VECTOR CONTROL OF AN ASYNCHRONOUS MACHINE IN SLIDING MODE: CONTRIBUTION OF FUZZY LOGIC

Abdesselem. CHIKHI, Khaled. CHIKHI and Sebti. BELKACEM
LEB-Research Laboratory, Department of Electrical Engineering, University of Batna,
Street Chahid Mohamed El hadi Boukhlouf, 05000, Batna, Algeria.
E-mail: chikhi_aslem@yahoo.fr

Abstract-- The presented work proposes a simulation study under Matlab/Simulink environment of the synthesis of nonlinear control laws, or more precisely, a synthesis of two control strategies, the control by sliding mode and the hybrid fuzzy-sliding control, and to apply them to an asynchronous machine.

*Key words**:** Asynchronous Machine, Vector Control by Rotor Flux Orientation, Sliding Mode, Fuzzy Logic, Fuzzy-Sliding Mode.*

1. Introduction

The use of the asynchronous machines is increasingly widespread in industry. In fact, these robust and very economic machines, associated to vector control by flux orientation allow it to carry out independently the flux adjustment and the speed regulation, but, on the other hand, the variations and non linearity of its parameters can move away, in a notable way, the machine from its optimal operation. In this context, several approaches of robust controls incorporate, during their development, the parametric fluctuations and the load disturbances injected into the process. The system theory with variable structures and sliding modes are is technique of nonlinear control, it is characterised by a discontinuity control to the itinerary surface of Switching, any response, thus depends on the suitable choice of this surface, called still slid surface. To solve the problem of control agitation, new strategies based on the expertise of the operator were elaborate. The bases of this fuzzy logic theory generalises the concept of membership of an object to a given unit and is based on a knowledgebase and rules of treatment (mode of reasoning or inference). The application of the fuzzy logic based on the ideas of sliding mode for speed regulation and flux control of an asynchronous machine represents the adequate solution with the phenomenon of chattering which is The major disadvantage of the sliding mode control technique.

2. Sliding Mode Control Theory

2.1. Mathematical Bases of Sliding Mode Control

The mathematical modelling of a variable structure control (formalisation in the context of the theory of the differential equations) led to differential equations of the form [1].

$$\frac{dx}{dt} = f(x,t) + g(x,t)u \qquad (1)$$

Where

x : State vector $\in R^n$

f : (vector functions of x and t)$\in R^n$.

g : (matrix of functions of x and)$\in R^{nm}$.

u : (Vector control).

The surface can be written as:

$$s(x) = [s_1(x) \qquad s_m(x)]^T$$

After the design of the surface s, the vector control.

$$u = [u_1, \qquad u_m]^T$$

Which each component (u_i) undergoes a discontinuity on s, is given by [2].

$$u_i \begin{cases} u_i^+ & if \quad s_i(x,t) > 0 \\ u_i^- & if \quad s_i(x,t) < 0 \end{cases} \qquad (2)$$

$$i = 1,......,m.$$

The equation (2) shows that, the variation of vector control (u) depends on the sign of surface s with x and t as parameters, the surface s(x,t) is called surface of Switching, and the control law is unspecified on this surface. For a surface of closed Switching, the vectors of control are selected so that the vectors tangent of each point of the trajectory of state move towards this surface such as the state is controlled to be maintained on the surface S(x ,t) = 0

2.2. Sliding Mode Solving

A rather general form is proposed to determine the sliding surface, which ensures a convergence of the quantity towards its value of reference, if x_i is an output to be controlled; it is associated to the surface:

$$s_i(x) = (\frac{d}{dt} + \lambda)^{r-1} . \ x_i \qquad (3)$$

With $\tilde{x_i} = x_i - x_{id}$, λ a constant positive.

r : is the degree corresponds to the number of times that it is necessary to derive the output to disclose the control law.

