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HIGH PERFORMANCE ADAPTIVE FIELD–ORIENTED MODEL REFERENCE CONTROL OF CURRENT–FED INDUCTION MOTOR

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This paper develops the application of an adaptive model reference approach to the direct field-oriented control of the current-fed induction motor. The proposed algorithm decomposes the control task into three loops, namely, the speed loop, the d-axis flux loop and the q-axis flux loop. In this way the matching conditions are always fulfilled. Then, a model reference tracking adaptive control is designed for each loop. Proportional-Integral update laws are used to adjust the control parameters, which increases the tracking performance. As compared to standard adaptive control schemes, no special knowledge about the drive parameters is required. Extensive simulation studies have shown good robustness against parameter variations, high tracking performance and simplicity of implementation.

K e y w o r d s: induction motor, field-oriented control, reference model, adaptive control

1 INTRODUCTION

Even though it is highly nonlinear, thus requiring much more complex control algorithms, the induction machine is traditionally and for a long time used in fixed speed applications for reasons of cost, size, reliability and efficiency. Consequently, when a variable speed is required, the DC machine appears to be the most appropriate electromechanical device where torque and flux are naturally decoupled and can be controlled independently, thus allowing a fast torque response and high precision of regulation to be achieved.

The field-oriented control for induction motors was introduced for the first time by Blaschke in the early 1970s [1]. The main objective of this control method is, as in separately excited DC machines, to independently control the torque and the flux; this is done by choosing a $d-q$ rotating reference frame synchronously with the rotor flux space vector. Once the orientation is correctly achieved, the torque is controlled by the torque producing current, which is the q-component of the stator current space vector. At the same time, the flux is controlled by the flux producing current, which is the d-component of the stator current space vector [2, 3]. However, this decoupling characteristic is highly sensitive to variations of electrical parameters. If the electrical parameters set in the field-orientation scheme cannot be tuned according to their actual values, the torque generating characteristics will become sluggish and oscillatory. On the other hand, in many industrial applications the drive operates under a wide range of changing load characteristics and the mechanical system parameters vary substantially [4].

In order to cope with the problems mentioned above, various adaptive field-oriented control schemes with on-line estimation of the induction motor parameters were developed [5]–[11]. In the magnetic part, several algorithms were proposed to tune the rotor mutual and time-constant. On the other hand, in the mechanical part the load torque is usually considered as the only changing parameter. Since in adaptive control the parameters update generally does not, converge to the true parameters, the tracking performance is very sensitive to the transient change in the drive parameters. Moreover, since the friction coefficient and inertia change with the load, they play a great role in the speed and position control performance.

In recent years, the reference model control for dynamic systems have been a topic of considerable interest. A reference model can be used not only to characterize the desired performance objectives but also to reflect the possibility of achieving them [12, 13]. However, the application of the reference model to the induction motor drive was limited by the coupled nonlinear dynamics of the drive and the difficulty to realize the matching conditions. Thus, the application of the model reference control to the induction motor drive was only considered for the speed control due to the linearity of the mechanical part, and facility to realize matching conditions [14–19].

Based on the adaptive model reference technique, this paper proposes a new robust architecture to realize the field-oriented control of the induction motor drive. The control problem is broken into three servo control problems, namely, the speed loop, the d-axis flux loop and the q-axis loop. In this manner, the problem is reduced to three SISO sub-systems where the matching conditions are always verified. Then, for each subsystem, an adaptive control input is designed to achieve the reference model tracking objective with compensation of the coupling due to the other loops.

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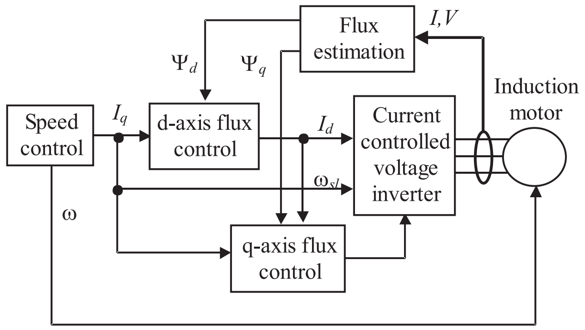

Fig. 1. Proposed induction motor control scheme.

The major contributions of the work presented in this paper are: (1) considering the whole current-fed drive dynamics, *ie*, no simplification is made, which permits mastering of both the transient and steady state dynamics; (2) considering all the electrical and mechanical parameters as unknown, and designing the control loops to account for this situation; (3) Proportional-Integral update laws are used to tune the control parameters, which, compared with simple Integral update laws, provides faster tracking and convergence performance.

This paper is organized as follows. In Section 2, we briefly review the current-fed induction motor model and the field-orientation control principle. The proposed adaptive model reference control of the induction motor speed and fluxes is discussed in Section 3. Section 4 presents the stability analysis of the closed loop drive dynamic. The simulation results are presented and discussed in Section 5. Finally, some concluding remarks end the paper.

2 INDUCTION MOTOR MODEL

The current-fed induction motor model established in d-q synchronously rotating frame is given by the following equations

$$\dot{\psi}_d = -\alpha\psi_d + \omega_{sl}\psi_q + \beta I_d \tag{1}$$

$$\dot{\psi}_q = -\alpha\psi_q - \omega_{sl}\psi_d + \beta I_q \tag{2}$$

$$\dot{\omega} = -a\omega + b\big(\mu(\psi_d I_q - \psi_q I_d) - T_l\big) \tag{3}$$

where
ω is the electrical rotor speed; ω_{sl} is the slip frequency;
I_d, I_q are the d, q axis stator currents;
ψ_d, ψ_q are the d, q axis rotor fluxes;
R_r is the rotor resistance; L_r is the rotor inductance;
M is the mutual inductance; J is the moment of inertia;
f is the viscosity coefficient;
P is the number of pairs of poles; T_l is the load torque;
$\alpha = R_r/L_r$ is the rotor time constant,
$\beta = \alpha M$, $\mu = PM/L_r$, $a = f/J$ and $b = P/J$.

