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Robust Feedback linearization and Observation Approach for Control of an Induction Motor

[1]O. Asseu, [1]M. Koffi, [1]Z. Yeo, [2]X. Lin-Shi, [1]M.A. Kouacou and [1]T.J. Zoueu
[1]Department of Electrical and Electronic Engineering,
Institut National Polythechnique Houphouet Boigny,
(INP HB) BP 1093 Yamoussoukro Côte d'Ivoire, France
[2]Centre de Genie Electrique INSA,
20 Avenue A. Einstein 69621 Villeurbanne Cedex, France

Abstract: This study presents a feedback linearization strategy and a robust controller to permit a decoupling and regulation of the motor states in order to assure a good dynamic performance and stability of the global system. As the control required the knowledge of the instantaneous flux of the rotor and the rotor parameter estimation can improve the control quality, a six-dimensional discrete-time extended sliding mode observer is proposed for on-line estimation of rotor fluxes and rotor time constant. The simulation results for a 1.8 kW induction motor are presented to illustrate the validity and the high robustness of the proposed approach against parameter variations and disturbances.

Key words: Extended sliding mode observer, robust control, feedback linearization, induction motor

INTRODUCTION

During this last decade, the Induction Motor (IM) is widely used in industrial applications due to its reasonable cost, robust qualities and simple maintenance. To effectively control the torque dynamics of an Induction Motor, it is necessary to use more elaborate control strategies. The control usually used is the Field Oriented Control (FOC) (Blaschke, 1972) which allows the control of the torque transient. Since the first work of Blaschke at the beginning of the 70's, improvements and alternatives of the FOC appeared (Montanari *et al*., 2000; Roncero-Sanchez *et al*., 2007). Moreover, the naturally structure of non-linear and multivariable state of IM models induced the use of the non-linear control methods and in particular the techniques of input-outputs linearization and decoupling (Isidori, 1989). Many results have been published such as (Marino *et al*., 1993; Mohanty *et al*., 2002). However, this technique required the knowledge of the rotor fluxes which are not usually measurable in practice. An observer for estimation of the rotor fluxes is necessary. Furthermore, the control quality depends on the model accuracy. A variation of the rotor resistance (which varies with temperature) can induce a state-space coupling which can induce a performance degradation of the system. In order to achieve better system dynamic performance, the approach proposed in this paper consists in, on the one hand, synthesizing robust controllers combined with input-output decoupling and on the other hand, to design extended observers allowing an on-line estimation of rotor time constant.

The Extended Kalman Filter presented in El Moucary *et al*. (1999), Said *et al*. (2000) and Chbeb *et al*. (2006) can be used for real-time estimation of rotor fluxes and resistance. Unfortunately the initialization and the optimal choice of covariance and gain matrix are delicate. These matrixes play a critical role in robustness of the Extended Kalman Filter (EFK).

Corresponding Author: M.A. Kouacou, INP-HB, BP 1093 Yamoussoukro, Côte d'Ivoire, France
Tel: (+00225) 08 45 39 84 Fax: (+00225) 30 64 04 06

Another approach proposed in Benchaib *et al*. (1999), Derdiyok (2005) and Amuliu and Ali (2007) to estimate the state variables in an IM is the use of Sliding Mode Observer (SMO). This continuous-mode approach observer, based on the variable structure system theory, has been known to produce excellent functional performances and robustness. Some gains of this observer can be easily adjusted compared with the EKF.

This research proposes a six-dimensional Discrete-time Extended Sliding Mode Observer (DESMO) to provide not only rotor fluxes estimation but also the estimations of the rotor time constant and torque in the induction motor.

ROBUST DECOUPLING CONTROL

Model of Induction Motor

By assuming that the saturation of the magnetic parts and the hysteresis phenomenon are neglected, the dynamic model of the induction motor in a (d, q) synchronous reference frame can be described by a fifth-order non-linear differential equation, with as state variables the stator currents (I_{ds}, I_{qs}), the rotor fluxes (Φ_{dr}, Φ_{qr}) and the rotor pulsation (ω_r):

$$\dot{x}_c = f_c(x_c) + g_c.u \quad \text{with: } x_c = [I_{ds}\ I_{qs}\ \Phi_{dr}\ \Phi_{qr}\ \omega_r]^t,\ u = [V_{ds}\ V_{qs}]^t \tag{1}$$

