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Performance Analysis of a Robust Positional Control with an Induction Actuator by Using a Simplified Indirect Field Oriented Control Algorithm

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Abstract

The aim of this paper is to study the performance of a simplified indirect field oriented control algorithm suited for small power induction actuators. The main particularities of the control strategy under study are the use of a disturbance observer in the speed and position control loops, and the absence of any current measurement. The good performance of the proposed control strategy, particularly as concerns the flux control sensitivity to parameter uncertainties, is shown by theoretical results and digital simulations.

Keywords: Field oriented control, Induction actuator, Performance analysis, Disturbance observer

1. Introduction

High performance motion control with induction actuators requires to control separately the flux and the current producing the torque. As the flux measurement in an induction actuator has numerous drawbacks, the flux in the actuator is usually indirectly controlled by controlling an intermediate variable, which is, in a d-q generalized reference frame, the stator d axis current provided that the reference frame position is selected in such a way that the rotor flux is along the d axis (Bose, 2002; Bin, 2006). However current i_{sd} related to the flux by a function which depends on the electrical parameters. Moreover the computing of the reference frame position depends also on the electrical parameters. Therefore the flux control is sensitive to errors on the parameters (Peresada and al; 2003; Robyns and al; 1993).

In some field oriented control schemes commonly used the d and q axes currents are controlled by PI regulators (Singh and al; 2005). For small power motors, current regulators may be avoided and only estimated values of the currents may be used in the control algorithm (Gorez and al; 1991; Larabi and al; 1998).

In this paper we study the performance of a simplified indirect field oriented control algorithm suited for small power induction actuators improved by the introduction of a disturbance observer in the speed and position control loops.

A main characteristic of the control algorithm under study is that it does not involve any current measurement. The effect of using estimated value of the currents instead of measured ones is therefore investigated. Particularly, the interest of this solution as concerns the sensitivity of the flux control to parameter uncertainties is made clearly apparent.

The good performance of the proposed control algorithm is emphasized by a theoretical analysis, digital simulations; on 0.25Kw induction actuator.

2. Actuator modeling

In a generalized two axes reference frame, the electrical equations of a two pole induction machine are:

$$\frac{d\psi_{sd}}{dt} = \omega\psi_{sq} - R_s i_{sd} + U_d$$

$$\frac{d\psi_{sq}}{dt} = -\omega\psi_{sd} - R_s i_{sq} + U_q \qquad (1)$$

$$\frac{d\psi_{rd}}{dt} = \omega_{sr}\psi_{rq} - R_r i_{rd}$$

$$\frac{d\psi_{rq}}{dt} = -\omega_{sr}\psi_{rd} - R_r i_{rq}$$

The electromagnetic torque is given by:

$$T_{em} = \frac{M}{L_r}\left(i_{sq}\psi_{rd} - i_{sd}\psi_{rq}\right) \qquad (2)$$

The fluxes are related to the currents by the following equations:

$$\psi_{sd} = L_s i_{sd} + M i_{rd} \qquad \psi_{rd} = L_r i_{rd} + M i_{sd} \qquad (3)$$
$$\psi_{sq} = L_s i_{sq} + M i_{rq} \qquad \psi_{rq} = L_r i_{rq} + M i_{sq}$$

In these equations, ψ_{sd} ψ_{sq} ψ_{rd} ψ_{rq} are the fluxes along the stator and rotor d and q axes; M is the mutual inductance between the stator and the rotor d, q windings; L_s and L_r are the inductances of the stator and the rotor d, q equivalent windings. $L_s=M+l_{s0}$ and $L_r=M+l_{r0}$ where l_{s0} and l_{r0} are the leakage inductances of the stator and the rotor windings. R_s and R_r are the resistances of the stator and the rotor d, q windings; ω is the angular speed of the d, q reference frame with respect to the actuator stator and θ its position; ω_{sr} is the sleep frequency: $\omega_{sr}= \omega- \omega_m$,where ω_m is the rotor angular speed.

The position of the reference frame may be selected in order to obtain $\psi_{rq}=0$ (Leonhard, 2001; Blaschke, 1972; Vas, 1990). From equation (1), (2) and (3) with $\psi_{rq}=0$, we obtain the induction motor block diagram shown in full line in Figure1. In this diagram T_R is the load torque (considered as a perturbating torque), J is the inertia of the actuator rotor and of the mechanical load, K is the viscous torque coefficient, σ is the dispersion coefficient [$\sigma=1-M^2/(L_sL_r)$].