In the direct field-oriented control, the speed is controlled by the torque producing current I_q to track the speed reference command. The d-axis flux is forced to follow some reference flux command using the flux producing current I_d. Further, the slip frequency ω_{sl} is used as the third control input to force the q-axis flux to zero, *ie*, to achieve the correct flux orientation. Since we are not, here, concerned with the flux estimation, any of the flux observers proposed in the literature (see *eg*, [20] for a detailed survey) can be used to realize this task.

3 MODEL REFERENCE ADAPTIVE CONTROL

In what follows, we present the design of adaptive model-reference control for current-fed induction motor (1)–(3), under general parameters uncertainties. To reduce the design complexity, the control problem is broken into three simpler sub-systems. Namely, the speed control loop, the d-axis flux loop and the q-axis flux loop (see Fig. 1).

The reference model of each control loop is designed to reflect the desired behavior. Thus, the reference model for the speed loop is given by

$$\dot{\omega}_m = -a_m\omega_m + a_m\omega_{ref} \tag{4}$$

where $a_m > 0$, ω_m is the reference model state, and ω_{ref} is the reference speed command.

The flux reference models are chosen to reflect the field-orientation principle described above. Then, the d-axis and q-axis reference models are designed such as

$$\dot{\psi}_{dm} = -\alpha_m\psi_{dm} + \alpha_m\phi_{ref} \tag{5}$$

$$\dot{\psi}_{qm} = -\alpha_m\psi_{qm} \tag{6}$$

with $\alpha_m > 0$, ϕ_{ref} is the flux reference command generated by some energy saving algorithm, and ψ_{dm}, ψ_{qm} are the d-axis and q-axis reference models states, respectively. To reflect the field-orientation situation, the initial conditions for the reference models states are set to: $\psi_{dm}(0) = \psi_{ref}$, $\psi_{qm}(0) = 0$. Hence we get $\psi_{dm}(t) = \psi_{ref}$, $\psi_{qm}(t) = 0$ $\forall t \geq 0$, *ie*, the fluxes reference states are always in the field-orientation conditions.

3.1 Speed Loop Design

Considering (3)–(4), the speed tracking error is given by

$$\dot{e} = -a_m e - (a - a_m)\omega + a_m\omega_{ref} - b(\mu\psi_{dm}I_q - T_l) + b\mu(e_d I_q - e_q I_d) \tag{7}$$

where $e = \omega_m - \omega$ is the speed tracking error, $e_q = \psi_{dm} - \psi_d$ is the d-axis flux tracking error, and $e_q = \psi_{qm} - \psi_q = -\psi_q$ is the q-axis flux tracking error.

To achieve the speed tracking objective, the torque producing current is defined as

$$I_q = \frac{1}{\psi_{dm}}\big(k_\omega^1\omega + k_\omega^2\omega_{ref} + k_\omega^3\big) \tag{8}$$

with

$$k_\omega^1 = k_{\omega_I}^1 + k_{\omega_P}^1, \quad k_\omega^2 = k_{\omega_I}^2 + k_{\omega_P}^2, \quad k_\omega^3 = k_{\omega_I}^3 + k_{\omega_P}^3$$

and $k_{\omega_I}^j$, $k_{\omega_P}^j$, for $j = 1, 2, 3$, are the control input integral and proportional adaptive terms, respectively. Introducing (8) in (7), the resulting expression can be arranged as

$$\dot{e} = -a_m e - b\mu[K_{\omega_I} z_\omega + K_{\omega_P} z_\omega] + b\mu(e_d I_q - e_q I_d) \quad (9)$$

where

$$K_{\omega_I} = \left[\left(k_{\omega_I}^1 - \tfrac{(a-a_m)}{b\mu}\right) \ \left(k_{\omega_I}^2 - \tfrac{a_m}{b\mu}\right) \ \left(k_{\omega_I}^3 - \tfrac{T_l}{\mu}\right) \right] \quad (10)$$

$$K_{\omega_P} = \left[k_{\omega_P}^1 \quad k_{\omega_P}^2 \quad k_{\omega_P}^3 \right] \quad (11)$$

$$z_\omega = [\omega \quad \omega_{ref} \quad 1]^\top \quad (12)$$

Observing that $\dot{K}_{\omega_I} = \left[\dot{k}_{\omega_I}^1 \quad \dot{k}_{\omega_I}^2 \quad \dot{k}_{\omega_I}^3 \right]$, we chose the following expressions for the integral and proportional terms

$$\dot{K}_{\omega_I} = \gamma_1 e z_\omega^T \quad (13)$$

$$K_{\omega_P} = \gamma_2 e z_\omega^T \quad (14)$$

where $\gamma_1, \gamma_2 > 0$ are the update step sizes.

Remark 1. The first two terms in (8) represent the standard model reference state feedback, and the third term is added to compensate for the load torque, which is considered unknown but constant. This is not a restriction and the proposed approach can be easily extended to variable load torque with known form.

Remark 2. The last term in (9) reflects the coupling between the speed loop and the fluxes loops, which indicates that the speed tracking error is affected by the fluxes tracking errors. This coupling term should be accounted for when designing the fluxes control loop.

3.2 d-axis Flux Loop Design

Considering the d-axis flux dynamic (1) and the reference model (5), the d-axis flux tracking error is given by

$$\dot{e}_d = -\alpha_m e_d - (\alpha_m - \alpha)\psi_d + \alpha_m \phi_{ref} + \omega_{sl} e_q - \beta I_d \,. \quad (15)$$

To achieve the d-axis reference flux tracking, the d-axis current is chosen as

$$I_d = k_d^1 \psi_d + k_d^2 \psi_{ref} + k_d^3 \lambda e I_q \quad (16)$$

with

$$k_d^1 = k_{d_I}^1 + k_{d_P}^1\,, \quad k_d^2 = k_{d_I}^2 + k_{d_P}^2\,, \quad k_d^3 = k_{d_I}^3 + k_{d_P}^3$$

and $k_{d_I}^j$, $k_{d_P}^j$, for $j = 1, 2, 3$, are the control input integral and proportional adaptive terms, respectively. $\lambda > 0$ is small positive constant.

