NOVEL PROPULSION SYSTEM APPLIED FOR FOUR WHEELS ELECTRIC VEHICLE USING HYBRID FUZZY SLIDING MODE CONTROLLER

Abdelfatah Nasri[1]**, Brahim Gasbaoui**[2] **,Ben Mohammed Fayssal**[3]

[123] Bechar University, B.P 417 Bechar (08000), Algeria, *nasriab1978@yahoo.fr*

Abstract:*In this work a hybrid control schema of four wheel drive (4WD) propulsion system control is presented. This present paper introduces novel studies of hybrid sliding mode control applied on (4WD) four independent wheels electric vehicle systems, the proposed propulsion system consists of four Induction independent motors that ensure the driving of back and front driving wheels. The proposed control structures use an electronic differential for speeds references computations of four wheels. This Novel four propulsion is studied and tested using hybrid Fuzzy-sliding mode control (FSMC) strategy for the electric vehicle driving wheels, to improve stability, the fuzzy logic system replace the discontinuous control action of the classical SMC law. Our electric vehicle sliding mode control's simulated in the Matlab Simulink environment, the result obtained present satisfactory and show the efficiency of the proposed control comparing with the classical PI controller with no overshoot, the rising time is perfected with good disturbances rejections.*

Keywords: *FSMC, SMC, PI,4WD, Electronic Differential*

1 .Introduction

An electric automobile is car propelled by one or many electric motors, using electrical energy stored in battery or other power source. Electric motors give an instant torque to the vehicle, creating an acceleration[1]. EVs can be classified into various categories according to their configurations, functions of power sources. The first invented electric car is attributed to many people[2,3]. In 1828, Ányos Jedlik, a invented a small model car powered by his new motor[3]. In 1834, Vermont blacksmith built a similar contraption which operated on a short, circular, electrified track.[4] .In 1890 William Morrison present the first four-wheel electric road model in America to demonstrate his battery[5]. Four years ago Henry G. Morris and Pedro G. Salom in Philadelphia design a heavy four-wheel electric wagon similar to the Morrison car. It runs at 15 mph. They were designers of battery streetcars and saw potential in electrifying smaller road vehicles.[4,5] In 1899 to Fred J. Newman and Joseph Ledwinka build a four-wheel drive prototype in New Jersey.[5]A small number of Lohner-Porsche four-wheel drive version, were produced in 1900. The next few years' production included hybrid cars, some of which could reach top speeds of 35 mph.[5,7].Ten years ago the first hybrid car was released . The hybrid was a commercial failure because of it's cost. Researches on the power propulsion system of EVs have drawn significant attention in the automobile industry , Fuel cell development , the power electronics upgrowth made the four wheel electric vehicle in competitions. The basic vehicle configuration of this research has four directly driven wheel motors installed and operated inside the driving wheels on a pure EV[6,7,8]. These wheel motors can be controlled independently and have so quick and accurate response to the command that the vehicle chassis control or motion control becomes more stable and robust, compared to indirectly driven EV [5,6,7]. Like most research on the torque distribution control of wheel motor, many researches were made on the electric vehicle linear speed control improvement, in this way we propose a novel demonstration on four wheels drive using an hybrid robust control based on fuzzy sliding mode controller FSMC for real estimation of driving force and optimal distribution current control for an EV driven by four wheel motors, thereby improving vehicle handling and stability[5,7,8]. The assumption of this work that four motors are not disturbed in the beginning of test that wheel motors were all identical with the same constant torque. In this paper, a fuzzy-sliding mode decoupling controller for electric vehicle control is proposed. The reminder of this paper is organized as follows: Section 2 reviews the description of the electric traction chain component ,then it's necessary to present the indirect field-oriented control (IFOC) of the induction motor , after that the development of sliding mode controller design for electric vehicle and the fuzzy-sliding mode controller .Section 5 gives some simulation results carried on Matlab. Finally, the conclusion is drawn in the end of manuscript.

Nomenclature

Abbreviation	Nomenclature
SMC	Sliding Mode Controller
ED	Electronic Differantial
FSMC	Fuzzy-Sliding mode Control
IFOC	Indirect Field Oriented Control
IM	Induction Motor
FLC	Fuzzy Logic Controller
EV	Electric Vehicle
4WD	Four Wheels Drive
PWM	Pulse Modulation Width
DC	Direct Crurent
PI	Proportional Intergral

2. Four wheel electric vehicle modelling and description

The general schema of the four wheel drive propulsion system is shown on Figure.1 , the following structure presents an multi motor system using four induction motors for motion (IM) ,each motor is connected to the wheel forming an in-wheel motor , this technology is widely used in electric traction to reduces motions losses , the in-wheel motor system is supplied by voltage inverter [7,8,910].