It is noticed that the trajectories of phase are directed towards the line of Switching.

$$s(x) = \lambda x + \frac{dx}{dt} = 0 \qquad (4)$$

The Switching phenomenon along the sliding line can be shown by means of (Fig. 1)

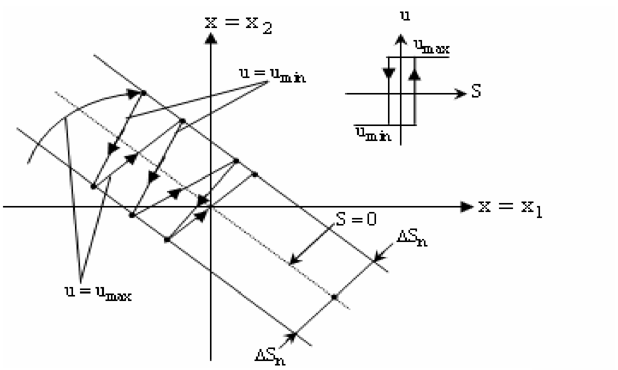


Fig. 1. Sliding mode solving

2. 3. Existence Conditions of Sliding Mode

The existence of a sliding mode requires the state trajectory stability on the sliding surface ($s(x,t) = 0$), after a certain terminated time [1]. Thus, the choice of a generalized function of Lyaponov ($v(t,x)$ positively definite, whereas its derivative is negatively definite, is necessary [2].

$$v(t,x) = \frac{1}{2} s(x,t) s(x,t)^T \qquad (5)$$

The feed backed system is stable if: $\dot{V} = s \dot{s}^T$, the condition of sliding mode existence, is used to solve the problem of the synthesis of the systems with variable structure, and allows us to determine the parameters of adjustment as long as $s(x)\dot{s}(x)^T < 0$ is verified

2. 4. Equivalent Control

A vector control equivalent u_{eq} is defined as the equations of the ideal sliding mode, when the sliding mode of east establishes, then, for all:

$$t > t_1 \qquad s(x,t) = 0 \text{, and } \dot{s}(x,t) = 0 \qquad (6)$$

The equation of ideal sliding regime is given by [2]:

$$\dot{x}(t) = \left[1 - g(x,t)\left[\frac{\partial s}{\partial t} g(x,t)\right]^{-1} \frac{\partial s}{\partial x}\right] f(x,t) - g(x,t)\left[\frac{\partial s}{\partial x} g(x,t)\right]^{-1} \frac{\partial s}{\partial t} \qquad (7)$$

This equation represents the dynamics of the system equivalent to the sliding surface.

2. 5. Basic Discontinuous Control

Several choices for the discontinuous command u_n can be made, discontinuous control is expressed by $u_n = [u_1 .... u_m]$ with the function signs with respect to $s = [s_1, s_2, ..., s_m]$.

$$\begin{cases} sign(s) = +1 & if \quad s > 0 \\ sign(s) = -1 & if \quad s < 0 \end{cases} \qquad (8)$$

In the goal to reduce the oscillations, we replace the function $(sign(s))$ by a function of saturation is characterized by one or two thresholds.

3. Application of the Sliding Mode

The importance of the application of this technique is to:

- To assure the rapidity and the precision of the response of the largeness regulated.
- Ensure the robustness of the system with respect to disturbances and changes in parameters and mechanical loads.
- limit the amplitudes of voltages and currents during the transient regimes.

We have proposed a structure for regulating the induction machine whose purpose is to control the speed and flux.

