

## Hybrid Fuzzy Sliding Mode Speed Control for an Electric Vehicle Drive

Ibrahim Farouk Bouguenna<sup>1</sup>, Ahmed Azaiz<sup>2</sup>, Ahmed Tahour<sup>3</sup>, Ahmed Larbaoui<sup>4</sup>

<sup>1,2</sup> Department of Electronics, University of Sidi Bel Abbes, University of Mascara, Algeria

<sup>3,4</sup> Department of Electrotechnics, University of Sidi Bel Abbes, Algeria

---

### Article Info

#### Article history:

Received Mar 17, 2017

Revised Jul 22, 2017

Accepted Aug 3, 2017

---

#### Keyword:

Dynamics

Electric vehicle

Fuzzy sliding

PMSM

Sliding mode control

---

### ABSTRACT

This paper present a speed hybrid fuzzy-sliding mode control (HFSMC) of a permanent magnet synchronous motor (PMSM) to ensure the traction of an electric vehicle; at the first we applied the sliding mode control (SMC) with three surfaces on the PMSM by taking into account the dynamics of the vehicle; And afterwards we applied the fuzzy-sliding mode in which the surface of the speed is replaced by a Fuzzy-PI controller; Simulation under Matlab/Simulink has been carried out to evaluate the efficiency and robustness of the proposed control on a system drive. It should be noted that the reference speed is the European urban driving schedule ECE-15 cycle.

Copyright © 2017 Institute of Advanced Engineering and Science.  
All rights reserved.

---

### Corresponding Author:

Ibrahim Farouk Bouguenna,  
Department of Electronics,  
University of Sidi Bel Abbes,  
Faculté de Technologie, Rue Kadi Ben Kadi, Sidi Bel Abbes.  
Email: vd-peda-ing@univ-sba.dz

---

## 1. INTRODUCTION

Due to the increasing requirements with regard to introducing environmental-friendly vehicles and electrification of vehicle systems, much research on electric vehicles has been carried out [1]. In particular control system as electric vehicle's brain which is a very important part of the whole system and, to a great extent, determines the entire vehicle performance, as it is the key to improve motor efficiency. in this context a Permanent magnet synchronous motor has been adopted as the electric vehicle (EV) propulsion.

Permanent magnet synchronous motors (PMSMs) have extensive industrial applications including electric vehicles, robotics, and wind energy conversion systems [2]-[4]. This can be attributed to desirable performance characteristics including high power density, high torque to weight ratio, high reliability and high efficiency [2]. Many control techniques for PMSMs have been developed in literature studies. While the PI controller is still a popular choice due to its simplicity and ease of implementation, it does not take disturbances and uncertainties into account, leading to poor performance [5].

It is difficult to attain the high performance control of PMSM with the conventional linear control methods like PI control algorithm. Nonlinear and robust control methods with the ability to reject disturbances have been applied to improve the performance of PMSM drives. One such method is sliding mode control (SMC) [6], fuzzy logic control (FLC) [7].  $H_\infty$  robust control methods have been applied in [8]-[9]. Model predictive control [10] have also found applications. Additionally, intelligent control methods have utilized [11]. Sliding mode control is a popular control due to its ability to reject internal parameter variations and external disturbances. SMC has found extensive applications in the areas of power electronics and electric machines [12]. Consequently, SMC has been widely and successfully applied into the position and velocity control of PMSM. However, SMC has its own disadvantage, i.e., chattering

phenomenon, which originated from the interaction between parasitic dynamics and high frequency switching control [13]. In order to avoid the phenomenon, a control method was proposed to reduce or completely eliminate the chattering, such as a hybrid fuzzy sliding mode control (HFSMC). The hybrid fuzzy sliding mode control [14] is one of the most common controls associated two techniques: fuzzy control [15] and sliding mode [16] to exploit the advantages of both techniques at the same time, to limit the disadvantages of regulation by conventional adjustment algorithms and to improve the performance of the controller system (stability, accuracy, speed, robustness, etc.).

In this paper, the surface of speed is substituted by a fuzzy-PI controller to obtain a robust performance. One part of the equivalent control (SMC) and part of fuzzy logic control (FLC) are contained in this hybrid control (HFSMC). The remainder of this paper is organized as follows: section 2 reviews the principle components of the traction system and their model equations. Section 3 shows the development of sliding mode controllers for electric vehicle motorization. Section 4 shows the proposed fuzzy-sliding mode control law model to remedy the chattering phenomena. The proposed structure of the studied propulsion system is given in the section 5. Section 6 a simulation results verify the validity of the proposed method of control. Finally the conclusion is drawn in section 7.

## 2. ELECTRIC VEHICLE TRACTION SYSTEM MODELING

Explaining this part is devoted to the dynamics of the electric vehicle and the different components on board the vehicle and their equations models. Figure 1 represents a diagram of an electric traction system.

