ADAPTIVE SELF-TUNING FUZZY BACKSTEPPING CONTROLLER FOR THE CONTROL OF ELECTRIC VEHICLE WITH TWO-MOTOR-WHEEL DRIVE

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ABSTRACT

In this work we proposed a backstepping controller adapted by a fuzzy inference for the control of the electric vehicle with two motor wheel drives. This proposed combine controller has significantly improved control performance compared to conventional backstepping. The different speeds of the wheels are ensured by the electronic differential, this driving process makes it possible to direct each driving wheel to any curve separately. Modeling and simulation are performed using the Matlab / Simulink tool to study the performance of the proposed controller.

Keywords: *Fuzzy logic, Backstepping controller, Electrical vehicle, Electronic differential, Adaptive control.*

1. INTRODUCTION

Electric vehicles (EV) are developing fast during this decade due to drastic issues on the protection of environment and the shortage of energy sources, so new technologies allow the development of electric vehicles (EV) by means of electric motors associated with static converters [1]. As the environmental pollution and energy shortage is increasing, the electric car technology gets more and more attention by the government and academia. The electric vehicle technology research has become a hot spot of research at home and abroad. The electric vehicle drive control strategy research has become an important research direction. At present the electric cars are mainly divided into two drive forms including centralized drive and distributed drive. Compared with the centralized drive form, the distributed driving form omits the traditional mechanical structure, shortens the transmission chain and improves the transmission efficiency greatly. Each driving wheel of distributed driving vehicle could be controlled independently. The directly yawing moment control, electronic differential control, anti-slip regulation (ASR) and other advanced control could be achieved by controlling each wheel coordinately. It is therefore very necessary to design a vehicle control system with high performance, easy implementation and low cost. Backstepping is a systematic and recursive design methodology for nonlinear feedback control. The backstepping design alleviates some limitations of other approaches (Kanellakopoulos et al, 1991; Krstic et al., 1995; Benaskeur, 2000; Lin and Lee, 2000; Waiet al; 2001; Pozo et al, 2008) [8,9,10,11,12]. The idea of backstepping design is to select recursively some appropriate functions of state variables as pseudo-control inputs for lower dimension subsystems of the overall system. Each backstepping stage results into a new pseudo-control design, expressed in terms of the pseudo-control designs from the preceding design stages. When the procedure terminates, a feedback design for the true control input results and achieves the original design objective by virtue of a Lyapunov function, which is formed by summing up the Lyapunov functions associated with each individual design stage. An adaptive robust nonlinear controller can be derived using this control method in a straightforward manner (Kanellakopoulosetal., 1991; Krstic et al., 1995; Benaskeur, 2000; Pozoet al, 2008) [8,9,10,11]. Recently, the newly developed adaptive backstepping technique has been used in the design of speed controllers for DC, induction motors and permanent magnet motors (Lin and Lee, 2000; Waiet al, 2001; Huang et al., 2002 Derdiyok, M. K. Guven, H. Rahman, N. Inane, L. Xu, Oct. 2002 and F. Khoucha, K. Marouani, A. Kheloui, K. Aliouane, June 2004 [12,13,14,15,16]. In this paper we proposed a novel design of the backstepping controller adapted by a fuzzy inference for the control of the electric vehicle with two motor wheel drives.

The remainder of this paper is organized as follows: The first part reviews the main components of the electric vehicle model. The second part shows the electronic differential and its implementation. Third part shows the development backstepping controller design for electric vehicle engines. Fourth part shows the model of fuzzy-backstepping control law proposed. The proposed structure of the propulsion system studied is given in the fifth part.The sixth part gives simulation results of the different cases studied. Finally, the conclusion is drawn to the seventh parties.

2. ELECTRIC VEHICLE MODEL

Fig. 1 represents general diagram of an electric traction system using an asynchronous squirrel cage motors supplied by voltage inverter [3].

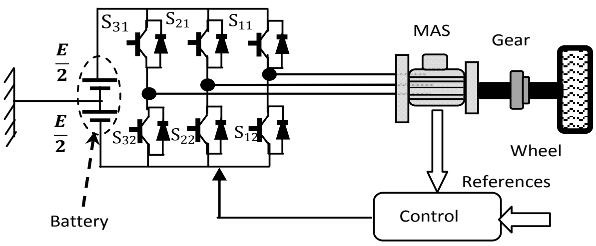

Fig. 1 Electrical traction chain

For the design presented in this paper it is considered that the two rear wheels of the vehicle are driven by asynchronous squirrel cage motors.