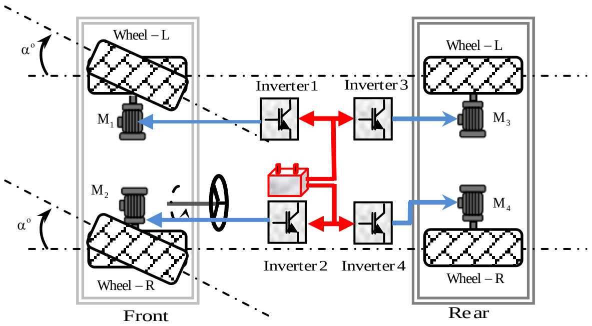

Fig.1. Electrical Propulsion system of four wheels electric vehicle system

The most power sources used in electric vehicle , is accumulators , in this work we use Lithium-Ion battery for it's high performance on charging-discharging and high autonomous [10].In this electric traction system, the voltage DC-AC inverter is controlled using Pulse Modulation Width (PWM) technology to obtain three balanced alternating current phases with variable frequency from the current battery. The employed motor is a three phase Induction Motor type (IM).A model based on circuit equivalent equations is generally sufficient in order to make control synthesis is presented in [11,12].

$$\begin{bmatrix} v_{an} \\ v_{bn} \\ v_{cn} \end{bmatrix} = \frac{U_{dc}}{2} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \qquad (1)$$

The logic of the switches are obtained by comparing the control inverter signals with the modulation's signal.

3. Mechanical Load part of the used electric vehicle

The vehicle's load is characterized by three resistive torques [9,10,11,13,14]. These torques includes:

1. The aerodynamics torque is :

$$T_{aero} = \frac{1}{2} \rho S.T_x.R_r^3.w_r^2 \qquad (2)$$

2. The slope torque is given as :

$$T_{slope} = Mg.\sin\alpha \qquad (3)$$

The maximal torque of the tire which can be opposed to the motion has the following expression:

$$T_{\max} = Mgf_r.R_r \qquad (4)$$

We obtain finally the total resistive torque:

$$T_v = T_{slope} + T_{tire} + T_{aero} \qquad (5)$$

The modelling of the traction system allows the implementation of some controls such as the vector control and the speed control in order to ensure the globally system stability.

3.The Indirect Field Oriented Control (IFOC)

The aim object of the vector control of induction motors is, to control independently the flux and he torque as DC machines [4,7,12,13,17]. In ideally field-oriented control, the rotor flux linkage axis is forced to align with the d-axes, and it follows that [4, 7, 17]:

$$\phi_{rq} = \frac{d\phi_{rq}}{dt} = 0 \qquad (6)$$

$$\phi_{rd} = \phi_r = constant \qquad (7)$$

Applying the result of (6) and (7), defined the indirect field-oriented control (IFOC), the torque equation become similar to the DC machine and can be given by:

$$T_e = \frac{3}{2} \frac{p \cdot L_m}{L_r} \cdot \phi_r \cdot i_{qs} \qquad (8)$$

According to the obtained results given above, the IFOC [4, 7, 13] applied to an induction motor with current-regulated should be presented by the block diagram shown in the Fig. 2. In this step we use the classical controller (PI) for IFOC tuning control parameter.