Then, substituting (16) in (15) and arranging the resulting terms yields

$$\dot{e}_d = -\alpha_m e_d - \beta[K_{d_I} z_d + K_{d_P} z_d] - \lambda b\mu e I_q + \omega_{sl} e_q \quad (17)$$

with the following notations

$$K_{d_I} = \left[\left(k_{d_I}^1 - \tfrac{\alpha_m - \alpha}{\beta}\right) \ \left(k_{d_I}^2 - \tfrac{\alpha_m}{\beta}\right) \ \left(k_{d_I}^3 - \tfrac{b\mu}{\beta}\right) \right], \quad (18)$$

$$K_{d_P} = \left[k_{d_P}^1 \quad k_{d_P}^2 \quad k_{d_P}^3 \right], \quad (19)$$

$$z_d = [\psi_d \quad \psi_{ref} \quad \lambda e I_q]\,. \quad (20)$$

Further, observing that $\dot{K}_{d_I} = \left[\dot{k}_{d_I}^1 \quad \dot{k}_{d_I}^2 \quad \dot{k}_{d_I}^3 \right]$, we chose the following expressions for the integral and proportional terms

$$\dot{K}_{d_I} = \gamma_3 e_d z_d^T\,, \quad (21)$$

$$K_{d_P} = \gamma_4 e_d z_d^T \quad (22)$$

where $\gamma_3, \gamma_4 > 0$ are the update step sizes.

Remark 3. The last term in (16) is added to compensate for the corresponding coupling term in (9). The parameter λ is introduced to reduce the effects of the I_q current and the rotor speed variations on the d-axis flux dynamic.

3.3 q-axis Flux Loop Design

Considering the q-axis flux dynamic (2) and the reference model (6), the q-axis flux tracking error is given by

$$\dot{e}_q = -\alpha_m e_q - (\alpha_m - \alpha)\psi_q + \omega_{sl}\psi_{dm} - \omega_{sl} e_d - \beta I_q \,. \quad (23)$$

To force the q-axis reference flux tracking error to zero, the slip frequency is used as an additional adaptive control input, and defined as

$$\omega_{sl} = \frac{1}{\psi_{dm}}(k_q^1 \psi_q + k_q^2 I_q + k_q^3 \lambda e I_d) \quad (24)$$

with

$$k_q^1 = k_{q_I}^1 + k_{q_P}^1, \quad k_q^2 = k_{q_I}^2 + k_{q_P}^2, \quad k_q^3 = k_{q_I}^3 + k_{q_P}^3$$

and k_{qI}^j, k_{qP}^j, for $j = 1, 2, 3$, are the control input integral and proportional adaptive terms, respectively.

Substituting (24) in (23), and arranging the resulting terms gives

$$\dot{e}_q = -\alpha_m e_q + K_{q_I} z_q + K_{qP} z_q - \omega_{sl} e_d + \lambda b\mu e I_d \quad (25)$$

with

$$K_{q_I} = \left[(k_{q_I}^1 + \alpha) \ (k_{q_I}^2 - \beta) \ (k_{q_I}^3 - b\mu) \right], \quad (26)$$

$$K_{qP} = \left[k_{qP}^1 \quad k_{qP}^2 \quad k_{qP}^3 \right], \quad (27)$$

$$z_q = [\psi_q \quad I_q \quad \lambda e I_d]^T \quad (28)$$

Further, observing that $\dot{K}_{q_I} = \begin{bmatrix} \dot{k}^1_{q_I} & \dot{k}^2_{q_I} & \dot{k}^3_{q_I} \end{bmatrix}$, we chose the following expressions for the integral and proportional terms

$$\dot{K}_{q_I} = \gamma_5 e_q z_q^T, \tag{29}$$

$$K_{q_P} = \gamma_6 e_q z_q^T \tag{30}$$

where $\gamma_5, \gamma_6 > 0$ are the update step sizes.

Remark 4. The last term in (24) is added to compensate for the corresponding coupling term in (9). The parameter λ is introduced to reduce the effects of the I_d current and the rotor speed variations on the q-axis flux dynamic.

4 STABILITY ANALYSIS

The stability results for proposed model reference adaptive approach to the field-orientation control of the current-fed induction motor drive are summarized by the following theorem.

THEOREM. *The current-fed induction motor drive given by the induction motor model* (1)–(3), *reference models* (4)–(6), *adaptive control inputs* (8), (16), (24) *and control parameters update laws* (13)-(14), (21)-(22), (29)-(30) *is globally asymptotically stable and:*

1. *e, e_d and e_q converge asymptotically to zero, ie,* $\lim_{t\to\infty} e, e_d, e_q = 0$.
2. *The control inputs integral terms are bounded, ie,* $K_{\omega_I}, K_{d_I}, K_{q_I} \in L_\infty$.