The reduced nonlinear model of IM using the orientation of the rotor flux is given by the following equation system:

$$\frac{\mathrm{di}_{ds}}{\mathrm{dt}} = a_1 i_{ds} + \omega_s . i_{qs} + a_2 . \emptyset_r + b v_{ds} \quad (1)$$

$$\frac{\mathrm{di}_{qs}}{\mathrm{dt}} = -\omega_s . i_{ds} + a_1 i_{qs} + a_3 . \emptyset_r \omega + b v_{qs} \quad (2)$$

$$\frac{\mathrm{d}\emptyset_r}{\mathrm{dt}} = a_4 . i_{ds} + a_5 . \emptyset_r \quad (3)$$

$$\frac{\mathrm{d}\omega}{\mathrm{dt}} = \frac{P}{J} a_6 . \left(i_{qs} . \emptyset_r\right) + a_7 . \omega + a_8 . C_r \quad (4)$$

Where:

C_r– Load torque

$$a_1 = \frac{1}{\sigma L_s}\left(-R_s - \left(\frac{L_m}{L_r}\right)^2 . R_r\right); a_2 = \frac{1}{\sigma C}\left(\frac{L_m . R_r}{L_r^2}\right);$$
$$a_3 = \frac{1}{\sigma L_s}\left(\frac{L_m}{L_r}\right); a_4 = \left(\frac{L_m . R_r}{L_r}\right);\ a_5 = \frac{R_r}{L_r}; a_6 = \frac{P . L_m}{L_r}; a_7 = \frac{f_c}{J}\ ;$$
$$a_8 = \frac{P}{J}$$

In this electric traction system, a two-stage inverter is used to obtain three balanced phases of alternating current with variable current frequency of the battery.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{U_{dc}}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (5)$$

Where:

$S_{a,b,c}$– are logical switches obtained by comparing the control inverter signals with the modulation signal

The general scheme of the driving wheels control is represented by Fig. 2. 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. [7]

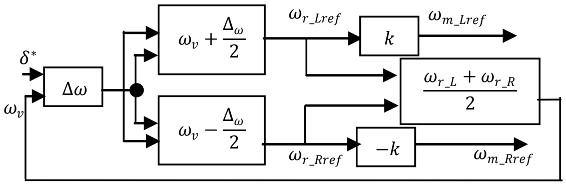

Fig. 2 Block diagram show use of the electronic differential

It is possible to determine the speed references according to the requirements of the driver. When the vehicle arrives at the beginning of a curve, the driver applies a curve angle on each driving wheels [17, 18].

The electronic differential acts immediately on the two motors reducing the driving wheel speed situated inside the curve, and increases the speed of the driving wheel situated out-side the curve. The driving wheels angular speeds are:

$$w_{mR}^* = \frac{V_h}{R_r} + K_b . \Delta\omega\ ; w_{mL}^* = \frac{V_h}{R_r} - K_b . \Delta\omega \quad (6)$$

The Fig. 3 represents the electric vehicle (EV) driving wheels system, where M_R and M_L represent the right driving motor and left driving motor respectively [7].

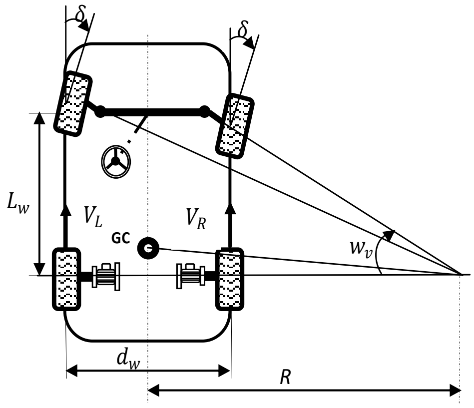

Fig. 3 Driving trajectory model

The driving wheels speed variation is imposed by the trajectory desired by the driver and it's given by:

$$\Delta\omega = \frac{d_w}{2} . \frac{\sin(\delta+\beta)}{l_w . \cos\delta} . \frac{V_h}{R_r} \quad (7)$$

where:

V_h– tangential velocity of the vehicle
K_b– choice of direction coefficient
R_r– diameter of the wheel