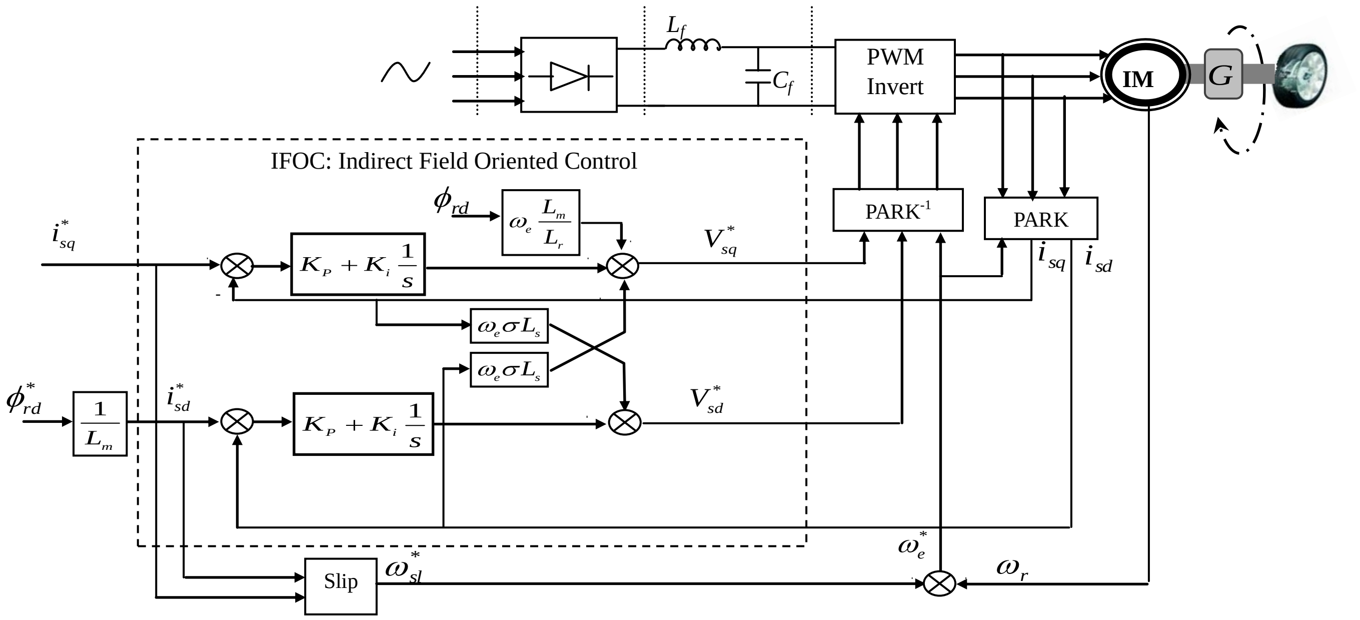

Fig. 2. IFOC strategy for one wheel induction motor.

4. Sliding Mode Controller (SMC)

Sliding modes as phenomenon may appear in a dynamic system computing by ordinary differential equations with discontinuous right-hand sides. the function of control system state switches at high frequency, this motion is called sliding mode. It may be known in the simplest tracking relay system with the state variable x(t) [15,16]:

$$\frac{\partial x}{\partial t} = f(x) + u \qquad (9)$$

With the bounded function $f(x)$ Sliding Mode Control (SMC)

$|f(x)| < f_0$; f_0 is constant and the control as a relay

function of the tracking error $e = r(t) - \frac{\partial x}{\partial t}$; $r(t)$ is the

reference input and u is given by:

$$u = \begin{cases} +u_0 & ;if \quad e > 0 \\ -u_0 & ;if \quad e < 0 \end{cases} \qquad (10)$$

Or: $u = u_0 sign(e)$; u is constant.

Figure.3 shows the relay control scheme:

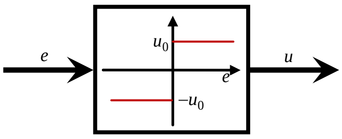

Fig.3: relay control

$$The\ values\ of\ e\ and\ \frac{\partial e}{\partial t} = \dot{e} = \dot{r} - f(x) - u_0 sign(e)$$

According to Lyapunov criteria of the system's stability , if the system is stable if it does verify the following condition: $e.\dot{e} < 0$

By means that we have the different signs if $u_0 > f_0 + |\dot{r}|$. And finally u_0 must be positive constant.

4.1. Design of sliding mode speed and current controller

The speed error of the system target is de fined by [15,16,17, 18]:

$$e = w_{ref} - w \qquad (11)$$

The derivative of the sliding surface can be given as:

$$\dot{s}(\omega) = \dot{\omega}_r^* - \dot{\omega}_r \qquad (12)$$

From the equation (12) and equation cited in [4], we can obtain:

$$\dot{s}(\omega_m) = \dot{\omega}_m{}^* - \left(\frac{3}{2} \frac{P^2 L_m \phi_{dr}^*}{J L_r} .i_{qs} - \frac{f_c}{J} \dot{\omega}_m - \frac{P}{J} T_l \right) \qquad (13)$$

The current quadrate stator control is given by:

$$i_{qs} = i_{qs}^{equ} + i_{qs}^{n} \qquad (14)$$

To reduce the chattering phenomenon produced by the $Signs$ function we use the saturation function Sat in the discontinuous control defined as follow:

$$sat\left(\frac{S}{\phi}\right) = \begin{cases} \frac{S}{\phi} & ; \quad if \quad \left|\frac{S}{\phi}\right| < 1 \\ Sign\left(\frac{S}{\phi}\right) & ; \quad if \quad \left|\frac{S}{\phi}\right| > 1 \end{cases}$$

Where ϕ is the boundary layer thickness.

The discontinuous control action can be given as:

$$i_{qs}^{n} = k_{iqs} \cdot sat(s(\omega)/\phi_\omega) \qquad (15)$$

k_{iqs} : positive constant.

The current control is defined by:

$$i_{qs}^{equ} = \frac{2}{3}\frac{JL_r}{P^2 L_m \phi_{dr}^*}\left(\dot{\omega}_m^* + \frac{f_c}{J}\omega_m + \frac{P}{J}T_l\right) \qquad (16)$$

The figure.4 shows the SMC control strategy scheme for one wheel electric traction chain.