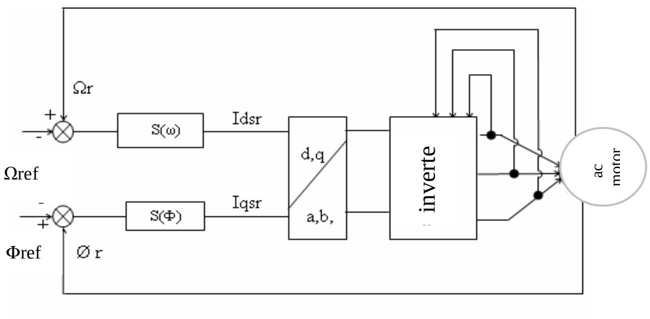


Fig. 2. Block diagram of the regulator

3.1 Selection of Switching Surfaces

The switching surfaces are chosen in the goal to impose a desired behaviour to the motor in the transient regime, they are given by:

$$\begin{cases} s_1 = \frac{1}{2}(z_1 - \phi_{ref}) \\ s_2 = (z_2 - \omega_{ref}) \end{cases} \quad (9)$$

3.2. Determination of the Parameters

The control parameters are defined starting from only one condition, necessary and sufficient, correlated with the existence of the sliding mode [4].

$s\dot{s} < 0$; The inequality is verified while imposing on the surfaces:

$\dot{s}_1 = -k_1 sign(s_1)$ and $\dot{s}_2 = -k_2 sign(s_2)$ (10)

The reference current expressions are then given by:

$$\begin{bmatrix} i_{dref} \\ i_{qref} \end{bmatrix} = \begin{bmatrix} d_1 x_3 & d_1 x_4 \\ -e_1 x_4 & e_1 x_3 \end{bmatrix}^{-1} \begin{bmatrix} h_1(x) - k_1 sign(s_1) \\ h_2(x) - k_2 sign(s_2) \end{bmatrix} \quad (11)$$

3.3. The Gains and the Switching Function

The gains of sliding surface are selected to ensure a desired response time: K1 = 900; K = 900. We choose a switching function of the function signs with a dead zone

$$\begin{cases} sign(s) = 1 & if \quad s > \varepsilon_2 \\ sign(s) = 0 & if \quad \varepsilon_1 \le s \le \varepsilon_2 \\ sign(s) = -1 & if \quad s \le \varepsilon_1 \end{cases} \quad (12)$$

In the case of speed: $\varepsilon_1 = -1$ and $\varepsilon_2 = 1$

In the case of flux: $\varepsilon_1 = -0.01$ and $\varepsilon_2 = 0.01$

4. Control by Fuzzy Sliding Technique

The chattering phenomenon is the major disadvantage of the sliding mode technique. However to eliminate the oscillations and to reduce the complexity of the practical implementation, one proposes the application of fuzzy logic based on the concept of the sliding mode for the speed regulation as well as for the flux control of an asynchronous machine[5].

4.1. Description of Fuzzy-Sliding Controller

The inputs of this controller are the sliding surface (S), its derivative (ds); in the same time the error (e) and the variation of the error (de) [3].

The structure of this controller comprises two parts which are the sliding mode controller and the fuzzy logic controller, so:

$$\begin{aligned} i_d &= i_{ds} + i_{df} \\ i_q &= i_{qs} + i_{qf} \end{aligned} \quad (13)$$

With:

i_{df} : The output the fuzzy logic controller $FLC(\phi)$.

i_{qf} : The output the fuzzy logic controller $FLC(\omega)$.

i_{ds} : The output the sliding mode controller $S(\phi)$.

i_{qs} : The output the sliding mode controller $S(\omega)$.

The variables to be controlled by the sliding mode controller FLC (Φ**)** if (s_1) and its derivative meanwhile for fuzzy logic $(\dot{s}_1)$ [6].

FLC (ω) it is (s_2) and its derivative $(\dot{s}_2)$.

