Comparison between Fuzzy Sliding Mode and Traditional IP Controllers in a Speed Control of a Doubly Fed Induction Motor

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ABSTRACT

Many industrial applications require new control techniques in order to obtain fast response and to improve the dynamic performances. One of the techniques users, fuzzy sliding mode control which is characterizes by robustness and insensitivity to the parameters variation. In this paper, we present a comparative study of a direct stator flux orientation control of doubly fed induction motor by two regulators: traditional IP controller and fuzzy sliding mode. The three regulators are applies in speed regulation of doubly fed induction motor (DFIM). The robustness between these two regulators was tested and validated under simulations with the presence of variations of the parameters of the motor, in particular the face of disturbances of load torque. The results show that the fuzzy sliding mode controller has best performance than the traditional IP controller.

Keywords: Doubly Fed Induction Motor, Direct Stator Flux Orientation Control, Fuzzy Sliding Mode Controller, Fuzzy-PI, IP Controller.

Nomenclature

i_{rd}, i_{rq} : rotor current components
ϕ_{sd}, ϕ_{sq} : stator flux components
V_{sd}, V_{sq} : stator voltage components
V_{rd}, V_{rq} : rotor voltage components
R_s, R_r : stator and rotor resistances
L_s, L_s : stator and rotor inductances
M : mutual inductance
σ : leakage factor
p : number of pole pairs
C_e : electromagnetic torque
C_r : load torque
J : moment of inertia
Ω : mechanical speed
ω_s, ω : stator pulsation
f : friction coefficient
T_s, T_r : statoric and rotoric time-constant
$k_{V_{rd}}, k_{V_{rq}}$: positive constants
e : speed error
x : state vector

x_d : desired state vector
$S, \sigma(x,t)$: sliding surface
$[\cdot]^T$: transposed vector
u : control vector
u^{eq} : equivalent control vector
u^n : switching part of the control
k_f : controller gain
λ : positive coefficient
n : system order
η : positive constant.

1. INTRODUCTION

The doubly fed induction machine (DFIM) is a very attractive solution for variable-speed applications such as electric vehicles and electrical energy production. Obviously, the required variable-speed domain and the desired performance depend on the application. The use of a DFIM offers the opportunity to modulate power flow into and out the rotor winding. In general, when the rotor is fed through a cycloconverter, the power range can reach the order of megawatts-a level usually confined to synchronous machines [1]. The DFIM has some distinct advantages compared to the conventional squirrel-cage machine. The DFIM can be fed and controlled stator or rotor by various possible combinations. Indeed, the input-commands are done by means of four precise degrees of control freedom relatively to the squirrel cage induction machine where its control appears quite simpler. The flux orientation strategy can transform the non linear and coupled DFIM-mathematical model to a linear model conducting to one attractive solution as well as under generating or motoring operations [2].

Several methods of control are used to control the induction motor among which the vector control or field orientation control that allows a decoupling between the torque and the flux, in order to obtain an independent control of torque and the flux like DC motors [3].

The overall performance of field-oriented-controlled induction motor drive systems is directly related to the performance of current control. Therefore, decoupling the control scheme is required by compensation of the coupling effect between q-axis and d-axis current dynamics [3].

With the field orientation control (FOC) method,

induction machine drives are becoming a major candidate in high-performance motion control applications, where servo quality operation is required. Fast transient response is made possible by decoupled torque and flux control [4].

Fuzzy logic has proven to be a potent tool in the sliding mode control of time-invariant linear systems as well as time-varying nonlinear systems. It provides methods for formulating linguist rules from expert knowledge and is able to approximate any real continuous system to arbitrary accuracy. Thus, it offers a simple solution dealing with the wide range of the system parameters. All kinds of control schemes, including the classical sliding mode control, have been proposed in the field of AC machine control during the past decades [5].

Among these different proposed designs, the sliding mode control strategy has shown robustness against motor parameter uncertainties and unmodelled dynamics, insensitivity to external load disturbance, stability and a fast dynamic response [6]. Hence it is found to be very effective in controlling electric drives systems. Large torque chattering at steady state may be considered as the main drawback for such a control scheme [6]. One way to improve sliding mode controller performance is to combine it with Fuzzy Logic (FL) to form a Fuzzy Sliding Mode (FSM) controller [7].

In this paper, we treat direct stator flux orientation control (DSFOC) of doubly fed induction motor with two types of regulators, the IP and fuzzy sliding mode controllers.

