Asian Journal of Information Technology 6 (4): 468-473, 2007

Non Linear Control of an Induction Motor

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Abstract: We study the non-linear control of an Induction Motor (IM).So we applied the technique of input-output linearization to the (IM), how is based on the differential geometry, where we can linearized the model of the (IM) which is strongly nonlinear, then we study the internal dynamics of linear system, we control separately flux and speed, finally we estimate the rotor flux and observe the reference torque. The simulation is realised with an MLI inverter.

Key words: Non linear control, induction motor, internal dynamics, observer reference torque

INTRODUCTION

Several techniques of control are used for (IM) ,The technique of control oriented flux (FOC) which permits the decoupling between input and output variables ,so (IM) is assimilate to continuous current motor , this method has a problem is how exactly oriented the axis d on the flux. However feedback linearization amounts to cancelling the nonlinearities in a nonlinear system so that the Closed- Loop (CL) dynamics is in a linear form (Jaques, 2000; Isiodori, 1989).

A goal of nonlinear control is to can controlled separately flux and the speed ,the motor model is strongly nonlinear then it's composed to the autonomous and mono-variables too under systems, so every under system presented an independence loop of control for each variables is given.

Also for high speeds, field weakening is necessary in order to avoid the saturation of the stator voltages. Since field weakening depends on the speed, the dynamic of the flux may interfere with the dynamic of the speed. This coupling of the flux and speed dynamics can be eliminated by considering an input-output scheme (Merroufel *et al.*, 2004; Tarbouchi and Le, 1996).

MODEL OF THE INDUCTION MOTOR

The state equations in the stationary reference frame of an induction motor can be written as (Maaziz and Mendes, 2003; Benyahia, 2001):

$$X = F(X)+GU \qquad (1)$$

$$Y = H(X) \qquad (2)$$

With

$$X = \begin{bmatrix} i_{S\alpha} & i_{S\beta} & f_{r\alpha} & f_{r\beta} & O \end{bmatrix}^T$$
$$U = \begin{bmatrix} u_{S\alpha} & u_{S\beta} \end{bmatrix}$$

$$F(X) = \begin{bmatrix} -\gamma i_{s\alpha} + \frac{K}{Tr}\varphi_{r\alpha} + p\Omega K\varphi_{r\beta} \\ -\gamma i_{s\beta} - p\Omega K\varphi_{r\alpha} + \frac{K}{Tr}\varphi_{r\beta} \\ \frac{M}{T_r} i_{s\alpha} - \frac{1}{T_r}\varphi_{r\alpha} - p\Omega_{r\beta} \\ \frac{M}{T_r} i_{s\beta} + p\varphi_{r\alpha} - \frac{1}{Tr}\varphi_{r\beta} \\ p\frac{M}{JL_r}\left(\varphi_{r\alpha} i_{s\beta} - \varphi_{r\beta} i_{s\alpha} - \frac{1}{J}(C_r + f\Omega\right) \end{bmatrix}$$

$$G = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 & 0 & 0 & 0 \\ 0 & \frac{1}{\sigma L_s} & 0 & 0 & 0 \end{bmatrix}$$

and

$$K = \frac{M}{\sigma LsLr}, \sigma = 1 - \frac{M^2}{L_s L_r}, \gamma = \frac{R_s}{\sigma L_s} + \frac{R_r M^2}{\sigma L_s L_r^2}$$

The variables which are controlled are the flux and the electromagnetic torque.

$$Y(X) = \begin{bmatrix} h_1(X) \\ h_2(X) \end{bmatrix} = \begin{bmatrix} \varphi_r^2 \\ T_{em} \end{bmatrix} \qquad (2)$$

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FEEDBACK LINEARIZATION OF IM