$\tau_s= L_s/ R_s$ and $\tau_r= L_r/ R_r$ are the stator and rotor electrical time constant and s is the Laplace operator.

3. Control strategy

It is assumed that the flux can be controlled in open loop and kept constant and equal to its reference value $(\psi_{rd})_{ref}$ after a transient associated to its build up, by considering for the d axis control voltage

$$U_d = \frac{R_s}{M}(\psi_{rd})_{ref} - \omega\sigma L_s i_{sq} \qquad (4)$$

With $\omega = \omega_m + \frac{M R_r}{L_r}\frac{i_{sq}}{(\psi_{rd})_{ref}}$ (5)

In equation (4) the term $-\omega\sigma L_s i_{sq}$ corresponds to a state feedback (shown in broken line in Figure1) which ensures the decoupling of the d axis from the q axis.

As no current measurement is performed the value of current i_{sq} which is involved in this computation must be estimated. This estimation is performed by considering the SISO system to which the block diagram of the actuator reduces when the rotor flux ψ_{rd} is constant (this block diagram is shown in Figure 2 inside the frame in dotted line) and by neglecting the electrical time constant $\sigma L_s/(R_s+(L_s/L_r)R_r)$ in this block diagram:

$$i_{sq} = \frac{U_q - \frac{L_s}{M}(\psi_{rd})_{ref}\,\omega_m}{R_s + \frac{L_s}{L_r}R_r} \qquad (6)$$

The actuator rotor position is controlled through the q axis voltage U_q by using a regulator comprising a subordinate speed loop with a disturbance observer. As the block diagram of the actuator reduces to the linear SISO system shown in Figure2 (inside the frame in dotted line), when the rotor flux is constant, the synthesis of this controller is straightforward (Gorez and al; 1991). The model H of the disturbance observer is deduced from the SISO equivalent system after compensating the emf $(\psi_{rd})_{ref}\,\omega_m L_s / M$ and by neglecting the viscous torque coefficient and the electrical time constant:

$$H = \frac{M\,(\psi_{rd})_{ref}}{(R_s L_r + R_r L_s) J s} \tag{7}$$

As an integral action exists in the disturbance observer, the position and speed controllers may be simply proportional regulators. More details about the disturbance observer used are given in (Robyns and al; 1992).

4. Flux control sensitivity to parameter uncertainties

As the flux is controlled in open loop in the proposed control scheme, errors in the electrical parameters imply errors on the flux. These errors can be computed in steady state.

From (1) and (3), one gets the following steady state equations:

$$U_d = R_s . i_{sd} - \omega\sigma L_s i_{sq} - \omega \frac{M}{L_r}\psi_{rq} \tag{8a}$$

$$U_q = \omega\sigma L_s i_{sd} + R_s i_{sq} + \omega \frac{M}{L_r}\psi_{rd} \tag{8b}$$

$$i_{sd} = \frac{1}{M}\psi_{rd} - \omega_{sr}\frac{L_r}{MR_r}\psi_{rq} \tag{8c}$$

$$i_{sq} = \omega_{sr}\frac{L_r}{MR_r}\psi_{rd} + \frac{1}{M}\psi_{rq} \tag{8d}$$

By introducing (8c) and (8d) in (8a) and (8b), one gets the following relations between U_d and U_q and ψ_{rd} and ψ_{rq}:

$$U_d = A\,\psi_{rd} - B\,\psi_{rq} \tag{9a}$$

$$U_q = B\,\psi_{rd} + A\,\psi_{rq} \tag{9b}$$

With $A = \frac{1}{M}(R_s - \omega\,\omega_{sr}\frac{\sigma L_s L_r}{R_r})$

$$B = \frac{1}{M}(\omega_{sr}\frac{L_r R_s}{R_r} + \omega L_s)$$

According to the control strategy adopted, voltage U_d and U_q can be related to the reference value of the rotor flux, $(\psi_{rd})_{ref}$ by

$$U_d = A^*\,\psi_{ref} \tag{10a}$$

$$U_q = B^*\,\psi_{ref} \tag{10b}$$

The * indicating that estimated values of the parameters have been used in the computation of A and B.