2. THE DFIM MODEL

Its dynamic model expressed in the synchronous reference frame is given by voltage equations [2]:

$$\bar{u}_s = R_s \bar{i}_s + \frac{d\bar{\phi}_s}{dt} + j\omega_s \bar{\phi}_s$$
$$\bar{u}_r = R_r \bar{i}_r + \frac{d\bar{\phi}_r}{dt} + j\omega_r \bar{\phi}_r \tag{1}$$

Flux equations:

$$\bar{\phi}_s = L_s \bar{i}_s + M \bar{i}_r$$
$$\bar{\phi}_r = L_r \bar{i}_r + M \bar{i}_s \tag{2}$$

From (1) and (2), the state-all-flux model is written like:

$$\bar{u}_s = \frac{1}{\sigma T_s}\bar{\phi}_s - \frac{M}{\sigma T_s L_r}\bar{\phi}_r + \frac{d\bar{\phi}_s}{dt} + j\omega_s \bar{\phi}_s$$
$$\bar{u}_r = -\frac{M}{\sigma T_r L_s}\bar{\phi}_s + \frac{1}{\sigma T_r}\bar{\phi}_r + \frac{d\bar{\phi}_r}{dt} + j\omega_r \bar{\phi}_r \tag{3}$$

The electromagnetic torque is done as:

$$C_e = \frac{PM}{\sigma L_s L_r}\Im m[\bar{\phi}_s \bar{\phi}_r] \tag{4}$$

and its associated motion equation is:

$$C_e - C_r = J\frac{d\Omega}{dt} \tag{5}$$

3. DIRECT STATOR FLUX ORIENTATION CONTROL

In this section, the DFIM model can be described by the following state equations in the synchronous reference frame whose axis d is aligned with the stator flux vector, [8], [9]:

$$i_{rd} = \frac{\phi_{s.}^*}{M} \tag{6}$$

$$i_{rq} = -\frac{L_s}{P.M\phi_s^*}C_e^* \tag{7}$$

$$\frac{d\theta_s}{dt} = \omega_s = \left(\frac{R_s.M}{L_s}i_{rq} + V_{sq}\right)/\phi_s^* \tag{8}$$

$$\dot{i}_{rd} = -\frac{1}{\sigma}\left(\frac{1}{T_r} + \frac{M^2}{L_s.T_s.L_r}\right)i_{rd} - \frac{M}{\sigma.L_r.L_s}V_{sd}$$
$$+ \frac{M}{\sigma.L_r.L_s.T_s}\phi_{sd} + (\omega_s - \omega)i_{rq} + \frac{1}{\sigma L_r}V_{rd} \tag{9}$$

$$\dot{i}_{rq} = -\frac{1}{\sigma}\left(\frac{1}{T_r} + \frac{M^2}{L_s.T_s.L_r}\right)i_{rq} - \frac{M}{\sigma.L_r.L_s}V_{sq}$$
$$+ \frac{M}{\sigma.L_r.L_s}\omega\phi_{sd} - (\omega_s - \omega)i_{rd} + \frac{1}{\sigma L_r}V_{rq} \tag{10}$$

$$\phi_{sd}^* = V_{sd} + \frac{M}{T_s}i_{rd} - \frac{1}{T_s}\phi_{sd} \tag{11}$$

$$\phi_{sq}^* = V_{sq} + \frac{M}{T_s}i_{rq} - \omega_s\phi_{sd} \tag{12}$$

$$\dot{\Omega} = \frac{P.M}{J.L_s}(i_{rq}.\phi_{sd}) - \frac{C_r}{J} - \frac{f}{J}\Omega \tag{13}$$

With:

$$T_r = \frac{L_r}{R_r}; T_s = \frac{L_s}{R_s}; \sigma = 1 - \frac{M^2}{L_s L_r}$$

where:

4. STATOR FLUX ESTIMATOR

For the DSFOC of DFIM, accurate knowledge of the magnitude and position of the stator flux vector is necessary. In a DFIM motor mode, as stator and rotor current are measurable, the stator flux can be estimated (calculate). The flux estimator can be obtained by the following equations [10]:

$$\phi_{sd} = L_s i_{sd} + M i_{rd} \tag{14}$$

$$\phi_{sq} = L_s i_{sq} + M i_{rq} \qquad (15)$$

The position stator flux is calculated by the following equations:

$$\theta_r = \theta_s - \theta \qquad (16)$$

In which:

$$\theta_s \int \omega_s dt, \theta = \int \omega dt, \omega = P\Omega.$$

Where:

θ_s is the electrical stator position,
θ is the electrical rotor position.

5. SLIDING MODE CONTROL

A Sliding Mode Controller (SMC) is a Variable Structure Controller (VSC). Basically, a VSC includes several different continuous functions that can map plant state to a control surface, whereas switching among different functions is determined by plant state represented by a switching function [10].