Relative degree of the flux:

$$h_1(X) = (\varphi_{ra}^{2} + \varphi_{r\beta}^{2}) \quad (3)$$

$$L_f h_1(X) = \frac{2}{T_r}\begin{bmatrix} M(\varphi_{r\alpha} i_{s\beta} + \varphi_{r\beta} + i_{s\beta}) - \\ (\varphi_{r\alpha}^2 + \varphi_{r\beta}^2) \end{bmatrix} \quad (4)$$

$$L_{g1} L_f h_1 = 2R_r K f_{r\alpha} \quad (5)$$

$$L^2_f h_1(X) = \left(\frac{4}{T_r^2} + \frac{2K}{T_r^2} M\right)(\varphi_{r\alpha}^2 + \varphi^2_{r\beta}) - \left(\frac{6M}{T_r^2} + \frac{2\gamma M}{T_r^2}\right)(\varphi_{r\alpha} i_{s\alpha} + \varphi_{r\beta} i_{s\beta}) + \frac{2Mp\Omega}{T_r}(\varphi_{r\alpha} i_{s\beta} - \varphi_{r\beta} i_{s\alpha}) + 2\frac{M^2}{T^2_r}(i^2_{s\alpha} + i^2_{s\beta}) \quad (6)$$

$$L_{g2} L_f h_1 = 2R_r K \varphi_{r\beta} \quad (7)$$

The degree of $h_1(x)$ is $r_1 = 2$.

Relative degree of torque

$$h_2(X) = T_{em} \quad (8)$$

$$T_{em} = J\frac{d^2\Omega}{dt} + f\frac{d\Omega}{dt} + \dot{T}_1 \quad (9)$$

$$L_f h_2(X) = -\frac{pM}{L_r}\begin{bmatrix} \left(\frac{1}{T_r} + \gamma\right)\left(\varphi_{r\alpha} i_{s\beta} - \varphi_{r\beta} i_{s\alpha}\right) + \\ p\Omega\left(\varphi_{r\alpha} i_{s\alpha} - \varphi_{r\beta} i_{s\beta}\right) \\ + p\Omega K\left(\varphi_{r\alpha}^2 - \varphi_{r\beta}^2\right) \end{bmatrix} \quad (10)$$

$$L_{g1} L_f h_2 = -pK\varphi_{r\beta} \quad (11)$$

$$L_{g2} L_f h_2 = -pK\phi_{r\alpha} \quad (12)$$

The degree of h2(x) is r_2=1.

Global relative degree: The global relative degree is lower than the order n of the system ($r = r_1 + r_2 = 4 < n = 5$).
The system is said partly linearized

Decoupling matrix: The matrixdefines a relation between the input (U) and the output (Y(X) is given by the expression 13:

$$\begin{bmatrix} \ddot{h}_1(X) \\ \ddot{h}_2(X) \end{bmatrix} = \begin{bmatrix} \frac{d^2\varphi_r^2}{dt} \\ \frac{dT_{em}}{dt} \end{bmatrix} = A(X) + D(X)\begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \end{bmatrix} \quad (13)$$

Where

$$A(X) = \begin{bmatrix} L_f^2 h_1 & L_f h_2 \end{bmatrix}$$

The decoupling matrix is:

$$D(X) = \begin{bmatrix} L_{g1} L_f h_1 & L_{g2} L_f h_1 \\ L_{g1} L_f h_2 & L_{g2} L_f h_2 \end{bmatrix}$$

And

$$\det(D) = \frac{2pR_r KM}{J\sigma L_s l_r}(\varphi_{r\alpha}^2 + \varphi_{r\beta}^2) \neq 0$$

The nonlinear feedback provide to the system a linear comportment input/output

$$\begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \end{bmatrix} = D(X)^{-1}\left[-A(X) + \begin{bmatrix} V_1 \\ V_2 \end{bmatrix}\right] \quad (14)$$

CONTROL FLUX AND TORQUE OF LINEAR SYSTEM

The internal outputs (V_1, V_2) are definite

$$V_1 = \frac{d^2\varphi^2_r}{dt} = -K_{11}(\varphi_r^2 - \varphi^2_{ref}) - K_{12}\left(\frac{d}{dt}\varphi^2_r - \frac{d}{dt}\varphi^2_{ref}\right) + \frac{d^2\varphi^2_{ref}}{dt} \quad (15)$$

$$V_2 = \frac{d^2 T_{em}}{dt} = -K_{22}(T_{em} - T_{ref}) \quad \frac{dT_{ref}}{dt} \quad (16)$$