From (10a) and (10b), one gets the following expressions for the errors due to parameter uncertainties on the flux along the d axis (which should be equal to reference flux ψ_{ref}), and on the flux along the q axis ψ_{rq} (which should be equal to zero):

$$\frac{\psi_{rd}}{\psi_{ref}} = \frac{A A^* + B B^*}{A^2 + B^2} \tag{11a}$$

$$\frac{\psi_{rq}}{\psi_{ref}} = \frac{A B^* - A^* B}{A^2 + B^2} \tag{11b}$$

From (11a) and (11b), it is possible to obtain the error on the flux amplitude ψ_r and on the flux orientation ρ:

$$\frac{\psi_r}{\psi_{ref}} = \frac{\sqrt{(\psi_{rd}^2 + \psi_{rq}^2)}}{\psi_{ref}} = \sqrt{\frac{A^{*2} + B^{*2}}{A^2 + B^2}} \tag{12a}$$

$$\rho = arctg\,\frac{\psi_{rq}}{\psi_{rd}} = arctg\left(\frac{A\,B^* - A^* B}{A^2 + B^2}\right) \tag{12b}$$

By introducing (8c), (8d), (11a) and (11b) in (2), one gets the following expression for the electromagnetic torque:

$$T_{em} = \frac{\omega_{sr}}{R_r}\frac{\left(A^{*2} + B^{*2}\right)}{\left(A^2 + B^2\right)}\psi_{ref}^2 \tag{13}$$

5. Simulated Results and Discussions

The parameters of the used machine model are given in Table 1. Figure 3 shows the speed, torque, fluxes, voltages and currents responses of the system to a step in the speed reference from *0* to *1500RPM* and to a step of torque equal to the rated torque at *t=1s* until *t=1.5s*. The very low sensitivity of the system to the step of torque, due to the disturbance observer, is clearly apparent.

In figure 4 an error of *50%* on the rotor and stator resistances is introduced. This induces an error on the flux when the actuator is loaded at *t=1.5*s, but owing to the robustness of the controller, this error remains small.

Figure 5 shows the position response of the system to a step in the position reference from *0* to *100Rad*. In spite of the fact that the sensitivity of the flux control to parameter uncertainties is more important at low speed; the position response is very satisfactory.

6. Conclusion

It has been shown in this paper that it is possible to design a simplified indirect field oriented control system which has, in spite of the simplifications, good performance owing to the design of a speed or position controller based on techniques of robust control evolved for linear systems, and on an appropriate choice of the decoupling method which allows to obtain a very reduced flux control sensitivity to parameter uncertainties.

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Table1. Induction machine data

Components	Rating values
Voltage	$V = 110V$
Power	$P = 0.25Kw$
Speed	$N_m = 1500r/min$
Moment of inertia	$J = 0.012kg.m^2$
Coefficient of viscous friction	$K = 0.0011Nms$
Stator resistance	$R_s = 1.923\ \Omega$
Rotor resistance	$R_r = 1.739\ \Omega$
Stator inductance	$L_s = 0.1157\ H$
Rotor inductance	$L_r = 0.1154\ H$
Mutual inductance	$M = 0.1126\ H$

