

# THE EFFICIENCY OF THE INFERENCE SYSTEM KNOWLEDGE STRATEGY FOR INDUCTION MOTOR LINEAR SPEED CONTROL OF AN URBAN ELECTRIC VEHICLE

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## Abstract:

This paper presents a real induction vehicle motor speed estimation technique, based on the fuzzy logic inference system knowledge for electric vehicle safety based on differential electronics as essential element for two wheeled electric vehicle driving which utilize the two back separately induction motors for motion. The aim object of the fuzzy logic controller is to give more and more safety for the electric propulsion system safety during motion against road topology. Our electric vehicle fuzzy inference system control's simulated in Matlab SIMULINK environment, the results obtained present the efficiency and the robustness of the proposed control with good performances compared with the traditional PI speed control, the FLC induction traction machine presents not only good steady characteristic, but with no overshoot too. The electronic differential system ensures the robust control of the vehicle behavior on the road. It also allows controlling, independently, every driving wheel to turn at different speeds in any curve.

**Keywords:** electric vehicle, electronic differential, induction motor, vector control, fuzzy logic speed control.

## 1. Introduction

Electric vehicles (EVs) are developing fast during this decade due to drastic issues on the protection of environment and the shortage of energy sources. While commercial hybrid cars have been rapidly exposed on the market, fuel-cell-powered vehicles are also announced to appear in 5-10 years. Researches on the power propulsion system of EVs have drawn significant attention in the automobile industry and among academics. EVs can be classified into various categories according to their configurations, functions or power sources. Pure EVs do not use petroleum, while hybrid cars take advantages of energy management between gas and electricity [1].

Indirectly driven EVs are powered by electric motors through transmission and differential gears, while directly driven vehicles are propelled by in-wheel or, simply, wheel motors [2]. The basic vehicle configurations of this research has two directly driven wheel motors installed and operated inside the driving wheels on a pure EV. 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 EVs. Like most research on the torque distribution control of wheel motor, wheel motors [3] proposed a dynamic optimal tractive force distribution control for an EV driven by four-wheel motors, thereby improving vehicle

handling and stability.

The researchers assumed that wheel motors were all identical with the same torque constant; neglecting motor dynamics the output torque was simply proportional to the input current with a prescribed torque constant.

The reminder of this paper is organized as follows: Section II reviews the principle components of the Electric traction chain with their equations model. Section III shows the fuzzy logic control strategy of the electric vehicle motorization. The proposed structure of the studied propulsion system is given in the section IV. Section V gives some simulation results of the different studied cases. Finally, the conclusion is drawn in section VI.

## 2. Electric traction system elements modeling

Figure 1 represents the general diagram of an electric traction system using an induction motor (IM) supplied by voltage inverter [4], [8].

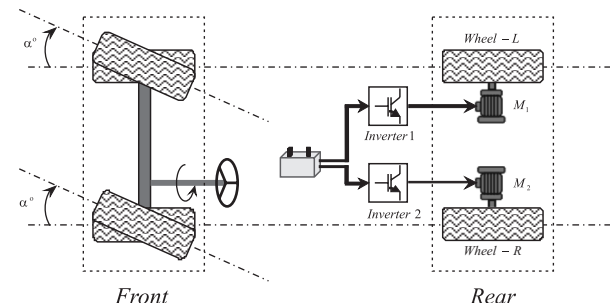


Fig. 1. General diagram of an electric traction system using an induction motor (IM) supplied by voltage inverter.

### A. Energy source

The battery considered in this paper is of the Lithium-Ion [9], the battery current is calculated by:

$$I_{bat} = \frac{V_{oc} - \sqrt{V_{oc}^2 - 4 \cdot (R_{int} + R_t) \cdot P_b}}{2 \cdot (R_{int} + R_t)} \quad (1)$$

where:

- $P_b$ : Output power of battery
- $R_{int}$ : Internal resistance
- $V_{oc}$ : The open circuit voltage
- $R_t$ : The terminal voltage of the battery

### B. Static converter

In this electric traction system, we use a three-balanced phases of alternating current inverter with variable frequency from the current battery [4].

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

The  $S_i$  are logical switches obtained by comparing the control inverter signals with the modulation signal.

### C. Traction motor

The used motorization consists of three-phase induction motor (IM) supplied by a voltage inverter controlled by Pulse Width Modulation (PWM) techniques. The dynamic model of three-phase, Y-connected induction motor can be expressed in the  $d$ - $q$  synchronously rotating frame as [4], [6], [13]:

$$\begin{cases} \frac{di_{ds}}{dt} = \frac{1}{\sigma L_s} \left( - \left( R_s + \left( \frac{L_m}{L_r} \right)^2 R_r \right) i_{ds} + \sigma L_s \omega_e i_{qs} + \frac{L_m R_r}{L_r^2} \phi_{dr} + \frac{L_m}{L_r} \phi_{qr} \omega_r + V_{ds} \right) \\ \frac{di_{qs}}{dt} = \frac{1}{\sigma L_s} \left( - \sigma L_s \omega_e i_{ds} - \left( R_s + \left( \frac{L_m}{L_r} \right)^2 R_r \right) i_{qs} - \frac{L_m}{L_r} \phi_{dr} \omega_r + \frac{L_m R_r}{L_r^2} \phi_{qr} + V_{qs} \right) \\ \frac{d\phi_{dr}}{dt} = \frac{L_m R_r}{L_r} i_{ds} - \frac{R_r}{L_r} \phi_{dr} + (\omega_e - \omega_r) \phi_{dr} \\ \frac{d\phi_{qr}}{dt} = \frac{L_m R_r}{L_r} i_{qs} - (\omega_e - \omega_r) \phi_{dr} - \frac{R_r}{L_r} \phi_{qr} \\ \frac{d\omega_r}{dt} = \frac{3 P^2 L_m}{2 L_r J} (i_{qs} \phi_{dr} - i_{ds} \phi_{qr}) - \frac{f_c}{J} \omega_r - \frac{P}{J} T_l \end{cases} \quad (3)$$