Proof. Let us define the following Lyapunov function

$$V = V_\omega + V_\psi \tag{31}$$

with

$$V_\omega = \frac{1}{2}e^2 + \frac{b\mu}{2\gamma_1} K_{\omega_I} K_{\omega_I}^T \tag{32}$$

and

$$V_\psi = \frac{1}{2\lambda}e_d^2 + \frac{1}{2\lambda}e_q^2 + \frac{\beta}{2\lambda\gamma_3} K_{d_I} K_{d_I}^T + \frac{1}{2\lambda\gamma_5} K_{q_I} K_{q_I}^T. \tag{33}$$

In a first step, we study the speed closed loop dynamics. The differentiation of (32) along the trajectory of (9) yields

$$\dot{V}_\omega = -a_m e^2 - eb\mu[z_\omega^T K_{\omega_I}^T + z_\omega^T K_{\omega_P}^T] + eb\mu(e_d I_q - e_q I_d) + \frac{b\mu}{\gamma_1} \dot{K}_{\omega_I} K_{\omega_I}^T. \tag{34}$$

This can be arranged as

$$\dot{V}_\omega = -a_m e^2 - b\mu e z_\omega^T K_{\omega_P}^T + \frac{b\mu}{\gamma_1}[\dot{K}_{\omega_I} - \gamma_1 e z_\omega^T] K_{\omega_I}^T + eb\mu(e_d I_q - e_q I_d). \tag{35}$$

Then, substituting the update laws (13)-(14) in (35) yields

$$\dot{V}_\omega = -a_m e^2 - \gamma_2 b\mu z_\omega^T z_\omega e^2 + eb\mu(e_d I_q - e_q I_d). \tag{36}$$

Then, observing that the second term in (36) is semi-definite negative yields

$$\dot{V}_\omega \le -a_m e^2 + eb\mu(e_d I_q - e_q I_d). \tag{37}$$

In a second step, we consider the fluxes closed loops dynamics. The differentiation of (33) along (17) and (25) yields

$$\dot{V}_\psi = -\frac{\alpha_m}{\lambda}e_d^2 - \frac{\alpha_m}{\lambda}e_q^2 - \frac{1}{\lambda}e_d\beta\left[z_d^T K_{d_I}^T + z_d^T K_{d_P}^T\right] + \frac{1}{\lambda}e_q\left[z_q^T K_{q_I}^T + z_q^T K_{q_P}^T\right] + \frac{1}{\lambda}\omega_{sl} e_q e_d - \frac{1}{\lambda}\omega_{sl} e_d e_q - b\mu e I_q e_d + b\mu e I_d e_q + \frac{\beta}{\lambda\gamma_3}\dot{K}_{d_I} K_{d_I}^T + \frac{1}{\lambda\gamma_5}\dot{K}_{q_I} K_{q_I}^T. \tag{38}$$

Further, (38) can be arranged as

$$\dot{V}_\psi = -\frac{\alpha_m}{\lambda}e_d^2 - \frac{\alpha_m}{\lambda}e_q^2 - \frac{\beta}{\lambda}e_d z_d^T K_{d_P}^T + \frac{1}{\lambda}e_q z_q^T K_{q_P}^T + \frac{\beta}{\lambda\gamma_3}\left(\dot{K}_{d_I} - \gamma_3 e_d z_d^T\right) K_{d_I}^T + \frac{1}{\lambda\gamma_5}\left(\dot{K}_{q_I} + \gamma_4 e_q z_q^T\right) K_{q_I}^T + b\mu e(I_d e_q - I_q e_d). \tag{39}$$

Then, introducing the update laws (21)-(22) and (29)-(30) in (39) yields

$$\dot{V}_\psi = -\frac{\alpha_m}{\lambda}e_d^2 - \frac{\alpha_m}{\lambda}e_q^2 - \frac{\beta}{\lambda}\gamma_4 e_d^2 z_d^T z_d - \frac{1}{\lambda}\gamma_6 e_q^2 z_q^T z_q - b\mu e(I_q e_d - I_d e_q). \tag{40}$$

Hence, observing that the third and fourth terms in (40) are semi-definite negative yields

$$\dot{V}_\psi \le -\frac{\alpha_m}{\lambda}e_d^2 - \frac{\alpha_m}{\lambda}e_q^2 + b\mu e(I_d e_q - I_q e_d). \tag{41}$$

At this point, differentiating (31) and using the results (36), (41) yields

$$\dot{V} \le -a_m e^2 - \frac{\alpha_m}{\lambda}e_d^2 - \frac{\alpha_m}{\lambda}e_q^2. \tag{42}$$

Hence, using standard stability arguments [21] with the last result (42), one can conclude that the induction motor drive with the proposed adaptive model-reference control is globally asymptotically stable, the tracking errors e, e_d, e_q converge to zero, and the control inputs adaptive gains are bounded.

Remark 5. From the above analysis it can be seen the proportional terms do not play any role in the stability achievement. However, as it will be seen in the simulation results, they are of great importance for the tracking and convergence performances [13].

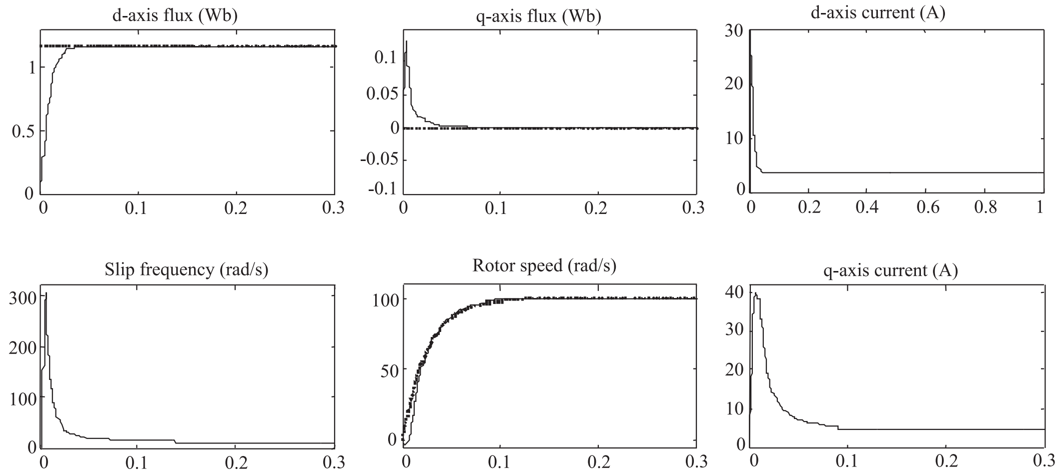

Fig. 2. Drive response under no parameters change.