3. BACKSTEPPING CONTROL

The foundation of backstepping is the identification of virtual control variable and forcing it to become a stabilizing function. Thus, it generates a corresponding error variable which can be stabilized by proper input selection via Lyapunov's stability theory (Kanellakopoulos et al., 1991; Krstic et al., 1995; Lin and Lee, 2000; Wai et al., 2001; Huanget al., 2002). The backstepping technique can be perfectly applied for nonlinear system (Benaskeur, 2000; Pozoet al, 2008).

$$e_1 = \omega^* - \omega \quad (8)$$

Deriving equation (8) term by term, we obtain

$$\dot{e}_1 = \dot{\omega}^* - \left(\frac{P}{J} a_6 . i_{qs} . \emptyset_r + a_7 . \omega + a_8 . C_r\right) \quad (9)$$

We choose i_{qs}^* as our first virtual command, the stabilizing function is chosen as follows:

$$i_{qs}^* = \frac{1}{a_6 \emptyset_r}\left(\dot{\omega}^* - a_7\omega - a_8 C_r - c_1 e_1\right) \quad (10)$$

Replacing (10) in (9) so the derivative error is:

$$\dot{V}(e_1) = -c_1 . e_1^2 \leq 0 \quad (11)$$

Where:

$\dot{V}(e_1)$– The function of Lyapunov
c_1 – Backstepping Controller Adjustment Coefficient

Since i_{qs}^* is not an input control of the system to be adjusted, an error variable $\dot{e}_2$ is chosen to display the input command v_{qs}^*.

3.1 . Case of straight way

Flat road with 10% slope at 60km/h speed: In this test, the system is submitted to the same speed reference. The driving wheels speeds stay always the same and the road slope does not affect the control of the wheel and the Backstepping control act immediately on the speed loop's and rejects the disturbance 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 behavior of these speeds is illustrated by Fig.4; Fig. 6 describe the electromagnetic Torque variations. It seemshas the two motors develop the same efforts in order to pass the slope The resistant torques is shown in Fig. 5.

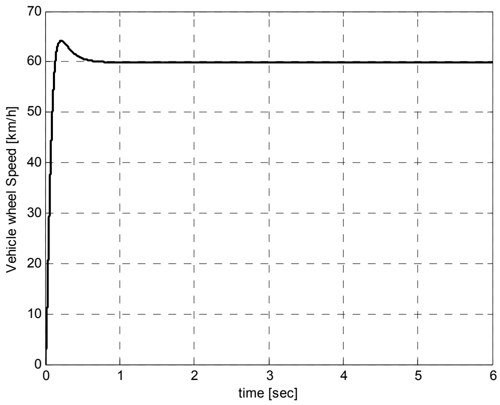

Fig. 4 Vehicle wheel speed

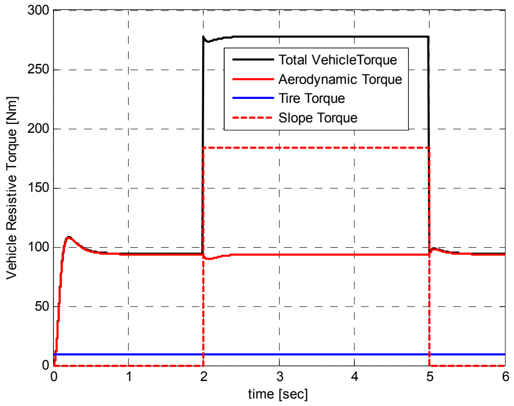

Fig. 5 Resistive Torques

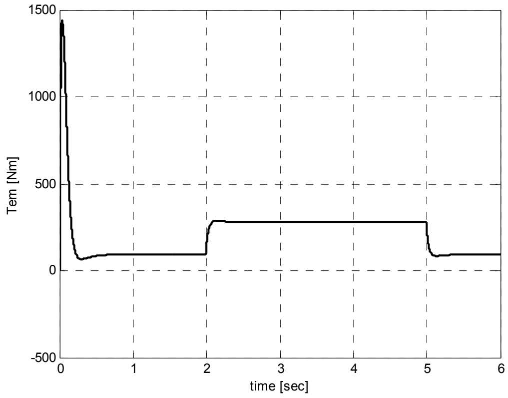

Fig. 6 Motor Electromagnetic Torque

3.2 . Case of curved way

Curved road at right side with speed of 60km/h: The vehicle is driving on a curved road on the right side with 60km/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 Backstepping control 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 Fig. 9, the variation of the vehicle torques and the electromagnetic torques are illustrated in Fig. 7 and Fig. 8.

