



High Performance Speed Control of Induction Motor Drive using a new Hybrid Fuzzy Sliding Mode Structure

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Abstract_ A new of hybrid fuzzy-sliding mode control strategy associated with the field-oriented control of induction motor drives is focused in this paper. The analysis, design and simulation of the fuzzy-sliding mode controller for indirect vector control of induction motor are analyzed and presented. The model is carried out using Matlab/Simulink. The main advantages of the proposed chattering-free speed controller are robustness to parameter variations and external load disturbance. The simulation results are shown to verify the effectiveness of the proposed speed controller, and its advantages are shown in comparison with the conventional SMC.

Keywords- Induction motor, vector control, fuzzy-sliding mode controller, high performance, robustness.

1. Introduction

Induction motors are widely used in many industrial applications due to their low maintenance, robustness and high performance. Due to the nonlinear characteristic of induction motor, linear controller such as PI type controller fails to give optimum performance. This controller is also sensitive to parameter variation, external disturbance, loads change. To solve these problems, intelligent controller such as sliding mode controller (SMC), Fuzzy logic Controller (FLC) etc. have been recently applied to drive systems [9]. Sliding mode control, which is a variable structure control class, attracts the attention of several researches in the field of electrical drive control. It is one of the popular strategies to deal with uncertain control systems. Currently, application of the Variable Structure System (VSS) control using sliding mode [9] has received wide attention in order to cope with these features. The main feature of SMC is the robustness against parameter variations and external disturbances. This control technique has many good properties to offer such as insensitivity to parameter variation, external disturbance and fast dynamic response [6]. SMC has been successfully implemented to control drive systems like Induction motor drives [2]. The importance of Sliding Mode



Controllers relies on the high accuracy, the simplicity of implementation and the robustness in respect to the parametric uncertainties of the modeling errors and certain external disturbances affecting the process. However, the commuting discontinuous nature of this technique can cause chattering, which can have a detrimental effect on the processes and can excite the high frequencies until it damages the process to regulate [6], [3]. The combination of intelligent control based on nonlinear fuzzy logic and sliding mode control, eliminates chattering problems [6], [12]. This combination is the most popular method to reduce the chattering phenomenon in sliding mode control (SMC) for uncertain nonlinear systems. Robustness being the best advantage of a SMC, it has been widely employed to control industrial systems, especially systems that have model uncertainty and external disturbance [12]. These advantages justify the necessity of applying this type of control for the IM drive systems.

This article is organized as follows: the model dynamic of induction motor is presented in section 2, then the command FOC is presented in section 3. Section 4 describes the sliding mode control Section 5, defines the fuzzy logic controller. The simulation results of this methods are presented in the section 6. Then, section 7 provides conclusions.

2. Differential Equations of Induction Motor

Mathematical description of the induction motor is based on complex space vectors, which are defined in a coordinate system rotating with angular speed. In per unit and real time representation the following vector equations describe behaviour of the motor. The dynamics of the induction motor in the $d-q$ motor reference frame, which is rotating at the synchronously speed, can be simply described by the following nonlinear differential [8], [10],[14]:

$$\left\{ \begin{array}{l} \frac{d}{dt} i_{sd} = \frac{1}{\sigma \cdot L_s} \left[+\omega_s \cdot \sigma \cdot L_s \cdot i_{sq} - \left(R_s + \frac{L_m^2}{L_r \cdot \tau_r} \right) \cdot i_{sd} \right. \\ \quad \left. + \frac{L_m}{L_r} \omega_r \cdot \phi_{rq} + \frac{L_m}{L_r \cdot \tau_r} \cdot \phi_{rd} + v_{sq} \right] \\ \frac{d}{dt} i_{sq} = \frac{1}{\sigma \cdot L_s} \left[-\omega_s \cdot \sigma \cdot L_s \cdot i_{sd} - \left(R_s + \frac{L_m^2}{L_r \cdot \tau_r} \right) \cdot i_{sq} \right. \\ \quad \left. - \frac{L_m}{L_r} \omega_r \cdot \phi_{rd} + \frac{L_m}{L_r \cdot \tau_r} \cdot \phi_{rq} + v_{sq} \right] \\ \frac{d}{dt} \phi_{rd} = \frac{L_m}{\tau_r} \cdot i_{sd} - \frac{1}{\tau_r} \cdot \phi_{rd} + (\omega_s - \omega_r) \cdot \phi_{rq} \\ \frac{d}{dt} \phi_{rq} = \frac{L_m}{\tau_r} \cdot i_{sq} - (\omega_s - \omega_r) \cdot \phi_{rd} - \frac{1}{\tau_r} \cdot \phi_{rq} \\ \frac{d}{dt} \omega = \frac{P^2 \cdot L_m}{L_r \cdot J} (i_{sq} \phi_{rd} - i_{sd} \phi_{rq}) - \frac{F}{J} \omega - \frac{P}{J} T_r \end{array} \right. \quad (1)$$