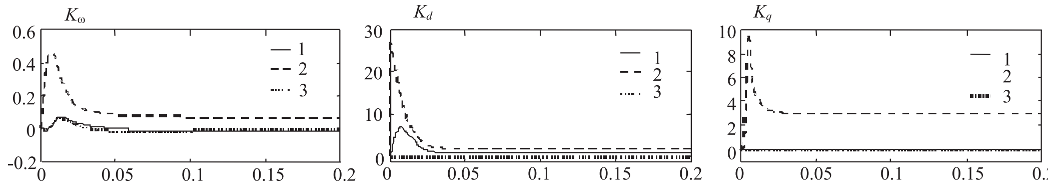

Fig. 3. Control gains evolutions.

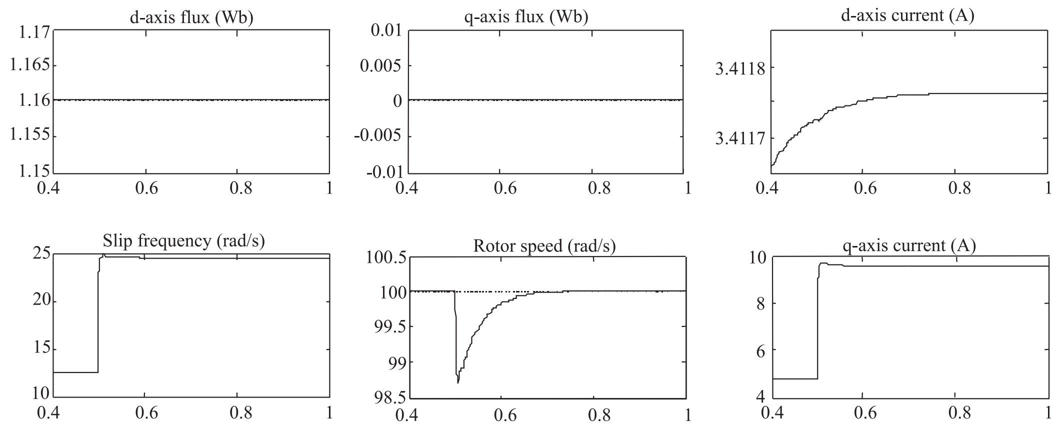

Fig. 4. Drive response under load torque change.

5 SIMULATION RESULTS

In this section the effectiveness of the proposed algorithm for speed and flux control of an induction motor is verified by computer simulations. The specifications for the used induction motor are listed in the appendix. The reference models are chosen as $a_m = 40$ for the speed loop and $\alpha_m = 100$ for the flux loops. The update steps are: $\gamma_1 = 0.0040$, $\gamma_2 = 0.0002$ for speed control parameters, $\gamma_3 = 200$, $\gamma_4 = 20$ for the d-axis flux control, and $\gamma_5 = 100$, $\gamma_6 = 2$ for the q-axis flux control.

A series of tests were conducted to check the performance of the proposed model reference adaptive control. In all sketched figures the time axis is scaled in seconds.

First, the drive response under 5 Nm load torque, without any change in parameters during the operating time. As can be seen from Fig. 2, the speed and flux responses are fast without any overshoot. The control adaptive parameters evolution is shown in Fig. 3. These parameters converge to bounded constant values.

The first series of tests consist in studying the drive response under mechanical parameters change. Figure 4 depicts the drive under a load torque change from 5 to 10 Nm at 0.5 sec. It can be seen that the speed transient error is less than 1.5 % and the flux responses are not affected by this perturbation. Figure 5 shows the drive performance for a brusque change in the viscosity coefficient. In both cases the speed tracking error transient is not greater than 0.01 % for the speed,whereas the flux tracking performance is not perturbed. Figure 6 shows the drive dynamic under different values of the inertia with constant speed reference and with speed inversion.

