Journal of Fundamental and Applied Sciences

Research Article

ISSN 1112-9867

Available online at http://www.jfas.info

NONLINEAR PI CONTROLLER FOR THE CONTROL OF ELECTRIC VEHICLE WITH TWO-MOTOR-WHEEL DRIVE

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Received: 01 November 2019 / Accepted: 29 December 2019 / Published online: 01 January 2020

ABSTRACT

In this work we proposed a nonlinear PI (NLPI) controllerof the electric vehicle with two motor wheel drives. This proposed combine controller has significantly improved control performance compared to conventional linear fixed-gain PI controller. 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: Electrical Vehicle;Electronic Differential;PI Controller; Nonlinear PI Controller; Induction Machine; Ifoc.

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doi: http://dx.doi.org/10.4314/jfas.v12i1.13

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. The conventional linear fixed-gain PI controlleris a systematic and recursive design methodology for nonlinear feedback control. The conventional linear fixed-gain PI controllerdesign alleviates some limitations of other approaches (Z. Yinhai et al, 2009; Gunawan Dewantoro., 2016; Benaskeur, 2000; Lin and Lee, 2000; Waiet al; 2001; Pozo et al, 2008) [12,13]. The idea of conventional linear fixed-gain PI controllerdesign is to select recursively some appropriate functions of state variables as pseudo-control inputs for lower dimension subsystems of the overall system. Each conventional linear fixed-gain PI controllerstage results into a new pseudo-control design, expressed in terms of the pseudo-control designs from the preceding design stages. 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) [8,10,11].Recently, the newly developed aconventional linear fixed-gain PI controllertechnique 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 nonlinear PI controller for the control of the electric vehicle with two motor wheel drives (Z. Yinhai*, et al* Z. Yinhai*, et al,2009;* Cruz, M. A. Gallegos, R. Alvarez, and F. Pazos, Cruz, M. A. Gallegos, R. Alvarez, and F. Pazos,2004; Y.X. Su, Dong Sun, B.Y.

Duan,2005) [8-11].

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 conventional linear fixed-gain PI design for electric vehicle engines. Fourth part shows the nonlinear PI controller 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].

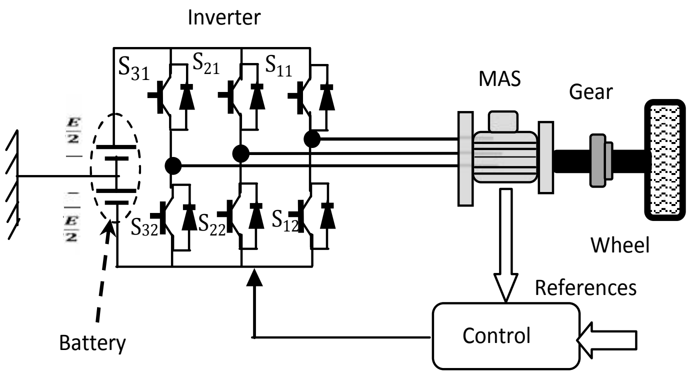

Fig.1. Electrical traction chain

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 general scheme of the driving wheel 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].

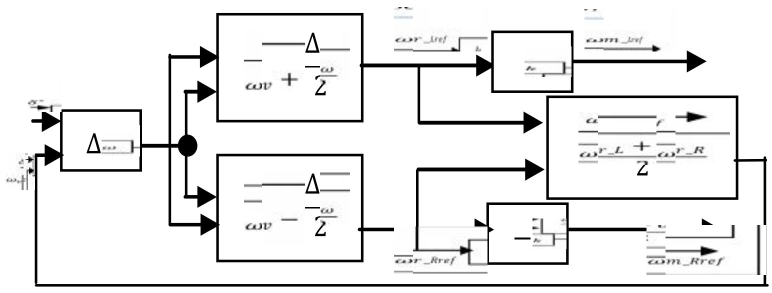

Fig.2. Block diagram show use of the electronic differential

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:

$$w_{mR}^{*} = \frac{V_h}{R_r} + K_b.\Delta\omega \;;\; w_{mL}^{*} = \frac{V_h}{R_r} - K_b.\Delta\omega \quad (1)$$

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].

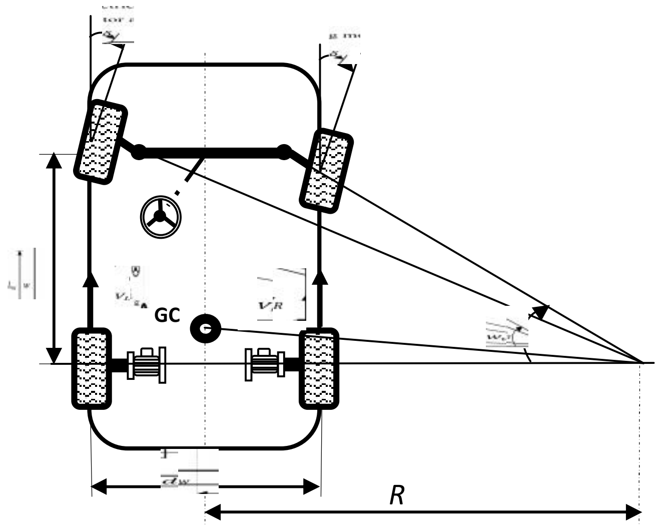

Fig.3. Driving trajectory model

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

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

where:

V_h: tangential velocity of the vehicle

K_b: choice of direction coefficient

R_r: diameter of the wheel

3. INDIRECT FIELD-ORIENTED CONTROL OF THEELECTRICVEHICLE

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

$$\frac{di_{ds}}{dt} = a_1 i_{ds} + \omega_s.\, i_{qs} + a_2.\, \emptyset_r + bv_{ds} \quad (3)$$

$$\frac{di_{qs}}{dt} = -\omega_s.\, i_{ds} + a_1 i_{qs} + a_3.\, \emptyset_r\omega + bv_{qs} \quad (4)$$

$$\frac{d\emptyset_r}{dt} = a_4.\, i_{ds} + a_5.\, \emptyset_r \quad (5)$$

$$\frac{d\omega}{dt} = \frac{P}{J} a_6.\left(i_{qs}.\, \emptyset_r\right) + a_7.\, \omega + a_8.\, C_r \quad (6)$$

Where:

C_r:Load torque

$$a_1 = \frac{1}{\sigma L_s}\left(-R_s - \left(\frac{L_m}{L_r}\right)^2 .\, R_r\right); a_2 = \frac{1}{\sigma L_s}\left(\frac{L_m.R_r}{L_r^2}\right); a_3 = \frac{1}{\sigma L_s}\left(\frac{L_m}{L_r}\right); a_4 = \left(\frac{L_m.R_r}{L_r}\right);\ a_5 = \frac{R_r}{L_r};$$

$$a_6 = \frac{P.L_m}{L_r}; a_7 = \frac{f_c}{J}\ ;\ a_8 = \frac{P}{J};\ \sigma = 1 - \frac{L_m^2}{L_r.L_s}$$

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.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{U_{dc}}{3}\begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix}\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (7)$$

Where:

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

σ: is a constant, which can be set empirically to a small value.