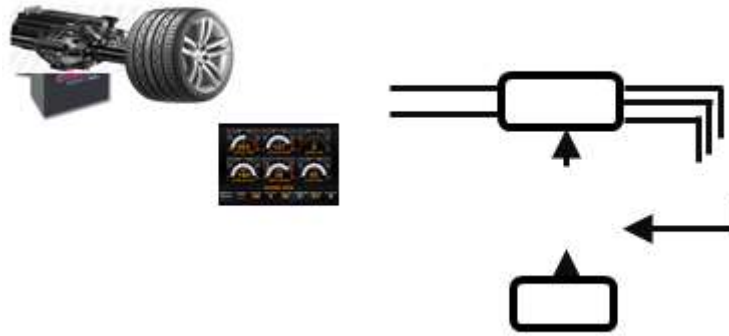


Figure 1. Block diagram of Electrical Traction System

### 2.1. Vehicle Dynamics

In this work the proposed control strategy takes into account the dynamic vehicle, so the first step in vehicle performance modeling is to write an electric force model. This is the force transmitted to the ground through the drive wheels, and propelling the vehicle forward. This force must overcome the road load and accelerate the vehicle [17]. Consider a vehicle of mass,  $m_v$  proceeding at a velocity  $v$ , up a slope of angle  $\alpha$ , as in Figure 2. The force propelling the vehicle forward  $F_t$ , the tractive effort, has to accomplish the following [19]-[21]:

- Overbear the rolling resistance;
- Overbear the aerodynamic drag;
- Provide the force needed to overcome the component of the vehicle's weight acting down the slope;
- Accelerate the vehicle, if the velocity is not constant.

The elementary equation describing the longitudinal dynamics of a vehicle in the road is in the following form:

$$m_v \frac{d}{dt} v(t) = F_t(t) - (F_{ad}(t) + F_r(t) + F_g(t)) \quad (1)$$

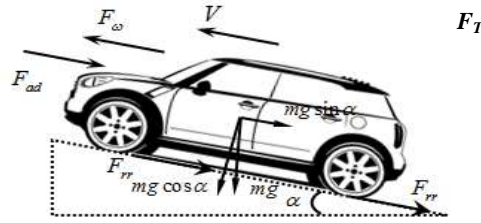


Figure 2. Block diagram of the forces acting on the vehicle

### 2.1.1 Rolling Resistance Force

The rolling resistance force is related to the mass of the vehicle  $m_v$ , the gravitational acceleration and the rolling coefficient of the wheels. Practically, with modern tires with very low rolling resistance, the coefficient of rolling resistance  $C_{rr}$  is equal to About 0.01 (about 0.015 for conventional tires) [19]. This coefficient depends on the width of the Tires and road surfacing. Consequently, the rolling resistance force is equal to [18]:

$$F_{rr} = C_{rr} \cdot m_v \cdot g \cdot \cos(\alpha) \quad (2)$$

### 2.1.2 Aerodynamic Resistance Force

The aerodynamic resistance force is proportional to the density of the air  $\rho$ , to the square of the vehicle speed  $v$  and to the wind speed  $v_0$ , to the frontal surface of the vehicle  $A_r$  and its coefficient of penetration into the air which takes values  $C_d$  [0.25-0.5] according to the forms of body. Its expression is given by the following relation [18].

$$F_{ad} = \frac{1}{2} \cdot \rho \cdot A_r \cdot C_d \cdot (v - v_0)^2 \quad (3)$$

### 2.1.3 Force of Gravity (Hill climbing force)

The gravitational force is induced by gravity when driving on a non-horizontal road depends on the slope of the road. According to Figure 2, the force is positive when the vehicle is traveling up and negative when on a descent. It is modeled as:

$$F_g = \pm m_v \cdot g \cdot \sin(\alpha) \quad (4)$$

### 2.1.4 Acceleration Force

The force due to the acceleration  $F_{acc}$  ensures the dynamic behavior desired by the driver. This force is obtained by the product between the vehicle mass and the acceleration imposed by the driver [22].

$$F_{acc} = m_v \cdot \frac{d}{dt} \cdot v(t) \quad (5)$$

### 2.1.5 Total Traction Effort

The traction force in an electric vehicle is supplied by the electric motor in overcoming the road load. The Equation of motion is given by:

$$m_v \cdot \frac{d}{dt} \cdot v(t) = F_T - (F_{rr} + F_{ad} + F_g) \quad (6)$$

### 2.1.6 Gear

The speed gear ensures the transmission of the motor torque to the driving wheels. The gear is modeled by the gear ratio  $i$ , the transmission efficiency and its inertia. The mechanical Equation is given by [22]:

$$J \frac{d\omega_r}{dt} = T_m - f \omega_r - C_r \quad (7)$$

The following Equation is derived due to the use of a reduction gear.

$$\begin{cases} \omega_{\text{wheel}} = \frac{\omega_r}{i} \\ T_{\text{wheel}} = T_m \cdot i \cdot \eta_i \end{cases} \quad (8)$$

The load torque in the motor referential is given by :

$$C_r = \frac{C_{\text{wheel}}}{i} = \frac{R}{i} (F_r + F_{\text{ad}} + F_v) \quad (9)$$

The vehicle global inertia moment in the motor referential is given by:

$$\begin{cases} J = J_\omega + J_v \\ J_v = \frac{1}{2} m \frac{R^2}{i^2} (1 - \lambda) \end{cases} \quad (10)$$

If the adhesion coefficient of the road surface is high, then  $\lambda$  is usually low and can be neglected.

## 2.2. Mathematical model of the PMSM

In this work we use a three phase induction motor type PMSM In the stationary (d-q) reference frame, the mathematics mode of permanent-magnet synchronous motor is shown as below [23]-[25]:

$$\begin{cases} \dot{i}_d^* = -\frac{R_s}{L_d} i_d + \frac{L_q}{L_d} p \omega_r i_q + \frac{1}{L_d} u_d \quad (a) \\ \dot{i}_q^* = -\frac{R_s}{L_q} i_q - \frac{L_d}{L_q} p \omega_r i_d - \frac{p \psi_f}{L_q} \omega_r + \frac{1}{L_q} u_q \quad (b) \\ \dot{\omega}_r^* = \frac{p(L_d - L_q) i_d + p \psi_f i_q}{J} - \frac{1}{J} C_r - \frac{f}{J} \omega_r \quad (c) \end{cases} \quad (11)$$

With  $R_s$ : Stator resistance,  $L_d, L_q$ : d and q axis stator inductances  $\psi_f$ : Permanent-magnet flux linkage,  $i_d, i_q$ : Stator currents  $u_d, u_q$ : Stator voltages,  $\omega_r$ : Speed mechanic,  $J$ : Moment of inertia,  $f$ : Coefficient of viscous friction,  $P$ : Number of pole pairs,  $C_r$ : Load torque. Several types of batteries can be distinguished, but for the current electric vehicles, lithium-ion, lead-acid and nickel-cadmium batteries are frequently used. In this section, we will be interested in storage systems based on Li-ion batteries [26].