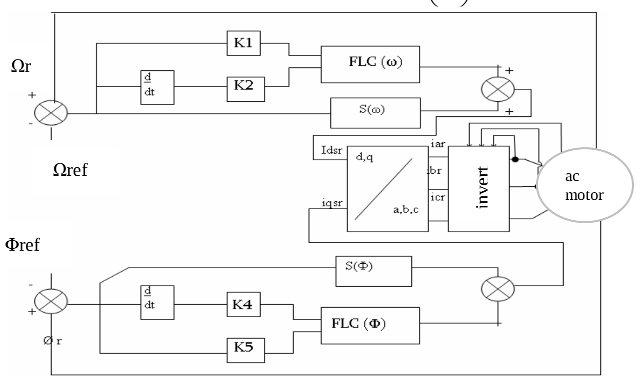
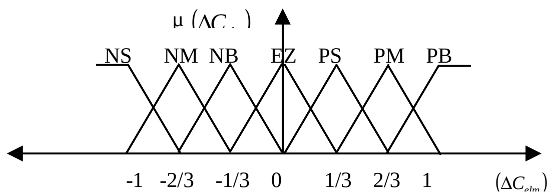


Fig.3. Fuzzy-sliding controller



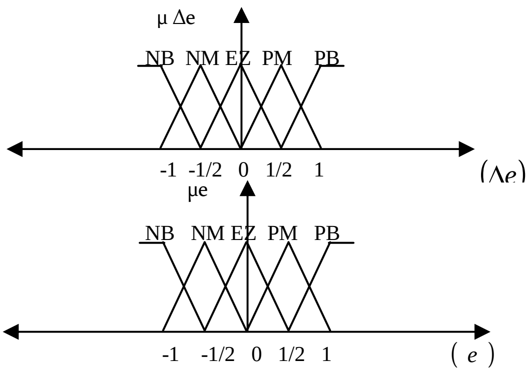


Fig. 4. Membership Function of the various linguistic variables

4.2. Inference Table

Table1. Rules of Fuzzy Decisions (Inference)

e / Δe	NB	NM	EZ	PM	PB
NB	NB	NM	NS	NS	EZ
NM	NM	NS	NS	EZ	PS
EZ	NS	NS	EZ	PS	PS
PM	NS	EZ	PS	PS	PM
PB	EZ	PS	PS	PM	PB

4.3. Deffuzzification Method

The most used defuzzification method is that of the "gravity center of the weighted the heights", our choice is done on the latter due to the fact that it is easy to implement and does not require much of calculation [3].

5. Simulation Results

In order to illustrate the improvements obtained by using this type of hybrid controller (fuzzy-sliding) with respect to the sliding alone, to the static and dynamic performances of the three phase asynchronous machine with oriented flux; a simulation study is carried out, in the same test conditions for the transient modes: no load starting with an introduction of a load torque and an inversion of the direction of rotation speed, and to test the robustness of the controller with respect to the parametric variations.

6. Results Interpretations

6.1. Sliding Mode Controlling

In (Figure. 6) we see that the fuzzy controller has shown its success in providing a significant improvement in dynamic performance of speed. In (Figure. 7), a disturbance was introduction, it can be observed that that it is rejected by the control unit, nevertheless the intervention of this last appeared with the appearance of the chattering. However during an inversion speed the machine follows the value of reference perfectly (Figure. 8). With an aim of testing the robustness of the controller by sliding mode, we have introduced the parametric variations rotor.It can be observed as well that from (Figure. 9), this type of controlling has a good robustness.

6.2. Hybrid Controlling

The performances of the tuning by this new controlling strategy are very satisfactory. When the system is subjected to parametric variations, we notice the total rejection of the disturbances, insensitivity to the parametric variations, and in the end a total disappearance of the phenomenon of chattering (figure. 7).