$$f_c(x_c) = \begin{bmatrix} -\lambda.I_{ds} + \omega_s.I_{qs} + \sigma_r.\beta.\Phi_{dr} + \beta.\omega_r.\Phi_{qr} \\ -\omega_s.I_{ds} - \lambda.I_{qs} - \beta.\omega_r.\Phi_{dr} + \beta.\sigma_r.\Phi_{qr} \\ \sigma_r.L_m.I_{ds} - \sigma_r.\Phi_{dr} + \omega_{sl}.\Phi_{qr} \\ \sigma_r.L_m.I_{qs} - \omega_{sl}.\Phi_{dr} - \sigma_r.\Phi_{qr} \\ p^2.\frac{L_m}{L_r.J}.(\Phi_{dr}.I_{qs} - \Phi_{qr}.I_{ds}) - \frac{p}{J}.C_r - \frac{f}{J}.\omega_r \end{bmatrix}; \quad g_c = \begin{bmatrix} \frac{1}{\sigma.L_s} & 0 \\ 0 & \frac{1}{\sigma.L_s} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

$$\sigma_r = \frac{1}{T_r}; \quad \lambda = \lambda(\sigma_r) = \frac{1}{\sigma}\left(\frac{1}{T_s} + (1-\sigma).\sigma_r\right); \quad \beta = \frac{1-\sigma}{\sigma.L_m}; \quad \sigma = 1-\frac{L_m^2}{L_s.L_r}$$

Moreover, by choosing a rotating reference frame (d, q) so that the direction of axe d is always coincident with the direction of the rotor flux representative vector (field orientation), it is well known that this rotor field orientation in a rotating synchronous reference frame realizes:

$$\Phi_{dr} = \Phi_r = \text{Constant and } \Phi_{qr} = 0 \tag{2}$$

Thus the dynamic model of the IM, completed with the output equation, can be rewritten as:

$$\dot{x} = f(x) + g.u; \quad y = [h_1(x)\ h_2(x)]^t = [\Phi_r\ \omega_r]^t \tag{3}$$

with $x = [\ I_{ds}\ I_{qs}\ \Phi_r\ \omega_r\ ]^t$, $u = [\ V_{ds}\ V_{qs}\ ]^t$;

$$f(x) = \begin{bmatrix} -\lambda.I_{ds} + \omega_s.I_{qs} + \sigma_r.\beta.\Phi_r \\ -\omega_s.I_{ds} - \lambda.I_{qs} - \beta.\omega_r.\Phi_r \\ \sigma_r.L_m.I_{ds} - \sigma_r.\Phi_r \\ p^2.\frac{L_m}{L_r.J}.\Phi_r.I_{qs} - \frac{p}{J}.C_r - \frac{f}{J}.\omega_r \end{bmatrix}; \quad g = \begin{bmatrix} \frac{1}{\sigma.L_s} & 0 \\ 0 & \frac{1}{\sigma.L_s} \\ 0 & 0 \\ 0 & 0 \end{bmatrix}$$

From the expressions (1) and (2), one can write:

$$\begin{cases} \dfrac{dI_{mr}}{dt} = \sigma_r.I_{ds} - \sigma_r.I_{mr} \\ \sigma_r = \omega_{sl}.\dfrac{I_{mr}}{I_{qs}} \qquad \text{with} \qquad I_{mr} = \dfrac{\Phi_r}{L_m} \\ C_{em} = \dfrac{p.L_m}{L_r}\Phi_r.I_{qs} \end{cases} \tag{4}$$

This relation (4) shows that the dynamic model of the IM can be represented as a non-linear function of the rotor time constant. A variation of this parameter can induce, for the IM, a lack of orientation, performance and stability. Thus the next section uses a feedback linearization strategy and a robust controller to regulate the motor states with respect to the parameter variations and disturbances.

Robust Input-output Linearization via Feedback for a Nonlinear System

The aim of this research is to show how we can analyze the synthesis of feedback control for the nonlinear dynamic model of the IM given by the system (3) and (4). Thus, we can see that the system (3) has relative degree $r_1 = r_2 = 2$ and can be transformed into a linear and controllable system by chosen:

- A suitable change of coordinates $z = \Psi(x)$ given by:
  $z_1 = h_1(x)$; $z_2 = L_f h_1(x)$; $z_3 = h_2(x)$; $z_4 = L_f h_2(x)$;
- And the feedback control having the following form:

$$u = \begin{bmatrix} L_{g1}L_f h_1(x) & L_{g2}L_f h_1(x) \\ L_{g1}L_f h_2(x) & L_{g2}L_f h_2(x) \end{bmatrix}^{-1} \cdot \begin{bmatrix} v_1 - L_f^2 h_1(x) \\ v_2 - L_f^2 h_2(x) \end{bmatrix} = \Delta^{-1}(x)\begin{bmatrix} v_1 - L_f^2 h_1(x) \\ v_2 - L_f^2 h_2(x) \end{bmatrix}$$

where, v_1 and v_2 are the new inputs of the obtained decoupled systems.