With: $\sigma = 1 - \frac{L_m^2}{L_s L_r}$

3. IndirectField Oriented Control

Indirect Field Oriented Control (IFOC) technique is intended to control the motor flux, and thereby be able to decompose the ac motor current into “fluxproducing” and “torque producing” components. The well-known indirect field orientation strategies provide a linear and decoupled control between the flux and torque of the induction machine [4],[5]. Then the rotor flux orientation process is given by the imposed zero constraint of quadrate rotor flux component. Such as:

$$\phi_{rq}=0 \text{ and } \phi_{rd}=\phi_r \quad (2)$$

Hence, the rotor flux can be controlled directly from the stator direct current component i_{sd} , while the torque can be linearly controlled from the stator quadrate current component i_{sq} when the rotor flux is maintained constant. Separating the real and imaginary parts of (1) by using (2) leads to:[8], [10], [14]:

$$\left\{ \begin{array}{l} v_{sd} = \sigma L_s \frac{d}{dt} i_{sd} + \left(R_s + R_r \frac{L_m^2}{L_r^2} \right) i_{sd} - \omega_s \sigma L_s i_{sq} - \frac{L_m}{L_r^2} R_r \phi_r \\ \quad = v_{sd}^r - \omega_s \sigma L_s i_{sq} \\ v_{sq} = \sigma L_s \frac{d}{dt} i_{sq} + \omega_s \sigma L_s i_{sd} + \left(R_s + R_r \frac{L_m^2}{L_r^2} \right) i_{sq} + \frac{L_m}{L_r^2} p \Omega \phi_r \\ \quad = v_{sq}^r - \omega_s \sigma L_s i_{sd} + \frac{L_m}{L_r^2} p \Omega \phi_r \end{array} \right. \quad (3)$$

The slip frequency can be calculated from the values of the stator current quadrate and the rotor flux oriented reference frame as follow:

$$\omega = \omega_s - \omega_r = \frac{L_m}{\tau_r} \frac{i_{sq}}{\phi_r} \quad (4)$$

And the rotor flux position is given by:

$$\theta_s = \int \omega_s dt \quad (5)$$

The voltages v_{sd} and v_{sq} should act on the current i_{sd} and i_{sq} separately and consequently the flux and the torque. The two-phase stators current are controlled by two PI controllers taking as input the reference values i_{sd}^* , i_{sq}^* and the measured values. Thus, the common thought is to realize the decoupling by adding the compensation terms (e_{sd} and e_{sq}) as usually done [1],[4].

$$\left\{ \begin{array}{l} e_{sd} = \omega_s \sigma L_s i_{sq} \\ e_{sq} = \omega_s \sigma L_s i_{sd} - \omega_s \frac{L_m}{L_r^2} \phi_r \end{array} \right. \quad (6)$$

The module of rotoric flux is obtained by a block of field weakening given by the following non-linear relation:

$$\phi_r^* \left\{ \begin{array}{ll} \phi_{rN} & \text{if } |\omega| \leq \omega_m \\ \phi_{rN} \frac{\omega_m}{|\omega|} & \text{if } |\omega| > \omega_m \end{array} \right. \quad (7)$$

The rotor flux is controlled by PI controller taking as input the reference value ϕ_r^* and the calculated value. The overall block diagram of indirect field orientation control for