Where  $\sigma$  is the coefficient of dispersion and is given by:

$$\sigma = 1 - \frac{L_m^2}{L_s L_r} \quad (4)$$

$L_s, L_r, L_m$	Stator, rotor and mutual inductances;
$R_s, R_r$	Stator and rotor resistances;
$\omega_e, \omega_r$	Electrical and rotor angular frequency;
$\omega_{sl}$	Slip frequency;
$\tau_r$	Rotor time constant;
$P$	Pole pairs

### D. Electric vehicle Mechanical Load's:

The vehicle is considered as a load is characterized by many torques, which are mostly considered as resistive torques [4], [8], [12], [15], [17], [18]. The different torques includes:

- The vehicle inertia torque defined by the following relationship:

$$T_{in} = J_v \cdot \frac{dw_v}{dt} \quad (5)$$

- The aerodynamics torque is:

$$T_{aero} = \frac{1}{2} \rho S T_x R_r^3 \cdot w_r^2 \quad (6)$$

- The slope torque is:

$$T_{slope} = Mg \cdot \sin \alpha \quad (7)$$

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

$$T_{max} = Mg f_r \cdot R_r \quad (8)$$

We obtain finally the total resistive torque:

$$T_v = T_{slope} + T_{tire} + T_{aero} \quad (9)$$

### E. Gear

The speed gear ensures the transmission of the motor torque to the driving wheels. The gear is modelled by the gear ratio, the transmission efficiency and its inertia.

The mechanical equation is given by:

$$J_e \frac{dw_m}{dt} + f w_m = p(T_{em} - T_r) \quad (10)$$

with:

$$T_r = \frac{I}{\eta N_{red}} T_v \quad (11)$$

$$J_e = J + \frac{J_v}{\eta N_{red}^2} \quad (12)$$

The modelling of the traction system allows the implementation of some controls such as the vector control [4], [13], [14] and the speed control in order to ensure the globally system stability.

## 3. Fuzzy logic speed control strategy

To be fitted with complex load environment of electric vehicles, induction traction machine needs higher specific power, efficiency and rotation speed than common industrial machines. Therefore, dimension of stator and rotor iron core of induction traction machine is smaller, and wound specific current is larger. Although small resistance and inductance is helpful to use voltage, it also produces large current wave and easy saturation magnetic circuit, which results in controlling machine difficultly.

Fuzzy logic control (FLC) has been applied to induction machine drive, which makes drive less sensitive to parameter variation [1], [4], [5], [7], [16] and more efficient [6], [10], [11], [16]. In this paper, the fuzzy logic control drive system of induction traction machine is presented, on which the fuzzy logic is applied to Improve machine's speed control performance to start up quickly and smoothly.

### Design of fuzzy logic speed regulator:

According to indirect field orientation mathematical model of induction machine [4] speed control drive system based on dual PI current regulators is shown as Fig. 5.

This fuzzy logic control is nonlinear regulator, which Control the torque current quantity adaptive to pedal input by motor speed error and its difference.

$$e(k) = w_r(k) - w_{ref} \quad (13)$$

$$e(k) = \frac{e(k) - e(k-1)}{\Delta t} \quad (14)$$

Where  $\Delta t$  is sample cycle,  $w_r(k)$  is real time sample value, and is  $w_{ref}$  reference value of motor speed.

Generally, a fuzzy logic controller needs input, output variables and inference, which is a term set based on rule

base. (13) and (14) determine the input variables. Clearly, Output variable is also determined by fuzzy logic speed regulator. Because of no particular theory in designing a best rule-base on terms, fuzzy inference [1], [4], [5], [7], [16] based on rule base is artificial from the designer's experiences and experts' knowledge. More terms, and more rules will result in more

Complicated fuzzy inference. In the proposed fuzzy logic control, a five-term set {negative big (NB), negative small (NS), zero (ZE), positive small (PS), positive big (PB)} is applied to defining input and output linguistic variable.

This present fuzzy logic control is shown in Fig. 5. In this figure,  $k_e$ ,  $k_{de}$  and  $k_u$  are gains of the speed error  $e$ , speed error difference and torque current variety output control  $u$  here  $u$  mean the stator current estimated.

A fuzzy set can convert fuzzy input-out term into quantitative description, which is called fuzzification.

Meanwhile, membership function and its discretization are first. to be qualified. The corresponding quantitative input field is defined as  $\{-4, -2, 0, 2, 4\}$  and  $\{-4, -2, 0, 2, 4\}$  as it shown in Figures 2, 3.

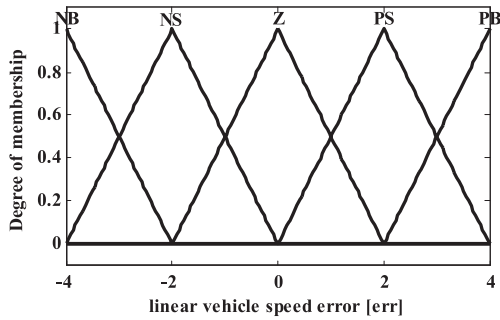


Fig. 2. Speed error derivate membership functions.

