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Performances Analysis of PI and Adaptive Law Applied to Double Feed Induction Machine (DFIM)

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Abstract: This study deals with the performances analysis of PI regulator used in vector control and the performance of adaptive law control in reference model applied to Double Feed Induction Machine (DFIM). The inverter feeding the rotor of the machine is controlled by a pulse width modulation technique which allows the adjustment of frequency and output voltage simultaneously. Simulation results are discussed and compared with reference to a specific case-study.

Key words: Double Fed Induction Machine, (DFIM) vector control, adaptive reference control, out put voltage, frequency

INTRODUCTION

The adaptive control is of great importance in the field of control where it deals with nonlinear ordered system where its parameter model varies (Capolino and Fu, 2000).

This control technique is dominant in the systems which present uncertainties, structural disturbances and variations of the environment (Oliver *et al*., 2003; Geet, 2004).

The principal goal of the adaptive control in the synthesis of adaptive law. It helps to adjustment in real time the regulators loops in order in order to maintain the performance it a certain level when the parameters of the process vary with time (Capolino and Fu, 2000; Olivier *et al*., 2003).

In this stduy the dynamical and statistical characteristics of two type of regulators regulator PI and adaptation law. The evaluating influence or the performances of the systems to be chosen of the two regulators based or the advantages and the disadvantages of then (Zidani, 1996; Vas, 1998).

The evaluating method is based or the criteria such as:

- Better response of the system;
- Robustness with respect to the fast variation of the consign.

This comparative study is undertaken for the same speed consign and the same torque.

MODEL REFERENCE ADAPTIVE CONTROL

The MRAC is one of the major approaches in adaptive control. The desired performance is expressed as a reference model, which gives the wished response to an input signal. The adjustment mechanism changes the parameters of the regulator by minimizing the error between the system output and the reference model. If the error is equal to zero, then the perfect model is achieved as shown in Fig. 1. Olivier *et al.* (2003) Astrom and Wittenmark (1989).

MATHEMATICAL MODELLING

In our case we are interested in voltage supply the state variables are the stator flux (ϕ_{sd}, ϕ_{sq}) and rotor current (ird, irq) the control variable are the speed and the voltages (vsd, vsq, vrd, vrq) like variables of order (Nemmour, 2002; Astrom and Wittenmark, 1989).

The equations of the asynchronous machine in the reference of Park are:

$$\begin{cases} V_{sd} = R_s I_{sd} + \dfrac{d\phi_{sd}}{dt} - \omega_s \phi_{sq} \\ V_{sq} = R_s I_{sq} + \dfrac{d\phi_{sq}}{dt} + \omega_s \phi_{sd} \\ V_{rd} = R_r I_{rd} + \dfrac{d\phi_{rd}}{dt} - \omega_r \phi_{rq} \\ V_{rq} = R_r I_{rq} + \dfrac{d\phi_{rq}}{dt} + \omega_r \phi_{rd} \end{cases} \quad (1)$$

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The equations of the flux:

$$\begin{cases}\phi_{sd} = L_s I_{sd} + M I_{rd} \\ \phi_{sq} = L_s I_{sq} + M I_{rq} \\ \phi_{rd} = L_r I_{rd} + M I_{sd} \\ \phi_{rq} = L_r I_{rq} + M I_{sq}\end{cases} \quad (2)$$

The mathematical model is written as a set of equations of state, both for the electrical and mechanical: We consider steady operation, we can write:

$$\frac{dx}{dt} = Ax + Bu \quad (3)$$

Where:

$$X = \begin{bmatrix}\phi_{sd} \\ \phi_{sq} \\ I_{rd} \\ I_{rq}\end{bmatrix}, \; U = \begin{bmatrix}v_{sd} \\ v_{sq} \\ v_{rd} \\ v_{rq}\end{bmatrix}$$

$$A = \begin{bmatrix}\frac{-1}{T_s} & \omega_s & \frac{M}{T_s} & 0 \\ -\omega_s & \frac{-1}{T_s} & 0 & \frac{M}{T_s} \\ \frac{\gamma}{T_r} & -\gamma\omega & -\left(\frac{1}{\sigma T_r} + k\right) & (\omega_s - \omega) \\ \gamma\omega & \frac{\gamma}{T_s} & -(\omega_s - \omega) & -\left(\frac{1}{\sigma T_r} + k\right)\end{bmatrix}$$

$$B = \begin{bmatrix}1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ -\gamma & 0 & \frac{1}{\sigma L_r} & 0 \\ 0 & -\gamma & 0 & \frac{1}{\sigma L_r}\end{bmatrix}$$