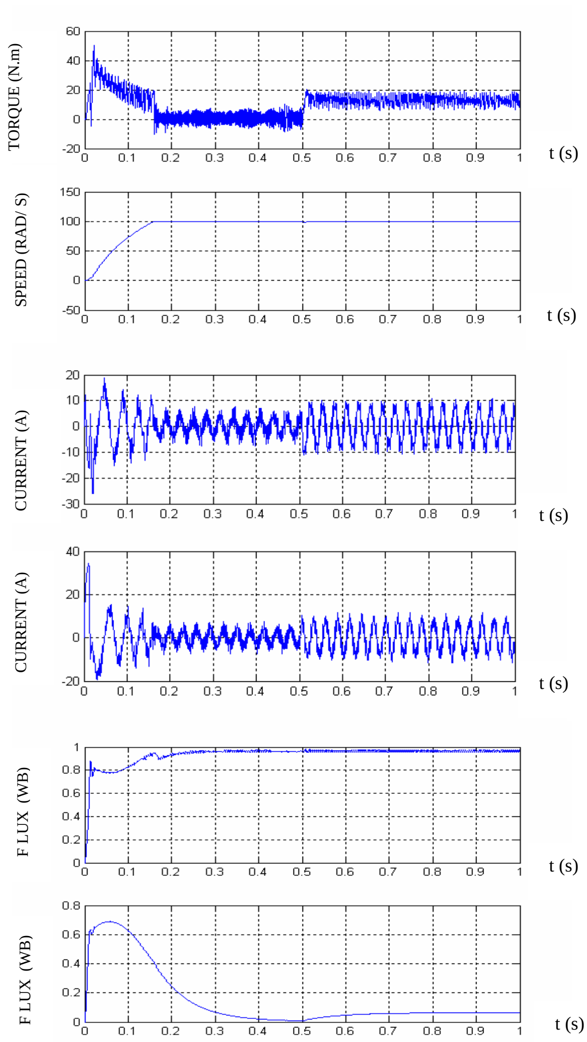


Fig.5. Control by sliding mode for Cr=15N.

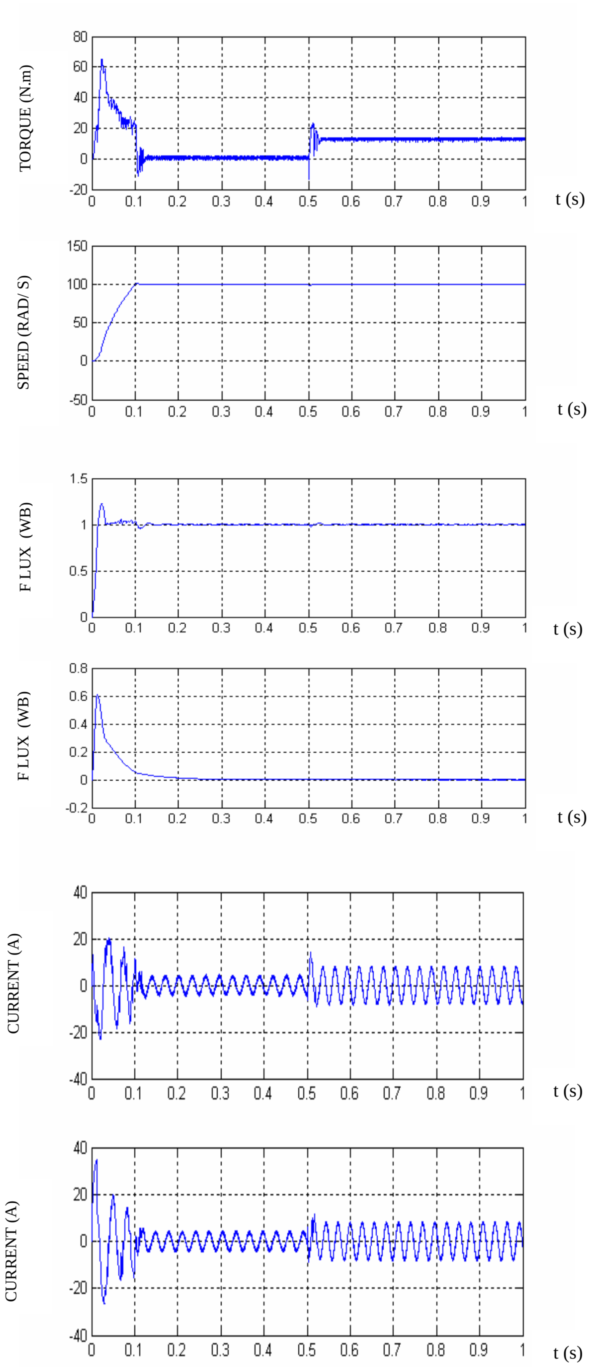
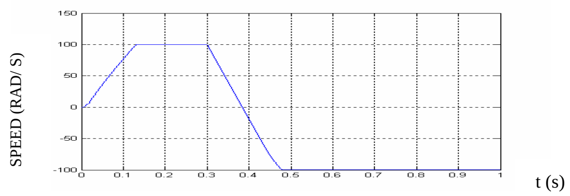