The design of the control system will be demonstrated for a following nonlinear system [11]:

$$\dot{x} = f(x,t) + B(x,t).u(x,t) \qquad (17)$$

Where $x \in \mathfrak{R}^n$ is the state vector, $f(x,t) \in \mathfrak{R}^n$, $B(x,t) \in \mathfrak{R}^{n \times m}$ and $u \in \mathfrak{R}^m$ is the control vector. From the system (17), it possible to define a set of the state trajectories x such as:

$$S = \{x(t) | \sigma(x,t) = 0\} \qquad (18)$$

Where:

$$\sigma(x,t) = [\sigma_1(x,t), \sigma_2(x,t), \ldots, \sigma_m(x,t)]^T \qquad (19)$$

and $[.]^T$ denotes the transposed vector, S is called the sliding surface.

To bring the state variable to the sliding surfaces, the following two conditions have to be satisfied:

$$\sigma(x,t) = 0, \ \dot{\sigma}(x,t) = 0 \qquad (20)$$

The control law satisfies the precedent conditions is presented in the following form:

$$u = u^{eq} + u^n$$
$$u^n = -k_f sgn(\sigma(x,t)) \qquad (21)$$

Where u is the control vector, u^{eq} is the equivalent control vector, u^n is the switching part of the control (the correction factor), k_f is the controller gain. u^{eq} can be obtained by considering the condition for the sliding regimen, $\sigma(x,t) = 0$. The equivalent control keeps the state variable on sliding surface, once they reach it.

For a defined function φ [12], [13]:

$$sgn(\varphi) = \begin{cases} 1, & if \ \varphi > 0 \\ 0, & if \ \varphi = 0 \\ -1, & if \ \varphi < 0 \end{cases} \qquad (22)$$

The controller described by the equation (21) presents high robustness, insensitive to parameter fluctuations and disturbances, but it will have high-frequency switching (chattering phenomena) near the sliding surface due to function involved. These drastic changes of input can be avoided by introducing a boundary layer with width ε [14]. Thus replacing $sgn(\sigma(t))$ by $sat(\sigma(t)/\varepsilon)$ (saturation function), in (21), we have:

$$u = u^{eq} - k, sat(\sigma(x,t)) \qquad (23)$$

Where $\varepsilon > 0$.

$$sat(\varphi) = \begin{cases} sgn(\varphi), & if|\varphi| \geq \varepsilon \\ \psi, & if|\varphi| \geq \varepsilon \end{cases} \qquad (24)$$

Consider a Lyapunov function [12]:

$$V = \frac{1}{2}\sigma^2 \qquad (25)$$

From Lyapunov theorem we know that if $\dot{V}$ is negative definite, the system trajectory will be driven and attracted toward the sliding surface and remain sliding on it until the origin is reached asymptotically [14]:

$$\dot{V} = \frac{1}{2}\frac{d}{dt}\sigma^2 = \sigma\dot{\sigma} \leq -\eta|\sigma| \qquad (26)$$

Where η is a strictly positive constant.
In this paper, we use the sliding surface proposed par J.J. Slotine:

$$\sigma(x,t) = \left(\frac{d}{dt} + \lambda\right)^{n-1} e \qquad (27)$$

Where:

$x = [x, \dot{x}, \ldots, x^{n-1}]^T$ is the state vector, $x_d = [x_d, \dot{x_d}, \ldots, x_d]^T$ is the desired state vector, $e = x_d - x = [e, \dot{e}, \ldots, e^{n-1}]$ is the error vector, and λ is a positive coefficient, and n is the system order.

6. SPEED CONTROL WITH SMC

The speed error is defined by:

$$e = \Omega_{ref} - \Omega \qquad (28)$$

For $n = 1$, the speed control manifold equation can be obtained from equation (27) as follow:

$$\sigma(\Omega) = e = \Omega_{ref} - \Omega \qquad (29)$$

$$\dot{\sigma}(\Omega) = \dot{\Omega}_{ref} - \dot{\Omega} \qquad (30)$$

Substituting the expression of equation (13) in equation (30), we obtain:

$$\dot{\Omega} = \dot{\Omega_{ref}} - \left(-\frac{P.M}{J.L_s}(i_{rq}.\phi_{sd}) - \frac{C_r}{J} - \frac{f}{J}\Omega \right) \quad (31)$$

We take:

$$i_{rq} = i_{rq}^{eq} + i_{rq}^{n} \quad (32)$$

During the sliding mode and in permanent regime, we have:

$$\sigma(\Omega) = 0, \dot{\sigma}(\Omega) = 0, i_{rq}^{n} = 0$$

Where the equivalent control is:

$$i_{rq}^{eq} = -\frac{J.L_s}{P.M.\phi_{sd}}\left(\dot{\Omega}_{ref} + \frac{C_r}{J} + \frac{f}{J}\Omega \right) \quad (33)$$

Therefore, the correction factor is given by:

$$i_{rq}^{n} = k_{i_{rq}}sat(\sigma(\Omega)) \quad (34)$$

k_{irq} : negative constant.