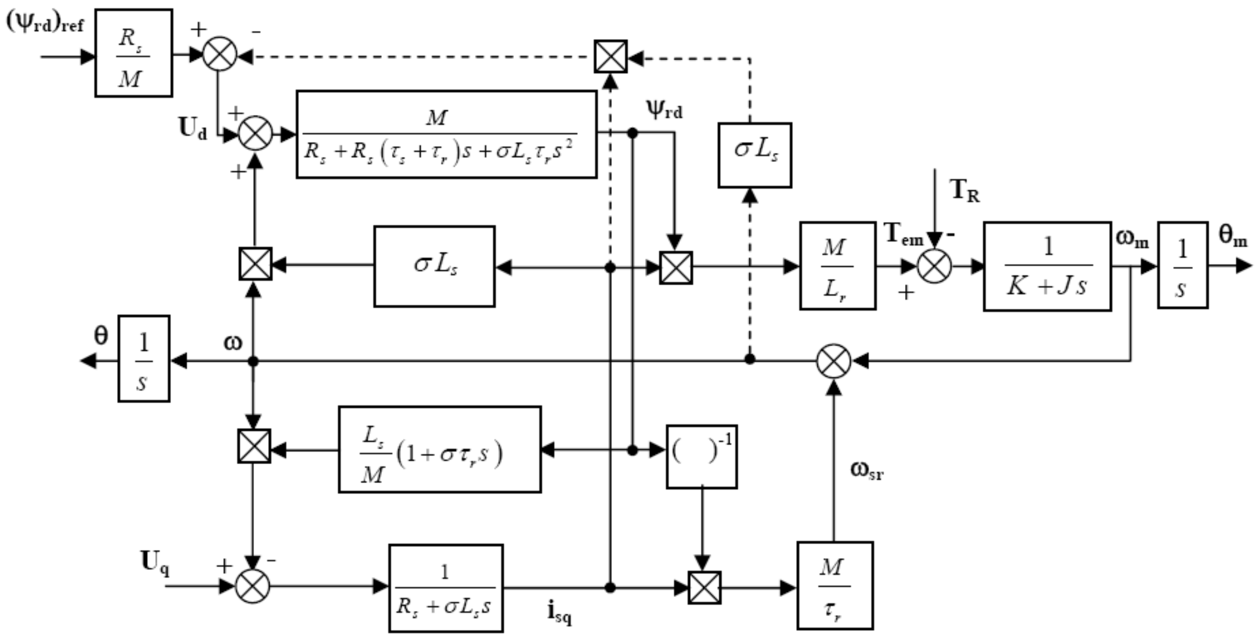

Figure 1. Induction actuator block diagram

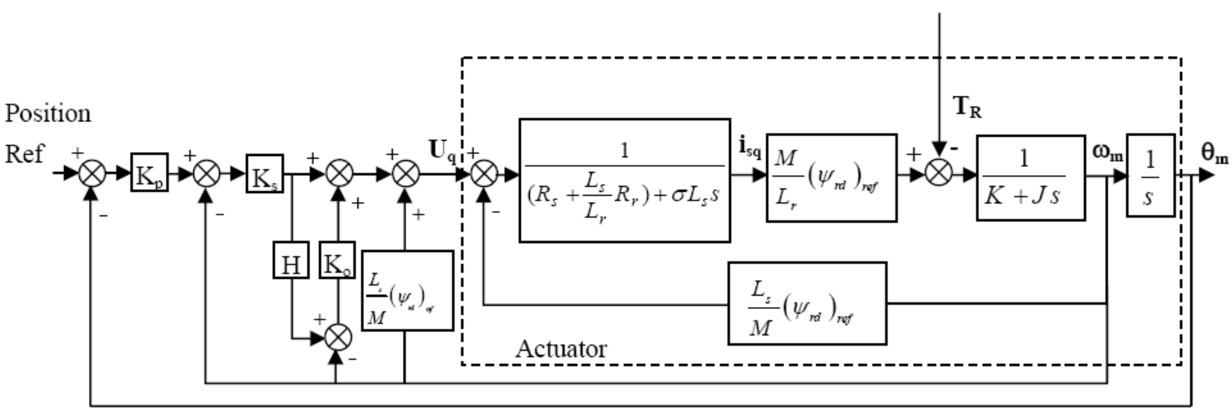

Figure 2. Block diagram of the position control

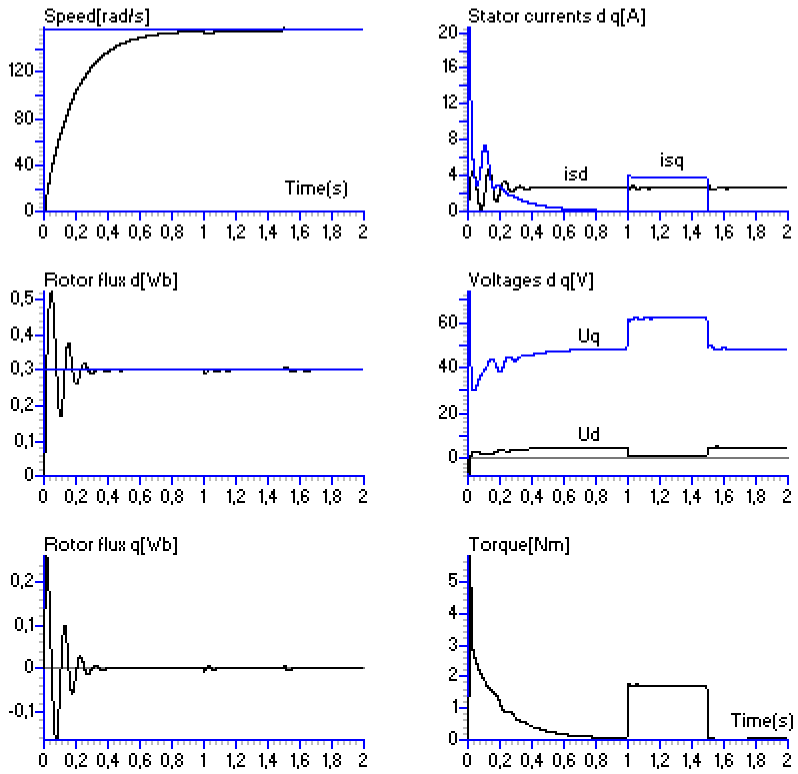

Figure 3. Simulation of the dynamic behavior of the system to a step in the speed reference and to a step in the load torque