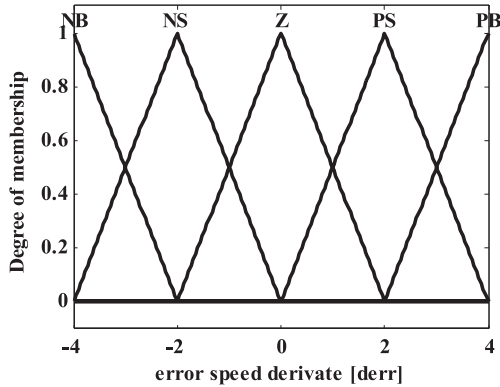


Fig. 3. Speed error membership functions.

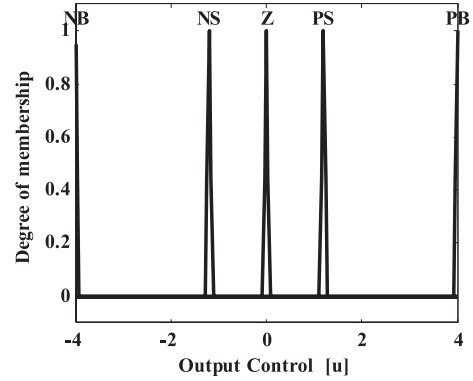


Fig. 4. Output control membership functions.

And the output field is selected as  $\{-4, -1, 0, 1, 4\}$ . The proposed membership function is figured as Fig. 4.

Building fuzzy logic rule is the key step in the improve-ment of system performance, which is a set of Statements as {**IF** . . . , **THEN** . . .}. For instance, **IF** input1 is **NB** and input2 is **NB**, **THEN** output is **PB**. These rules can be produced by rule base as Table 1. After rules finished, this fuzzy inference and defuzzification can be doned, which is based on the min-max method (**Mamdani**) [1], [4], [5], [7], [16]. By off-line calculation and regulation, this fuzzy logic inference rules is shown as Table 1. This fuzzy inference process is fussy. However, one can conveniently design a good fuzzy logic by MATLAB tools.

Table 1. Fuzzy inference rules.

$u(t)$		$e(t)$				
		NB	NS	Z	PS	PB
$de(t)$	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

Where: FUZZIFICA is the Fuzzification process and DEFFUZZIFF is the Deffuzification process.

#### 4. Structure of the studied system

The general scheme of the driving wheels control is represented by Figure 7. It's an electric vehicle, which the back driving wheels are controlled independently by two IM. The reference blocks must provide the speed references of each motor taking into consideration information from the different sensors.

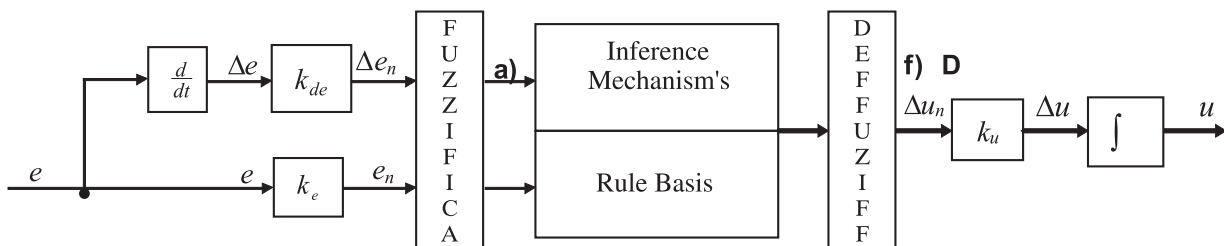


Fig. 5. Fuzzy Logic Controller Structure.

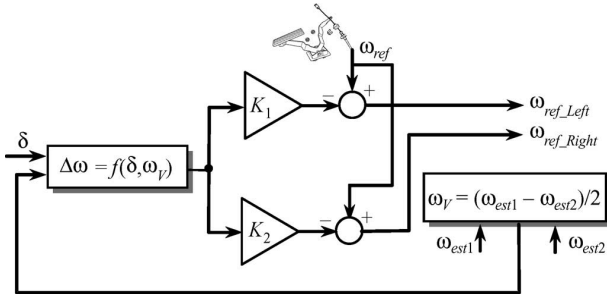


Fig. 6. Block diagram of the electric differential system.

The Figure 7 shows the vehicle geometry of the electronic differential studied system.

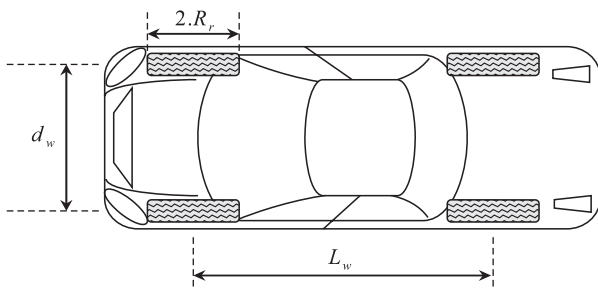


Fig. 7. Vehicle geometry.

**Speed references computation.**

Fig. 1 illustrates the implemented system (electric and mechanical components) in the Matlab-Simulink environment. It should be noted that the two inverters share the same dc bus whose voltage is supposed to be stable. Regenerative braking is not taken into account in this paper. The proposed control system principle could be summarized as follows: 1) A speed Fuzzy logic control is used to control each motor torque; 2) The speed of each rear wheel is controlled using speed difference feedback. Since the two rear wheels are directly driven by two separate motors, the speed of the outer wheel will need to be higher than the speed of the inner wheel during steering maneuvers (and vice-versa). This condition can be easily met if the speed estimator is used to sense the angular speed of the steering wheel. The common reference speed  $w_{ref}$  is then set by the accelerator pedal command as it shown on figure 6. The actual reference speed for the left drive  $w_{ref-left}$  and the right drive  $w_{ref-right}$  are then obtained by adjusting the common reference speed  $w_{ref}$  using the output signal from the fuzzy logic speed estimator. If the vehicle is turning right, the left wheel speed is increased and the right wheel speed remains equal to the common reference speed  $w_{ref}$ .