## 3. SLIDING MODE CONTROL DESIGN FOR PMSM

Sliding mode control (SMC) is a nonlinear control method that has become popular due to its inherent robustness, flexibility of design, and relative ease to implement with microprocessors. Sliding mode control utilizes a discontinuous control approach that rapidly switches from one continuous manifold to another, forcing the system dynamics to a predetermined location in the state space called the sliding surface [12]. SMC has its own disadvantage, i.e., chattering phenomenon, which originated from the interaction between parasitic dynamics and high frequency switching control. In order to avoid the phenomenon, several control methods were proposed in the literature [14],[27]. Consider the nonlinear switching system multivariable taking this form [28]:

$$\dot{x}^{(n)} = f(x, t) + g(x, t) \cdot u \quad (12)$$

Where  $x(t)$  is state variable vector,  $f(x, t)$  and  $g(x, t)$  are the smooth vector fields in the space, and  $u$  is the discontinuous control defined as :

$$f(x) = \begin{cases} U^-, s(x, t) < 0 \\ U^+, s(x, t) > 0 \end{cases} \quad (13)$$

$s(x)$  is known as the sliding surface and is chosen so that the state variables track their desired trajectories.  $U^+$  and  $U^-$  are either scalar values or function of  $x(t)$ . A system with this description exhibits sliding mode properties when the reachability, existence, and stability conditions are met. The reachability condition ensures that the trajectory of the system will approach and eventually reach the sliding surface. This can be stated mathematically

$$s(x)s^*(x) < 0 \quad (14)$$

### 3.1. Three surface control strategy

We take the general equation Proposed by J.J.Slotine to determine the sliding surface :

$$s(x, t) = \left( \frac{\partial}{\partial t} + \lambda \right)^{(n-1)} \cdot e \quad (15)$$

where:

$e$  : Error of the quantity to be controlled,

$\lambda$  : Vector of slopes of the  $s$ ,

$n$  : Relative degree, equal to the number of times it derives the output for the command to appear.

Once the switching function is established the problem of pursuit requires the design of a control law as the state vector  $e(t)$  rest on the sliding surface  $s(x, t) = 0$  for all  $t \geq 0$ . Figure 3 shows scheme of the sliding mode control of the electric traction system using the principle of the cascade control method, the structure comprises a speed control loop which generates the current reference  $i_{qref}$  which imposes the control  $v_{qref}$ , the control  $v_{dref}$  is imposed by the current regulation  $i_{dref}$ .

#### 3.1.1 Direct Axis Control Design

Expression of current  $i_d$  is given by the Equation 11a: We note that from Equation 11a, the relative level of current  $i_d$  with the control  $u_d$  is equal to one. So the error variable  $e_d$  is given by:

$$e_d = i_{dref} - i_d \quad (16)$$

The resulting error will be corrected by a regulator operating in the sliding mode and the surface of this control is given by:

$$s_1 = i_{dref} - i_d \quad (17)$$

Therefore the derivative of the surface:

$$s_1^* = i_{dref}^* - i_d^* \quad (18)$$

Considering the expression of the current  $i_d$  deduced in the equation system Equation 11a, the derivative of the surface becomes:

$$s_1^* = i_{dref}^* + \frac{R_s}{L_d} i_d - \frac{L_q}{L_d} p \omega_r i_q - \frac{1}{L_d} u_d \quad (19)$$

During the sliding mode we have  $s^*(i_d) = 0, U_{qN} = 0$

$$U_{deq} = (i_{dref}^* + \frac{R_s}{L_d} i_d - \frac{L_q}{L_d} p \omega_r i_q) L_d \quad (20)$$

$$U_{dN} = K_d \text{sign}(s(i_d)) \quad (21)$$

Where:  $K_d$  is positive gain for the direct current regulator.

### 3.1.2 Quadrature Axis Control Design

Expression of current  $i_q$  is given by the Equation 11b. The value of  $i_{qref}^*$  in the output of the speed controller is compared with that measured. The resulting error will be corrected by a regulator operating in sliding mode. Then, following the same previous procedure, we can calculate  $U_{qref}^*$  and  $U_{qN}$ . The surface of this control is given by the following Equation:

$$s_2 = i_{qref}^* - i_q \quad (22)$$

Its derivative is given by:

$$s_2^* = i_{qref}^* - \dot{i}_q \quad (23)$$

Replacing the value  $\dot{i}_q$  of Equation 11b in Equation 24, we obtain:

$$s_2^* = i_{qref}^* - (-\frac{R_s}{L_q} i_q - \frac{L_d}{L_q} p \omega_r i_d - \frac{p \psi_f}{L_q} \omega_r + \frac{1}{L_q} u_q) \quad (24)$$

During the sliding mode we have  $s^*(i_q) = 0, s(i_q) = 0, U_{qN} = 0$

$$U_{qeq} = (i_{qref}^* + \frac{R_s}{L_q} i_q + \frac{L_d}{L_q} p \omega_r i_d + \frac{p \psi_f}{L_q} \omega_r) L_q \quad (25)$$

$$U_{qN} = K_q \text{sign}(s(i_q)) \quad (26)$$

With:  $K_q$  is positive gain for the quadratic current regulator.