The main objective of the vector control of induction motors is, to control independently the flux and he torque as DC machines, this is done by using a d-q rotating reference frame synchronously with the rotor flux space vector [4]. In ideally field-oriented control, the rotor flux linkage axis is forced to align with the d-axes, and it follows that [1, 6]:

$$\emptyset_{qr} = 0 \quad (8)$$

$$\emptyset_{dr} = \emptyset_{r} \quad (9)$$

Electromagnetic Torqueis given by:

$$T_{em} = \frac{P.L_m}{L_r} \emptyset_{dr}.\, i_{qs} \quad (10)$$

The decoupling control method with compensation is to obtain the inverter output voltages such that [6]:

$$V_{ds}^{*} = \left(k_p + k_i \frac{1}{s}\right)(i_{ds}^{*} - i_{ds}) - \omega_s \sigma L_s i_{qs}^{*} \quad (11)$$

$$V_{qs}^{*} = \left(k_p + k_i \frac{1}{s}\right)\left(i_{qs}^{*} - i_{qs}\right) + \omega_s \sigma L_s i_{ds}^{*} + \omega_s \frac{L_m}{L_r} \emptyset_{dr} \quad (12)$$

By using, the placement poles method the proportional and integral gains of the PI speed controller ($k_p$andk_i) are determined by [6,13]:

$$k_p = \frac{2.\rho.J - f_c}{P} \quad (13)$$

$$k_i = \frac{2.\rho^2.J}{P} \quad (14)$$

Where the desired poles are: $s_{1,2} = \rho(-1 \mp J)$

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 sliding mode 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 seems has the two motors develop the same efforts in order to pass the slope the resistant torques is shown in fig.5.