Where the values of γ, k are:

$$\gamma = \frac{M}{\sigma L_s . L_r}, k = \frac{M^2}{\sigma L_s L_r T_s}$$

$$C_e = p\frac{M}{L_s L_r}\left[\phi_{sq} i_{rd} - \phi_{sd} i_{rq}\right] \quad (4)$$

$$J\frac{d\Omega}{dt} = C_e - C_r - f\Omega \quad (5)$$

VECTOR CONTROL

The control principal is based on the oriented flux laws with PI regulator or adaptive algorithm by simplified reference model (Grellet and Clerc, 2000; Vas, 1990; Cambronne *et al*., 1992; Hopfensperger *et al*., 2000).

Given that the "dq" axes are fixed in the synchronous rotating coordinate system, we have:

Since, $\phi_{sd} = \phi_s, \phi_{sq} = 0$

We can write the following equations:

$$I_{rd} = \frac{\phi_s^*}{M} \quad (6)$$

$$I_{rq} = -\frac{L_s}{P.M}\frac{C_e^*}{\phi_s^*} \quad (7)$$

$$\frac{d\phi_s}{dt} = \frac{-1}{T_s}\phi_s + \frac{M}{T_s} i_{rd} \quad (8)$$

$$\frac{d\phi_{sq}}{dt} = 0 = -\omega_s \phi_s + \frac{M}{T_s} + V_{sq} \quad (9)$$

The angular speed

$$\frac{d\theta_s}{dt} = \omega_s = \left(\frac{R_s . M}{L_s} I_{rq} + V_{sq}\right) / \phi_s^* \quad (10)$$

The mathematical model of the double–feed induction machine supplied by voltage with oriented flux for the stator is given by

$$\frac{1}{\sigma.L_r}V_{rd} = \frac{1}{\sigma}\left(\frac{1}{T_r} + \frac{M^2}{L_s.T_s.L_r}\right) I_{rd} - \frac{M}{\sigma.L_s.T_s.L_r}\phi_s - (\omega_s - \omega) I_{rq} + \frac{dI_{rd}}{dt} + \frac{M}{\sigma.L_s.L_r}V_{sd} \quad (11)$$

$$\frac{1}{\sigma.L_r}V_{rq} = \frac{1}{\sigma}\left(\frac{1}{T_r} + \frac{M^2}{L_s.T_s.L_r}\right) I_{rq} - \frac{M}{\sigma.L_s L_r}\omega\phi_s(\omega_s - \omega) I_{rd} + \frac{dI_{rq}}{dt} + \frac{M}{\sigma.L_s.L_r}V_{sq} \quad (12)$$

Where:

L_s, L_r : Stator and rotor main inductances.
M : Magnetizing inductance.
σ : Total leakage coefficient
T_s, T_r : Stator and rotor time constants.
V_{rd}, V_{rq} : Rotor voltage.

w_s : Stator angular speed
P : Number of pole pairs

REFERENCE MODEL EQUATIONS

The first order reference model can be written as:

$$J\frac{d\Omega_m}{dt} + f.\Omega_m = C_e - C_r \quad (13)$$

Where:
Ω_m : Mechanical speed.
f : Friction coefficient.
C_e : Electromechanical torque.
Cr : Load torque
The reference model for the system:

$$\frac{J}{K}\frac{d\Omega_m}{dt} + \Omega_m = U_m \quad (14)$$

The decoupling control of reference model is given by:

$$e = \Omega_m - \Omega \quad (15)$$

The control law U is given by:

$$U = K_u.U_m + K_p.x + K_e.e \quad (16)$$

Where the values of Ku, Kp are:

$$K_u(e,t) = \int_0^t \alpha.y.u_m^T \,.\, dt + \beta.y.u_m^T \quad (17)$$

$$K_p(e,t) = \int \alpha..y.x^T dt + \beta.y.x^T \quad (18)$$

However the static gain Ku and Kp will be function of DFIM but will have a general form in order to be used for others machines (Mimoun, 2001; Segal, *et al.*, 2000).

SIMULATION RESULTANTS OF THE DFIM

The simplified model under MATLAB- SIMULINK is give by Fig.1. The stator of the DFIM is supplied by the network where as rotor is supplied by a PWM inverter.

The bloc scheme used for simulation of two types of regulator is given by Fig. 2 and 3.