If the vehicle is turning left, the right wheel speed is increased and the left wheel speed remains equal to the common reference speed  $w_{ref}$  [8], [15], [17], [18].

Usually, a driving trajectory is adequate for an analysis of the vehicle system model. We therefore adopted the Ackermann-Jeantaud steering model [17], as it is widely used as a driving trajectory. In fact, the Ackermann steering geometry is a geometric arrangement of linkages in the steering system of a car or other vehicles designed to solve the problem of wheels on the inside and outside of a turn needing to trace out circles of different radii. Modern cars do not use pure Ackermann-Jeantaud steering, partly because it ignores important dynamic and compliant effects, but the principle is sound for low speed maneuvers [17], [18]. It is illustrated in Fig. 1.

From this model, the following characteristic can be calculated:

$$R_w = \frac{L_w}{\tan \delta} \tag{15}$$

where  $\delta$  is the steering angle. Therefore, the linear speed of each wheel drive is given by:

$$V_1 = w_v \left( R_w - \frac{d_w}{2} \right) \tag{16}$$

$$V_2 = w_v \left( R_w + \frac{d_w}{2} \right) \tag{17}$$

Where:  $L_w$  is the distance between front and rear wheels and  $R_w$  is the wheel radius and  $d_w$  is the distance between two driving heels and  $\delta$  the steering wheel angle. [4], [15], [17] and their angular speed by:

$$\begin{cases} w_{est1} = \frac{L_w - \left(\frac{d_w}{2}\right) \tan \delta}{L_w} w_v \\ w_{est2} = \frac{L_w + \left(\frac{d_w}{2}\right) \tan \delta}{L_w} w_v \end{cases} \tag{18}$$

where  $w_v$  is the vehicle angular speed according to the center of turn.

The difference between wheel drive angular speeds is then

$$\Delta w = w_{est1} - w_{est2} = -\frac{d_w \tan \delta}{L_w} w_v \tag{19}$$

and the steering angle indicates the trajectory direction

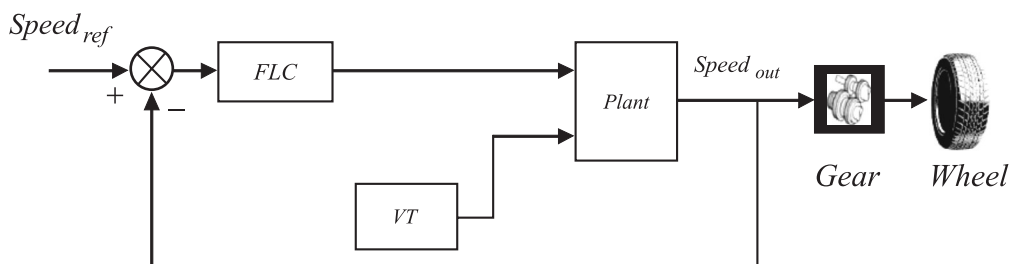


Fig. 8. The driving wheels control system.

$$\begin{cases} \delta > 0 \Rightarrow \text{Turn Left} \\ \delta = 0 \Rightarrow \text{Straight ahead} \\ \delta < 0 \Rightarrow \text{Turn Right} \end{cases} \quad (20)$$

In accordance with the above described equation, Figure 8 shows the electric differential system block diagram as used for simulations, where  $K1 = 1/2$  and  $K2 = -1/2$ .

Where:  $VT$  is the Vehicle resistive torque and  $FLC$  the fuzzy logic speed controller.

### 5. Simulation results

In order to characterize the driving wheel system behavior, simulations were carried using the model of Figure 8. They show vehicle speed variation for PI controllers and the Fuzzy logic speed controller.

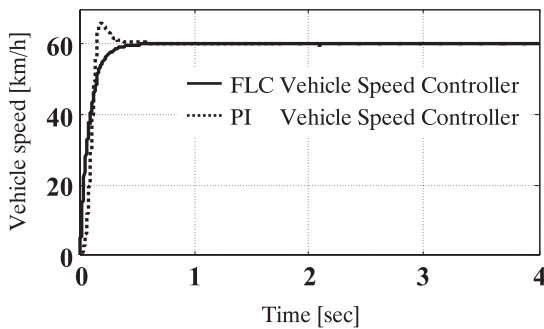


Fig. 9a). Vehicle speed variations for two controller cases.

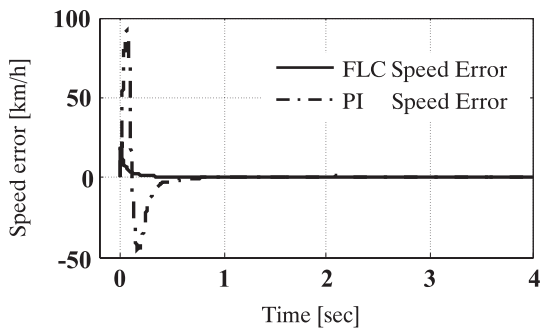


Fig. 9b). Vehicle Error speed variations for two controller cases.

In order to simplify the control algorithm and improve the control loop robustness, instead of using classical control, we use the Fuzzy logic control [1], [4], [5], [7], [10], [11], [16]. The advantage of this control is its robustness, its capacity to maintain ideal trajectories for two wheels control independently and ensure good disturbances rejections with no overshoot and stability of vehicle perfected ensured with the speed variation and less error speed.

To compare the effect of disturbances on the vehicle speed in the cases of two types of control, Figure 9a) and Figure 9b) shows the system response in two cases (robust and classical control).