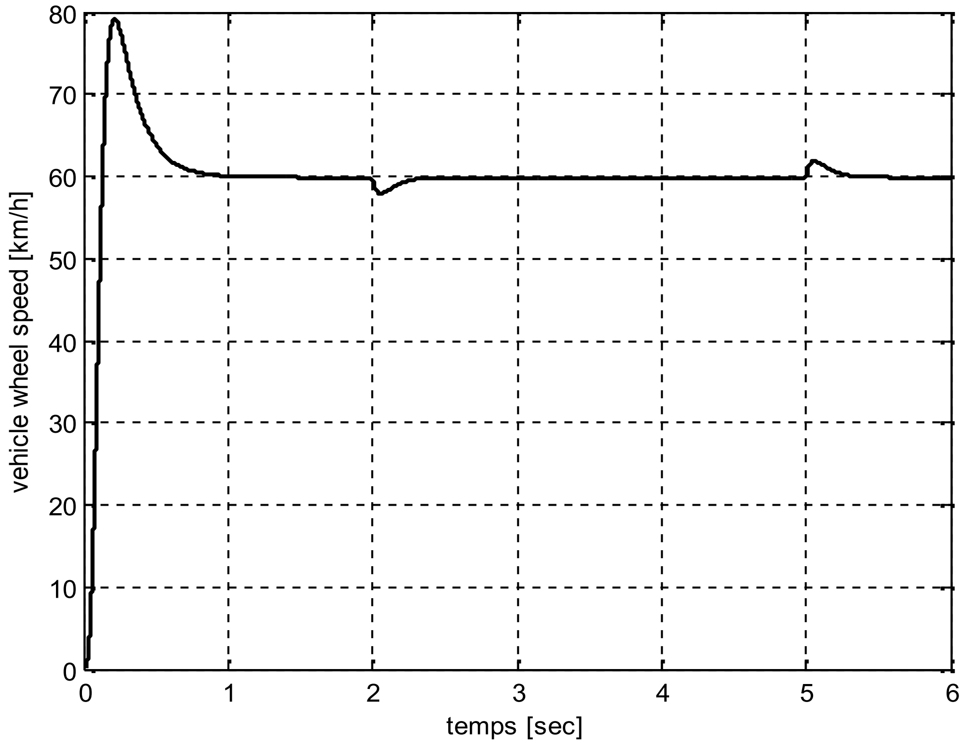

Fig.4. Vehicle wheel speed

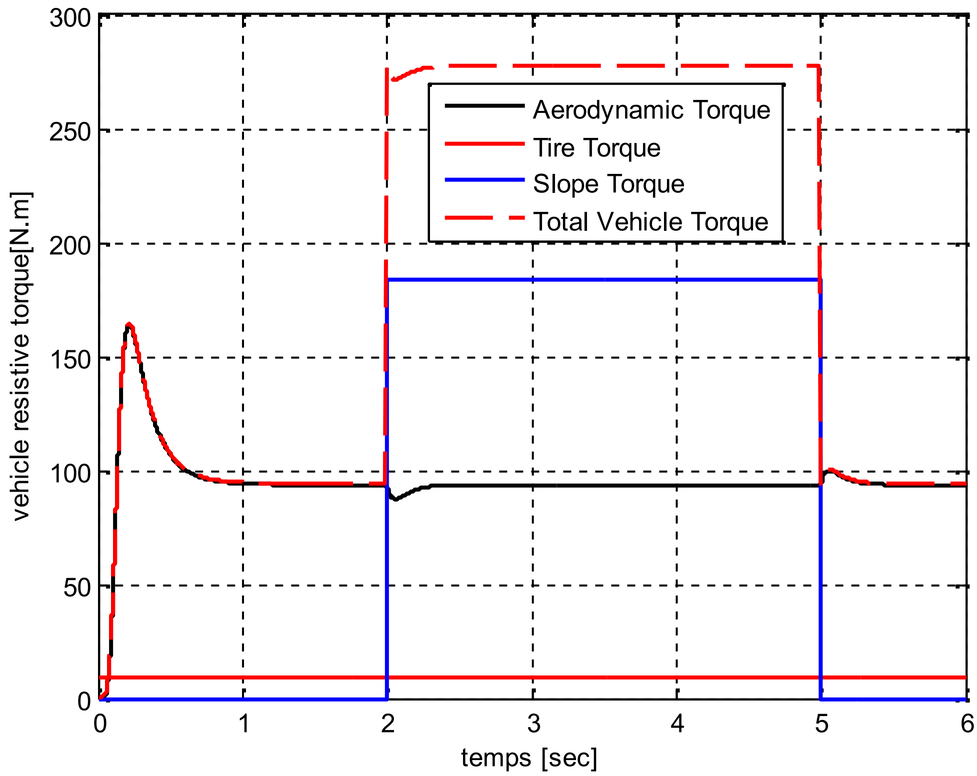

Fig.5. Resistive Torques

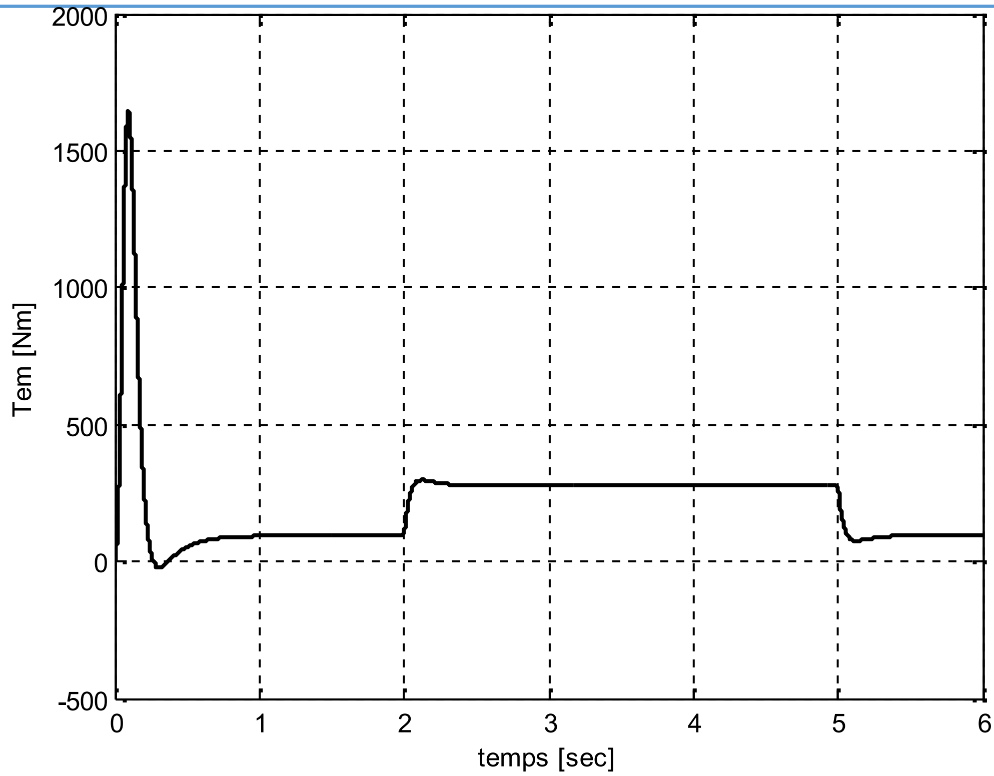

Fig.6. Motor Electromagnetic Torque

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 sliding mode 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.