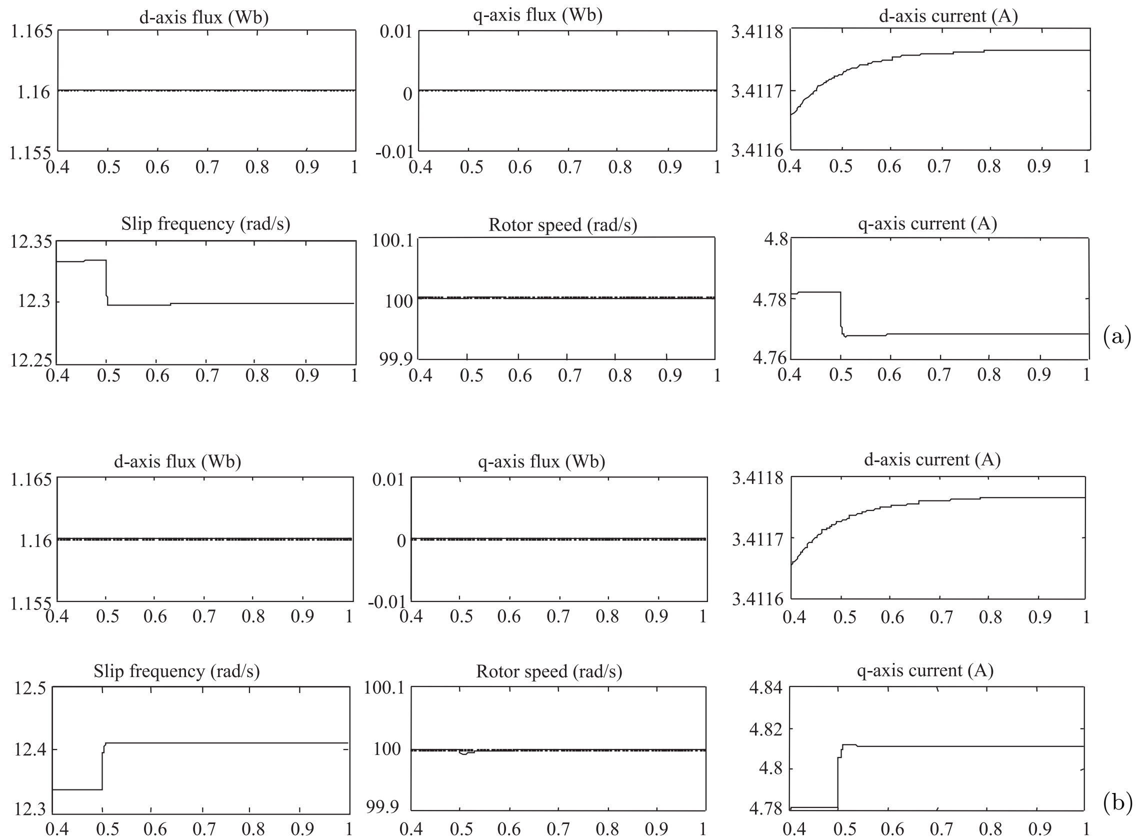

Fig. 5. Drive response under viscosity coefficient change: (a) Change $-50\,\%$, (b) Change $+100\,\%$

It is clear that the speed tracking is little affected by those changes, and the control effort is increased to compensate for this change of inertia.

The second series of tests investigate the influence of the electrical parameters change on the drive performance. Figures 7 to 9 depict the drive performance for brusque changes in the rotor resistance, rotor inductance and the mutual. The transient tracking errors for the speed and the d-axis flux are quantified in Table 1. From those results, it can be seen that the impact of the electrical parameters change on the drive performance is more important. However, those results shown also that the drive robustness and rejection of the perturbations is significantly enhanced compared to conventional control approaches.

The third test concerns the drive dynamic under flux-weakening operating. As depicted in Fig. 10, the flux and speed are not remarkably affected by the reference flux reduction.

The last test concerns the study of the effect of the proportional terms on the drive dynamic performance. Different values of the proportional terms gains γ_2 and γ_4 are tested. It can be seen from Fig. 11 that those values affect greatly the drive performance and the tracking errors convergence. This fact indicates, that adding proportional terms in the update laws improves greatly the drive performance.

Table 1. Effect of electrical parameters change.

Parameter	variation	Speed $\frac{e}{\omega_{ref}} \times 100$	d-axis flux $\frac{e_d}{\phi_{ref}} \times 100$
R_r	$-50\,\%$	0.05	0.4
	$+100\,\%$	0.08	0.8
L_r	$-50\,\%$	0.6	0.4
	$+100\,\%$	1.1	0.7
M	$-50\,\%$	1.2	5
	$+100\,\%$	0.7	2.5

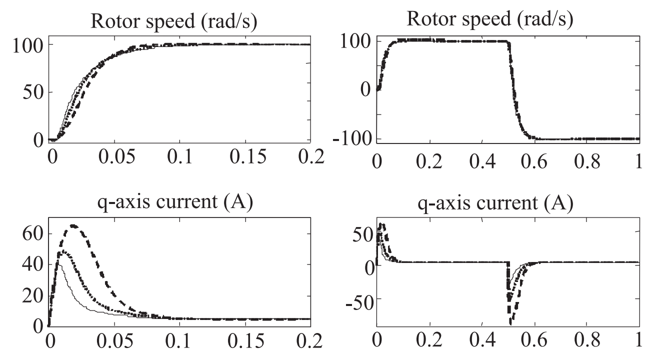

Fig. 6 Speed response under different inertia values: — J, ... $2J$, - - - $4J$.