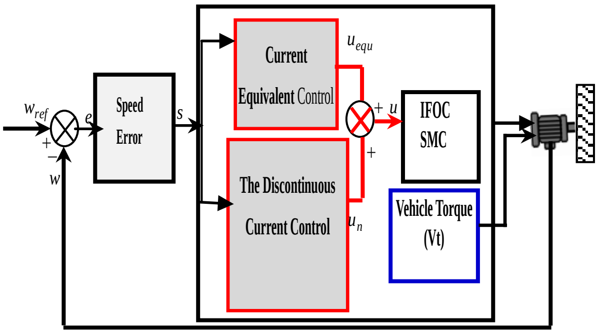

Fig.4: the SMC control strategy schema for One wheel electric vehicle

For the IFOC tuning parameters we need two surfaces S_1 and S_2 the first for the i_{ds} regulator and the second for i_{qs} regulator respectively for each wheel where:

$$s_1 = i_{ds}^* \quad i_{ds} \qquad (17)$$

$$s_2 = i_{qs}^* \quad i_{qs} \qquad (18)$$

The derivate of S_1 can be given as:

$$\dot{s}_1 = \dot{i}_{ds}^* \quad \dot{i}_{ds}$$

from equation cited in [12] and (18) we can obtain :

$$\dot{s}_1 = \dot{i}_{ds}^* - \left[-\left(\frac{R_s}{\sigma L_s} + \frac{1-\sigma}{\sigma\tau_r}\right)i_{ds} + \omega_e i_{qs} + \frac{L_m}{\sigma L_s L_r \tau_r}\phi_{rd} + \frac{1}{\sigma L_s}V_{ds}\right] \qquad (19)$$

The virtual voltage controller V_{ds} is given by:

$$V_{ds} = V_{ds}^{equ} + V_{ds}^{n} \qquad (20)$$

The voltage discontinuous control V_{ds}^n is defined as:

$$V_{ds}^n = k_1 \cdot sat(s_1/\phi_1) \qquad (21)$$

According to Lyapunov stability criteria [15,16] our speed loop system's sable if: $s_1\dot{s}_1 < 0$ by means that K_1 is positive constant.

The equivalent control V_{ds}^{equ} is given as:

$$V_{ds}^{equ} = \sigma.L_s\left(\dot{i}_{ds}^* + \frac{1}{\sigma.L_s}\left(R_S + R_r.\left(\frac{L_m}{L_r}\right)^2\right).i_{ds} - w_s.i_{qs} - \frac{L_m.R_r}{\sigma.L_s L_r^2}\phi_r^*\right)$$

(22)

The derivate of S_2 can be given as: $\dot{s}_2 = \dot{i}_{qs}^* \quad \dot{i}_{qs}$, From equation cited in [12] and (19) we can obtain:

$$\dot{s}_2 = \dot{i}_{qs}^* \qquad \frac{R_s}{\sigma L_s} + \frac{1 \quad \sigma}{\sigma\tau_r} \quad i_{qs} \quad \omega_e i_{ds} + \frac{L_m}{\sigma L_s L_r \tau_r}\varphi_{rd} + \frac{1}{\sigma L_s}V_{qs}$$

The voltage controller V_{qs} is given by:

$$V_{qs} = V_{qs}^{equ} + V_{qs}^{n} \qquad (23)$$

The V_{qs}^{equ} equivalent control actions defined as:

$$V_{qs}^{equ} = \sigma.L_s.[\dot{i}^*{}_{qs} + \omega_s.i_{ds} + \frac{1}{\sigma.L_s} \quad R_s + R_r \quad \frac{L_m}{L_r} \quad {}^2 \quad .i_{qs} + \frac{L_m}{\sigma L_s L_r}\varphi_r^*\omega_m]$$

(24)

The voltage discontinuous control V_{ds}^n is defined as:

$$V_{qs}^n = k_2 \cdot sat(s_2/\phi_2) \qquad (25)$$

For the same reason condition of K_1 : K_2 are positives constant.

4.2. Fuzzy-sliding mode control FSMC for one wheel

The disadvantage of SMC is the chattering phenomenon of the discontinuous control signal, the chattering is aggravated by small time delays in the system. In order to eliminate the chattering phenomenon, different schemes have been proposed in the literature [15,16, 17,18]. In this section, a Fuzzy-Sliding mode controller is developed, in which a fuzzy inference mechanism is used to generate the equivalent control law parameters by means that the employed fuzzy logic controller replace the discontinuous control in the SMC schema . The proposed hybrid fuzzy-sliding mode controller scheme for EV speed control is shown in Figure 5. The fuzzy logic controllers replace the inequalities given in (15) which determine the parameters of the equivalent control action. We show that a particular fuzzy controller is an extension of an SMC with a boundary layer [16,18]. The proposed fuzzy controller in this paper is constructed from the following IFTHEN rules which are the most adapted with this kind of hybrid robust control problem:

BN :	Big Negative	Bigger
MN :	Medium Negative	Big
ZE :	Zero	Medium
MP :	Medium Positive	Small
BP :	Big Positive	Smaller

The figure.5 shows the Fuzzy Sliding Mode Control (FSMC) control strategy scheme for the electric traction chain.