7. FUZZY SLIDING MODE CONTROL

7.1 Speed Control

The disadvantage of sliding mode controllers is that the discontinuous control signal produces chattering dynamics; chatter is aggravated by small time delays in the system. In order to eliminate the chattering phenomenon, different schemes have been proposed in the literature [7]. Another approach to reduce the chattering phenomenon is to combine (Fuzzy Logic) FL with a Sliding Mode control (SMC) [13]. Hence, a new Fuzzy Sliding Mode (FSM) controller is formed with the robustness of SMC and the smoothness of FL. The fuzzy sliding mode control combines the advantages of the two techniques [15] (SMC and FL). The control by fuzzy logic is introduced here in order to improve the dynamic performances of the system and makes it possible to reduce the residual vibrations in high frequencies [15] (chattering phenomenon). The switching functions of sliding mode and FSM schemes are shown in Fig. 1. In this technique, the saturation function is replaced by a fuzzy inference system to smooth the control action. The block diagram of the hybrid fuzzy sliding mode controller is shown in Fig. 2.

Fig. 3 shows the Speed fuzzy sliding mode controller detailed.

7.2 Synthesis of the Fuzzy-PI Regulator

With this intention, we take again the internal diagram of the fuzzy regulator as shown in Fig. 3. We have:

$$u = K_s.S \quad (35)$$
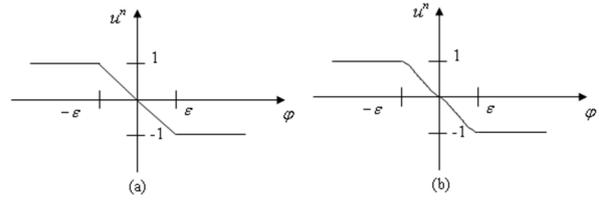
Fig.1: *Switching functions (a) Sliding mode (b) Fuzzy sliding mode.*
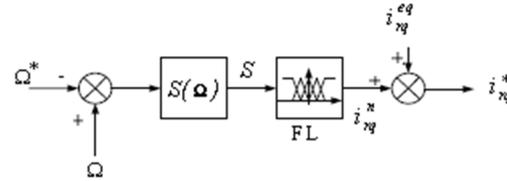
Fig.2: *Fuzzy sliding mode speed controller.*
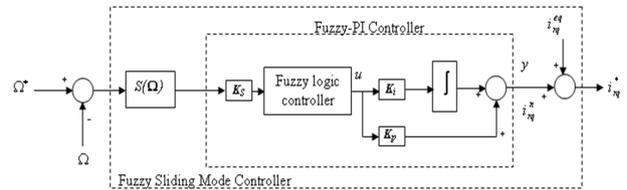
Fig.3: *Speed fuzzy sliding mode controller detailed.*

Or:

$$S = k_{i_{rq}}.sat(S(\Omega)) \quad (36)$$

Substituting the equation (36) in equation (35), we obtain:

$$u = K_s.k_{i_{rq}}.sat(S(\Omega)) \quad (37)$$

The Fuzzy-PI output is:

$$y = k_p.u + \int k_i.u \quad (38)$$

Substituting the equation (37) in equation (38), we obtain:

$$y = K_p.\left(K_S.k_{i_{rq}}.sat(S(\Omega)) \right) + \int K_i.\left(K_s.k_{i_{rq}}.sat(S(\Omega)) \right) \quad (39)$$

Where: K_s is the gain of the speed surface, K_p is the proportional factor; K_i is the integral factor, $k_{i_{rq}}$ is a negative constant, u is the fuzzy output, $S(\Omega)$ is the speed surface.

The membership functions for the input and output of the Fuzzy-PI controller are obtained by trial error to ensure optimal performance and are shown in Fig. 4.

The If-Then rules of the fuzzy logic controller can be written as [7]:

(a)