Figure 4 refer to the load less starting of the DFIM used or the two types of regulators.

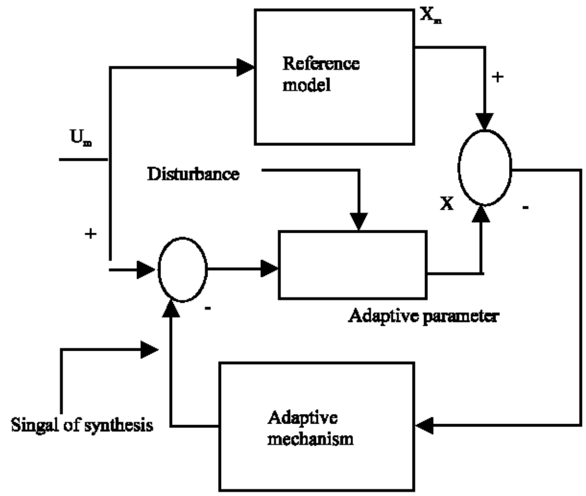

Fig. 1: Structure of model reference adaptive control

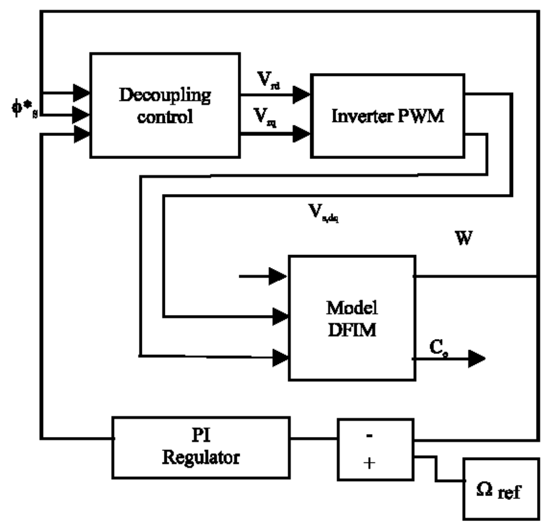

Fig. 2: Block-scheme of vector control for DFIM

We can see that response is lower in the adaptive law compared to the PI regulator.

Also the transition time in the torque is higher with the PI regulator than that given by the adaptive law.

However, the most significant remark we can is the amplitude of flux at the starting time is higher using PI regulator compared to the adaptive law.

Figure 5 show a comparison of the time response to 5% speed control either PI or adaptive law.

The response is better with the adaptive law and the starting torque in the case is free of pulsations.

The stator flux also can read twice the nominal flux during the starting period with the use of the PI regulator while with the adaptive law is improved.