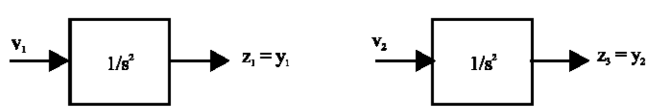
The Jacobian matrix of the transformation thus defined as:

$$\Delta^{-1}(x) = \begin{bmatrix} \dfrac{\sigma_r.L_m}{\sigma.L_s} & 0 \\ 0 & \dfrac{p^2..L_m}{\sigma.L_s.L_r.J}\Phi_r \end{bmatrix}^{-1}$$

is nonsingular for all x such that $\Phi_r \neq 0$ and in the new coordinates, the system appears as:

$$\begin{aligned} \dot{z}_1 &= z_2 \\ \dot{z}_2 &= L_f^2 h_1(x) + L_g L_f h_1(x) u \\ \dot{z}_3 &= z_4 \\ \dot{z}_4 &= L_f^2 h_2(x) + L_g L_f h_2(x) u \end{aligned} \qquad \text{i.e.,} \qquad \begin{aligned} \dot{z}_1 &= z_2 \\ \dot{z}_2 &= v_1 \\ \dot{z}_3 &= z_4 \\ \dot{z}_4 &= v_2 \end{aligned} \tag{5}$$

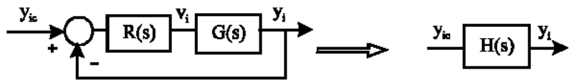
which is linear and controllable. The block diagram of system (5) is as follows :



In order to impose, after a closed loop, a second order dynamic behaviour defined by H(s):

$$H(s) = \frac{1}{1 + \dfrac{2\xi_0}{\omega_0}s + \dfrac{1}{\omega_0^2}s^2}$$

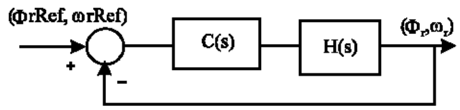
the two new block diagram structure for the control of (Φ_r, ω_r) can be chosen by:



with i = 1, 2 corresponding respectively to Φ_r and ω_r

$$\text{where, } G(s)=\frac{1}{s^2}\ ;\ R(s)=\frac{s}{r_1.s+r}\ ;\ r_1=\frac{1}{\omega_0^2}\ ;\ r=\frac{2.\xi_0}{\omega_0}\ \text{ and }\ H(s)=\frac{R(s).G(s)}{1+R(s).G(s)}$$

On the other hand, to preserve the reliability and stability of the system under parameters variation and noises, a second loop using robust control approach has been added on the motor drives. This control algorithm uses H_∞ synthesis and Doyle method presented in (Doyle *et al*., 1992; Asseu, 2000), to define two robust controllers C(s) in order to realize the regulation of the rotor flux and speed (Φ_r, ω_r).



$$\text{where, } C(s)=\frac{J(s).H(s)^{-1}}{1-J(s)}\quad \text{with}\quad J(s)=\frac{1}{(1+t_0 s)^2} \tag{6}$$

The real t_0 is an adjusting positive parameter, chosen adequately small ($t_0<1$), in order to satisfy the robustness performance, to have a good regulation and convergence of the rotor flux and speed. However the control of an induction motor generally required the knowledge of the instantaneous flux of the rotor that is not measurable. Also a variation of the rotor resistance can induce a lack of field orientation. In order to achieve better dynamic performance, an on-line estimation of rotor fluxes and resistance is necessary. Here, a six-dimensional extended sliding mode observer is proposed for on-line estimation of rotor fluxes (Φ_{dr}, Φ_{qr}), torque (C_{em}), speed (ω_r) and rotor time constant ($\sigma_r = 1/T_r = R_r/L_r$).

EXTENDED SLIDING MODE OBSERVER

Classical Sliding Mode Observer

Let us consider the dynamic model of the IM given by the system (1). Assume that among the state variable, only the stator currents noted z_1, z_2 and the rotor speed ω_r are measurable. Denote $\hat{x}_1$ and $\hat{x}_2$ the estimates of the fluxes Φ_{dr} and Φ_{qr}. Consider that $\hat{z}_1$, $\hat{z}_2$ and $\hat{z}_3$ are the estimates of the stator currents I_{ds}, I_{qs} and rotor speed ω_r. The SMO is a copy of the model (1) by adding corrector gains with switching terms:

$$\begin{cases}\dot{\hat{z}}_1=-\lambda.z_1+\omega_s.z_2+\beta.\sigma_r.\hat{x}_1+\beta.z_3.\hat{x}_2+\dfrac{1}{\sigma.L_s}V_{ds}+\Lambda_1.I_s\\ \dot{\hat{z}}_2=-\omega_s.z_1-\lambda.z_2-\beta.z_3.\hat{x}_1+\beta.\sigma_r.\hat{x}_2+\dfrac{1}{\sigma.L_s}V_{qs}+\Lambda_2.I_s\\ \dot{\hat{x}}_1=\sigma_r.L_m.z_1-\sigma_r.\hat{x}_1+\omega_{sl}.\hat{x}_2+\Gamma_1.I_s\\ \dot{\hat{x}}_2=\sigma_r.L_m.z_2-\omega_{sl}.\hat{x}_1-\sigma_r.\hat{x}_2+\Gamma_2.I_s\\ \dot{\hat{z}}_3=p^2.\dfrac{L_m}{L_r.J}.(\hat{x}_1.z_2-\hat{x}_2.z_1)-\dfrac{p}{J}.C_r-\dfrac{f}{J}.z_3+\Lambda_3.I_s\end{cases} \tag{7}$$

where, Γ_1, Γ_2 and Λ_1, Λ_2, Λ_3 are the observer gains. The switching I_s is defined as:

$$I_s = \begin{bmatrix} \text{sign}(s_1) \\ \text{sign}(s_2) \end{bmatrix} \text{ with } S = \begin{bmatrix} s_1 \\ s_2 \end{bmatrix} = \begin{bmatrix} \beta.\sigma_r & \beta.z_3 \\ -\beta.z_3 & \beta.\sigma_r \end{bmatrix} \begin{bmatrix} z_1 - \hat{z}_1 \\ z_2 - \hat{z}_2 \end{bmatrix} \tag{8}$$

Setting $\tilde{x} = x - \hat{x}$, $\tilde{z} = z - \hat{z}$ the estimation error dynamics is given by:

$$\begin{cases} \dot{\tilde{z}}_1 = \beta.\sigma_r.\tilde{x}_1 + \beta.z_3.\tilde{x}_2 - \Lambda_1.I_s \\ \dot{\tilde{z}}_2 = -\beta.z_3.\tilde{x}_1 + \beta.\sigma_r.\tilde{x}_2 - \Lambda_2.I_s \\ \dot{\tilde{x}}_1 = -\sigma_r.\tilde{x}_1 + \omega_{sl}.\tilde{x}_2 - \Gamma_1.I_s \\ \dot{\tilde{x}}_2 = -\omega_{sl}.\tilde{x}_1 - \sigma_r.\tilde{x}_2 - \Gamma_2.I_s \\ \dot{\tilde{z}}_3 = p^2.\dfrac{L_m}{L_r.J}.(\tilde{x}_1.z_2 - \tilde{x}_2.z_1) - \Lambda_3.I_s \end{cases} \tag{9}$$

The condition for convergence is verified by chosen the following observer gain matrices:

$$\begin{bmatrix} \Lambda_1 \\ \Lambda_2 \\ \Lambda_3 \end{bmatrix} = \begin{bmatrix} \beta.\sigma_r & \beta.z_3 \\ -\beta.z_3 & \beta.\sigma_r \\ p^2.\dfrac{L_m.z_2}{L_r.J} & -p^2.\dfrac{L_m.z_1}{L_r.J} \end{bmatrix}.\Delta \quad ; \quad \begin{bmatrix} \Gamma_1 \\ \Gamma_2 \end{bmatrix} = \begin{bmatrix} q-\sigma_r & \omega_{sl} \\ -\omega_{sl} & q-\sigma_r \end{bmatrix}.\Delta \, ; \; \Delta = \begin{bmatrix} n & 0 \\ 0 & n \end{bmatrix} \tag{10}$$

where, q and n are two positive adjusting parameters which play a critical role in the stability and the velocity of the observer convergence. From the fluxes estimation, it is easy to deduce the estimated torque defined by:

$$C_{em} = p.(\Phi_{dr}.I_{qs} - \Phi_{qr}.I_{ds})$$

As previously underline, a variation of the rotor resistance can induce performance degradation of the system.

This research will present an Extended Sliding Mode Observer for the IM to solve at the same time the problem of the rotor fluxes and rotor time constant estimations.