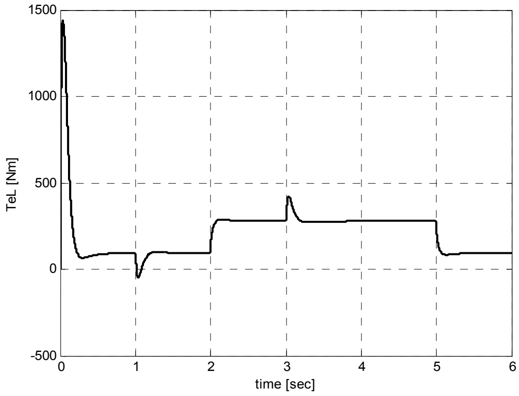

Fig. 7 Left motor Electromagnetic Torque

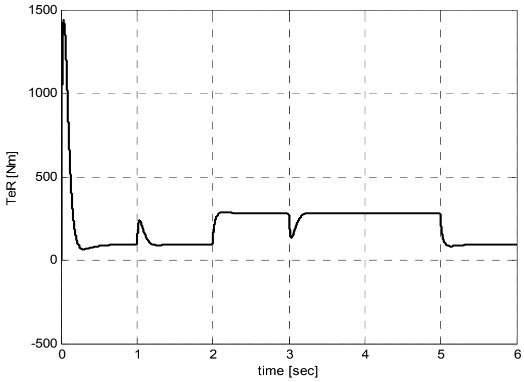

Fig. 8 Right motor Electromagnetic Torque

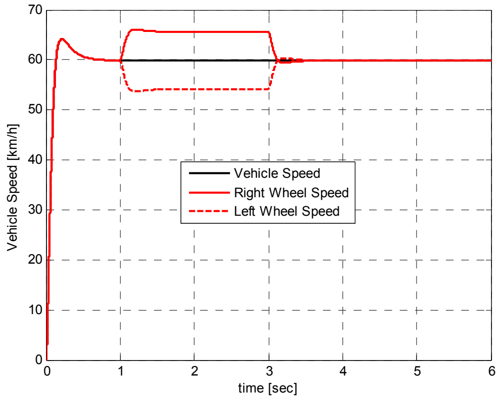

Fig. 9 Vehicle speed in right turn in curved way

4. FUZZY BACKSTEPPING CONTROL

In this section, Fuzzy-backstepping controller is developed, in which a fuzzy inference mechanism is used to generate the control law parameters. The proposed Fuzzy-backstepping controller scheme for EV speed control is shown in Fig. 10

$$i_{qs}^{*} = \frac{1}{a_6 \emptyset_r}(\dot{\omega}^{*} - a_7\omega - a_8 C_r - c_1 e_1)$$

The resulting fuzzy inference rules for the output variable α of as follows:

Rule 1: if e N and $\dot{e}$ N then α is VB ;Rule 2: if e N and $\dot{e}$ MN then α is VB; Rule 3: if e N and $\dot{e}$ Z then α is MB; Rule 4: if e N and $\dot{e}$ MP then α is MS ; Rule 5: if e N and $\dot{e}$ P then α is VS