Fig. 6. Control by fuzzy sliding for Cr=15N.m
Curves comparing between the two commands.
start with empty and application of a load



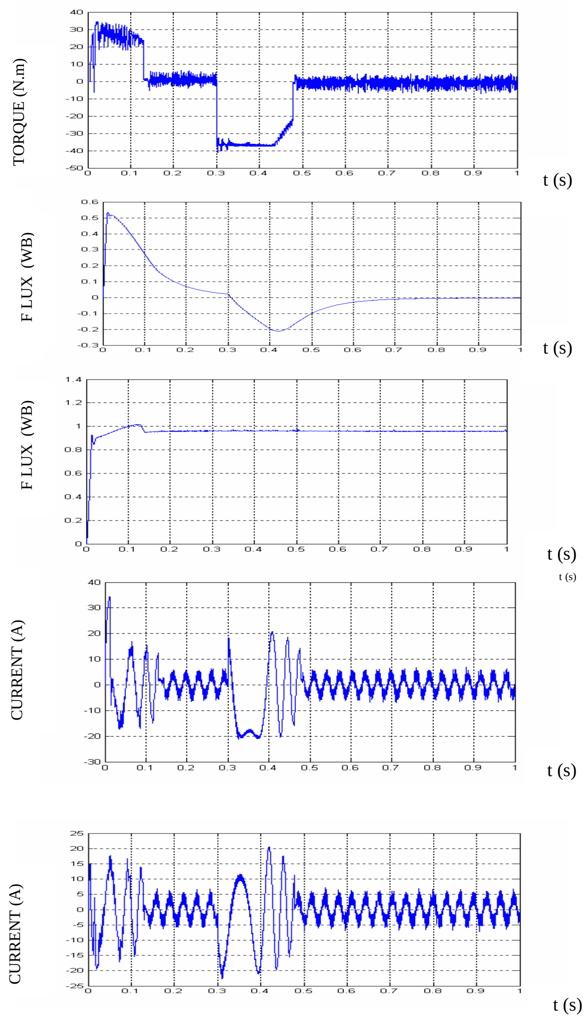
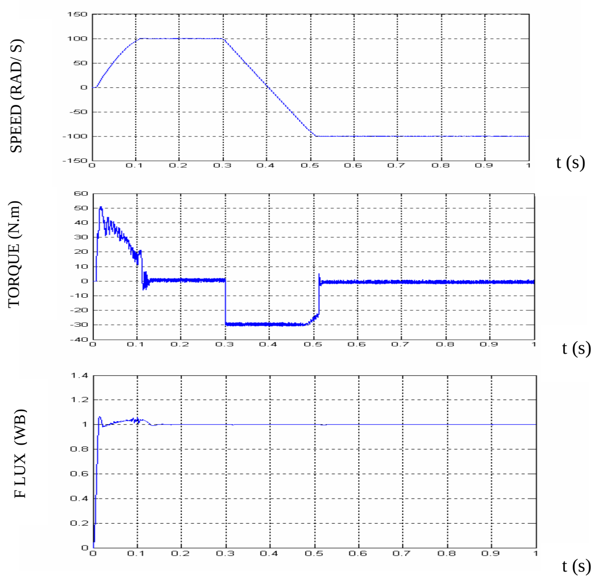