(b)
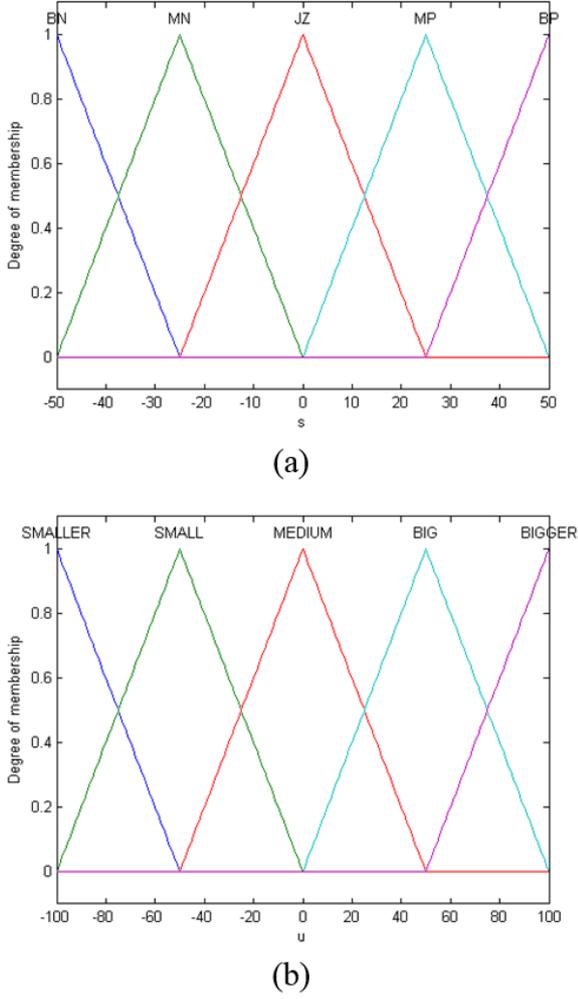
Fig.4: *Fuzzy logic membership functions (a) input (b) output.*

If s is BN then un is BIGGER
If s is MN then un is BIG
If s is JZ then un is MEDIUM
If s is MP then un is SMALL
If s is BP then un is SMALLER

7.3 Law of Control

The structure of a fuzzy sliding mode controller as a sliding mode controller comprises two parts: the first relates to the equivalent control u^{eq} and the second is the correction factor u^n, but into the case of a fuzzy sliding mode controller we introduce the fuzzy logic control into this last part u^n.
We have the equation (33):

$$i_{rq}^{eq} = -\frac{J.L_s}{P.M.\phi_{sd}}\left(\dot{\Omega}_{ref} + \frac{C_r}{J} + \frac{f}{J}\Omega\right) \quad (40)$$

and we have of Fig. 3:

$$i_{rq}^n = y \quad (41)$$

Substituting the equation (39) in equation (41), we obtain:

$$i_{rq}^n = K_p.\left(K_s.K_{i_{rq}}.sat(S(\Omega))\right) + \int K_i\left(K_s k_{i_{rq}} sat(S(\Omega))\right) \quad (42)$$

8. SPEED CONTROL WITH IP

The Fig. 5 shows the block diagram of speed control using IP (Integral Proportional) regulator.
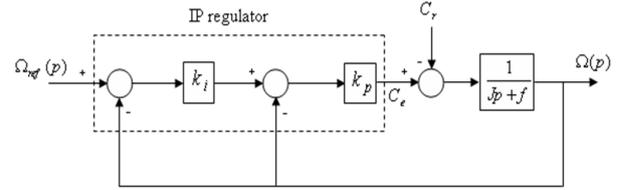
Fig.5: *Block diagram of speed control using IP regulator.*

The closed-loop speed transfer function is:

$$\frac{\Omega(p)}{\Omega_{ref}(p)} = \frac{1}{1 + \frac{k_p + f}{k_p k_i}p + \frac{J}{k_p k_i}p^2} \quad (43)$$

Where k_p and k_i denote proportional and integral gains of IP speed controller. $p = \frac{d}{dt}$ differential operator.

It can be seen that the motor speed is represented by second order differential equation:

$$\omega_n^2 + 2\xi\omega_n p + p^2 = 0 \quad (44)$$

By identification, we obtain the following parameter:

$$\begin{cases} \frac{J}{k_p k_i} = \frac{1}{\omega_n^2} \\ \frac{k_p + f}{k_p k_i} = \frac{2\xi}{\omega_n} \end{cases} \quad (45)$$

Since, the choice of the parameters of the regulator is selected according to the choice of the damping ratio (ξ) and natural frequency (ω_n):

$$\begin{cases} k_p = 2.J\xi\omega_n - f \\ k_i = \frac{J\omega_n^2}{k_p} \end{cases} \quad (46)$$

In this paper, a time domain criterion is used for evaluating the FSMC and IP controllers. The performance criteria used for comparison between the FSMC and IP controllers is include *Integrated Absolute Error (IAE)*.

The *IAE* performance criterion formulas are as follows [16]:

$$LAE = \int_0^\infty |r(t) - y(t)|.dt = \int_0^\infty |e(t)|.dt \quad (47)$$

9. RESULTS AND DISCUSSION

The IP and FSMC regulators in a DSFOC of DFIM are used as presented in Fig. 6. The DFIM used in this work is a 0.8 KW, whose nominal parameters are reported in the following: Rated values: 0.8 KW; 220/380 V-50 Hz; 3.8/2.2 A, 1420 rpm. Rated parameters: Rs = 11.98 Ω, Rr = 0.904 Ω, L_s = 0.414 H, L_r = 0.0556 H, M = 0.126 H, P = 2.0, J = 0.01 Kg.m^2, f = 0.00 I.S.