### 3.1.3 Speed control

It is noted that from Equation 11c, the relative degree of the speed with  $i_q$  is equals to one: In this case, the setting error is chosen as the surface:

$$s = \omega_{ref} - \omega_r \quad (27)$$

Therefore its derivative

$$s^* = \omega_{ref}^* - \dot{\omega}_r \quad (28)$$

By replacing Equation 11c in Equation 20, we obtain:

$$s^* = \omega_{ref}^* - \frac{p(L_d - L_q)i_d + p\psi_f i_q + \frac{1}{J}C_r + \frac{f}{J}\omega_r}{J} \tag{29}$$

During the sliding mode we have  $s^*(\omega_r) = 0, s(\omega_r) = 0, i_{qn} = 0$

$$i_{qsi} = \frac{\omega_{ref}^* + \frac{f}{J}\omega_r + \frac{1}{J}C_r}{\frac{p(L_d - L_q)}{J}i_d + p\frac{\psi_f}{J}} \tag{30}$$

$$i_{qn} = K_{sv} \text{sign}(s(\omega_r)) \tag{31}$$

with :  $K_{sv}$  is positive gain for the speed controller.

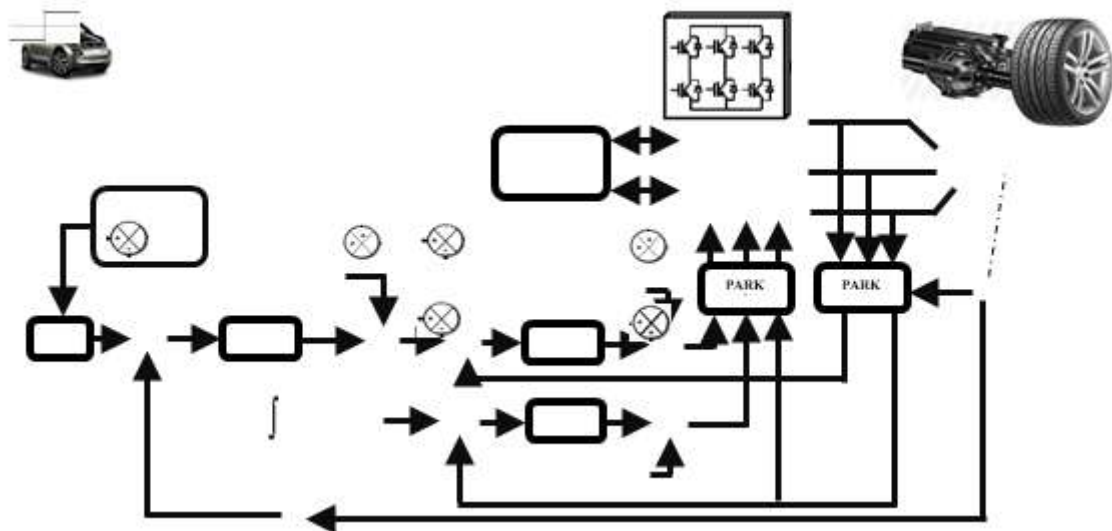


Figure 3. Block diagram of sliding mode control speed for an EV

#### 4. FUZZY SLIDING MODE STRATEGY DESIGN

Sliding The disadvantage of sliding mode controllers is that the discontinuous control signal produces chattering dynamics, for this reason the combination of SMC with the fuzzy logic control (FLC) aims to improve the robustness and the performance of controlled nonlinear systems [29], This work proposes a hybrid fuzzy sliding mode speed control that can remarkably attenuate chattering and accurately track the speed of PMSM. In this section, a fuzzy-sliding mode control is developed in which a fuzzy inference mechanism is used. The proposed hybrid fuzzy-sliding mode control (HFSMC) scheme for electric vehicle (EV) speed control is shown in Figure 4. The PI fuzzy logic controller replaces the speed surface sliding mode. This fuzzy-PI controller is a generalization of the conventional PI controller that uses an error signal and its derivative as input signals. Fuzzy-PI controllers have two inputs and one output. The PI-fuzzy logic controller in Figure 4 is developed using input membership functions for error  $e$  and change in error  $de$  and the output membership function for  $w_m$ , the measured speed for PMSM.

$$e = \omega_r - \omega_m \tag{32}$$

$$de = e_k - e_{k-1} \tag{33}$$

Where  $w_r$  is the referenced or desired output speed and  $w_m$  is the actual output speed. The block diagram of the fuzzy sliding mode control of PMSM is identical to that shown in Figure 3, replacing the speed SMC controller by fuzzy PI controller, as shown in Figure 4.

To convert these numerical variables into linguistic variables, the following seven fuzzy levels or sets are chosen as: NB (negative big), NM (negative medium), NS (negative small), ZE (zero), PS (positive small), PM (positive medium), and PB (positive big) as shown in Table 1. It is well known as one of the disadvantages of the SMC is the Chattering phenomenon. In this section, a fuzzy logic control FLC is introduced to replace the speed surface, such as the state trajectory can reach and move along the surface change, a good dynamic steady state can be achieved by the combination of SMC and FLC [30]-[31], the benefits of the proposed fuzzy sliding mode control is verified by simulation results.