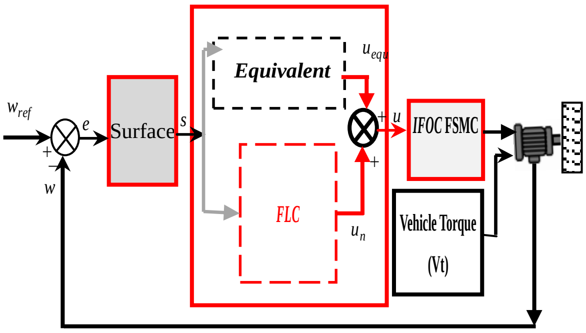

Fig.5: The FSMC of one wheel EV control strategy scheme.

we take five fuzzy subsets, BN, MN, ZE, MP and BP, are defined for , and ; the fuzzy inference mechanism contains five rules for the Fuzzy Logic Controller (FLC) output. The resulting fuzzy inference rules for the output variable of as follows:

Rule 1: IF , and is BN THEN is Bigger
Rule 2: IF , and is MN THEN is Big
Rule 3: IF , and is ZE THEN is Medium
Rule 4: IF , and is MP THEN is Small
Rule 5: IF , and is BP THEN is Smaller

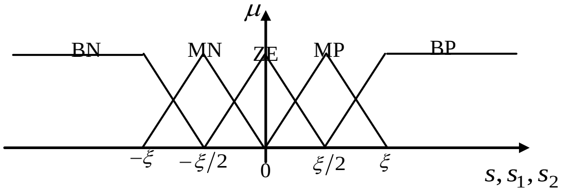

Fig.6 :The inputs s , s_1 and s_2 membership functions of the discontinuous control.

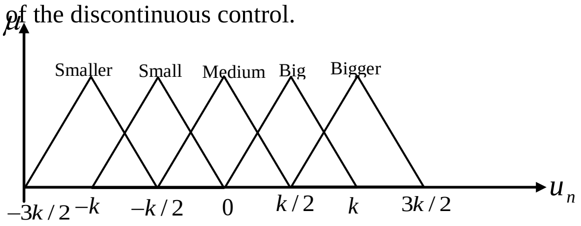

Fig.7: The output membership function of the discontinuous control.

Where S_1 , S_2 , S_3 present the sliding surface of speed error ws , iqs , ids respectively . The membership functions of input and output fuzzy sets are depicted in figures 6 and 7. In this study, the triangular membership functions and center average deffuzzification method are adopted for their efficiency in solving the chattering problem, they are computationally simple, intuitively plausible, and most frequently used in the opening literatures[15,16,17,18].

5.Simulation Results

The globally scheme of the four driving wheels using control FSMC is presented by figure 8. The reference blocks must provide the speed references of each motor taking into account all obtained information's from the different sensors such as motors and according to the real driver decision (break , acceleration)[8,9,10]. So the electronic differential presents an intelligent actuator for four wheels in the front and rear and acts immediately and compute the novel references speeds given for each wheel taking into account the road curve angle the linear speed input. In order to show the propulsion system behaviour by applying hybrid control FSMC, simulations were carried on Matlab using the model of figure.8. The specified trajectory is chosen as follows :

First , the vehicle is moving on straight road , the linear speed is changed from 60 km/h to 90 km/h at times of 2sec ,then the vehicle is moving curved road on right side at time of 3 Sec , then the slope road of 10 % at 3.5 Sec ,finally another curve on left side at time of 4 Sec. the results obtained given as follows in the tables 1,2,3 :

In the linear speed characteristics

Controller	**Speed range (60-90)**	**Speed error**	**overshoot**	**Rising time**	**Autonomous (meters)**	**Ability to follow the ED**	**Ability to drive during curve**
PI	60-90	exist	16 %	0.7	381.8	no	no
SMC	60-90	no	no	0.85	417.5	yes	yes
FSMC	60-90	no	no	0.8	427.5	yes	yes

-Mechanical load characteristics :

Controller	**Vehicle torque (Nm)**	**Aerodynamic torque (Nm)**	**Aerodynamic torque change**	**Ability to overcome the slope**
PI	312.2	210.8	0.003919	difficult
SMC	155.5	53.9	0.001287	easy
FSMC	154	48.49	0.0002847	Very easy

Table 2 : comparative studies on mechanical load results

-Propulsion system and developed effort analysis :

Controller	estimated driving force	estimated torque	estimated current	Stability to drive during curve and slope
PI	1201	312.4	239.3	bad
SMC	596.6	155.5	119.7	good
FSMC	593.4	154.3	118.2	Very good