Fig.6: *Block diagram of a DSFOC of DFIM using IP and FSMC regulators in a speed loop (speed regulator).*

The motor is operated at 157 rad/s under no load and a load disturbance torque (5 N.m) is suddenly applied at t=0.5s and eliminated at t=0.8s, followed by a consign inversion (-157 rad/s) at t=1s, also a load disturbance torque (-5 N.m) is suddenly applied at t=1.5s and eliminated at t=1.8s. In these tests, the IP controller rejects the load disturbance slowly with overshoot and with a static error as shown in Fig. 7.

The same tests applied for IP are applied with the FSMC. Fig. 8 shows the performances of the fuzzy sliding mode controller (FSMC).

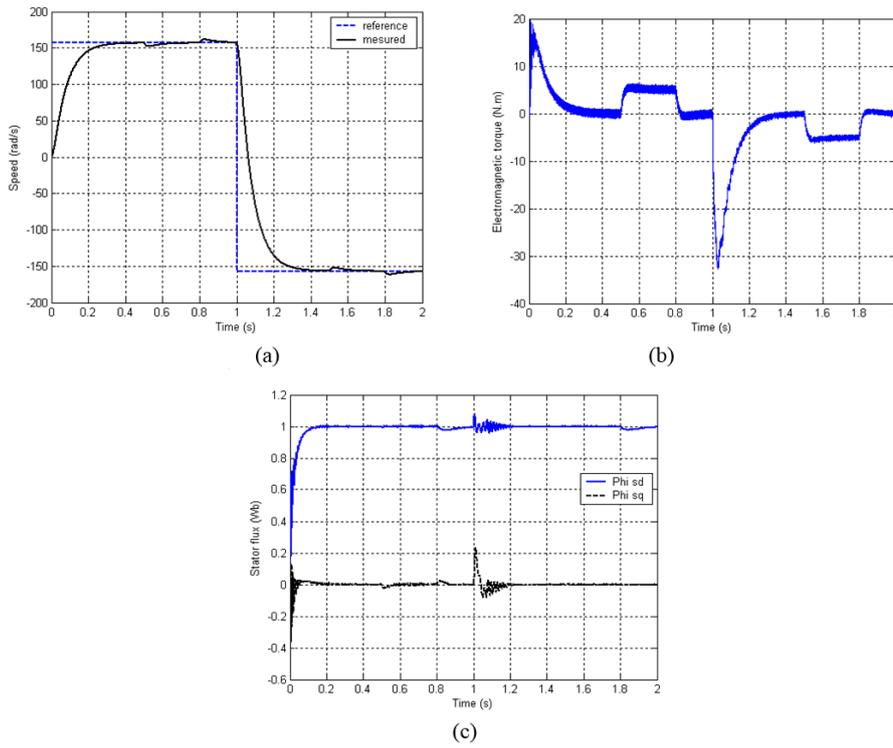The FSMC rejects the load disturbances instantaneous with no overshoot and without static error as shown in Fig. 8. The FSMC presents the best performances, to achieve tracking of the desired trajectory. The performance of FSMC of speed is compared to IP regulator for precedent tests. The speed response is shown in Fig. 9. It can be seen clearly that the FSMC provides a minimum response time and robust speed response compared to the traditional IP controller.

Fig. 10 shows a zoom of speed answer during the starting, the application of the disturbance, the reversal speed and the application of the disturbance in inverse sense. The FSMC controller based drive system can handle the sudden change in load torque without overshoot and undershoot and steady state error, whereas the traditional IP controller has steady state error and the response is not as fast as compared to FSMC controller, as shown in Fig. 10.

The controllers behaviour can be better compared using standard performance indexes. Table 1 shows the values of IAE for the traditional IP and FSMC controllers, during precedent tests conditions. These indexes show that the FSMC controller performs better than the IP controller.

Table 1: *Simulation Speed Response Performance.*

	IP	FSMC
Response time	0.2238	0.1181
Static error	0.2907	0
IAE	41.02	39.39

Fig.9: *Simulated results of the comparison between the IP and FSMC of DFIM.*

10. CONCLUSION

In this paper, the speed regulation of DFIM with two controllers, traditional IP and FSMC, has been designed and simulated. The comparative study shows that the FSMC controller can be enhance the performances of speed of the DFIM control. The simulation results have confirmed the efficiency of the FSMC for various operating conditions. The results show that the FSMC controller has good performance, and it is robust against external perturbations.

References

[1] S. Drid, M. Tadjine and M. S. Naît-Saîd, "Robust backstepping vector control for the doubly fed induction motor," *The Institution of Engineering and Technology, Control Theory Appl.*, vol. 1, no. 4, pp. 861–868, 2007.