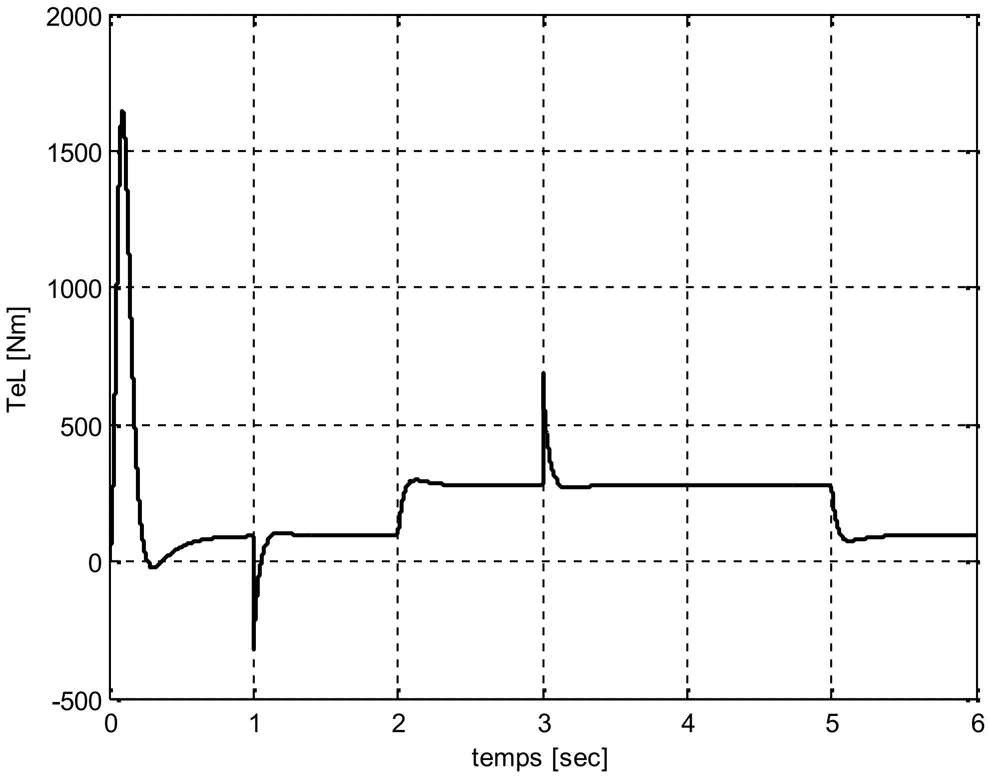

Fig.7. Left motor Electromagnetic Torque

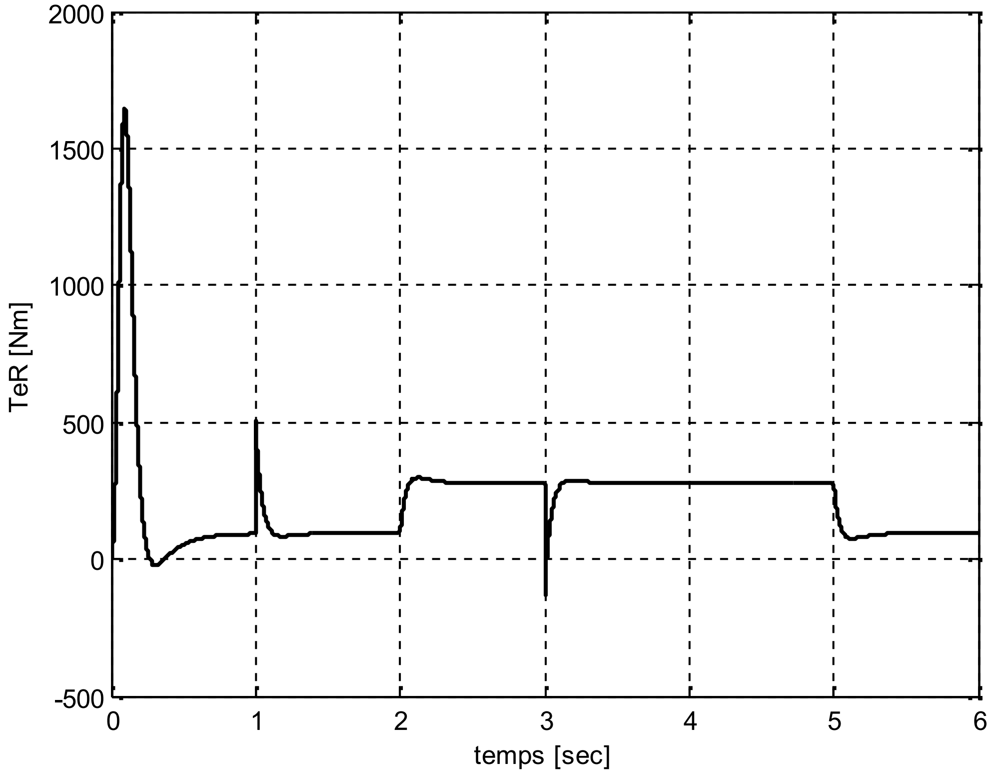

Fig.8. Right motor Electromagnetic Torque

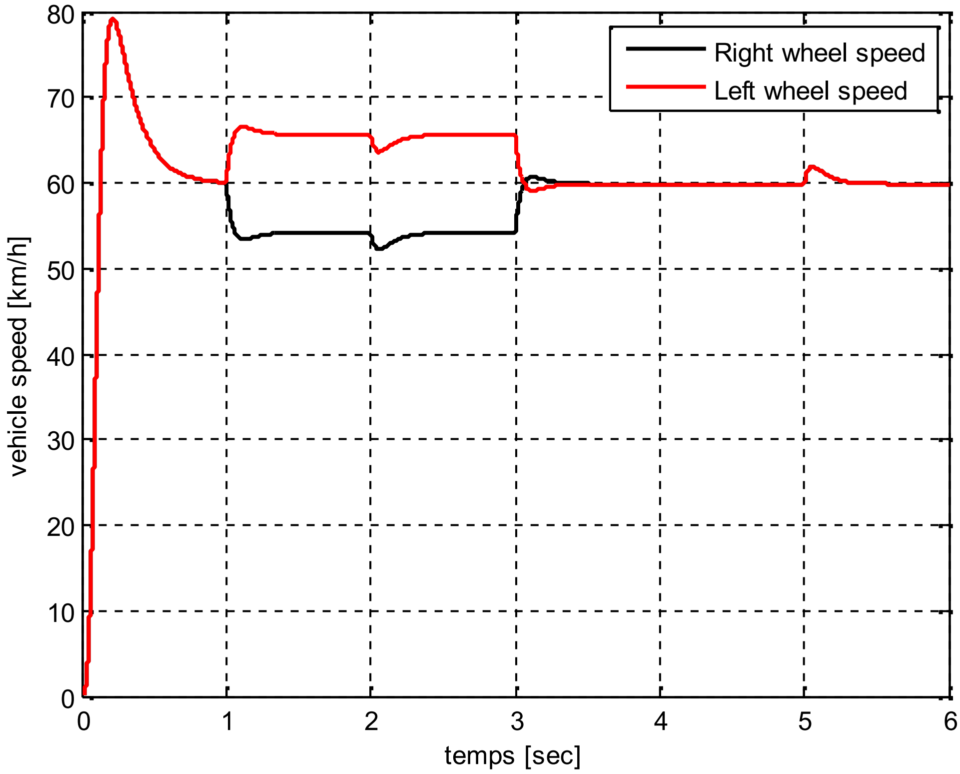

Fig.9. Vehicle speed in right turn in curved way

4. SPEED CONTROL OF THE EV BY THE NONLINEAR PI (NLPI)

In order to improve the control quality, a nonlinear PI (NLPI) IM speed controller can be constructed as shown in fig.10. The combination of nonlinear terms can provide additional degrees of freedom to achieve a much improved system performance. The nonlinear PI controller action is given by [9,10,11]

$$T_e^* = k_p . fal(e, \alpha_p, \delta_p) + k_i . fal(\int e, \alpha_i, \delta_i) \quad (15)$$

$$fal(x, \alpha, \delta) = \begin{cases} |x|^{\alpha} sign(x) & |x| > \delta, \delta > 0 \\ \frac{x}{\delta^{1-\alpha}} & |x| \leq \delta \end{cases} \quad (16)$$

Where:

$fal(x, \alpha, \delta)$ is a nonlinear function represented in fig.1

x is a variable which can be e or $\int e\,dt$

e is the error between the speed reference and real speed of the VE ($e = \omega_r^* - \omega_r$)

k_p and k_i are respectively proportional and integral gains of the PI controller, presented in

(13) and (14)

T_e^* is the referential torque (the control signal)

The parameters α_p and α_i are constant, empirically chosen in the range 0 to 1,

When, $\alpha_p = \alpha_i = 1$ the controller becomes a linear PI controller.

δ is a constant, which can be set empirically to a small value.