Extended Sliding Mode Observer

In order to estimate the rotor time constant, a six-dimensional extended state vector defined by $X_e = [I_{ds}\ I_{qs}\ \Phi_{dr}\ \Phi_{qr}\ \omega_r\ \sigma_r\ ]^t = [z_1\ z_2\ x_1\ x_2\ z_3\ x_3]^t$ has been introduced with $\sigma_r = R_r/L_r$. The corresponding extended state space equation become:

$$\begin{cases} \dot{z}_1 = -\lambda(x_3).z_1 + \omega_s.z_2 + \beta.x_3.x_1 + \beta.z_3.x_2 + \dfrac{1}{\sigma.L_s}V_{ds} \\ \dot{z}_2 = -\omega_s.z_1 - \lambda(x_3).z_2 - \beta.z_3.x_1 + \beta.x_3.x_2 + \dfrac{1}{\sigma.L_s}V_{qs} \\ \dot{x}_1 = x_3.L_m.z_1 - x_3.x_1 + \omega_{sl}.x_2 \\ \dot{x}_2 = x_3.L_m.z_2 - \omega_{sl}.x_1 - x_3.x_2 \\ \dot{z}_3 = p^2.\dfrac{L_m}{L_r.J}.(x_1.z_2 - x_2.z_1) - \dfrac{p}{J}.C_r - \dfrac{f}{J}.z_3 \\ \dot{x}_3 = \varepsilon \end{cases} \tag{11}$$

where, ε presents the slow variation of σ_r. The proposed ESMO has the following form:

$$\begin{cases} \dot{\hat{z}}_1 = -\lambda(\hat{x}_3).z_1 + \omega_s.z_2 + \beta.\hat{x}_3.\hat{x}_1 + \beta.z_3.\hat{x}_2 + \frac{1}{\sigma.L_s}V_{ds} + \Lambda_1.I_s \\ \dot{\hat{z}}_2 = -\omega_s.z_1 - \lambda(\hat{x}_3).z_2 - \beta.z_3.\hat{x}_1 + \beta.\hat{x}_3.\hat{x}_2 + \frac{1}{\sigma.L_s}V_{qs} + \Lambda_2.I_s \\ \dot{\hat{x}}_1 = \hat{x}_3.L_m.z_1 - \hat{x}_3.\hat{x}_1 + \omega_{sl}.\hat{x}_2 + \Gamma_1.I_s \\ \dot{\hat{x}}_2 = \hat{x}_3.L_m.z_2 - \omega_{sl}.\hat{x}_1 - \hat{x}_3.\hat{x}_2 + \Gamma_2.I_s \\ \dot{\hat{z}}_3 = p^2.\frac{L_m}{L_r.J}.(\hat{x}_1.z_2 - \hat{x}_2.z_1) - \frac{p}{J}.C_r - \frac{f}{J}.z_3 + \Lambda_3.I_s \\ \dot{\hat{x}}_3 = \varepsilon + \Gamma_3.I_s \end{cases} \tag{12}$$

where, is, Γ_1, Γ_2 and Λ_1, Λ_2, Λ_3 are, respectively defined by Eq. 8 and 10.

To determine observer gain Γ_3, it can be supposed that the observation errors of the fluxes converge to zero.

The estimation error dynamics of the fluxes $\tilde{x}_i = x_i - \hat{x}_i = 0$ (i = 1, 2) are then given by:

$$0 = -\tilde{x}_3.\hat{x}_1 + \hat{x}_3.\tilde{x}_1 + \omega_{sl}.\tilde{x}_2 + L_m.z_1.\tilde{x}_3 - \Gamma_1.Is$$
$$0 = -\omega_{sl}.\tilde{x}_1 - \tilde{x}_3.\hat{x}_2 + \hat{x}_3.\tilde{x}_2 + L_m.z_2.\tilde{x}_3 - \Gamma_2.Is$$

By replacing the expressions of Γ_1 and Γ_2, we obtain:

$$\begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \end{bmatrix} = \frac{1}{q}.\begin{bmatrix} L_m.z_1 - \hat{x}_1 \\ L_m.z_2 - \hat{x}_2 \end{bmatrix}.\tilde{x}_3 \tag{13}$$

The estimation error dynamics of the rotor time constant is given by:

$$\dot{\tilde{x}}_3 = -\Gamma_3.Is = -\Gamma_3.\Delta^{-1}\begin{bmatrix} \tilde{x}_1 \\ \tilde{x}_2 \end{bmatrix} = -\Gamma_3.\Delta^{-1}.\frac{1}{q}.\begin{bmatrix} L_m.z_1 - \hat{x}_1 \\ L_m.z_2 - \hat{x}_2 \end{bmatrix}.\tilde{x}_3$$