[2] S. Drid, M. Tadjine and M.S. Nait-Said, "Nonlinear feedback control and torque optimization of a doubly fed induction motor," *Journal of Electrical Engineering*, vol. 56, no. 3-4, pp. 57–63, 2005.

[3] A. Chaari, M. Soltani and M. Gossa, "Comparative study between the conventional regulators

Fig.7: *Results of speed control using IP controller: (a) speed, (b) torque (c) and stator flux.*
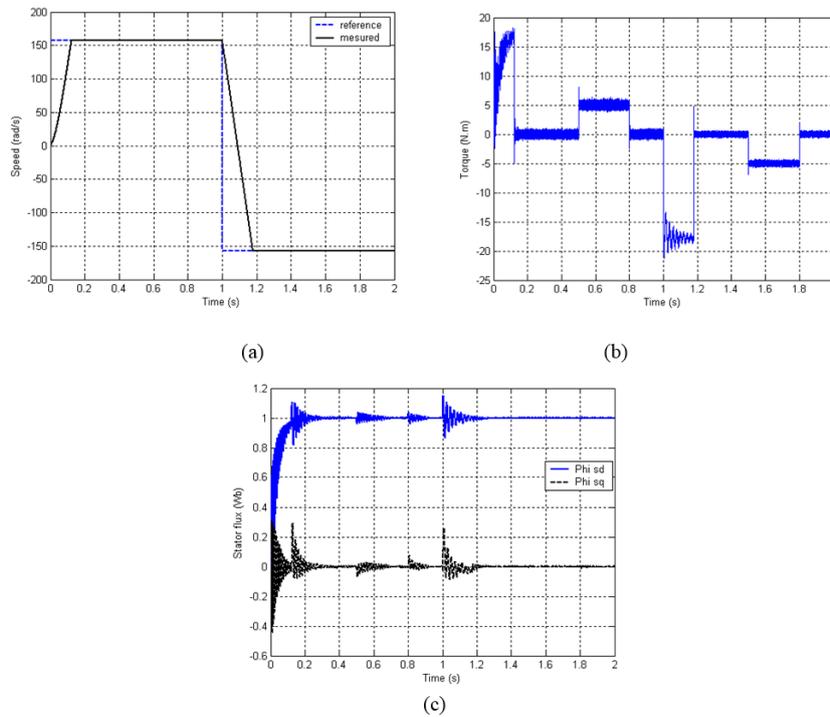

Fig.8: *Results of speed control using FSMC controller: (a) speed, (b) torque (c) and stator flux.*
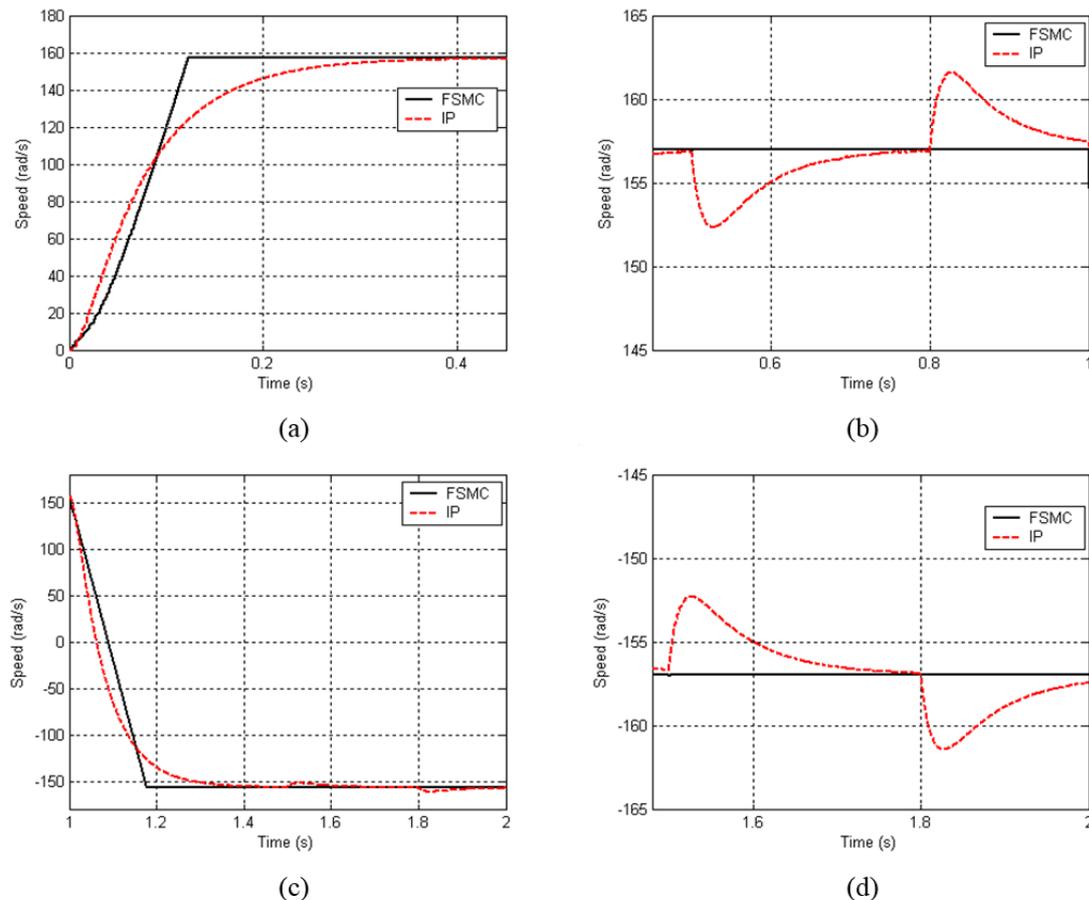
Fig.10: *Zoom of speed answer during: (a) starting, (b) application of the disturbance, (c) reversal speed (d) and application of the disturbance in inverse sense.*