From the Figure 9a) and Figure 9b) and the table we can say that: the effect of the disturbance is neglected in the case of the Fuzzy controllers. It appears clearly that the classical control with PI controller is easy to apply. However, the control with the Fuzzy controllers offers better performances in both of the overshoot control and

the tracking error.

In addition to these dynamic performances, it respects the imposed constraints by the driving system such as the robustness of parameter variations.

We can summaries the vehicle speed results in the following tables:

Table 2 Performances of the PI and Fuzzy logic controllers in the speed response.

Results	Rising time [Sec]	Overtaking [%]	Steady state error [%]	Disturbance application time (slope torque)
PI	0.1564	11.6666	0	At 2 Sec
FLC	0.7581	0	$2.7 \times 10^{-5}$	At 2 Sec

#### A. Case of straight way

##### Flat road with 10% slope at 60km/h speed at time 2 sec

In this test, the system is submitted to the same speed step. The driving wheels speeds stay always the same and the road slope does not affect the control of the wheel and the Fuzzy control act immediately to reduce the speed error caused by the slope road constraints and give's more and more efficiency to the electronic differential output references. We can say the slope sensitize the motorization to develop efforts in order to satisfy the electric traction chain demand.

The system behaviour of theses speeds is illustrated by figures 10d), 10b) and 10c) that describe the electromagnetic torque and driving forces variations. The resistant torques is shown in Figure 10a).

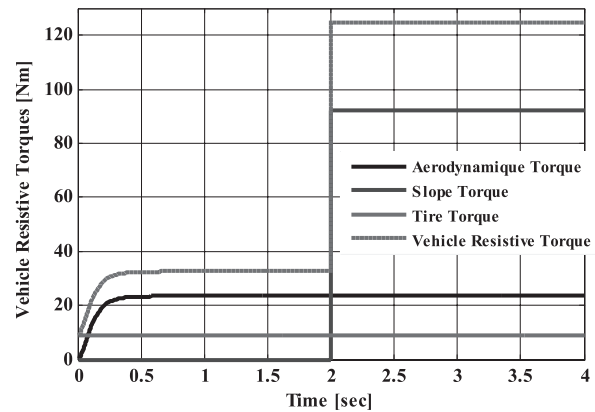


Fig. 10a). Vehicle Resistive Torques.

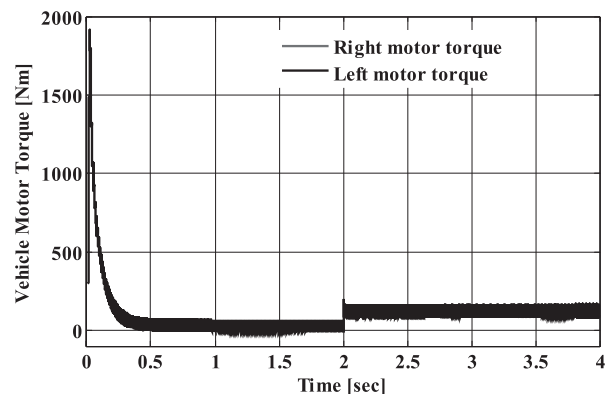


Fig. 10b). Vehicle Driving Forces.



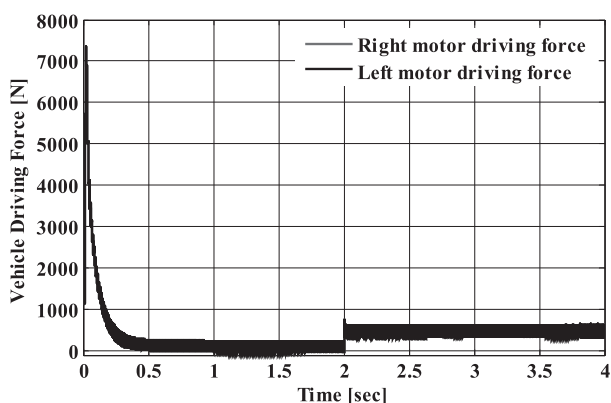


Fig. 10c). Vehicle Electromagnetic Torque.

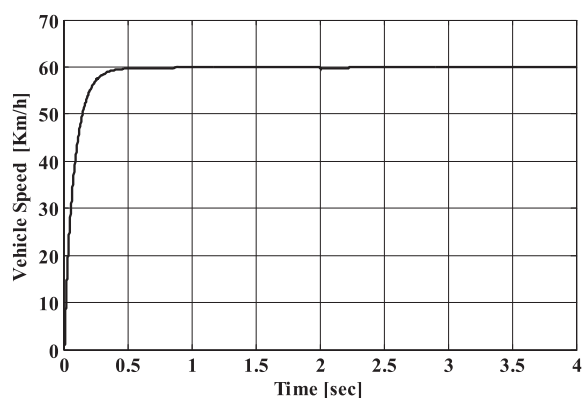


Fig. 10d). Vehicle speed variation.

**B. Case of curved way**

*Curved road at right side with speed of 60km/h at time 2 sec*

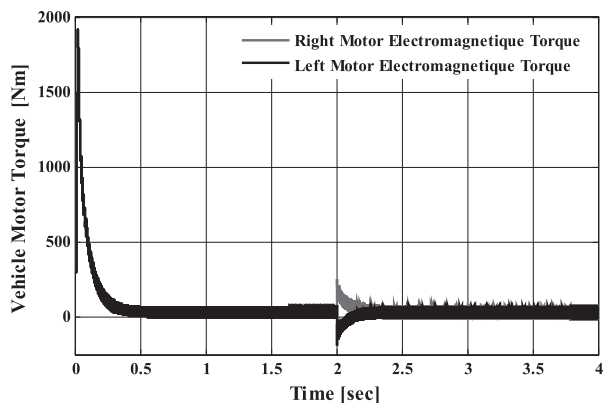


Fig. 11a). Vehicle electromagnetic torque.