Table 3 : comparative studies on developed effort analysis

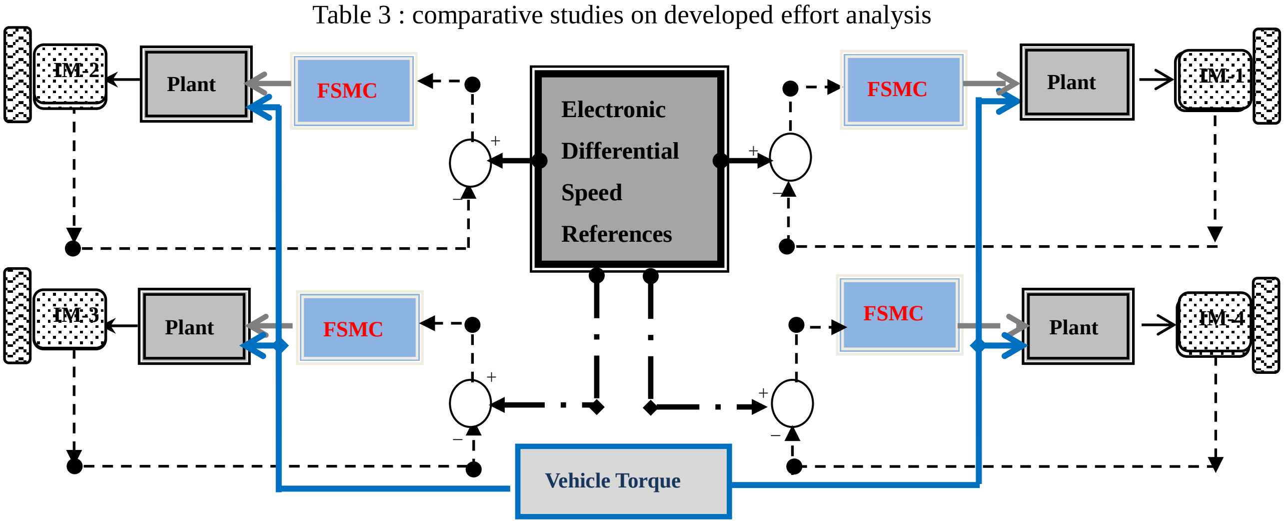

Fig.8.four wheels electric vehicle simulated model.

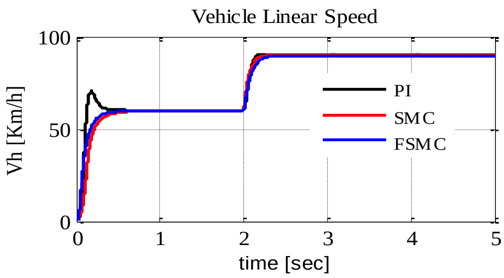

Fig.9: vehicle linear speed comparative studies .

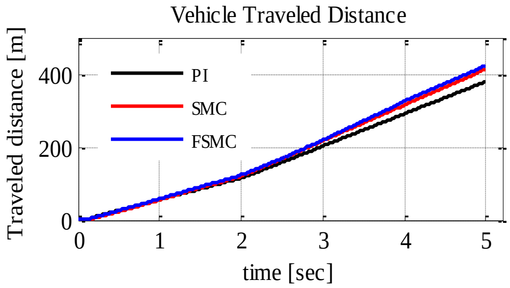

Fig.10:vehicle travelled distance.

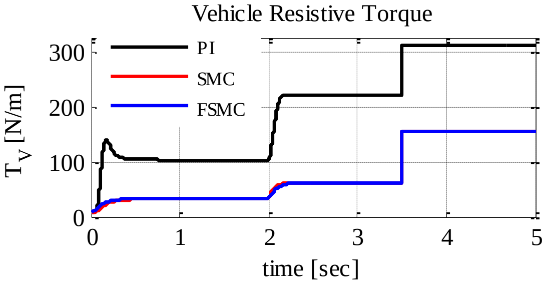

Fig.11:vehicle resistive torque.

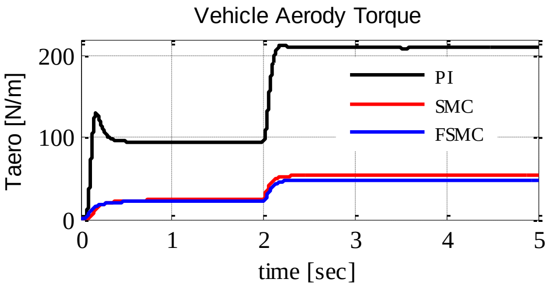

Fig.12:vehicle aerodynamic torque.

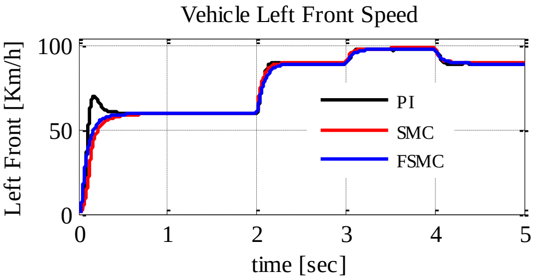

Fig.13:vehicle left front speeds compare.

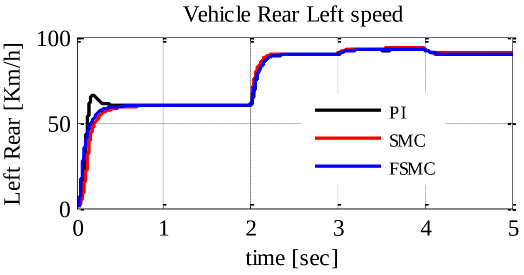

Fig.14:vehicle left rear speeds compare.