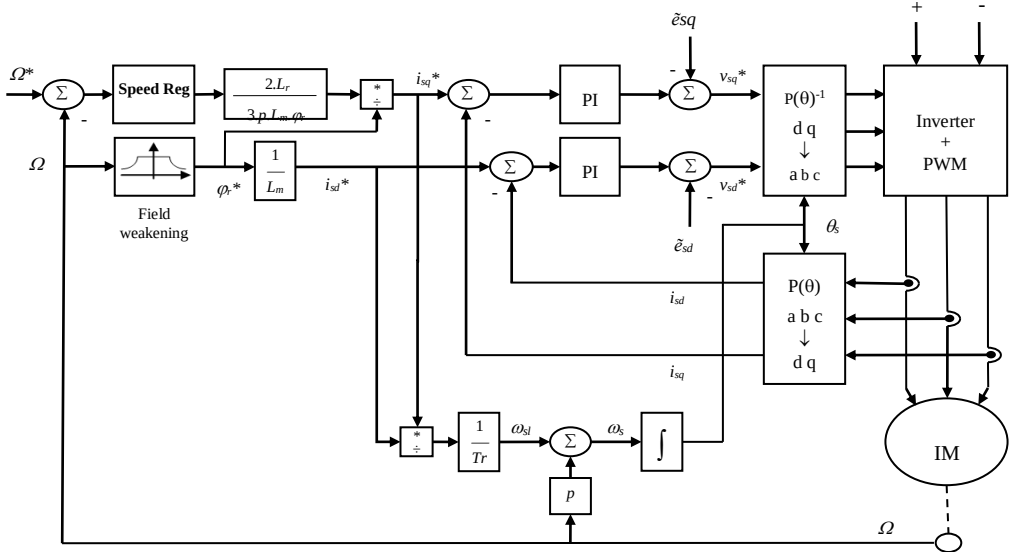


Fig.1. Indirect field-oriented control of IM

induction motor is given in Fig. 1. and the Fig.2. shows the fuzzy sliding mode control of the induction motor.

4. Sliding Mode Control

With sliding mode controller, the system is controlled in such a way that the error in the system states always moves towards a sliding surface. The sliding surface is defined with the tracking error e of the state and its rate of change $\dot{e}$ variables. The distance of the error trajectory from the sliding surface and its rate of convergence are used to decide the control input U to the system [13]. Determine a switching control strategy, U to drive the state trajectory into the equilibrium surface and maintain it on the surface. This strategy has the form:[7]

$$U = -k \operatorname{sign}(S) + U_{eq}(8)$$

Where U_{eq} is called equivalent control which is used when the system state is in the sliding mode. k is a constant and it is the maximal value of the controller output. S is the

switching function because the control action switches its sign on the two sides of the switching surface $s=0$. S is defined as [6], [7] and [9].

$$S = \dot{e} + \lambda e \quad (9)$$

Where $e = \Omega^* - \Omega$ and Ω^* is the desired state. λ is a constant, $\text{sign}(s)$ is a sign function, which is defined as:

$$\text{Sign}(S) = \begin{cases} -1 & \text{if } S < 0 \\ 1 & \text{if } S > 0 \end{cases} \quad (10)$$

Using a sign function often causes chattering in practice. One solution is to introduce a sat function. [6], [7]

Ω^* is the desired state and Ω is the measured speed which of the induction motor. Section 5 defines the fuzzy logic controller which gives the command U_{fuzzy} added with U_{eq} , we obtain U_{FSM} ; the fuzzy sliding mode command. So (8) becomes as follows: [13]

$$U_{\text{FSM}} = U_{\text{fuzzy}} + U_{\text{eq}} \quad (11)$$

The vector control with directed rotor flux can act on the flux and the electromagnetic torque via the stator voltcomponents V_{sd} and V_{sq} . In order to adjust the speed of the MAS using the sliding mode control, two sliding surfaces are required, represented by the size of the control vector U , namely the voltages V_{sd} and V_{sq} . The variables to be adjusted are the rotation speed Ω and the rotor flow φ_r . [6], [7].

The stability theory of Lyapunov is used to ensure the attractiveness and invariance of S , the following condition must be satisfied: [6]