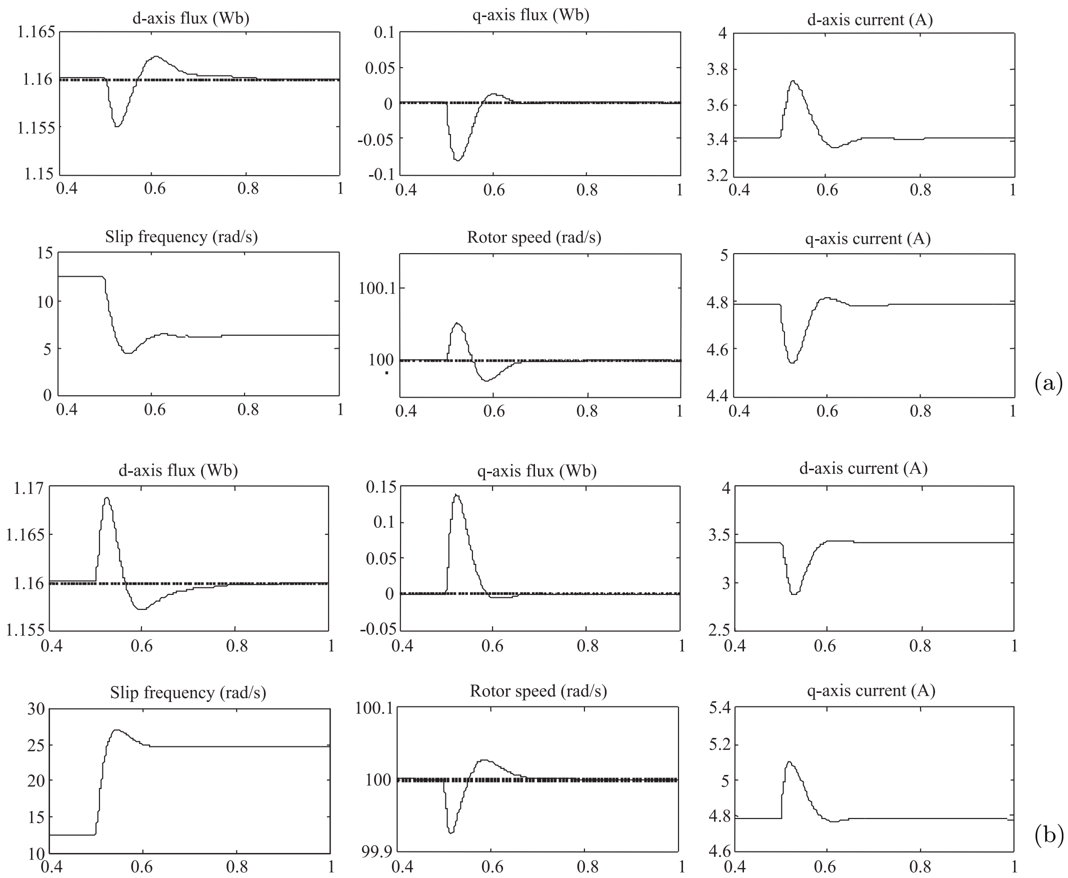

Fig. 7. Drive response under rotor resistance change: (a) Change −50 %, (b) Change +100 %

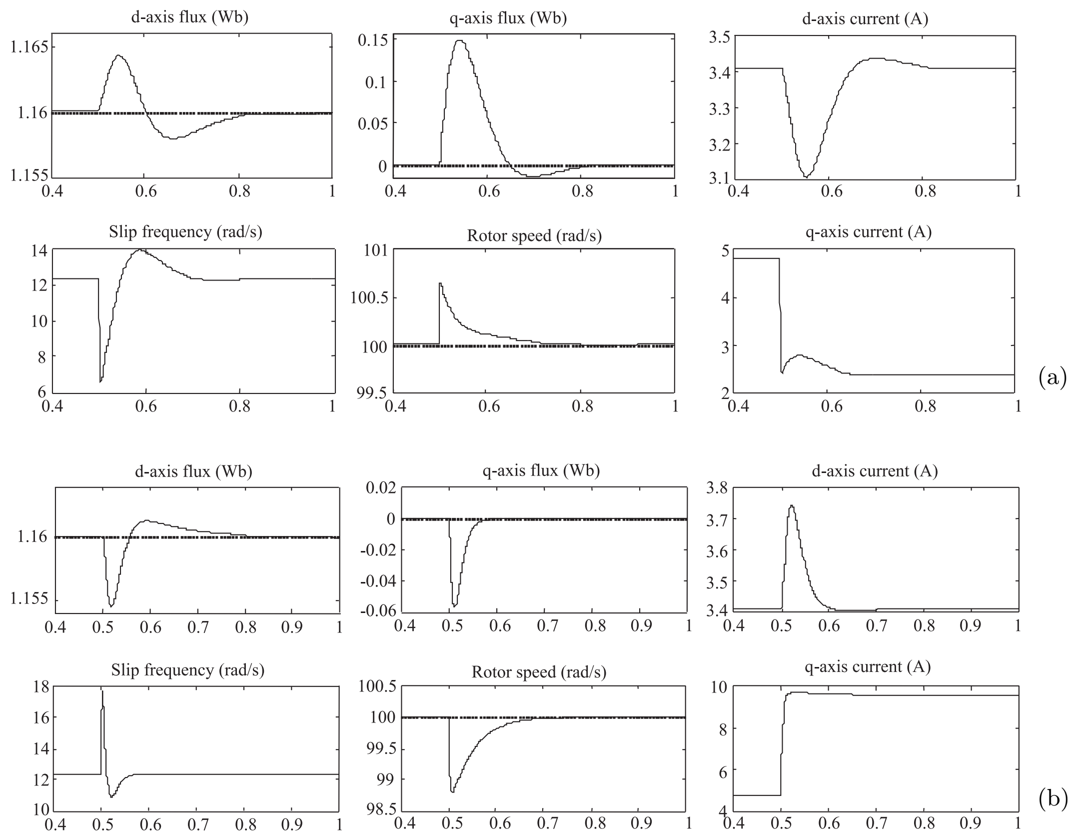

Fig. 8. Drive response under rotor inductance change: (a) Change −50 %, (b) Change +100 %