We can see that this error dynamics is locally and exponentially stable by chosen:

$$\Gamma_3 = m \cdot q \cdot \begin{bmatrix} L_m.z_1 - \hat{x}_1 \\ L_m.z_2 - \hat{x}_2 \end{bmatrix}^t \cdot \Delta \qquad \text{with } m > 0, \tag{14}$$

The proposed extended sliding mode observer has been implemented using Euler approximation. The Discrete-time Extended Sliding Mode Observer (DESMO) should be written as:

$$\hat{X}_e(k+1) = \hat{X}_e(k) + T_e.Q\left(\hat{X}_e(k), U(k)\right) + G(k).I_s(k) \tag{15}$$

where, k means the kth sampling time, i.e., t = k.Te with T_e the sampling period and

$$\hat{X}_e(k) = \left[\hat{I}_{ds}(k)\ \hat{I}_{qs}(k)\ \hat{\Phi}_{dr}(k)\ \hat{\Phi}_{qr}(k)\ \hat{\omega}_r(k)\ \hat{\sigma}_r(k)\right]^T \qquad \hat{Y}(k) = \left[\hat{\Phi}_{dr}(k)\ \hat{\omega}_r(k)\right]^T$$

$$Q\left(\hat{X}_e(k),U(k)\right)=\begin{Bmatrix} -\lambda(k).\hat{I}_{ds}(k)+\omega_s.\hat{I}_{qs}(k)+\beta.\hat{\sigma}_r(k).\hat{\Phi}_{dr}(k)+\beta.\hat{\omega}_r(k).\hat{\Phi}_{qr}(k)+\frac{1}{s.L_s}V_{ds} \\ -\omega_s.\hat{I}_{ds}(k)-\lambda(k).\hat{I}_{qs}(k)-\beta.\hat{\omega}_r(k).\hat{\Phi}_{dr}(k)+\beta.\hat{\sigma}_r(k).\hat{\Phi}_{qr}(k)+\frac{1}{\sigma.L_s}V_{qs} \\ \hat{\sigma}_r(k).L_m.\hat{I}_{ds}(k)-\hat{\sigma}_r(k).\hat{\Phi}_{dr}(k)+\omega_{sl}.\hat{\Phi}_{qr}(k) \\ \hat{\sigma}_r(k).L_m.\hat{I}_{qs}(k)-\omega_{sl}.\hat{\Phi}_{dr}(k)-\hat{\sigma}_r(k).\hat{\Phi}_{qr}(k) \\ p^2.\frac{L_m}{L_r.J}.\left(\hat{\Phi}_{dr}(k).\hat{I}_{qs}(k)-\hat{\Phi}_{qr}(k).\hat{I}_{ds}(k)\right)-\frac{p}{J}.C_r-\frac{f}{J}.\hat{\omega}_r(k) \\ \varepsilon \end{Bmatrix}$$

$$I_s(k)=\begin{bmatrix}\text{sign}(s_1)\\ \text{sign}(s_2)\end{bmatrix} \quad \text{with} \quad \begin{bmatrix}s_1(k)\\ s_2(k)\end{bmatrix}=\begin{bmatrix}\beta.\hat{\sigma}_r(k) & \beta.\hat{\omega}_r(k)\\ -\beta.\hat{\omega}_r(k) & \beta.\hat{\sigma}_r(k)\end{bmatrix}\begin{bmatrix}I_{ds}(k)-\hat{I}_{ds}(k)\\ I_{qs}(k)-\hat{I}_{qs}(k)\end{bmatrix}$$

$$G(k)=\begin{bmatrix}\Lambda_1(k) & \Lambda_2(k) & \Gamma_1(k) & \Gamma_2(k) & \Lambda_3(k) & \Gamma_3(k)\end{bmatrix}^T$$

From the expression s defined in Eq. 10 and 14, it can be seen that there are three positive adjusting gains: q, n and m which play a critical role in the potential stability of the scheme with respect to rotor time constant estimation. These three adjusting gains must be chosen so that the estimator satisfies robustness properties, global or local stability, good accuracy and considerable rapidity.

SIMULATED RESULTS

In order to verify the feasibility of the proposed DESMO, the simulation on SIMULINK from Mathwork has been carried out for a 1.8 kW induction motor controlled with a robust linearization via feedback algorithm (Fig. 1). The nominal parameters of the induction motor are shown in the Table 1.