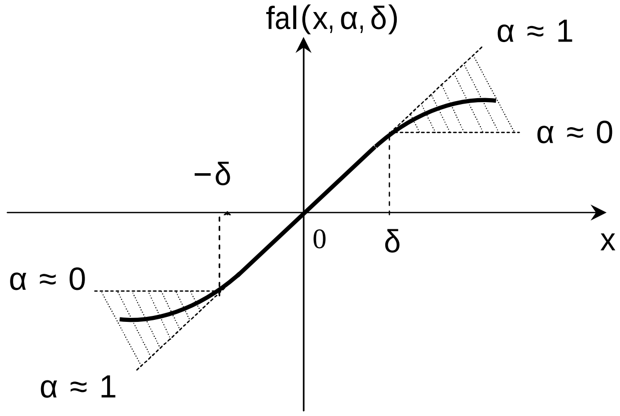

Fig.10. The nonlinear function $fal(x, \alpha, \delta)$

The principle of adjusting the speed of the EV by a nonlinear PI controller is presented by a block diagram as shown in Fig.11.

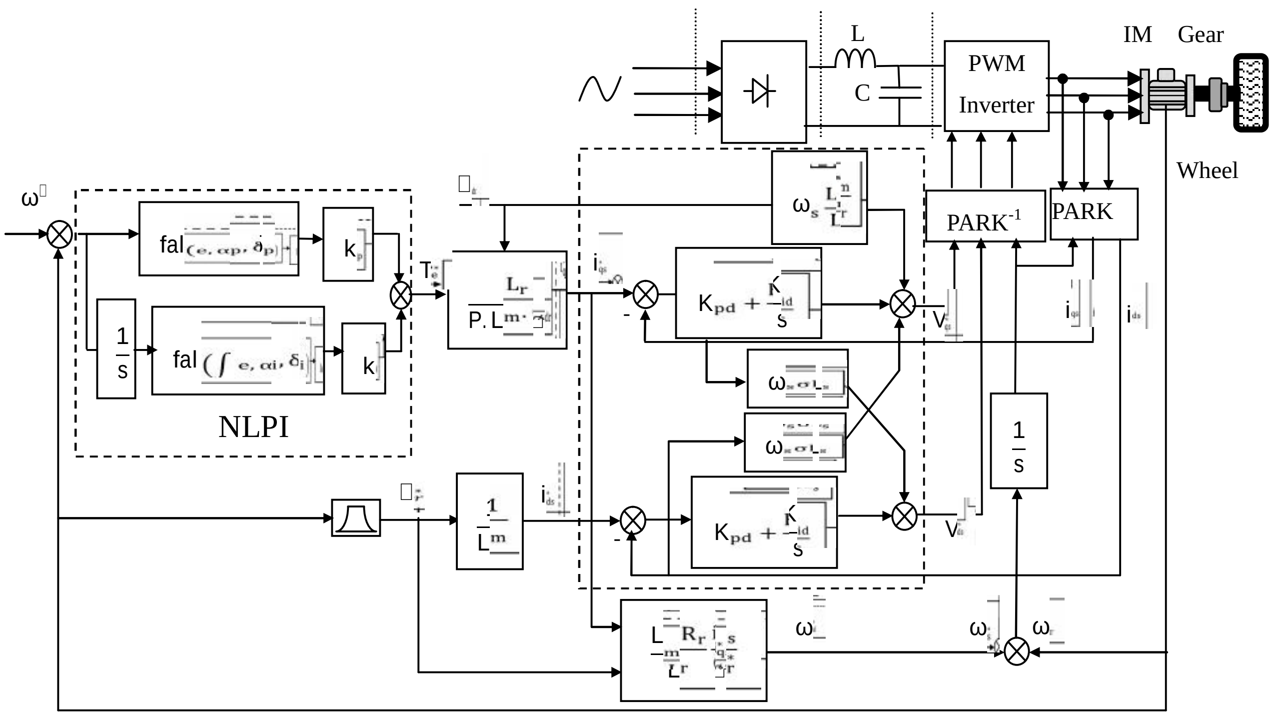

Fig.11. Block diagram of EV control by a nonlinear PI controller

The simulation tests in the case of straight way and curved way are the same used with nonlinear PI controller the results of the simulation are presented in the figures 12, 13, 14, 15, 16, and 17.