$$S \cdot \dot{S} < 0. \quad (12)$$

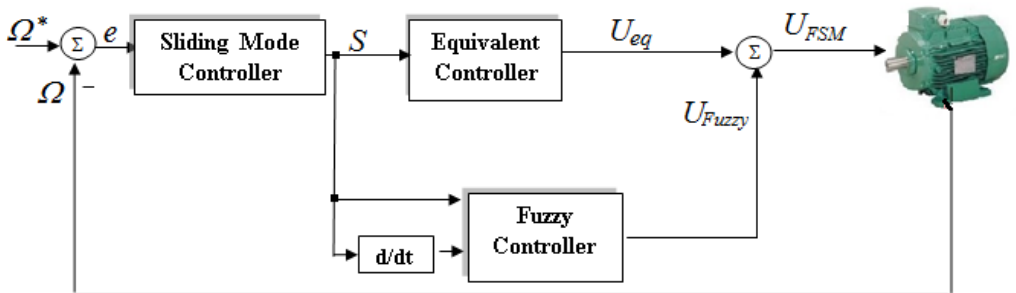


Fig.2. Fuzzy Sliding Mode Control of the Induction Motor

5. Fuzzy Logic Controller

The fuzzy controller (FLC) turn out to be interesting in most part of the commands in the industrial applications [11]. The proposed FLC is of type Mamdani where entries are the surface (S) and its derivative (ΔS), such as each variable of FLC has 7 sub-fuzzy sets. With NB: Negative Big, NM: Negative Medium, NS: Negative Small, ZE: Zero, PS: Positive Small, PM: Positive Medium and PG: Positive Big. The universe of discourse of the inputs and output of the FLC is chosen between -1 and 1 with a triangular type membership function as shown in Figures 3, 4 and 5. The table 1 shows the rules of fuzzy inference.

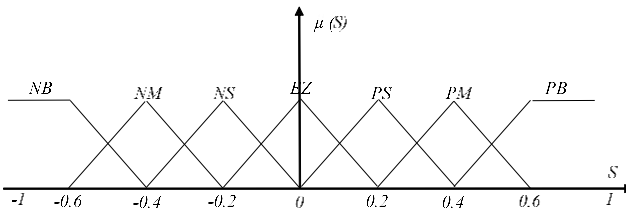


Fig.3. Membership function of the error S

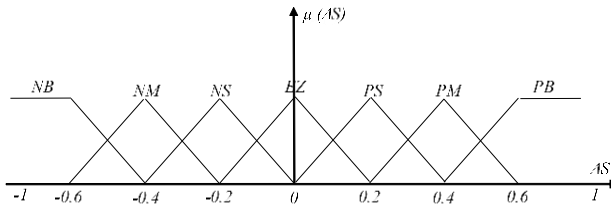


Fig.4. Membership function of the derivate error

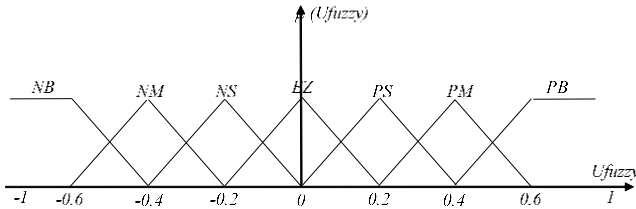


Fig.5. Membership function of the command U

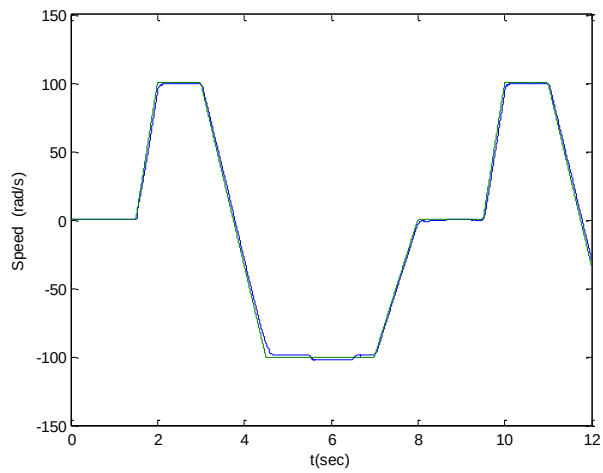


ΔS	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NM	NM	NS	NS	NS	ZE
NM	NM	NM	NS	NS	NS	ZE	PS
NS	NM	NM	NS	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PM
PS	NS	NS	ZE	PS	PS	PM	PM
PM	NS	ZE	PS	PS	PS	PM	PM
PB	ZE	PS	PS	PM	PM	PB	PB

Tale1.Fuzzy inference rules

6. Results and Interpretation

Figure 6 shows the results of simulation of each measured speed, measured torque and the stator current of the of the induction motor using a classic the fuzzy sliding mode control, under parameter variation of the rotor resistance (R_r) and the Inertia (J) about 20% of the nominal value. The result is depicted in Figure 7 and Figure 8. We note that despite the change of the rotor resistance and the Inertia about 20% of the nominal value using the fuzzy sliding mode control, this method remains robust.