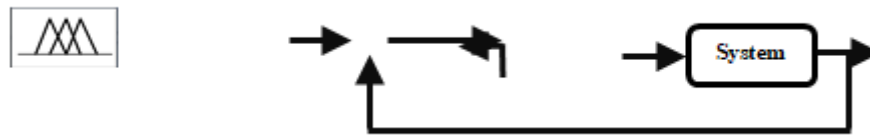


Figure 4. Block Diagram of Proposed Fuzzy Sliding Mode Control Speed

Table 1. Seven Fuzzy Levels

$e$ $de$	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

### 5. SIMULATION RESULTS

In order to characterize the vehicle traction system behavior, simulations were carried out using the model of the Figure 3 and Figure 4. They show the vehicle speed control using sliding mode controllers (SMC) and fuzzy sliding mode controllers (FMSC). Figure 5 show the linear speed of the vehicle.

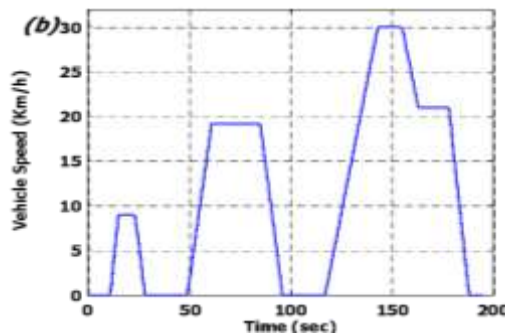


Figure 5. Linear speed of Vehicle

It should be noted that the simulation run under European urban driving cycle ECE-15, during this cycle three trapezoids speed (9 km/h, 19 km/h, 30 km/h) shall be requested by the driver. In addition we



applied a slope of 10% between 16s and 23s. The purpose of this simulation mode is to test our control technique through a real driving cycle.

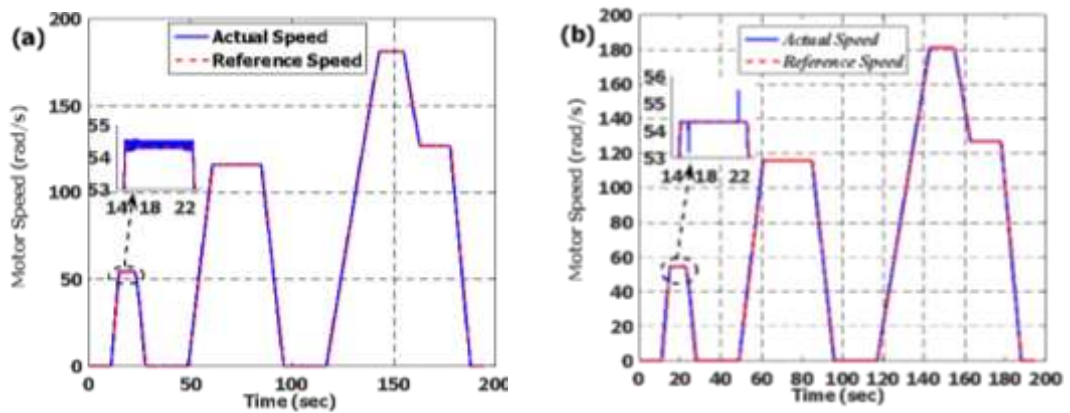


Figure 6. Motor Speed (SMC & HFSMC)

The classical sliding mode control (SMC) described above is compared to the proposed hybrid fuzzy sliding mode control law (HFSMC). Figure 6 shows the vehicle speed response in tow cases (SMC and HFSMC). From Figure 6 and Figure 7 the dynamic behaviour of the SMC and HFSMC differ. In Figure 6a the rotation speed of the motor can rapidly track the reference rotation speed, but this control commutes very rapidly between its two limits, which influences the total control of the vehicle, a relatively large sliding surface is observed which causes fluctuations in the response of the system and a considerable tracking error Figure 7a It is the phenomenon of chattering. In Figure 6b the hybrid fuzzy sliding mode control act immediately on the speed loop by a considerable reduce of the chattering phenomenon and the tracking error Figure 7b.

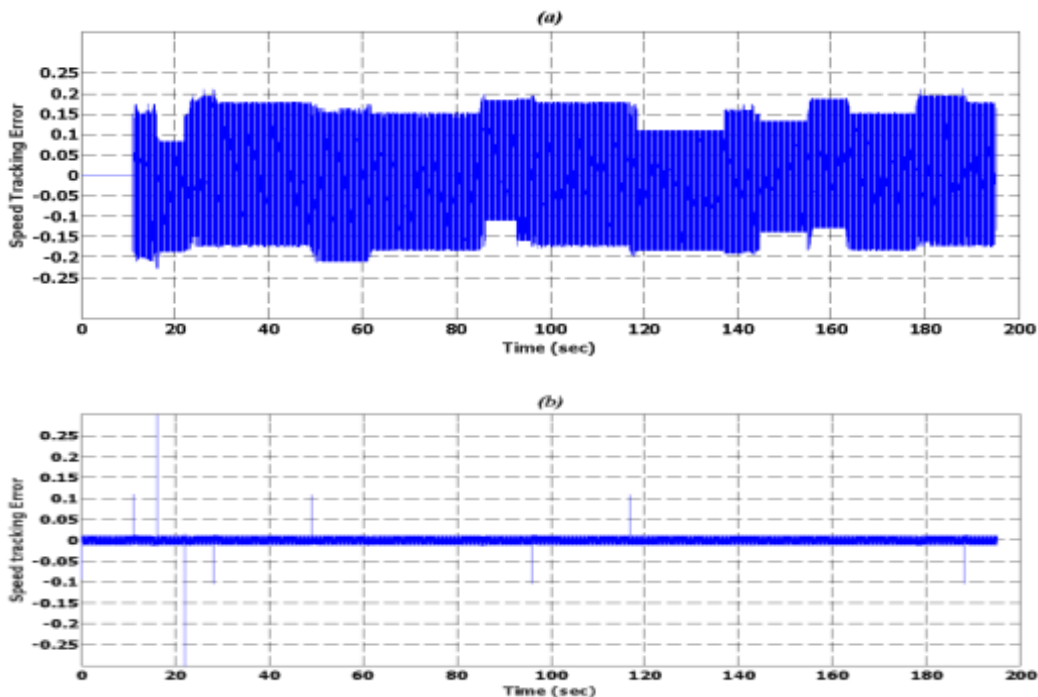


Figure 7. Speed Tracking Error (SMC & HFSMC)