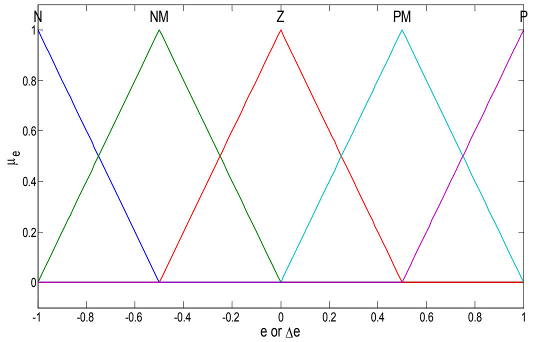

Fig. 10 The inpute or Δe membership function

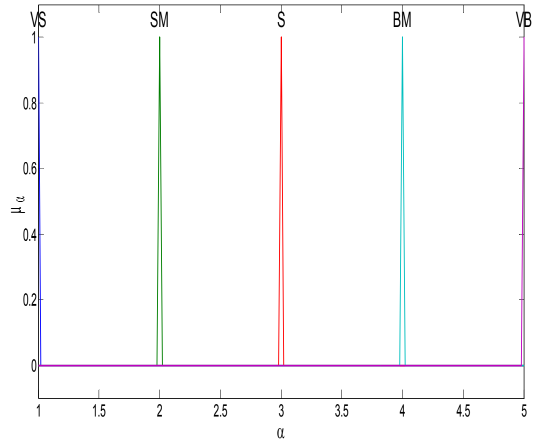

Fig. 11 The output α, membership function

Table 1 Fuzzy rule base

e / Δe	N	NM	Z	PM	P
N	BM	SM	VS	S	VB
NM	BM	SM	VS	S	VB
Z	BM	SM	VS	S	VB
PM	SM	VS	S	S	VB
P	SM	VS	S	VB	VB

The principle of adjusting the speed of the EV by a fuzzy backstraping controller is presented by a block diagram as shown in Fig. 12.

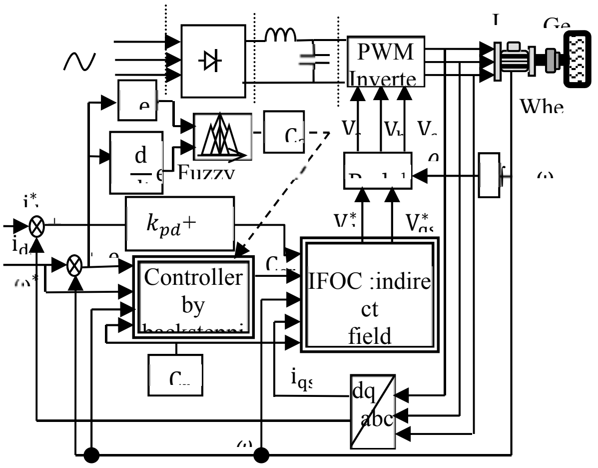

Fig. 12 Block diagram of the speed adjustment of EV by controller fuzzy backstepping

The simulation tests in the case of straight way and curved way are the same used with Backstepping controller the results of the simulation are presented in the figures 13, 14, 15, 16, 17 and 18.