The errors of the track in (CL) are:

$$\ddot{e}_1 + k_{12}\dot{e}_1 + K_{11}e_1 = 0 \quad (17)$$

$$\dot{e}_2 + K_{22}e_2 = 0 \quad (18)$$

With:

The coefficients k_{11}, k_{12}, k_{22} are chosen to satisfy asymptotic stability and excellent tracking.

$$\begin{bmatrix} u_{s\alpha} \\ u_{s\beta} \end{bmatrix} = D(X)^{-1}\left[-A(X) + \begin{pmatrix} -K_{11}e_1 - K_{12}\dfrac{d}{dt}\varphi_r^2 \\ -K_{22}e_2 + \dfrac{d\dot{T}_{ref}}{dt} \end{pmatrix} \right] \quad (19)$$

The plant will be transformed to another representation that is given by;

$$z = \left[h_1(X) \quad L_f h_1(X) \quad h_2(X) \quad \arctan(\frac{\varphi_{r\beta}}{\varphi_{ra}}) \quad \Omega \right]$$

FLUX ESTIMATOR AND OBSERVER REFERENCE TORQUE

Flux estimator: The flux components are not accessible for the measure, then it will be estimate, in our case we used a simple rotor flux estimator, based on the model of machine, in order to exhibit the robustness of the proposed control (Clerc and Grellet, 1999) (Fig. 1).

$$\begin{aligned} i_{\tilde{d}s} &= i_{\alpha s}\cos\tilde{\theta} \\ i_{\tilde{q}s} &= -i_{\beta s}\sin\tilde{\theta} \end{aligned} \quad (20)$$

$\tilde{d}$: is the axis of rotor flux

$$\tilde{\varphi}_r = M|\mathbf{i}_{mr}| \quad (21)$$

With

$$T_r \frac{d|\mathbf{i}_{mr}|}{dt} + |\mathbf{i}_{mr}| = \mathbf{i}_d$$

$$\tilde{\omega} = \omega_r + \frac{i_{\tilde{q}s}}{T_r|\mathbf{i}_{mr}|}$$

REFERENCE TORQUE OBSERVER

The measure of the error between the speed measured and the estimate one, is presented as an input of PI regulator so the output is given by: (Pioufle, 1993).

$$T_{ref} = \frac{(k_1 s + k_2)}{Js^2 + (f + k_1)s + k_2} \quad (22)$$

k_1 and k_2 are determined by a poles position (Fig. 2).

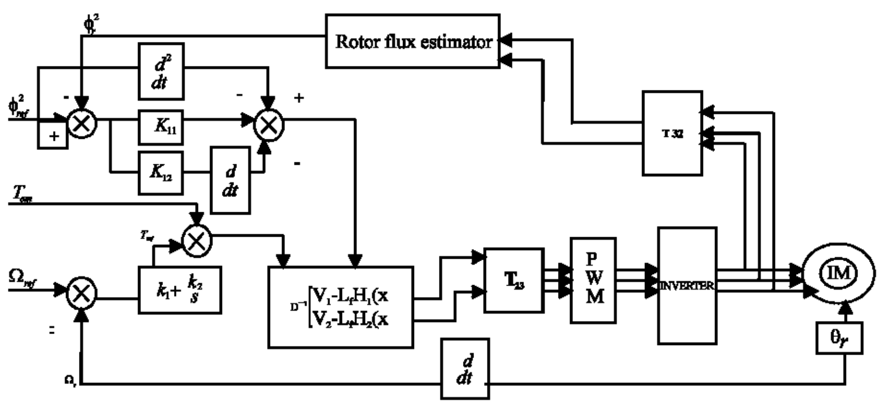

Fig. 1: Block diagram of the nonlinear control

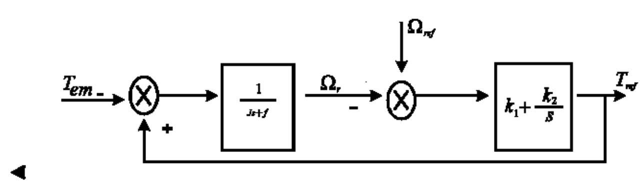

Fig. 2: Block diagram of reference torque observer

SIMULATION

The results are shown in Fig. (3-6) that response of speed for an echelon of 150 (rad s^{-1}), has a good tracking, for the flux norm remains tight to their reference, the test is given by application of the load at (0.5 s) and its effect is rejected after few seconds. The sec test Fig. (7-10) represented the variation of the speed among two