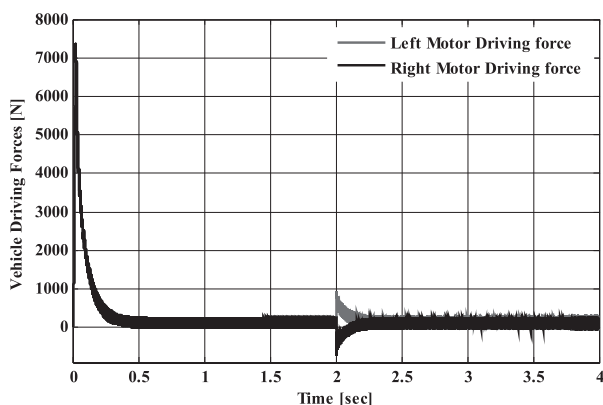


Fig. 11b). Vehicle driving force.

The vehicle driver turns the steering wheel on a curved road at the right side with 60 km/h speed. The assumption is that the two motors are not disturbed. In this case the driving wheels follow different paths, and they turn in the same direction but with different speeds. The electronic differential acts on the two motor speeds by decreasing the speed of the driving wheel on the right side situated inside the curve, and on the other hand by increasing the wheel motor speed in the external side of the curve. The Fuzzy controller ensure the stability of the propulsion system by maintaining the motorization error speed equal zeros and gives a good rising time and no over tracking error too. The behavior of these speeds is given by Figure 11c), the variation of the vehicle torques and the electromagnetic torques are illustrated in Figures 11a) and 11d), when the driving forces variations are shown in Figure 11b).

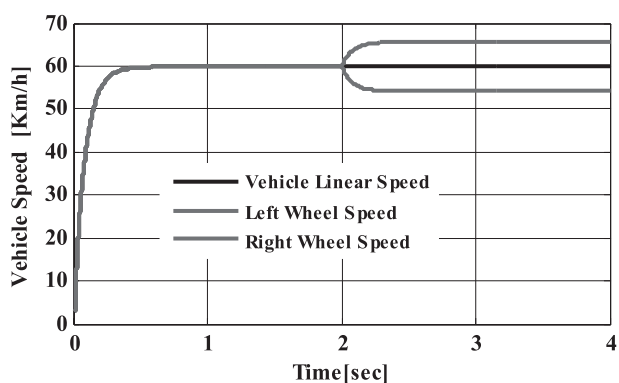


Fig. 11c). Vehicle speed variation.

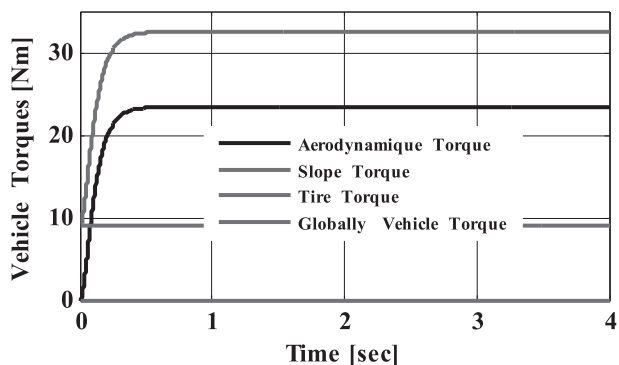


Fig. 11d). Vehicle resistive torques.

**C. The Electric vehicle Stability against vehicle torque variation impact:**

*- The Slope torque effect on Electric Vehicle Motion Stability in Straight way:*

In this case and according to the formula number (7), we introduce the slope torque effect's as a very important factor in the globally vehicle resistive torque tuning parameters in the straight way sloped case's. We can obtain a table, which summarise results simulated in Matlab Work Space given as follow:

Table 3. Vehicle Slope torque effect.

$\alpha^\circ$ (Slope angle)	3	5	8	10	15	20
Slope Torque [Nm]	47.7	79.43	126.8	158.3	235.9	311.7
Globally Vehicle Resistive Torque [Nm]	80.22	111.9	159.3	190.7	268.1	343.7
Slope Torque Impact in %	59.46%	70.98%	79.59%	83.09%	87.98%	90.68%

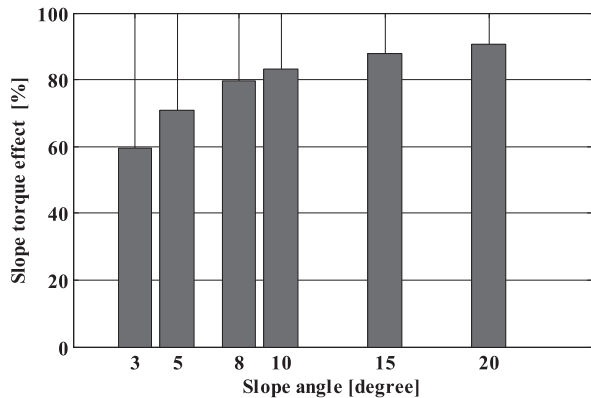


Fig. 12. Vehicle slope effect on the globally vehicle torque.

According to the result obtained in Figure 1. and the Table 3 it's appear clearly that:

When the slope torque constitute the 80 percent of the globally resistive torque, the vehicle haven't the ability to climb the slope by means that the effort developed on the motor drive shaft isn't sufficient to satisfy the hall demand of the vehicle traction chain, in this situation the vehicle became instable, furthermore the power torque developed produce a high temperature around the motor drive shaft as it shown in Figure 12 and all results are summarized in Table 3. 3.