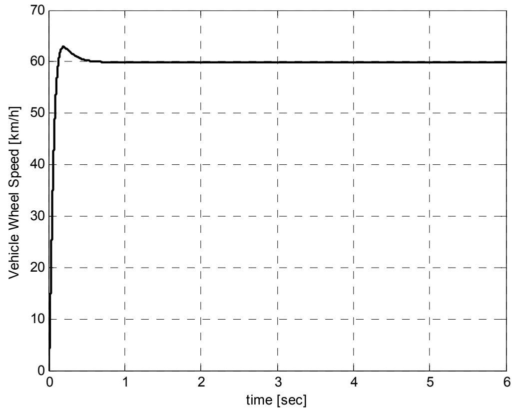

Fig. 13 Vehicle wheel speed

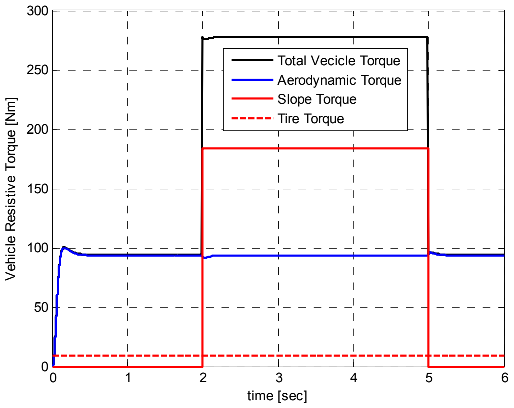

Fig. 14 Resistive Torques

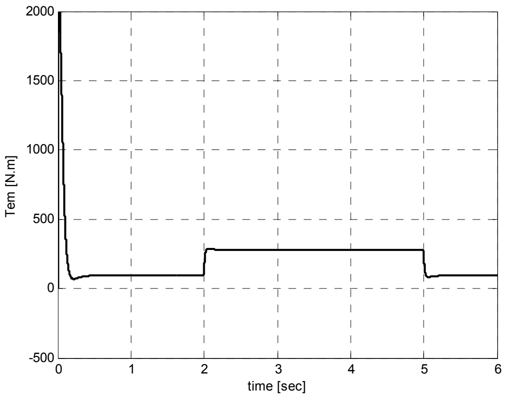

Fig. 15 Motor Electromagnetic Torque

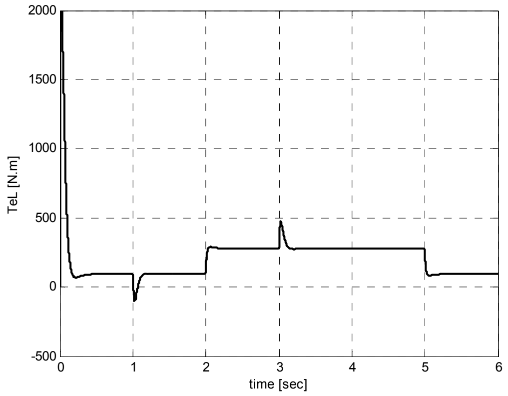

Fig. 16 Left motor Electromagnetic Torque

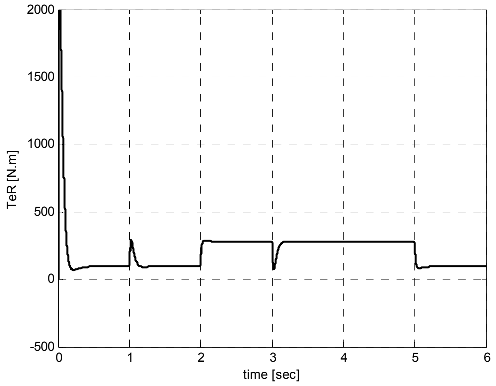

Fig. 17 Right motor Electromagnetic Torque

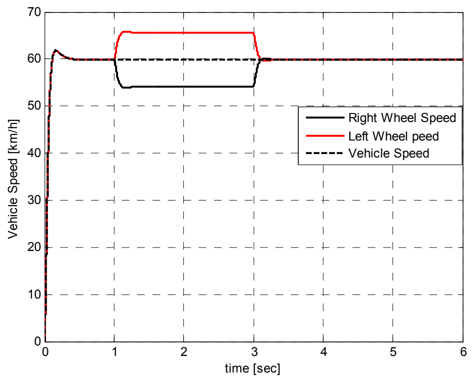

Fig. 18 Vehicle speed in right turn in curved way

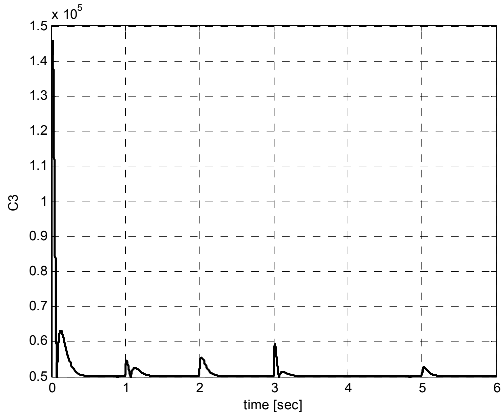

Fig. 19 The adjustment constant fuzzy backstepping

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, fig.19 shows the system response in two cases (Fuzzy-Backstepping, and Backstepping control).

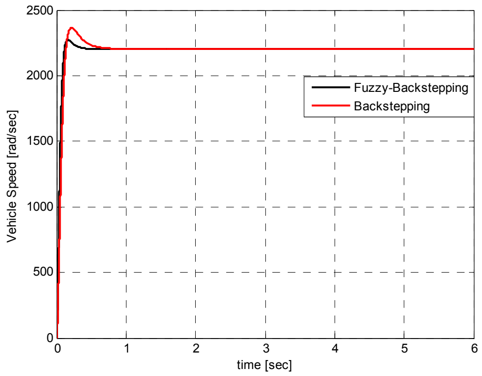

Fig. 20 Comparison of the vehicle speed for the two controllers

5. CONCLUSION

The research outlined in this paper has demonstrated the feasibility of an improved vehicle stability which utilizes two independent back drive wheels for motion by using the fuzzy-Backstepping control. This paper proposes an 'independent machine' control structure applied to a propulsion system ensuring by the electronic differential. The results obtained by simulation show that this structure permits the realization of the robust hybrid control based on Fuzzy inference system, with good dynamic and static performances for the multi-converters/multi-machines propulsed system.

The proposed Fuzzy-Backstepping controller improves 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 hybrid control gives good dynamic characteristics of the traction chain.

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