Figures 8(a) and (c) shows the variation of electromagnetic torque as load torque changes, Figures 8(b) and (c) illustrates the tow current components quadratic and direct and show good decoupling introduced by PMSM control (the current  $i_d = 0$ ), also the magnitude of q-axis current,  $i_q$  is proportional to the load torque. Figure 9 shows the three-phase current of the stator. From Figures 8 and 9 it can be seen clearly the effectiveness and performance of the fuzzy sliding mode control. It gives a good performance toward the future value of speed without overflow, decoupling and orientation are provided, the stator current has a sinusoidal, thus, a total disturbance rejection control.

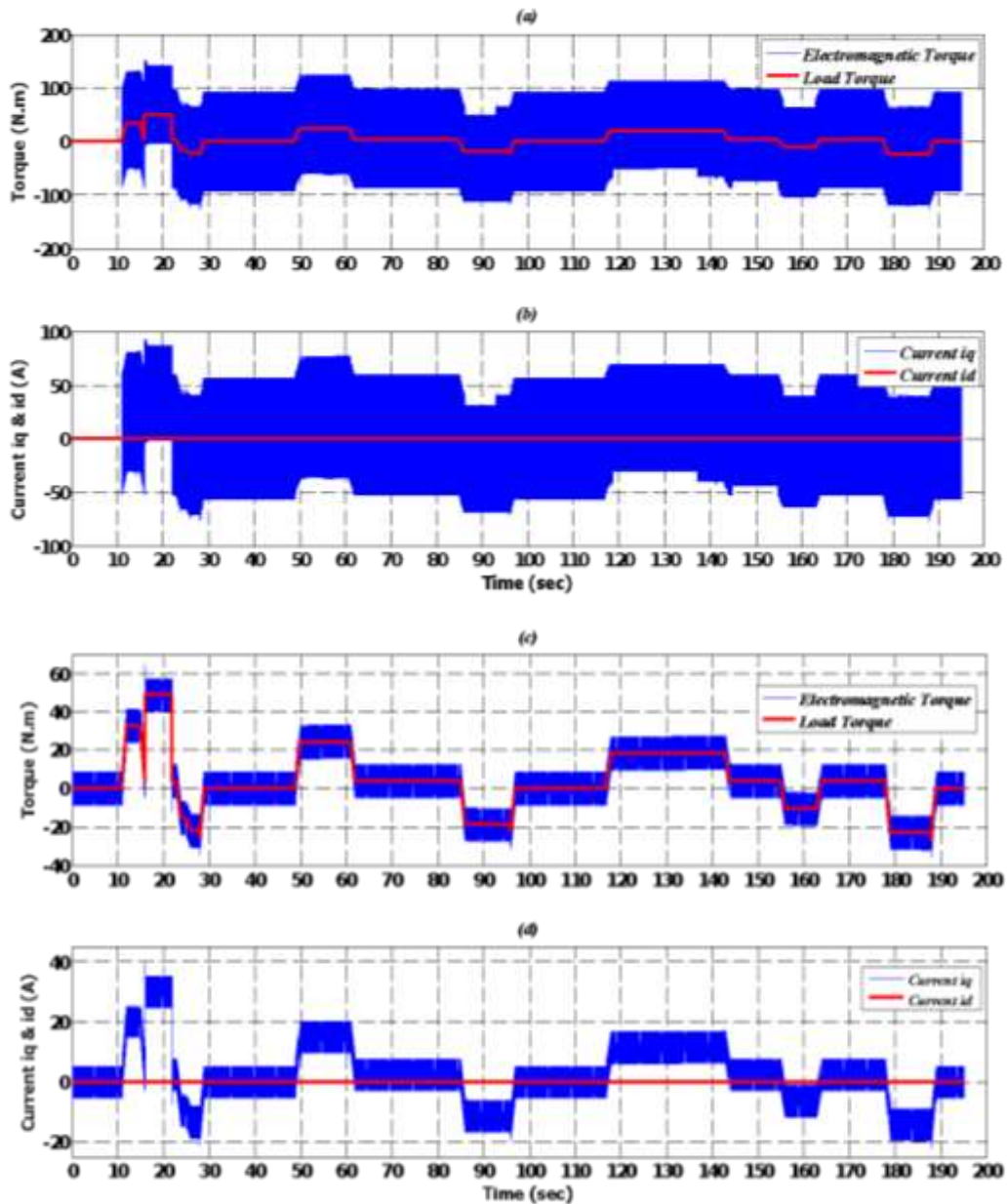


Figure 8. (a)&(c) Electromagnetic and load torque in SMC and HFSCM , (b)&(d) quadratic and direct currents in SMC and HFSCM