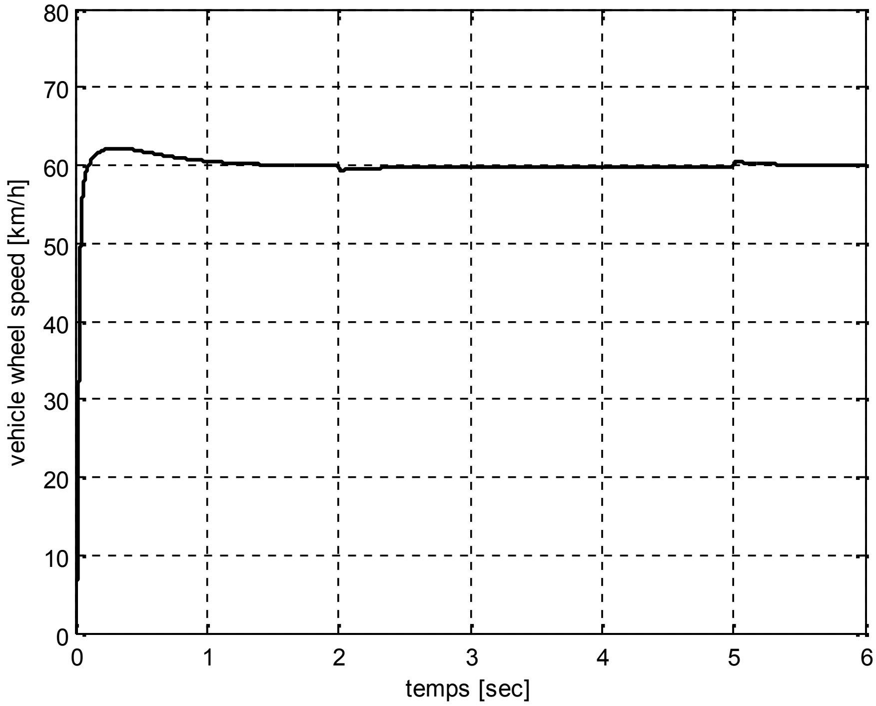

Fig.12. Vehicle wheel speed

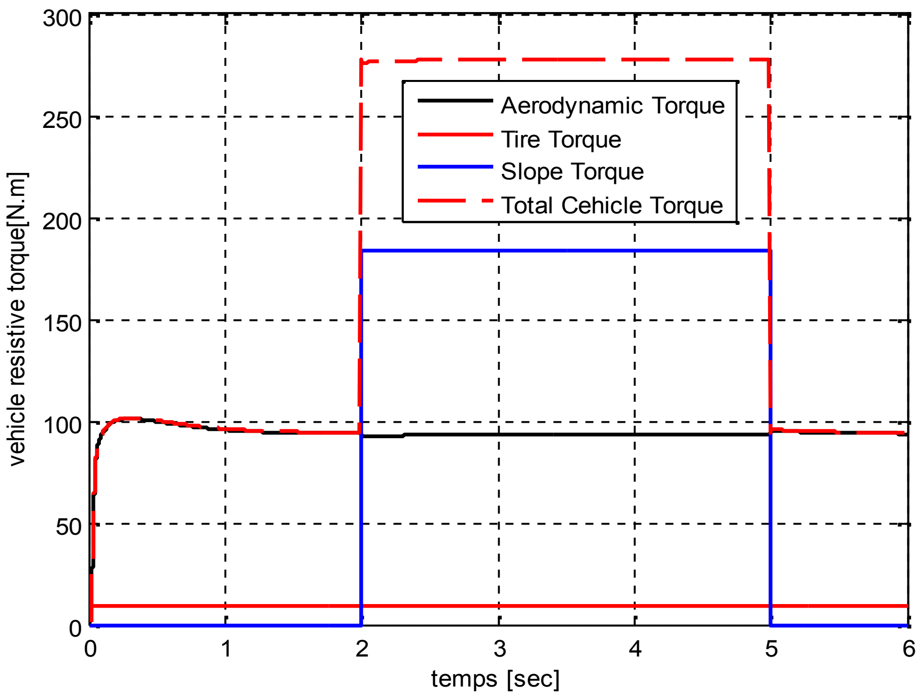

Fig.13. Resistive Torques

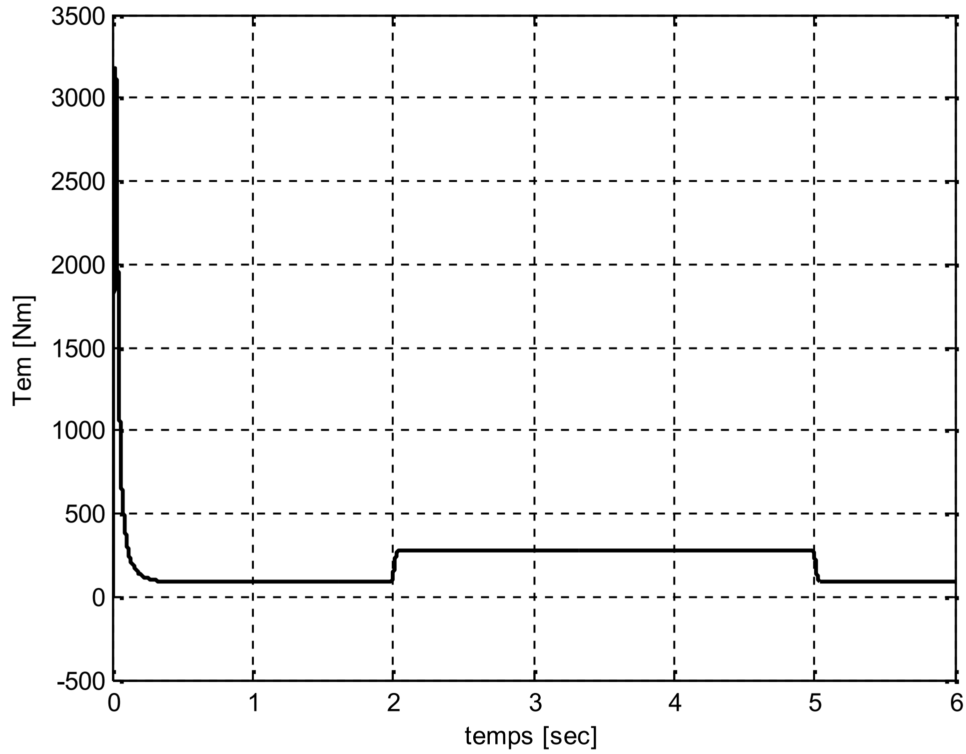

Fig.14. Motor Electromagnetic Torque

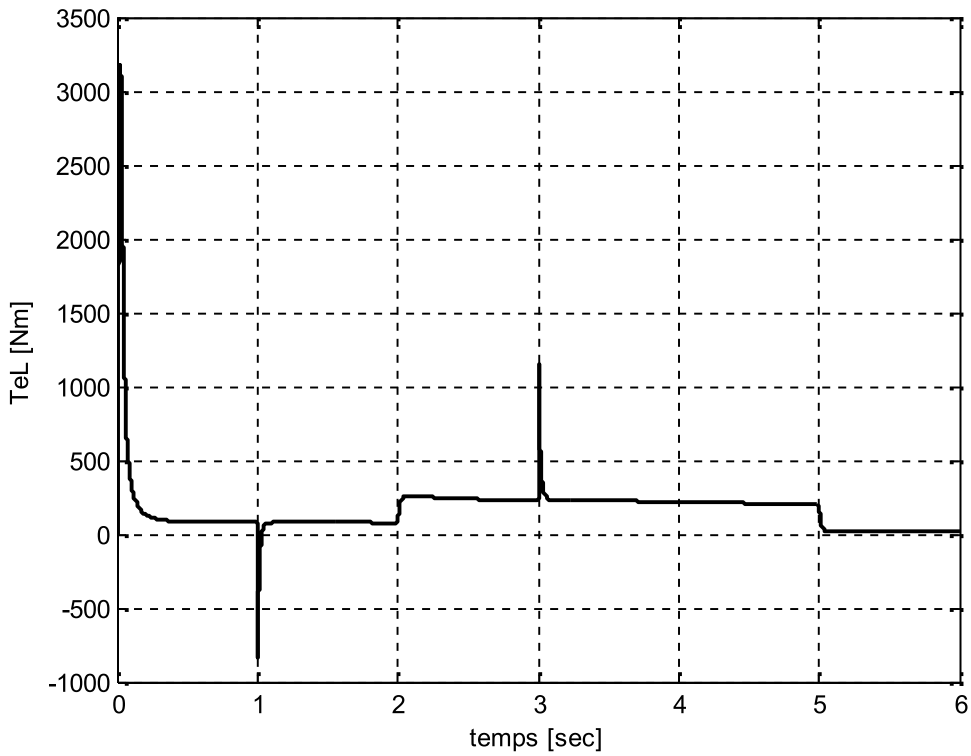

Fig.15. Left motor Electromagnetic Torque

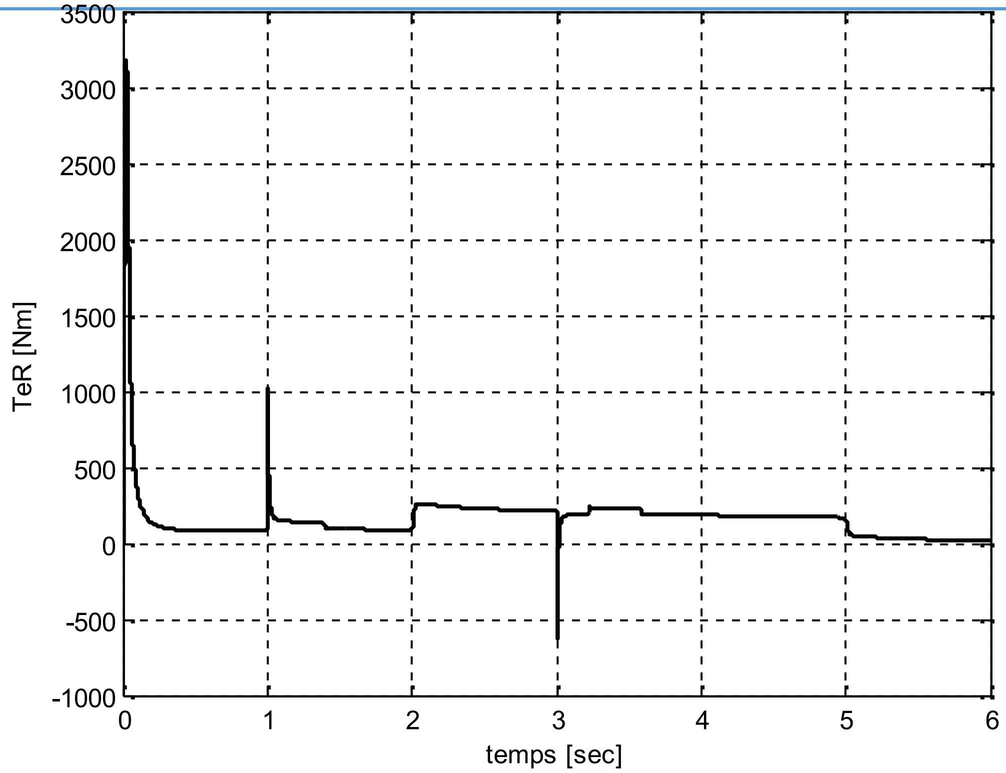