The DESMO is implanted in a S_function using C language. In order to evaluate its performances and effectiveness, the comparisons between the observed state variables and the simulated ones have been realized for several operating conditions with the presence of about 15% noise on the simulated

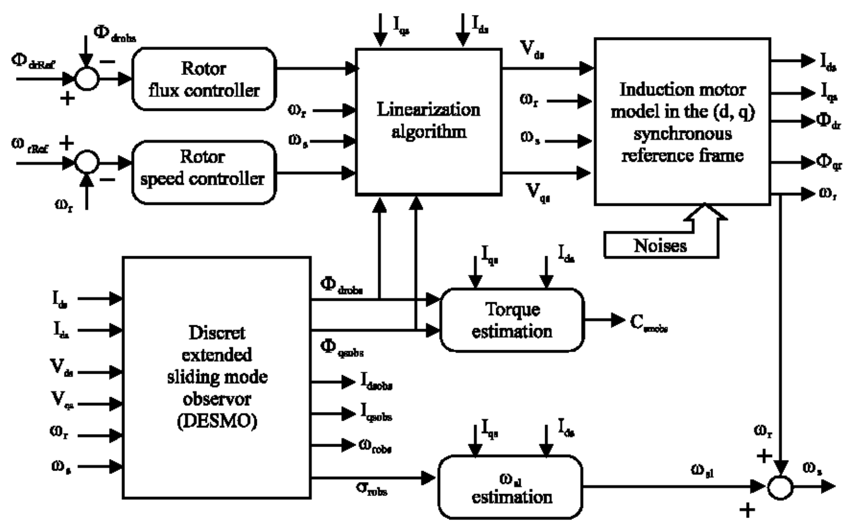


Fig. 1: Stimulation scheme

Table 1: Nominal parameters of the Induction motor

P_{mn} = 1.8 kW	Un = 220/380 V	In = 20.8/12 A	p = 2
Fn = 50 Hz	Ωn = 1420 rpm	Jn = 0.15 kg N m^{-2}	fn = 0.05 N.m.s/rad
R_{sn} = 5.7 Ω	R_{rn} = 1.475 Ω	L_{sn} = 0.1766 H	L_m = 0.1262 H
L_{fn} = 0.0504 H	L_{mn} = 0.1262 H		

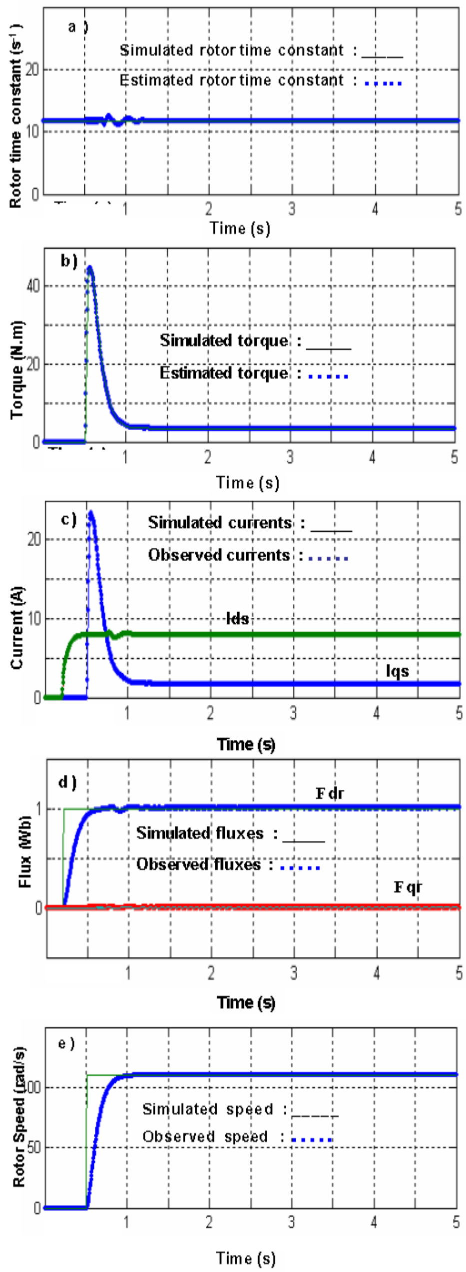


Fig. 2 (a, b, c, d, e) : Nominal case (Rr = Rrn)