After computations we can substitute a linear formula between the vehicle torque and Slope torque this Formula is given as follow:

$$V_t = P_1 * T_{slope} + P_2$$

Where:

$V_t$  and  $T_{slope}$  are the globally vehicle resistive torque and the Slope Torque respectively  $P_1$  and  $P_2$  are constants  $P_1 = 15.59$  and  $P_2 = 33.543$ .

The Grade angle of the Road effect on Electric Vehicle Motion Stability

Table 4. Vehicle speed angle road effect.

$\delta^\circ$ (Grade angle of Road)	5	7	9	11	13	15	17	19	21	23	25
w	5	7	9	11	13	15	17	19	21	23	25
$W_{refR}$	55	53	51	49	47	45	43	41	39	37	35
$W_{refL}$	65	67	69	71	73	75	78	79	81	83	85
Vehicle Linear speed	60	60	60	60	60	60	60	60	60	60	60
Stability State	S	S	S	PS	PS	PS	In	In	In	In	In

S: Vehicle Stable

PS: Vehicle Pseudo Stability 60 % Stable

In: Vehicle Instable

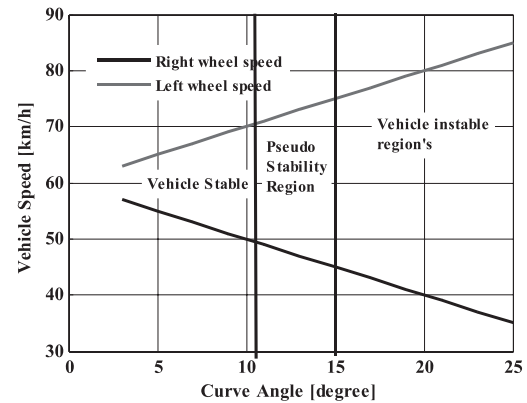


Fig. 13. Vehicle angle road stability effect.

Based on the formula (16 ,17,19) which gives the relationship between the grade angle of road and the speed references computation's, we say that when the driver turn the steering wheel in the curved road situation the angle of steer's must should be taken the values between 5 and 9 degrees in order to obtain the globally vehicle stability by means that the vehicle driver drive easily his engine when the steer's is less than 10 degrees, the second case when the steer's exceeds the 9 degrees and it's between 10 and 15 degree in this pseudo stability situation case's the vehicle driver has some difficulties to control the vehicle motion because there's an important difference between the left and the right speed reference as it shown in Figure 13 and Table 4, finally when the steers exceeds the 15 degrees the vehicle over go the curve because there's huge difference between the right and the left speed references.

## 6. Conclusion

This paper has demonstrate the feasibility of an improved urban electric vehicle dynamic stability which utilize two independent rear driving wheels for motion by using the fuzzy inference system - control. In the second part of this paper several simulations where carried in order to precise the electrical vehicle behavior against the

slope torque variation and the stability limits of the sloped angle in the other hand the steering angle take a great interest in the electronic vehicle speed computing. The results obtained by simulation show that this structure permits the realization of the robust control based on Fuzzy inference system, with good dynamic and static performances for the multi-converters/multi-machines propulsion system. The proposed Fuzzy controller model improve the driving wheels speeds control with high accuracy either in flat roads or curved ones. The disturbances do not affect the performances of the driving motors and the control law's efficiency gives a good dynamic characteristics of the traction chain.

**Appendix**

Table 5. Electric vehicle Parameters.

$T_e$	Motor traction torque	247 Nm
$J_e$	Moment on inertia of the drive train	7.07 Kg $m^2$
$R$	Wheel radius	0.36 m
$a$	Total gear ratio	10.0
$\eta$	Total transmission efficiency	93%
$M$	Vehicle mass	3904 Kg
$f_e$	Bearing friction coefficient	0.001
$K_d$	Aerodynamic coefficient	0.46
$A$	Vehicle frontal area	3.48 m $^2$
$f_v$	Vehicle friction coefficient	0.01
	Grade angle of the road	rad
	Distance between two wheels and axes	2.5 m
	Distance between the back and the front wheel	1.5m

Table 6. Induction Motors Parameters.

$R_r$	Rotor winding resistance (per phase)	0.003 $\Omega$
$R_s$	Stator winding resistance (per phase)	0.0044 $\Omega$
$L_s$	Stator leakage inductance (per phase)	16.1 $\mu H$
$L_m$	Magnetizing inductance (per phase)	482 $\mu H$
$L_r$	Rotor leakage inductance (per phase)	12.9 $\mu H$
$f_c$	Friction coefficient	0.0014
$P$	Number of poles	4

Table 7. Symbols, Designation and Units.

Symbols	Nomenclature	units
$P$	Pole pairs	
$J$	Rotor inertia	Kg.m $^2$
$J_e$	Moment of inertia of the drive train	Kg.m $^2$
$J_v$	Vehicle inertia	Kg.m $^2$
$T_{em}$	Electromagnetic torque	Nm
$T_v$	Vehicle torque	Nm
$T_{slope}$	Slope torque	Nm
$T_{aero}$	Aerodynamique torque	Nm
$T_{tire}$	Tire torque	Nm
$T_{in}$	Inertia vehicle torque	Nm