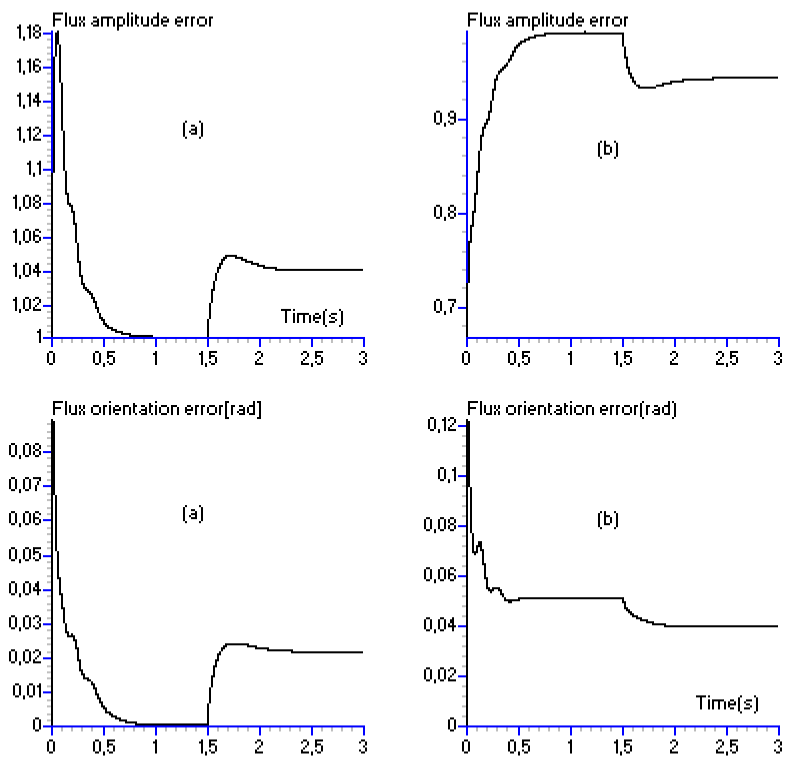

Figure 4. Flux error in steady state due to parameter uncertainties

a- Flux error when $R_r=1.5R_r^*$

b- Flux error when $R_s=1.5R_s^*$

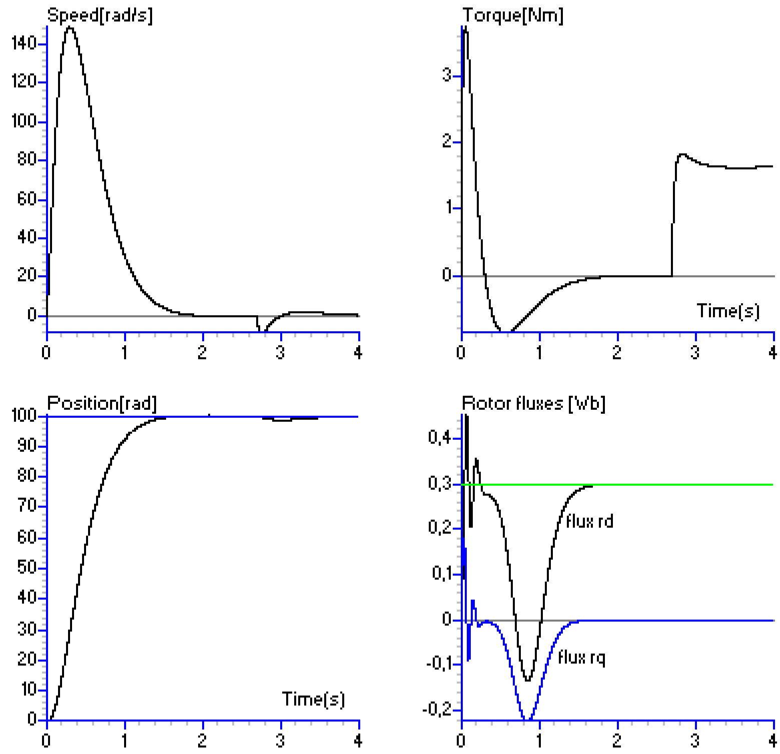

Figure 5. Simulation of the dynamic behavior of the system
to a step in the position reference