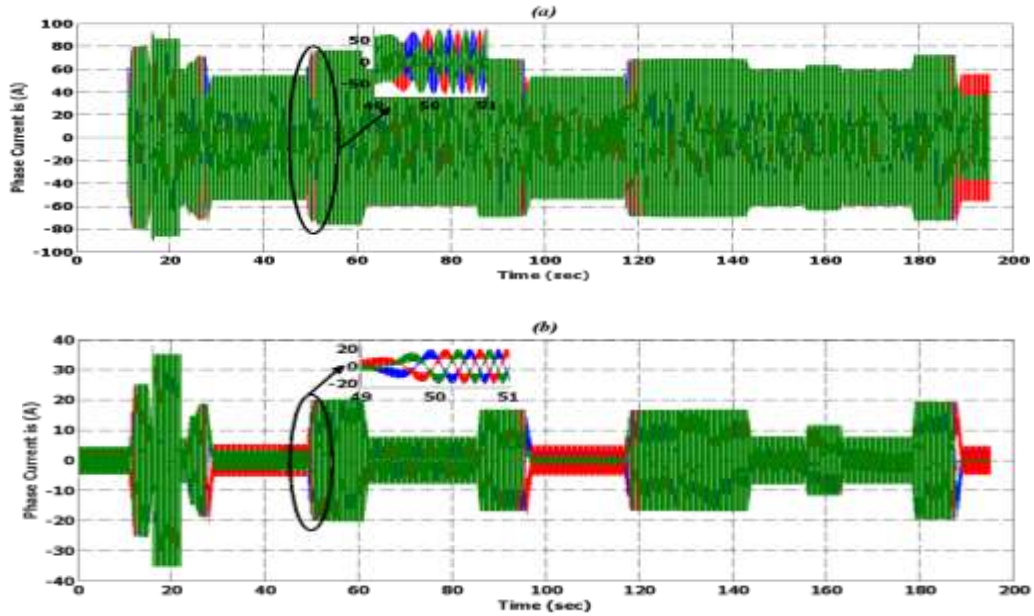


Figure 9. Three phase current  $i_a$  (SMC and HFSCM)

Figure 10 shows the traction force of the vehicle and the different load torques that resist to the advancement of the vehicle on a sloping road.

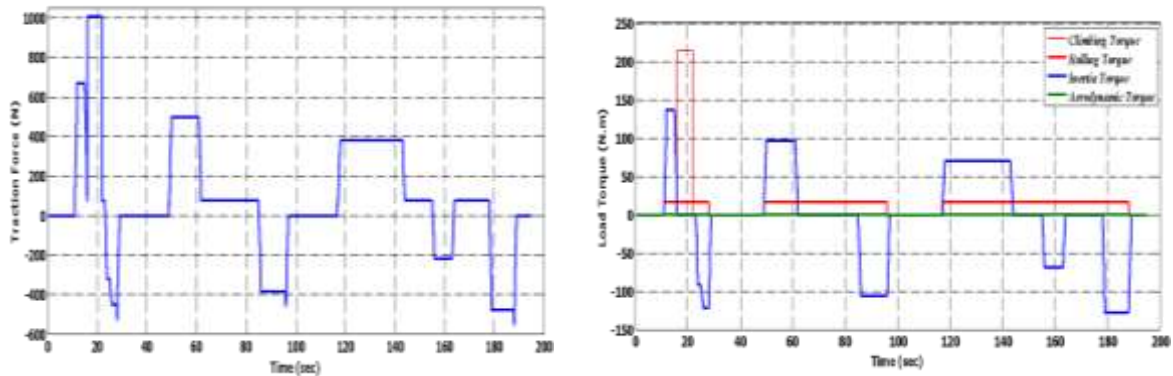


Figure 10. Traction force and Load torques

## 6. CONCLUSION

These studies demonstrate the robustness and the dynamic performance of the electric vehicle using hybrid fuzzy sliding mode control (HFSCM). Furthermore it's to improve control robustness and establish a bridge between fuzzy logic and sliding mode. The proposed hybrid FSMC simulation results show that the proposed controller overcomes the chattering phenomenon in the sliding mode control and the shortage of tools for analyzing the fuzzy logic control without forgetting the reduction rules blurred to improve control performance and to reduce chattering in the sliding mode. Moreover the proposed controller is robust in case of variations in the desired output caused by propulsion system load variations.

## REFERENCES

- [1] K. Nam, Y. Hori and C. Lee, " Wheel Slip Control for Improving Traction-Ability and Energy Efficiency of a Personal Electric Vehicle Energies" 2015, 8(7), 6820-6840; doi:10.3390/en8076820