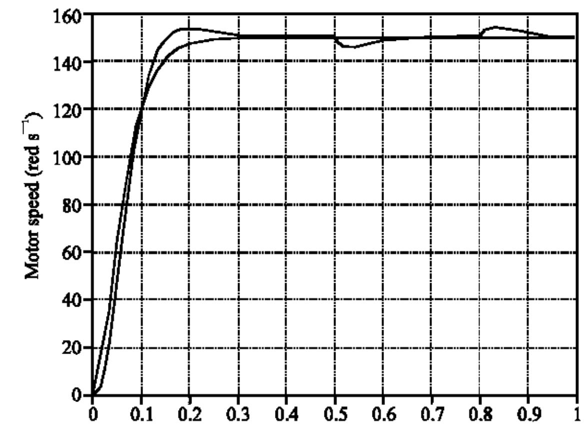

Fig. 3: Motor speed

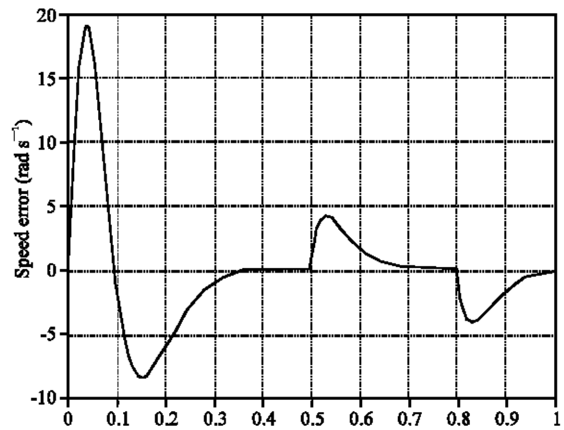

Fig. 6: Speed error

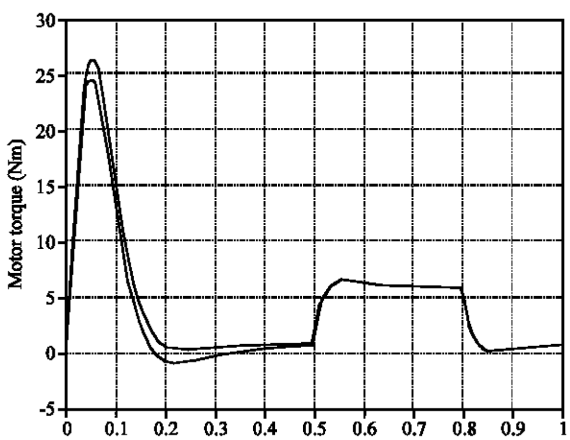

Fig. 4: Motor torque

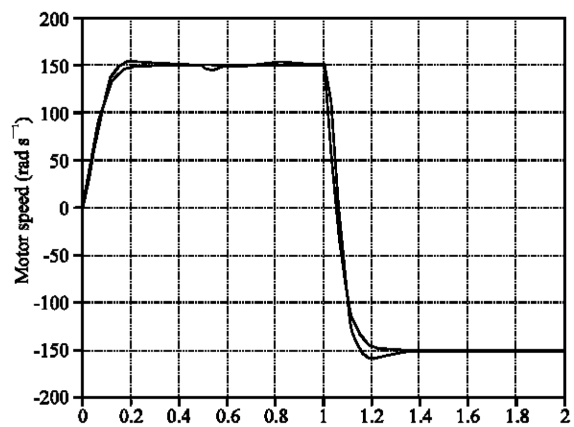

Fig. 7: Motor speed

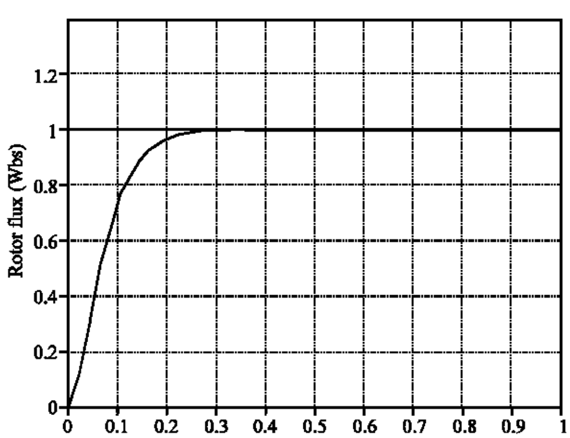

Fig. 5: Rotor flux

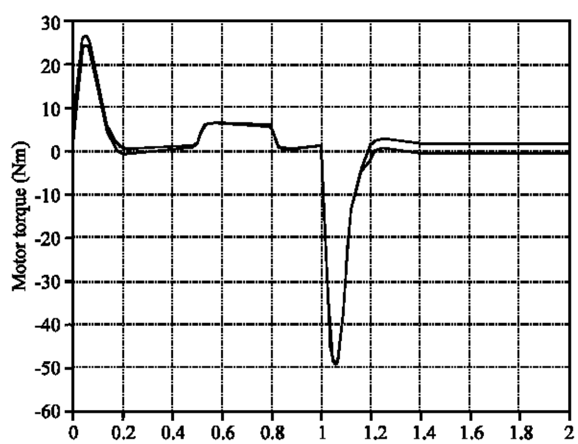

Fig. 8: Motor torque

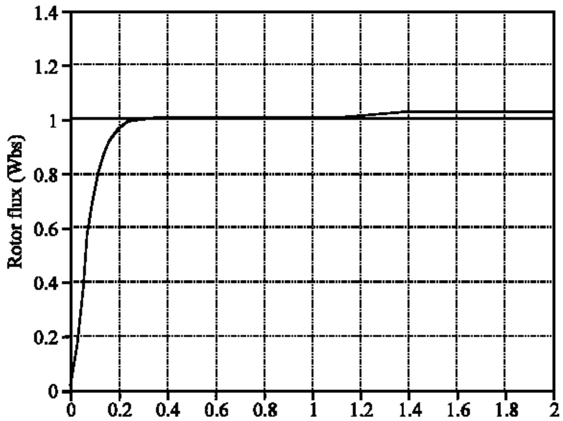

Fig. 9: Rotor flux

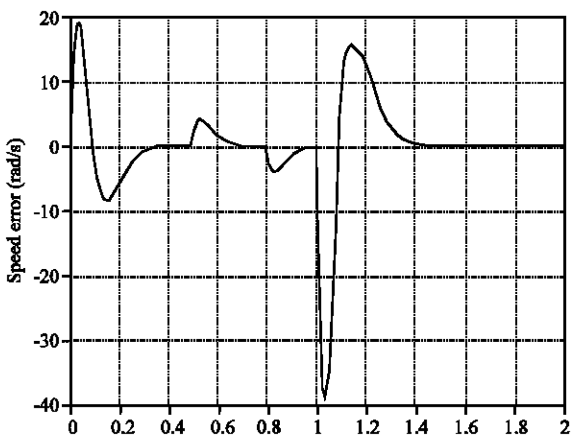

Fig. 10: Speed error

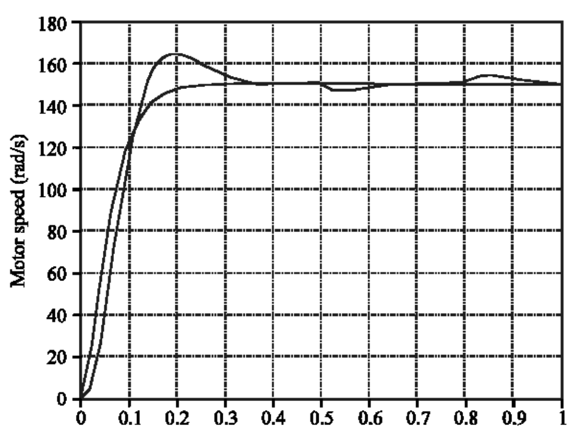

Fig. 11: Motor speed

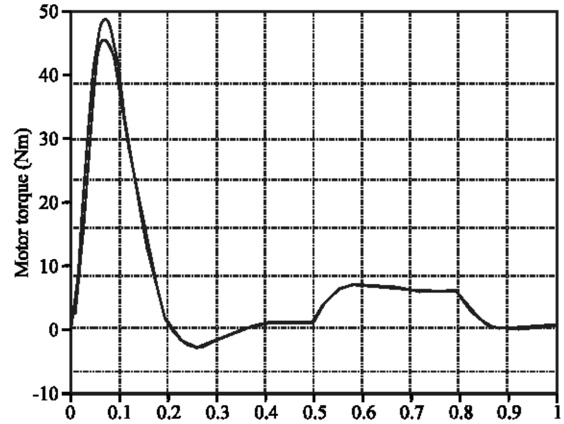

Fig. 12: Motor torque

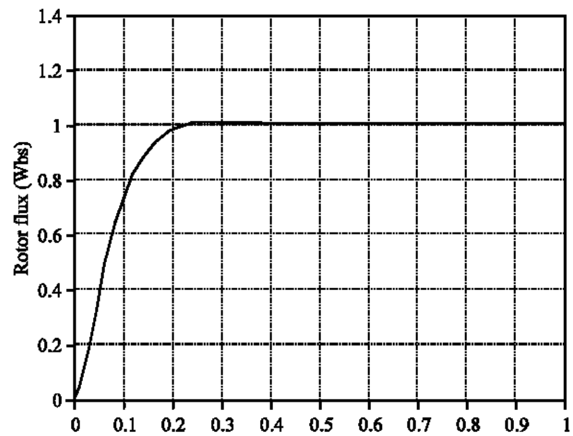

Fig. 13: Rotor flux

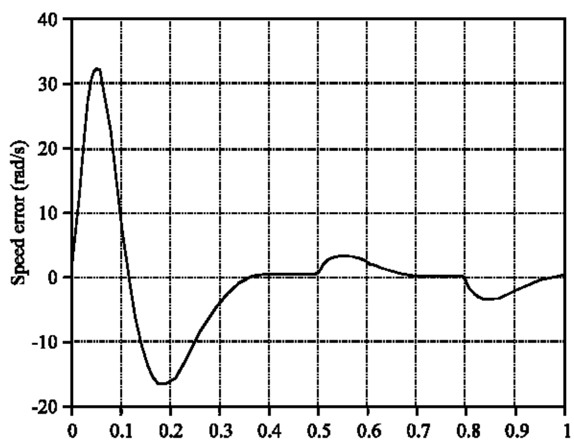

Fig. 14: Speed error