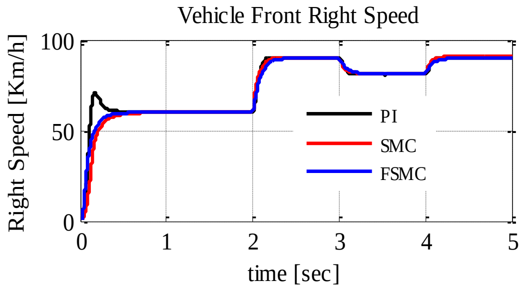

Fig.15:vehicle front right speeds compare

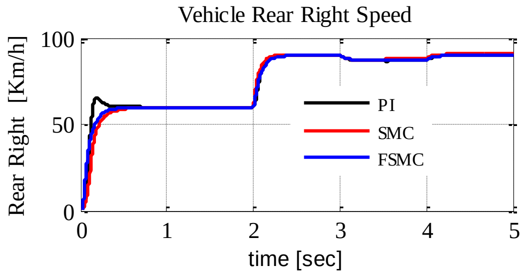

Fig.16:vehicle right rear speeds compare.

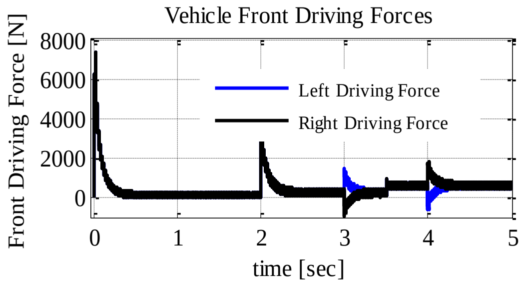

Fig.17:vehicle front driving force.

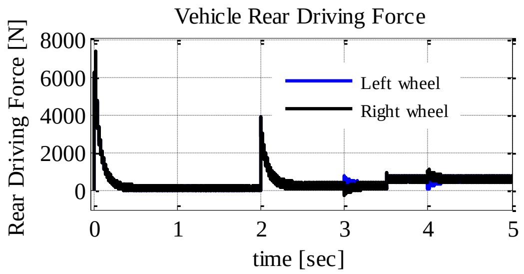

Fig.18:vehicle rear driving force.

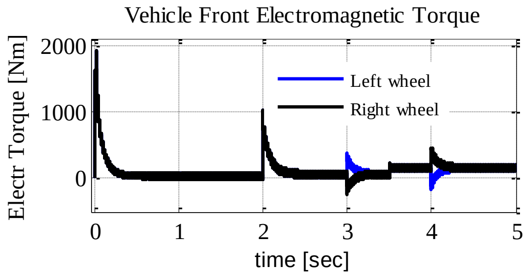

Fig.19:vehicle front electromagnetic torque.

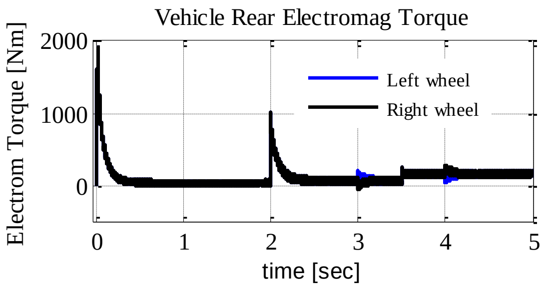

Fig.20:vehicle rear electromagnetic torque.

According to the obtained results as it shown and detailed in tables (1,2,3) and figures from 9-20 we can say that in FSMC the driver can drive in an easy way and safety comparing with SMC case , the stability is difficult in PI classical control and the losses in power and speeds clearly appear in this case with huge overshot and the vehicle can't pass the slope in safety way and the driving became very dangerous , the ED can provide all the vehicle needs and can do an economic distribution of speed and driving force and torque in FSMC , but the ability to follow the speed references in PI one is not possible , the aerodynamic torque is very important in PI compared with SMC and FSMC it has the value of 210 Nm compared with 48 Nm in FSMC and 53.9 Nm in SMC case , this value can be explained that the fontal surface used in FSMC is the most biggest compared with SMC and FSMC , it's appear clearly in aerodynamic torque changes ,the current estimated in PI case is very valuable compared of SMC an FSMC ,it's take a number of 239,3 A when the current demand for the same trajectory is only 118.2 A , at the driving force level for PI the driving force equal the double developed in FSMC case and SMC , so the driving of four wheels electric vehicle which utilizes four independent induction motor for motion is very easy in FSMC case comparing with SMC and PI at any trajectory ,that make this all road electric vehicles very demanded at the industry stage and the driver can drive the vehicle with security and safety .

6.Conclusion

The aim object of this work is the application of robust hybrid control on modern four wheel drive electric vehicle using an electronic differential , the results obtained have presented clearly that this type of propulsion system can be improved in the twin of autonomy and stability using the proposed control schema and comparing this choice with the SMC controller .The assumption of this work is the four motor are not distrusted and the global system use the independent machine structure as multi motor schema .After the chattering phenomena which produce a loss of energy and heat of cables inside the vehicle ,simulation where carried to compare the SMC and FSMC behavior and to ensure the driving on the chosen road trajectory with high safety conditions .The results obtained by Matlab simulation proves that this structure permits the realization of robust control and accuracy , the results obtained prove good performances of FSMC and make the driving easy of the four wheels drives and give good attention for industrials to applied this approach on multi motor vehicles.