Fig. 7. Sliding mode control



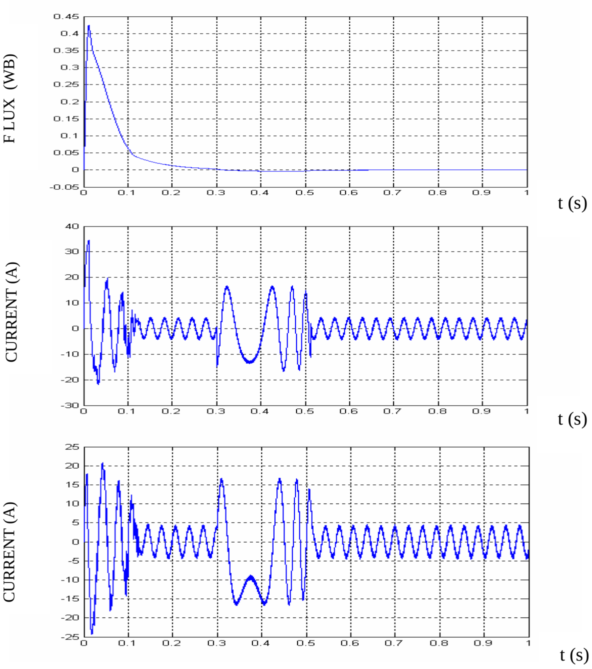
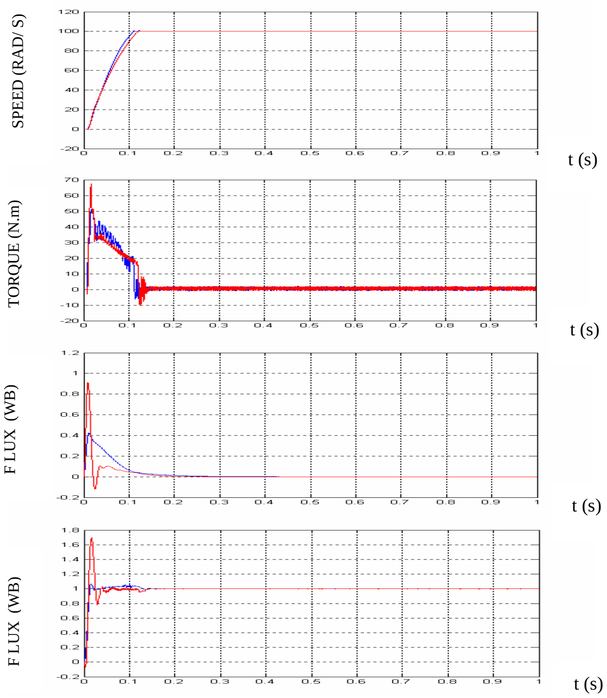


Fig. 8. Hybrid Fuzzy-sliding
Test speed for t=0.3 (s);100 (rd/s) et -100 (rd/s).



Red for a value Rt =2Rt; blue for a value Rt =Rt
Fig. 9. Test of robustness

7. Conclusion

The simulation results showed the potential possibilities of the sliding mode control strategy. The advantages of this technique are in the fact that it uses all the power of the controller to consolidate the external effects and the robustness which it has with respect to the parametric variations, unfortunately it strongly requests the control unit with a high frequency which is likely to damage this last one. In order to allow a regulation of flux and speed rather satisfactory, on determent of a significant activation causing a phenomenon called chattering and to implementation. We proposed another approach of reduce the complexity of the practical the tuning which uses the basic tools of fuzzy logic. Thus a fuzzy regulator–sliding based on the model of (Zada) combining the fuzzy and the sliding mode controllers showed the contribution of this new control strategy compared to the sliding mode control alone [7].

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