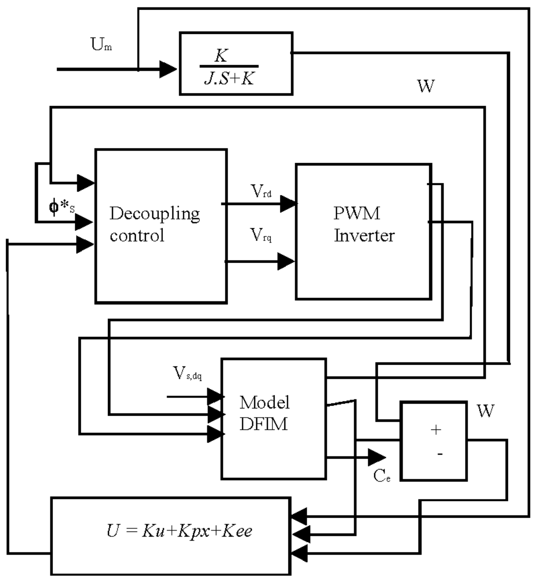

Fig. 3 Block-scheme of MRAC for DFIM

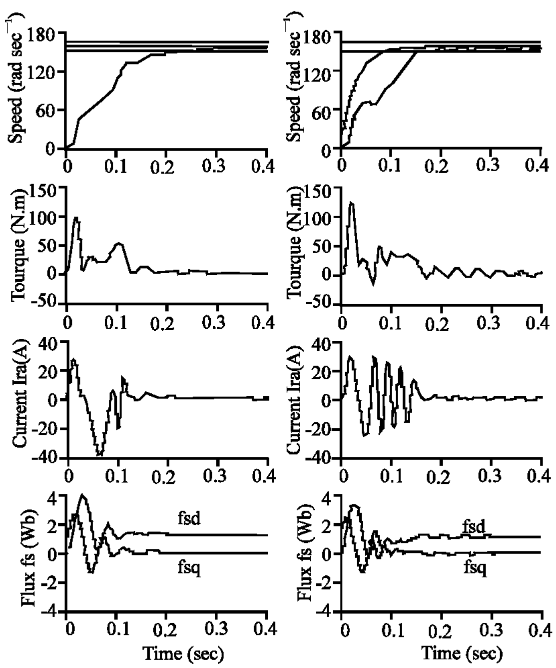

Fig. 4: Comparisons on the level of load less starting

Figure 6 referrer to the speed control from zero to 157 rad sec^{-1} then a nominal load of 10 N.m is applied at t = 2 sec after that a change in the consign from 157 rad s^{-1} to 130 rad sec^{-1} at t = 3 sec.

In this case the speed response follows the consign for the two type of regulators but with low time response in the case of the adaptive law regulator.

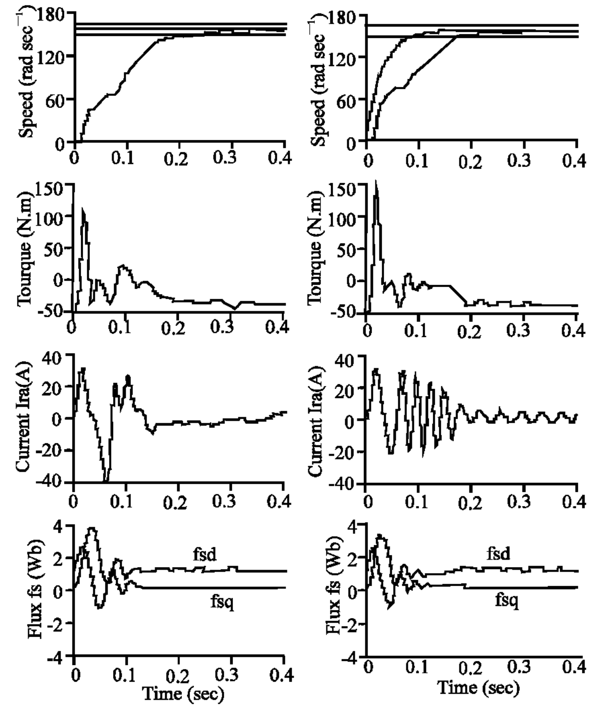

Fig. 5: Comparisons on the level of starting to full charges

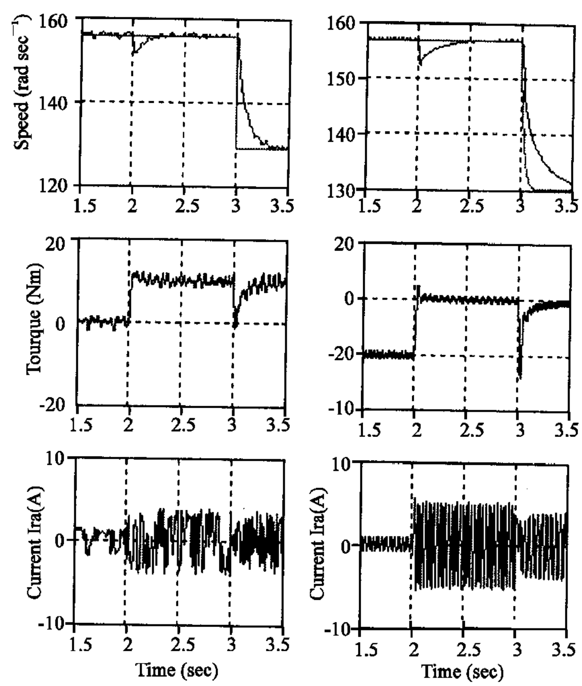

Fig. 6: Comparisons on the level of the speed regulation

CONCLUSION

The study presents performances analysis and study of statical of dynamical characteristics using two types of regulators PI and adaptive law applied to the control of double fed induction machine.

Better performances on the speed and flux response using adaptive law regulator compared with the PI regulator are presented.

Parameters of the DFIM :

P_n=1.5kW, V_{ns}=220V, V_{nr}=12V, W_n=1500tr/mn, R_s=4.85Ω, R_r=3.805Ω, L_s=0.274H, L_r=0.274H, M=0.258H, p=2, J=0.031kg/m^2, f =0.008 N.m.s/rd

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