and fuzzy logic controller: application on the induction machine," *International Journal of Sciences and Techniques of Automatic control & computer engineering IJ-STA*, vol. 1, no. 2, pp. 196–212, December 2007.

[4] H. Brian, X. Longya and T. Yifan, "Fuzzy logic enhanced speed control of an indirect field-oriented induction machine drive," *IEEE Trans. Power Electronics.* vol. 12, no. 5, pp 772–778, September 1997.

[5] A. Hazzab, I. K. Bousserhane, M. Kamli and M. Rahli, "Adaptive fuzzy PI-sliding mode controller for induction motor speed control," *International Journal of Emerging Electric Power Systems*, vol. 4, Issue 1, Article 1084, pp 1–13, 2005.

[6] F. Barrero, A. Gonzalez, A. Torralba, E. Galvan and L. G. Franquelo, "Speed control of induction motors using a novel fuzzy sliding mode structure," *IEEE Trans. Fuzzy Syst.*, vol. 10, no. 3, pp. 375–383, June 2002.

[7] A. TAHOUR, H. ABID, A. G. AISSAOUI, "Speed control of switched reluctance motor using fuzzy sliding mode," *Advances in Electrical*

and Computer Engineering, vol. 8, (15), Number 1 (29), pp 21–25, 2008.

[8] P. Guillemin, "Fuzzy logic applied to motor control," *IEEE Trans. On Ind. Appl.* vol.32, pp. 51–56, Feb.1996.

[9] C. C. Lee, "Fuzzy logic in control systems: Fuzzy logic controller Part 1," *IEEE Trans. Syst. Man, Cyber*, vol. 20, pp. 404–418, Apr. 1990.

[10] Y. Bekakra and D. Ben attous, "A sliding mode speed and flux control of a doubly fed induction machine," *Electrical and Electronics Engineering, IEEE Conference*, 2009, pp. I-174 - I-178.

[11] M. Abid, A. Aissaoui, H. Bounoua, "Sliding mode application in speed and flux control of an induction machine," *Journal of Electrical and Electronics Engineering*, vol. 6, no. 2, pp. 197–204, 2006, Istanbul university.

[12] M. Abid, A. Mansouri, A. Aissaoui and B. Belabbes, "Sliding mode application in position control of an induction machine : Journal of electrical engineering," vol. 59, no. 6, pp. 322–327, 2008.

[13] J. Lo and Y Kuo : "Decoupled fuzzy sliding mode control," *IEEE Trans. Fuzzy Syst.*, vol.6, no. 3,

pp. 426–435, Aug. 1998.

[14] A. Aissaoui, M. Abid, H. Abid, A. Tahour, "Position control of synchronous machine using sliding mode techniques," *Journal of electrical and electronics engineering*, vol. 7, no. 2, pp. 471–480, 2007, Istanbul University.

[15] E. Nechadi, M. N. Harmas, A. Ferhat-Hamida, and K. Zehar, "Stabilisation d'un système electro-énergétique par contrôleur flou en mode glissant," SETIT 2005, 3rd *International Conference: Sciences of Electronic, Technologies of Information and Telecommunications*, March 27-31, 2005, Tunisia.

[16] B. ALLAOUA, B. GASBAOUI and B. MEBARKI, "Setting up PID DC motor speed control alteration parameters using particle swarm optimization strategy," *Leonardo Electronic Journal of Practices and Technologies*, Issue 14, pp. 19–32, January-June 2009.

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