Fig.16. Right motor Electromagnetic Torque

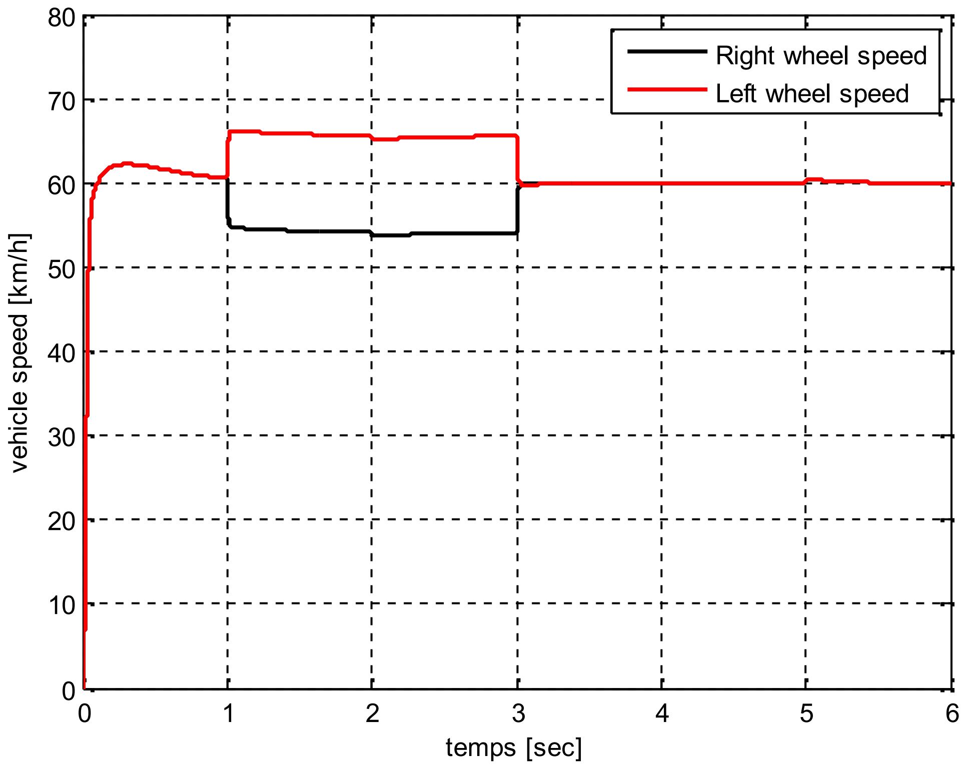

Fig.17. Vehicle speed in right turn in curved way

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.18 shows the system response in two cases (nonlinear PI controller and conventional linear fixed-gain PI controller) [10].

