C. LowSpeedOperation

The performance of the algorithm at a low speed of 1rad/sis shown in Fig.5. The estimated speed and the actual speed are shown in Fig.5(a).This shows that the proposed algorithm can estimate speed accurately even at a very low speed. The flux orientation is maintained, which can be seen from Fig.5(b).

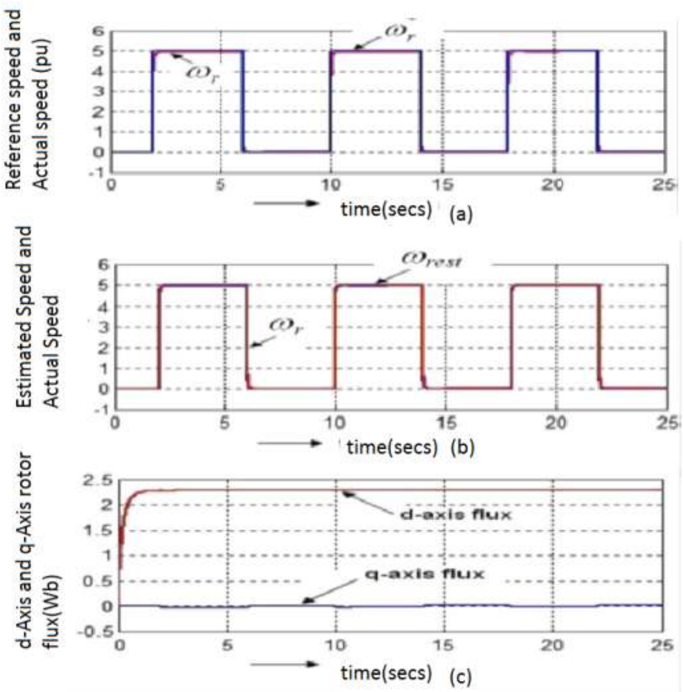

Figure 4 (a) Reference speed and actual speed [rad/s] versus time [s]. (b)Actual speed and estimated speed [rad/s] versus time[s](c) d-axisand q-axis rotor flux [Wb] versus time[s].

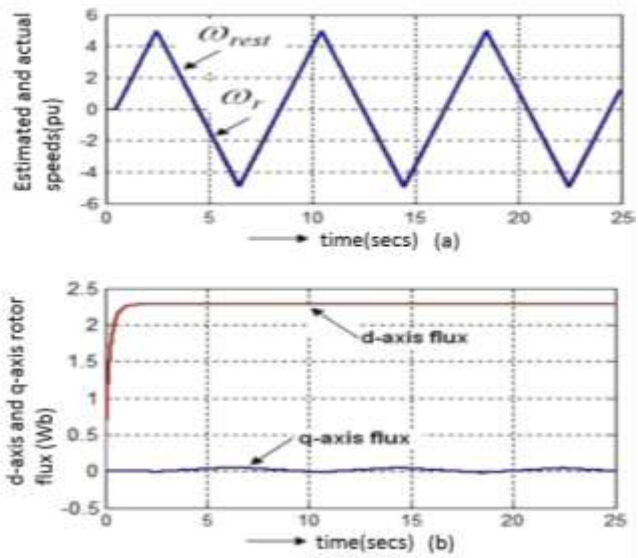

Figure5.(a) Actual speed and estimated speed [rad/s] versus time [s]. (b)d-axis and q-axis rotor flux[Wb]

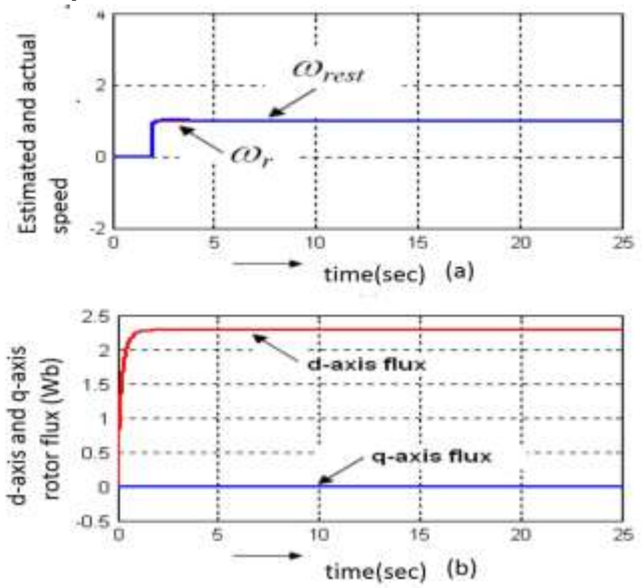

Figure6.(a)Actual speed and estimated speed[rad/s] versus time[s]
(b)d-axis and q-axis rotorflux[Wb]

V. CONCLUSION

From the simulation results, the following observations are made.

i) The transient response of the drive is fast, i.e. we are attaining steady state very quickly.

ii) By using MRACestimated speed is same as that of actual speed of induction motor.

iii) This technique is stable in all four quadrants of operation and also suitable for low speed and zero speed Operation.

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