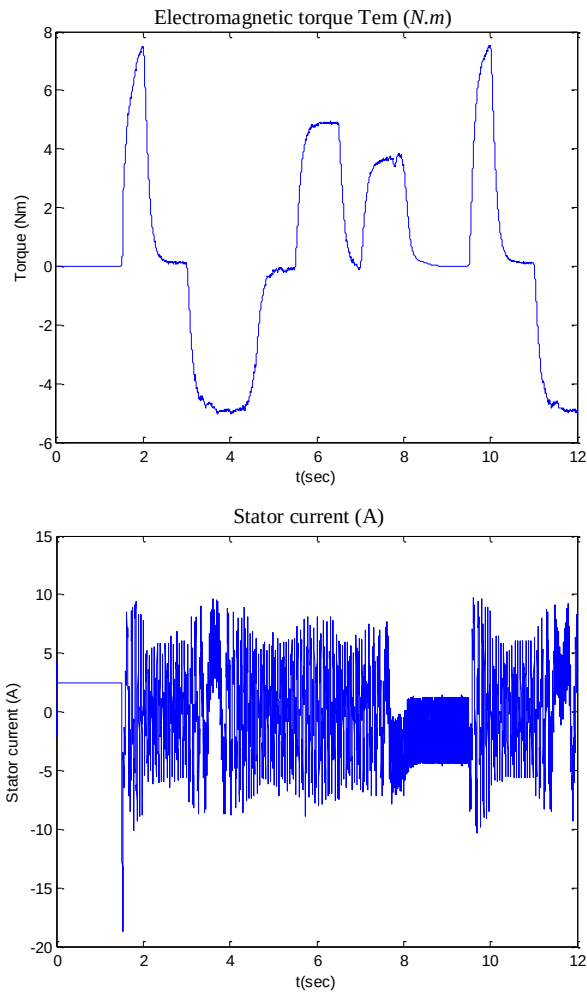
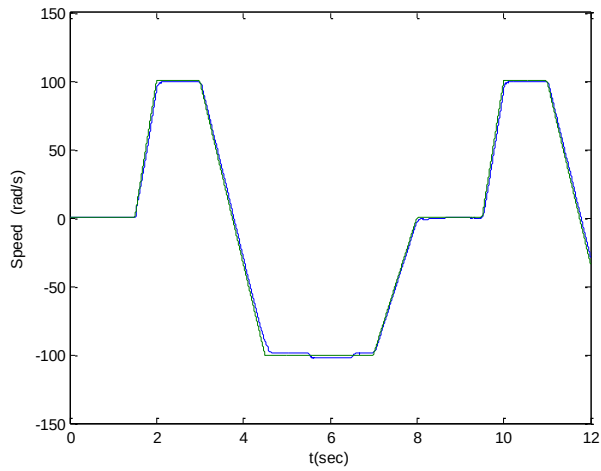
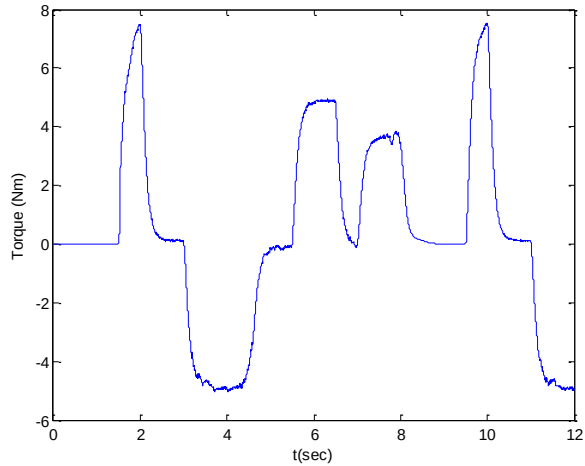


Fig 6: Evolution response system

Speed(rad/sec) under the resistance rotor variation about 20% of the nominal value



Electromagnetic torque T_{em} (N.m) under the resistance rotor variation about 20% of the nominal value