$N_{red}$	Report of speed gear	%
$G$	Gear box	
$\eta$	Transmission efficiency	%
$L_w$	Distance between two wheels	m
$d_w$	Distance between the back and the front wheel	m
$\rho$	Air density	
$S$	Frontal vehicle surface	m $^2$
$C_x$	Aerodynamic drag coefficient	
$M$	Vehicle mass	Kg
$g$	Gravitational acceleration	N/m
$\alpha$	Angle grade of road	rad
$f_r$	Wheels Rolling resistance coefficient	
$U_{dc}$	Battery voltage	Volt
$K_b$	Choice of direction coefficient	Rad/sec
$\Delta W$	Angular speed variation given by electronic differential	Rad/sec
$W_{rR}$	Right wheel angular speed	Rad/sec
$W_{rL}$	Left wheel angular speed	Rad/sec
$W_{mR}^*$	Right wheel angular speed of reference	Rad/sec
$W_{mL}^*$	Left wheel angular speed of reference	rad
$\delta$	Reel angle wheel curve's	rad
$\beta$	Vehicle slip angle	rad
$FLC$	Fuzzy Logic control	
$Vh$	Linear Speed	Km/h
$I\text{FOC}$	Indirect Field Oriented Control	
$PI$	Proportional integral	

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**References**

[1] Poursamad A., Montazeri M., "Design of Genetic-Fuzzy Control Strategy for Parallel Hybrid Electric Vehicles", *Control Engineering Practice*, DOI:10.1016/j.coneng-prac.2007.10.003.

[2] Pien Yang Y., Pin Lo C., "Current Distribution Control of Dual Directly Driven Wheel Motor for Electric Vehicles", *Control Engineering Practice*, vol.16, 2008, pp. 1285-1292.

[3] Hartani K., Bourahla M., Miloud Y., "Electric Vehicle Stability Improvement Based on Anti-Skid Control Using Behaviour Model Control", *Electro motion Cluj-Napoca*, vol. 14, part 4, pp. 209-171.

[4] Nasri A., Hazzab A., Bousserhane I.K., Hadjeri S., Sicard P., "Two Wheel Speed Robust Sliding Mode Control For Electric Vehicle Drive", *Serbian Journal of Electrical Engineering*, vol. 5, no. 2, November 2008, pp. 199-216.



- [5] Allaoua B., Laoufi A., Nasri A., "Intelligent Controller design of DC motor speed control based on Fuzzy Logic Genetic Algorithms Optimisations", *Leonardo Journal of Sciences*, issue 13, December 2008, pp. 90-102.
- [6] Rehman H., Dhaoudi R., "A fuzzy Learning-Sliding Mode Controller for Direct Field Oriented Induction Machines", *Neurocomputing*, Elsevier, vol. 71, 2008, pp. 2693-2701.
- [7] Aissaoui Ghani A., Abid M., Abid H., Tahour A., Zeblah A., "A Fuzzy logic Controller for Synchronous machine", *Journal of Electrical Engineering*, vol., 58, no. 5, 2007, pp. 285-290.
- [8] Yoichi H., Yasushi T., Yoshimasa T., "Traction Control of Electric Vehicle: Basic Experimental Results Using the Test EV UOT Electric March". *IEEE Transactions on Industry Applications*, vol. 34, no. 5, September/October 1998, pp. 1131-1138.
- [9] Kim I., "Non Linear State of Charge Estimator for Hybrid Electric Vehicle Battery", *IEEE Transactions*, vol. 23, no. 4, July 2008, pp. 2027-2034.
- [10] Tahour A., Hamza A., Aissaoui A.G., "Speed Control of Switched Reluctance Motor Using fuzzy Sliding Mode", *Advances in Electrical and Computer Engineering*, vol. 8(15), no. 1(29), 2008.
- [11] Shi G., Jing Y., Xu A., Ma J., "Study and Simulation of Based fuzzy logic parallel Hybrid Electric Vehicles". In: *Proceeding of the 6<sup>th</sup> international Conference on intelligent System Design and Applications (ISDA 06)*, IEEE 2006, vol. 1, pp. 280-284.
- [12] Chen C.Y., Li T.-H.S., Yeh Y.C., "EP-based kinematic control and adaptive fuzzy sliding-mode dynamic control for wheeled mobile robots", *Information Sciences*, vol. 179, issue 1-2, 2009, pp. 180-195
- [13] Hazzab A., Bousserhane I.K., Kamli M., Rahli M., "New Adaptive fuzzy PI-Sliding Mode Controller for Induction Machine Speed Control". *3<sup>rd</sup> IEEE International Conference on Conference on Systems, Signals & Devices SSD'05*, Tunisia, 2005.
- [14] Lin C.M, Hsu C.-F., "Adaptive Fuzzy Sliding-Mode Control for Induction Servomotor Systems", *IEEE Transactions on Energy Conversion*, vol. 19, no. 2, June 2004, pp. 362-368.
- [15] Keyun C., Alain B., Walter L., "Energetic Macroscopic Representation and inversion-based control Application to an Electric Vehicle With An Electrical Differential", *Journal of Asian Electric Vehicles*, vol. 6, no. 1, June 2008, pp. 1097-1102.
- [16] Allaoua B., Abderahmani A., Gasbaoui B., Nasri A., "The Efficiency of particle Swarm Optimization Applied On Fuzzy Logic DC Motor Speed Control", *Serbian Journal of Electrical Engineering*, vol. 5, no. 2, November 2008, pp. 247-262.
- [17] Haddoun A., Benbouzid M., Diallo D., "Modeling, Analysis, and Neural Network Control of An EV Electrical Differential", *IEEE Transactions*, vol. 55, no. 6, June 2008, pp. 2286-2294.
- [18] Pin Yang Y., Pin Lo C., "Current Distribution Control of Dual Directly Driven Wheel Motors for Electric Vehicles", *Control Engineering Practice*, vol. 16, 2008, pp. 1285-1292.
- [19] Larminie J., Lowry J., *Electric Vehicle Technology Explained*, John Wiley & Sons Ltd., England, 2003.