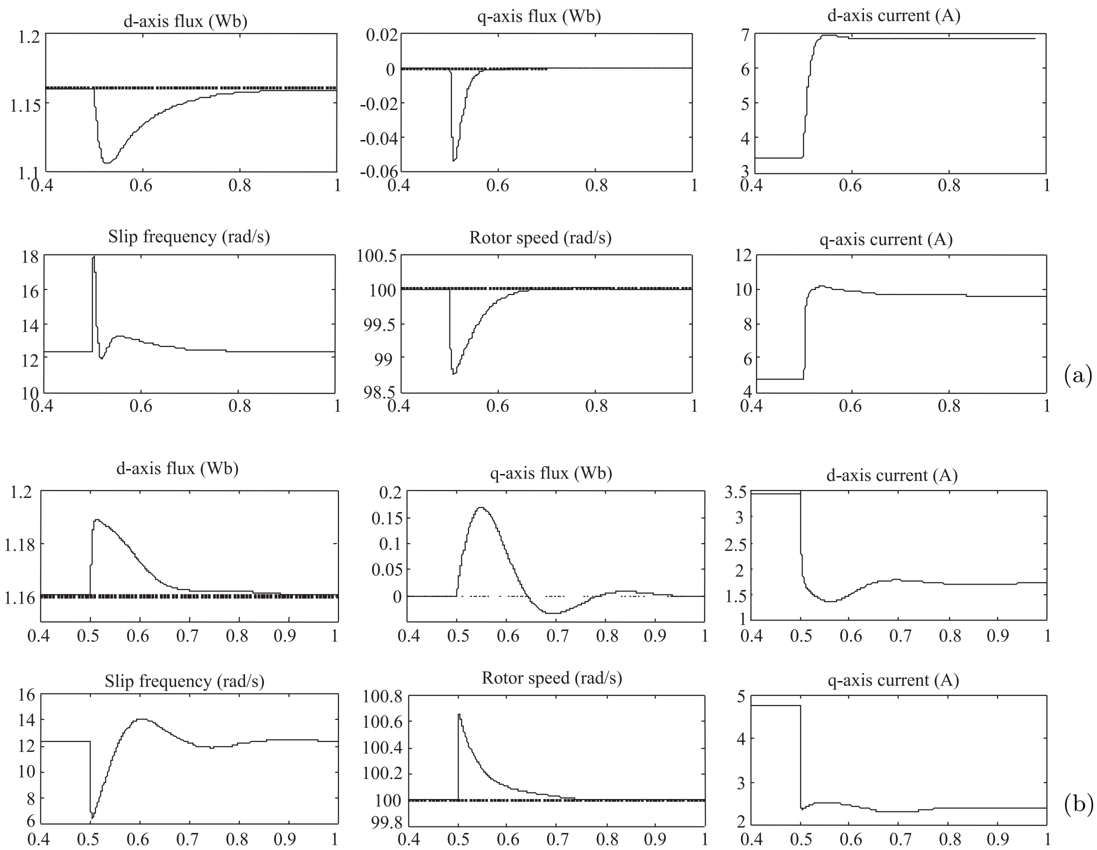

Fig. 9. Drive response under mutual change: (a) Change $-50\,\%$, (b) Change $+100\,\%$

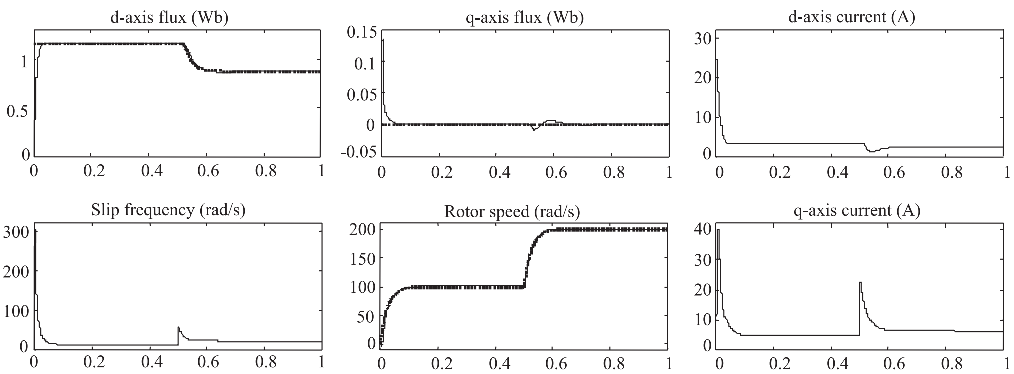

Fig. 10. Drive response under flux-weakening

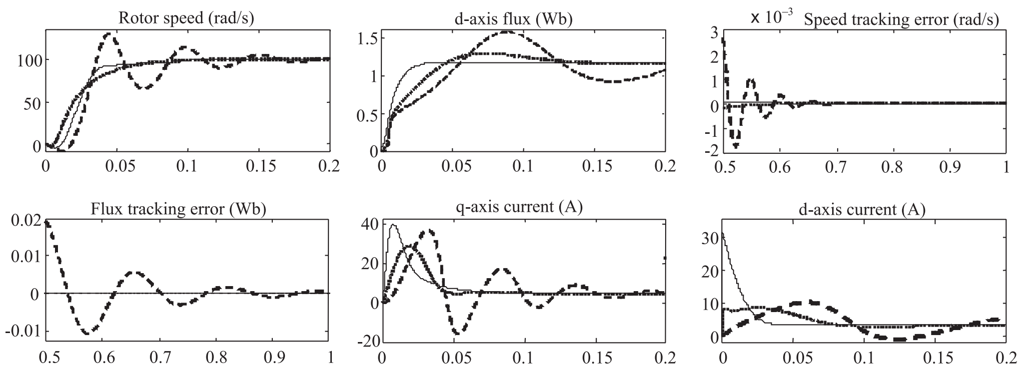

Fig. 11. Drive performance for various proportional terms gains: - - - $\gamma_2 = \gamma_4 = 0$, ... $\gamma_2 = 0.0001, \gamma_4 = 10$, — $\gamma_2 = 0.0002, \gamma_4 = 20$.

Table 2. Induction motor parameters.

Parameter	value
Poles pairs	$P = 2$
Stator resistance	$R_s = 5.3\,\Omega$
Rotor resistance	$R_r = 3.3\,\Omega$
Mutual inductance	$M = 0.34$ H
Stator inductance	$L_s = 0.365$ H
Rotor inductance	$L_r = 0.375$ H
Viscosity coefficient	$f = 0.0003$ Nms/rad
Inertia	$J = 0.005\,\mathrm{Nms}^2/\mathrm{rad}$
Rated speed	$\omega_n = 150$ rad/s
Rated flux	$\psi_n = 1.16$ Wb

6 CONCLUSION

A new adaptive model-reference field-oriented control of an induction motor drive was presented in this paper. The proposed control approach needs no specific knowledge about the motor parameters. Further, the adaptive controller has no singularities, so the scheme is globally defined, even in startup. The overall speed and flux control system was verified to be globally stable and robust to the variations of motor mechanical and electrical parameters variations. Simulation studies were used to demonstrate the characteristics of the proposed method. It is shown that the proposed adaptive controller has better tracking performance and robustness against parameters variations as compared with the conventional model reference adaptive controller. The proportional-integral update laws have been shown to provide more fast tracking and convergence performances compared to pure integral laws.

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