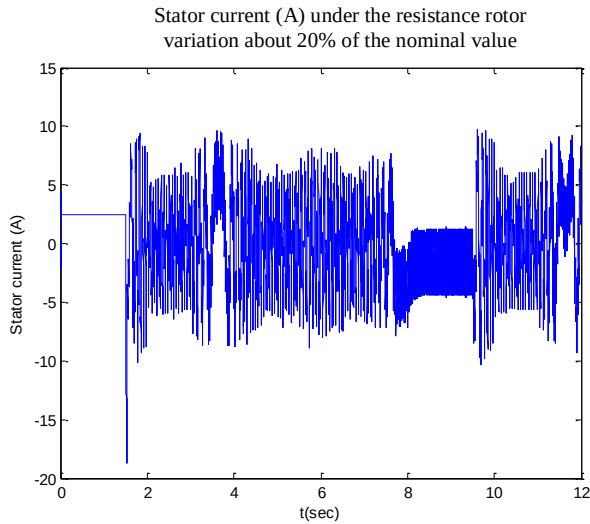
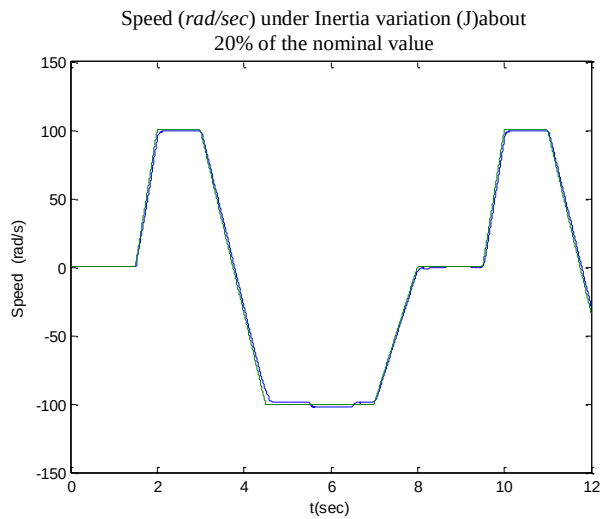


Fig .7. Evolution of the system under the resistance variation about 20% of the nominal value



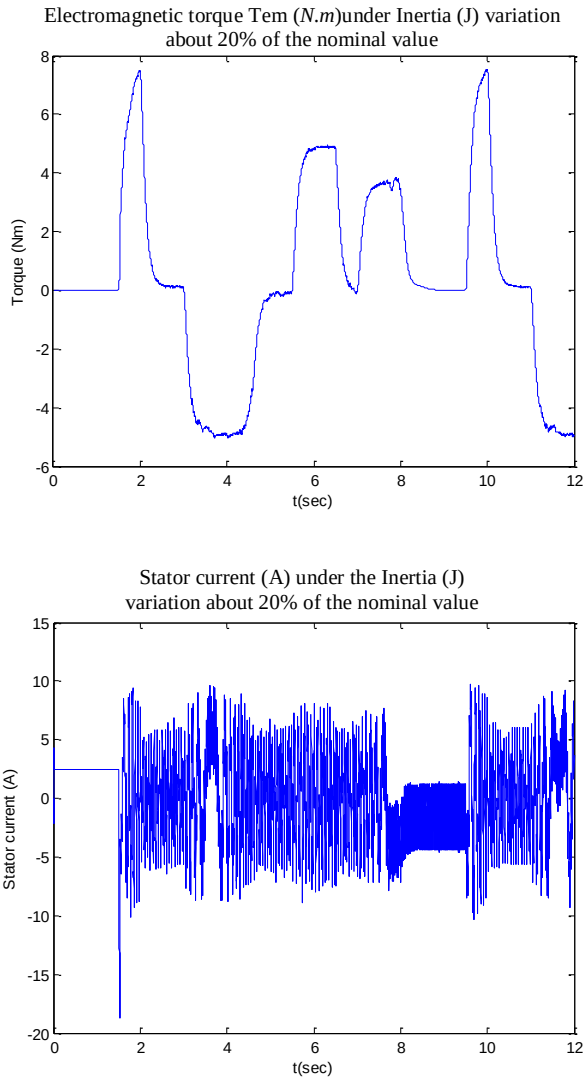


Fig 8. Evolution of the system under Inertia (J) variation about 20% of the nominal value

7. Conclusion

In this paper, hybrid fuzzy-sliding mode control strategy associated with the field-oriented control of induction motor drives is proposed to control the speed of the induction motor. The results obtained show that this method is robustness to parameter variations electrical: resistance rotor and mechanical: Inertia (J) and external load disturbance. This study shows also that the hybrid fuzzy sliding mode control strategy is efficient comparing than the sliding mode control method in eliminating chattering phenomena and response time.

APPENDIX: ENGINE PARAMETERS

1.5 kW, 3-phase, 220/380 V, 11.25/6.5 A, 50 Hz, 4 poles, 1420 rpm. $R_s = 4.85 \, \Omega$, $R_r = 3.805 \, \Omega$, $L_s = 0.274 \, \text{H}$, $L_r = 0.274 \, \text{H}$, $L_m = 0.278 \, \text{H}$, $J = 0.031 \, \text{kg.m}^2$, $F = 0.00114 \, \text{kg.m/sec}$.

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