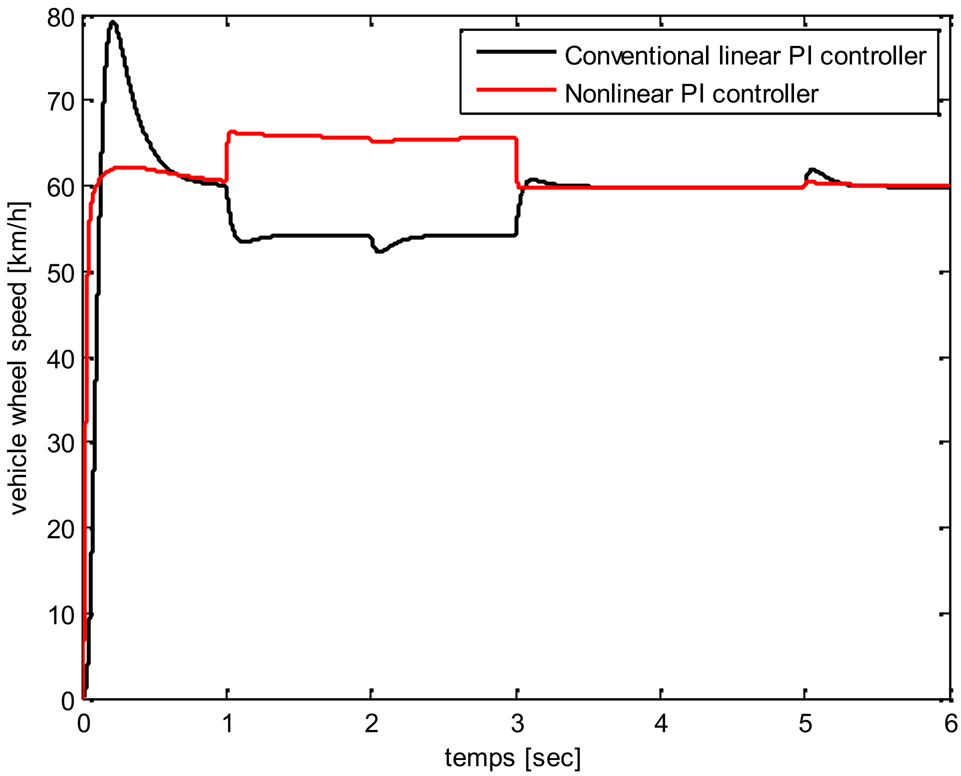

Fig.18. Comparison of the vehicle speed for the two controllers

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 nonlinear PI contoller. 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 nonlinear PI controller system, with good dynamic and static performances for the multi-converters/multi-machines propulsed system.

The proposed nonlinear PI controllerimproves 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.

6. REFERENCES

[1] 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,Part4, pp. 209-171.

[2] 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, No 2, November 2008, pp. 199-216.

[3] Yoichi, H., Yasushi, T., and Yoshimasa, T.: Traction control of electric vehicle:Basic experimental results using the test EV "UOT Electric march". IEEE Transactions on Industry Applications. September/October 1998. Vol.34, No.5. pp. 1131-1138.

[4] R. TRIGUI, "Asynchronous Motorization for Electric Vehicle" PhD Thesis in Electrical Engineering, National Institute of Polutechnics of Lorraine, Nancy, Paris, 1997

[5] C.Y.Chen, T.Hseng S. Li, Y. C.Yeh ," EP-based ki-nematic control and adaptive fuzzy sliding-mode dy-namic control for wheeled mobile robots" , Informa-tion Sciences 179 (2009) pp. 180–195 .

[6] A. Hazzab, I. K. Bousserhane, M. Kamli and M. Rahli: “New Adaptive fuzzy PI-Sliding Mode Con-troller for Induction Machine Speed Control”. Third IEEE International Conference on Conference on Systems, Signals & Devices SSD'05, Tunisia, (2005).

[7] Khessam Medjdoub,“Fuzzy controllers optimized by ant algorithms for the controlof electric vehicle’’ , Doctoral thesis LMD University of Tahri Mohamed Bechar 2016.

[8] R. Arulmozhiyal and K. Baskaran, "Implementation of a Fuzzy PI Controller for Speed Control of Induction Motors Using FPGA," *Journal of Power Electronics,* vol. 10, pp. 65-71, 2010.

[9] F. Mokhtari, P. Sicard and A. Hazzab, ‘Cascade Decentralized Nonlinear PI Control Continuous Production Process’ , ELECTRIMACS, Québec, Canada, Jun. 2008, CD-ROM.

[10] Cruz, M. A. Gallegos, R. Alvarez, and F. Pazos, "Comparison of several nonlinear controllers for induction motors," IEEE Int'l. Power Electronics Congress (CIEP), 2004, pp. 134 –139.

[11] Y.X. Su, Dong Sun, B.Y. Duan, 'Design of an Enhanced Nonlinear PID Controller, Mechatronics 15 (2005) 1005–1024

[12] Gunawan Dewantoro, 'Multi-objective Optimization Scheme for PID-Controlled DC Motor', International Journal of Power Electronics and Drive System (IJPEDS), Vol. 7, No. 3, September 2016, pp. 734~742

[13] Medjdoub khessam, Abdeldejbar Hazzab, Bouchiba Bousmaha, M Bendjima, 'Fuzzy Adaptive PI Controller for DTFC in Electric Vehicle', International Journal of Power Electronics and Drive System (IJPEDS), Vol. 4, No. 4, December 2013

[14] Derdiyok, M. K. Guven, H. Rahman, N. Inane, L. Xu: Design and Implementation of New Sliding-Mode Observer for Speed-Sensorless Control of Induction Machine,IEEE Trans. on Industrial Electronics, Vol. 49, No. 5, Oct. 2002, pp. 1177 – 1182.

[15] Zhou, J. and Wang, Y. (2005), "Real-time nonlinear adaptive backstepping speed control for a PM synchronous motor",Control Engineering Practice, Vol. 13, pp. 1259-69.

[16] F. Khoucha, K. Marouani, A. Kheloui, K. Aliouane: Experimental Performance Analysis of Adaptive Flux and Speed Observers for DirectTorque Control of Sensorless Induction Machine Drives, IEEE 35 Th Power Electronics Specialists Conference PESC2004, Vol. 6, Aachen, Germany, June 2004, pp. 2678 – 2683.

[17] S. Gair and al., Electronic differential with sliding mode controller for a direct wheel drive electric vehicle,in Proceedings of IEEE ICM‟04, pp.98-103,June2004.

[18] A. Haddoun, M. E. H. Benbouzid, D. Diallo, R. Abdessemed, J. Ghouili andK. Srairi, Sliding Mode Control of EV Electric Differential System, in ICEM06, Chania: Greece2006‟.

How to cite this article:
Laguidi A,Hazzab A, Boughazi O, Alaeli A, .Adaptive Self-Tuning Of Nonlinear PI ControllerFor The Control Of Electric Vehicle With Two-Motor-Wheel Drive. J. Fundam. Appl. Sci., 2020, *11(1)*, 181-197.