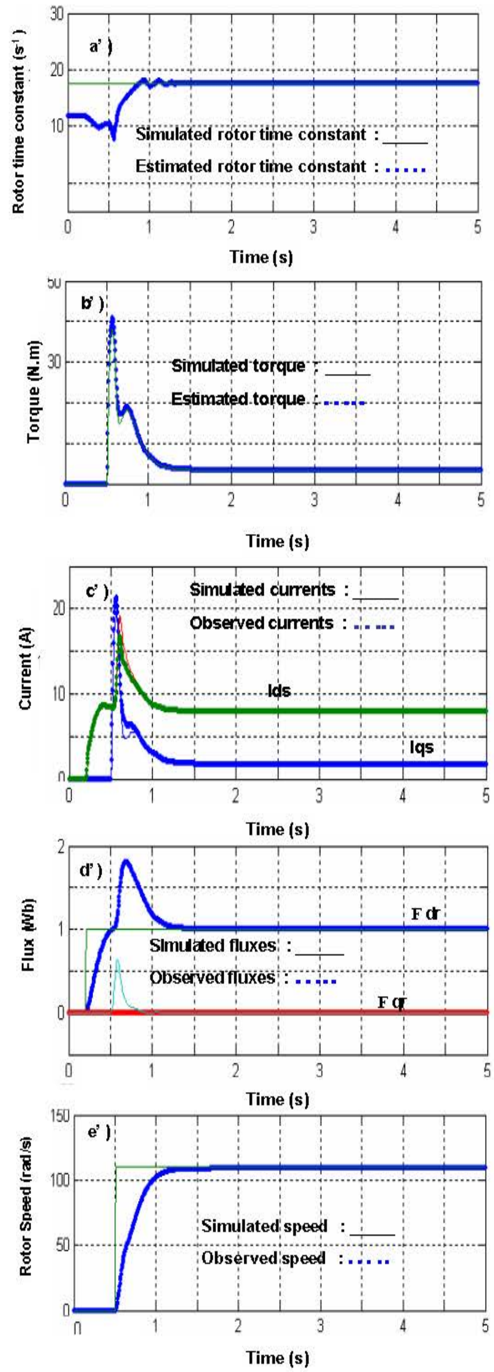


Fig. 3 (a, b, c, d, e): Non Nominal case (Rr = 1.5Rrn) currents or speed. Thus, using a sampling period Te = 2 ms, the simulations are realized at first in the nominal case with the nominal parameters of the induction motor (Table 1) and then, in the second case, with 50% variation of the nominal rotor time constant ($\sigma_r = 1.5\sigma_m$) in order to verify the rotor time constant tracking and flux estimation.

Figure 2 and 3 shows the simulation results for a step input of the rotor speed and flux. One can see that in both nominal (Fig. 2a-e) or non-nominal (Fig. 3a-e) cases, the estimated values of currents, fluxes, torque and speed converge very well to their simulated values.

The observed fluxes (Fig. 2d) indicate the good orientation (Φ_{dr} is constant and Φ_{qr} converges to zero) which is due to a favorable rotor time constant estimation (Fig. 2a, 3a). The estimated torque (Fig. 2b) is in good agreement with the simulated value.

Also the waveforms show the good uncoupling between the flux and the speed because a step variation in Φ_{dr} (Fig. 3d) can not generate a speed ω_r change (Fig. 3e). Thus the field orientation and the synthesis of robust linearization and decoupling control are well verified.

All those results show the satisfying tuning, the excellent performance of the robust decoupling control and DESMO against rotor resistance variations and perturbations or noises.

CONCLUSION

This research has proposed a feedback linearization strategy and a robust controller to permit a decoupling and regulation for the Induction motor states in order to assure a good dynamic performance and stability of the global system. Also a DESMO has been realized. It is based on SMO principle but extended for the reconstruction of the fluxes, the rotor time constant and the torque estimation. The parameter tuning, the choice of initial conditions are easier compared to EKF.

The interesting simulation results obtained on the induction motor show the effectiveness, the convergence and the stability of this robust decoupling control and DESMO against rotor resistance variations measured noise and load. Thus, in the industrial applications, one will appreciate very well the experimental implement of this robust estimator for the reconstitution of the fluxes and the torque as well as the rotor resistance.

NOMENCLATURE

C_{em}, C_l	=	Electromagnetic and load torques (N.m)
I_{ds}, I_{qs}, I_{mr}	=	Stationary frame (d, q)-axis stator currents and rotor magnetizing current (A)
p, J, f	=	Pole pair number, Inertia (kg m^2) and Friction coefficient (Nm.s/rad)
L_r, L_s, L_m, L_f	=	Rotor, stator, mutual and leakage inductances (H)
R_s, R_r	=	Stator and rotor referred resistance (Ω)
T_e, T_r, T_s	=	Sampling period, rotor and stator time constant ($T_r = L_r/R_r = 1/ ó_r$; $T_s = L_s/R_s$) (sec)
V_{ds}, V_{qs}	=	Stationary frame d- and q-axis stator voltage (V)
Φ_{dr}, Φ_{qr}	=	d-q components of rotor fluxes (Wb)
ω_s, ω_r, ω_{sl}	=	Stator, rotor and slip pulsation (or speed) (rad sec^{-1})

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