References

[1]. Roth, Hans (March 2011). Das erste vierrädrige Elektroauto der Welt *[The first four-wheeled electric car in the world] (in German)*. pp. 2–3.

[2]. Guarnieri, M. (2012). "*Looking back to electric cars"*. Proc. HISTELCON 2012 - 3rd Region-8 IEEE HISTory of Electro - Technology CONference: The Origins of Electrotechnologies: #6487583. doi:10.1109/HISTELCON.2012.6487583.

[3]. Sibrandus Stratingh (1785–1841), Professor of Chemistry and Technology, University of Groningen – English available, retrieved 2009-04-24 .

[4]. https://en.wikipedia.org/wiki/Electric_car#cite_note-Roth_2.E2.80.933-1.

[5]. .http://www.edisontechcenter.org/ElectricCars.html

[6]. Hiroshi Nakano Ken Okayama Jun Kinugawa and Kazuhiro Kosuge,"*Control of an Electric Vehicle with a Large Sideslip Angle Using Driving Forces of Four Independently-Driven Wheels and Steer Angle of Front Wheels*", 2014 IEEE/ASME International Conference on Advanced Intelligent Mechatronics (AIM) Besançon, France, July 8-11, 2014.

[7]. .Xiaodong Wu, Min Xu, Lei Wang, « *Differential Speed Steering Control for Four-Wheel Independent Driving Electric Vehicle*" IEEE International Symposium on Industrial Electronics (ISIE), 28-31May ,Taiwan 2013.

[8]. Abdelfatah Nasri ,Brahim Gasbaoui: " *A novel maximum control structure schema for 4 Wheels electric vehicle drive* ", Journal of Electrotehnică, Electronică, Automatică EEA, Vol.60 N°4,PP 38-44 December 2012, ,ISSN 1582-5175 .

[9]. Abdelfatah Nasri ,Brahim Gasbaoui: " *Artificial Intelligence Application's for 4WD Electric Vehicle Control System* ", Journal of Intelligent Control and Automation, Vol.3 N°3, August 2012, PP243-250, ISSN 2153-0653.

[10]. Brahim Gasbaoui, Abdelfatah Nasri : " *A Novel 4WD Electric Vehicle Control Strategy Based on Direct Torque Control Space Vector Modulation Technique* ", Journal of Intelligent Control and Automation, Vol.3 N°3, August 2012,PP 236-242,ISSN 2153-0653.

[11]. M. Zhiwen, T. Zheng, F. Lin and X. You, "*a New Sliding-Mode Current Controller for Field Oriented Controlled Induction Motor Drives*", IEEE Int. Conf. IAS (2005), pp. 1341-1346, 2005.

[12]. A.Nasri, A.Hazzab, I.K.Bousserhane, S.Hadjeri, P.Sicard,"*Two Wheel Speed Robust Sliding Mode Control For Electric Vehicle Drive* ",Serbian Journal of Electrical Engineering , Vol 5,N°2,November 2008 ,PP 199-216.

[13]. Xiaoshuai Xin, Hangen Zheng , Hongbin Xu and Gang Qin »*Control Strategies For Four In-wheel Driven Electric Vehicles When Motor Drive Systems Fail*", 2014 American Control Conference (ACC) June 4-6, 2014. Portland, Oregon, USA.

[14]. Abdelfatah Nasri ,Brahim Gasbaoui: " *The Slopped Road Angle Effect on Lithium Ions Battery Behavior for the Next Future Commercialized Electric Vehicle* ", Journal of Electrical and Electronic Engineering, Vol.4 N°2, October 2011, PP5-10,ISSN 1844-6085.

[15]. A.Tahour,Hamza.Abid.A.Aissaoui,"*Speed Control of Switched Reluctance Motor Using fuzzy Sliding Mode*",Advances in Electrical an Computer Engineering ,Vol,8.15,Number 1(29),2008.

[16]. Abdelfatah Nasri, Abdeldjabar Hazzab, Ismail K. Bousserhane, Samir Hadjeri, Pièrre Sicard."*Fuzzy-Sliding Mode speed control for electric vehicle drive* ", Korean Journal of Electrical Engineering Technology, JEET, volume 4, N° 4-December 2009,PP. 499-509,ISSN 1844-6085

[17]. R. -J. Wai, "*Adaptive Sliding-Mode Control for Induction Servomotor Drives*", IEE Proc. Elecrr. Power Appl., 2000,147, pp. 553-562.

[18]. C. M. Lin and C. -F. Hsu, "*Adaptive Fuzzy Sliding-Mode Control for Induction Servomotor Systems*", IEEE Transactions on Energy Conversion, vol. 19, n°2, June 2004, pp. 362-368.