- [2] S. Morimoto et al., "Experimental Evaluation of a Rare-Earth-Free PMSynRM With Ferrite Magnets for Automotive Applications," *IEEE Transactions on Industrial Electronics*, vol.61, no.10, pp. 5749-5756, Oct. 2014.
- [3] S. Wekhande and V. Agarwal, "High-resolution absolute position Vernier shaft encoder suitable for high-performance PMSM servo drives," *IEEE Transactions on Instrumentation and Measurement*, vol.55, no.1, pp. 357-364, Feb. 2006.
- [4] A. Leon et al., "An Improved Control Strategy for Hybrid Wind Farms," *IEEE Transactions on Sustainable Energy*, vol.1, no.3, pp. 131-141, Oct. 2010.
- [5] A. Sant and K. Rajagopal, "PM Synchronous Motor Speed Control Using Hybrid Fuzzy-PI With Novel Switching Functions," *IEEE Transactions on Magnetics*, vol.45, no.10, pp. 4672-4675, Oct. 2009.
- [6] X. Zhang et al., "Nonlinear Speed Control for PMSM System Using Sliding-Mode Control and Disturbance Compensation Techniques," *IEEE Transactions on Power Electronics*, vol. 28, no. 3, pp.1358-1365, March 2013.
- [7] P. Li, X. Yan, and J. Liu, "Study on inverse system of permanent magnet synchronous motor by decoupled Fuzzy Sliding Mode Control," in Proc. Int. Conf. Intell. Control Inform. Process., Aug. 2010, pp. 538-542.
- [8] L. Bingyou, "Research on H infinity Robust Tracking Controller for Permanent Magnet Synchronous Motor Servo System," International Conference on Information Engineering and Computer Science, pp. 1- 5, 19-20, Dec. 2009.
- [9] Y. Altun et al., "A novel feed-forward controller for PMSMs," 3rd International Conference on Electric Power and Energy Conversion Systems, pp.1-5, Oct. 2013.
- [10] A. Imura et al., "Instantaneous-current control of PMSM using MPC: Frequency analysis based on sinusoidal correlation," 37th Annual Conference on IEEE Industrial Electronics Society, pp. 3551-3556, Nov. 2011.
- [11] B. Mobarakeh, F. Meibody-Tabar, and F. Sargos, "A self organizing intelligent controller for speed and torque control of a PMSM," IEEE Industry Applications Conference, pp.1283-1290. 2000
- [12] Max Reitz, Xin Wang, Patrick Gu, "Robust Sliding Mode Control of Permanent Magnet Synchronous Motor Drives" 978-1-5090-0403-4/16, 2016, *IEEE*
- [13] Chung, S.C.Y., Lin, C.L.: A Transformed Lure Problem for Sliding Mode Control and Chattering Reduction. *IEEE Trans. Automatic Control* 44, 563-568 (1999)
- [14] N.K. Yadav and R. K. Singh, "Hybrid Fuzzy Sliding Mode Controller for Timedelay System", *International Journal of Artificial Intelligence & Applications (IJAA)*, Vol. 4, n°. 4, July 2013.
- [15] L. Jian, Z. Wang, "Fuzzy Control Simulation of the Magnetic Suspension Bearings System", *Microcomputer Information*, Vol. 23, n°. 9, pp. 22-24, 2007.
- [16] H. Bai, R. Qi, "Integral sliding mode variable structure control for active magnetic bearings", *Transactions of China Electrotechnical Society*, Vol. 23, n°. 8, pp. 36-40, 2008.
- [17] Sadeghi, S. & Mirsalim, M. (2010). Dynamic Modeling and Simulation of a Switched Reluctance Motor in a Series Hybrid Electric Vehicle, *International peer-reviewed scientific journal of Applied sciences*, Vol.7, No.1, (2010), pp. 51-71, ISBN 1785-8860.
- [18] L. Guzzela and A. Sciarretta, *Vehicle Propulsion Systems: Introduction to Modeling and Optimization*. Springer-Verlag Berlin Heidelberg, 2007.
- [19] C.C. Chan, Y.S. Wong: Electric Vehicles Charge Forward, *IEEE Power and Energy Magazine*, Vol. 2, No. 6, Nov/Dec. 2004, pp. 24 - 33.
- [20] Z.Q. Zhu, D. Howe: Electrical Machines and Drives for Electric, Hybrid, and Fuel Cell Vehicles, *Proceeding of the IEEE*, Vol. 95, No. 4, April 2007, pp. 746 - 765.
- [21] M. Vasudevan, R. Arumugam: New Direct Torque Control Scheme of Induction Motor for Electric Vehicles, *Asian Control Conference*, Melbourne, Australia, Vol. 2, July 2004, pp. 1377 - 1383.
- [22] Multon B., Hirsinger L. (1996), Problème de la motorisation d'un véhicule électrique. *revue 3EI*, pp. 55-64.
- [23] R.F. Fung, C.L. Chiang, G.C. Wu, System identification of a pick-and-place mechanism driven by a permanent magnet synchronous motor, *Appl. Math. Model.* 34 (2010) 2323-2335.
- [24] P.C. Krause, *Analysis of Electric Machinery*, McGraw-Hill, New York, 1984.
- [25] P. Pillay, R. Krishnan, Modelling of permanent magnet motor drives, *IEEE Trans. Indust. Electron.* 35 (1988) 537-541.
- [26] Gaoua Y., (2014), modèles mathématiques et techniques d'optimisation non linéaire et combinatoire pour la gestion d'énergie d'un système multi-source : vers une implantation temps réel pour différentes structures électriques de véhicules hybrides. Thèse de doctorat, université de Toulouse.
- [27] A.Tahour, A.Hamza, A.Aissaoui :Speed Control of Switched Reluctance Motor using Fuzzy Sliding Mode, *Advance in Electrical and Computer Engineering*, Vol.8.15, Number 1(29), 2008.
- [28] A. Kechich, B. Mazari, I.K. Bousserhane, "Application of nonlinear sliding-mode control to permanent magnet synchronous machine", *International journal of applied Engineering research*, Vol. 2, n°. 1, pp. 125-138, 2007.
- [29] F. Song, S.M. Smith, "A comparison of sliding mode controller and fuzzy sliding mode controller," *NAFIPS'2000*, The 19th Int. Conference of the North American Fuzzy Information Processing Society, pp. 480-484, 2000.
- [30] W. Rong-Jong, S. Kuo-Ho and T. Chun-Yen, "Implementation of Adaptive Enhanced Fuzzy Sliding-Mode Control for Indirect Field-Oriented Induction Motor Drive", *IEEE the IEEE International Conference on Fuzzy Systems*, Vol. 2, pp. 1440-1445, May 2003.
- [31] Zhao Junhui, Wang Mingyu, Li Yang, Zhou Yanjing and Liu Shuxi, "The Study on the Constant Switching Frequency Direct Torque Controlled Induction Motor Drive with a Fuzzy Sliding Mode Speed Controller", *IEEE the Natural Science Foundation of Chongqing (CSTC 2007BB3169)*, pp.1543-1548, 2007.