values-150 (rad s^{-1}) and +150 (rad s^{-1}) and the last one (Fig. 11-14) is the difference of the inertia at 100% of its value, we remarked that this variation effect on the response of the speed and the flux, then the parameters_machine variation represented a problem for the nonlinear control. In order to minimize the dependence of the system to parameter variations and external perturbations and reduce the number of variable states, a new model of the original system is proposed, this simple model will be suitable to cognitive approach such as fuzzy modelling and robust fuzzy controller could be applied to the induction motor basing in this new model.

CONCLUSION

The non-linear control gives a good tracking for the speed with basing of its static and dynamic properties. The results show that the decoupling between the parameters of IM is very excellent. This technique gives a better amelioration for the performances of system, nevertheless the problem of the parameters machine variation witch represent a difficulty for this control and the simple regulators (PI), can not resist to this variation, which necessities a robust one.

APPENDIX A; LIST OF PRINCIPAL SYMBOLS

R_s, R_r : Stator and rotor resistance.
L_s, L_r : Stator and rotor inductance.
M : Mutual inductance.
Ω : Motor speed.
ϕ_r : Rotor flux norm.
i_{mr} : Is the magnetic current.

APPENDIX B; MACHINE PARAMETERS

1.1KW, 220/380V, 50Hz, 1500 rpm.
Rr=3.6Ω,J=0.015Kgm^2,
Rs=8.0Ω, f = 0.005Nms
L_r = 0.47H
,P=2
L_s = 0.47, M = 0.452H,
Tnom = 5Nm, $\phi_{r\alpha\beta}$ = 1.14Wbs

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