

# NEW DRIVING WHEELS CONTROL OF ELECTRIC VEHICLE

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**Abstract:** New technologies allow the development of electric vehicles (EV) by means of electric motors association with static converters. All mechanical transmission devices are eliminated and vehicle wheel motion can be controlled by means of power electronics.

The proposed propulsing system consists of two permanent magnets synchronous machines (PMSM) that ensure the drive of the two back driving wheels. The proposed control structure-called independent machines- for speed control permits the achievement of an electronic differential. The electronic differential system ensures the control of the vehicle behavior on the road. It also allows to control, independently, every driving wheel to turn at different speeds in any curve. This paper presents the study and the control strategy of the electric vehicle driving wheels.

**Key words:** Electric vehicle, electronic differential, permanent magnets synchronous machine, driving wheels control, multiconverters multimachines systems.

## 1. Introduction.

The major technological progress for the mechanic vehicles is the partial or total introduction of electricity in their motorization and in the electric traction system. This is possible owing to the technology of power converters integration, to the energy storage in the batteries and to the development of super-condensers.

Some applications in the field of electrical drives require the use of several electric machines and as well as many static converters that have an important place among the electromechanic systems. These systems are called multiconverters-multimachines systems (MCMMS).

They are recognized through the existence of the coupling system type either of an electric nature, a magnetic and/or mechanical one used in several electric machines propulsing the vehicle. In such as a control we model the coupling by using appropriated control structures including independent control, average control, or slave master, by imposing criteria of energetic distribution in order to obtain a single machine or a single converter system. One of these control structures can be applied to the control of electric vehicle (EV) driving wheels.

In this situation we need the models of the elements constituting the electric traction system. In what follows we shall develop these models.

## 2. Electric traction system elements modeling.

Figure 1 represents the general diagram of an electric traction system using a permanent magnets synchronous motor (PMSM) supplied by voltage inverter. [1]

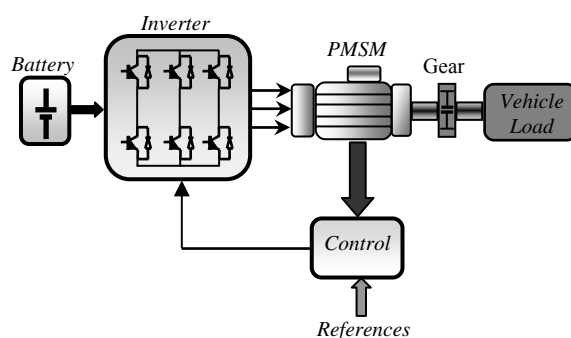


Fig. 1. Electric traction system.

### A. Energy source.

The source of energy is generally a Lithium-Ion accumulator's battery.

### B. Static converter.

In this electric traction system, we use an inverter to obtain three balanced phases of alternating current with variable frequency from the current battery.

The inverter can be considered as an element connected between the source and the machine. Its modeling is based upon the variable topology.

The voltages generated by the inverter are given as follows :

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

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

### C. Traction motor.

The used motor is a three phase permanent magnets synchronous type (PMSM) supplied by a voltage inverter controlled by Pulse Width Modulation (PWM) techniques. A model based on circuit equations is generally sufficient in order to make control synthesis.

The PMSM equations defined in the Park references applied to the rotor are as follows: [2,3]

$$v_d = R_s i_d + L_d \frac{di_d}{dt} - L_q \omega_m i_q \quad (2)$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + L_d \omega_m i_d + \Phi_f \omega_m \quad (3)$$

$$T_{em} = p[(L_d - L_q) i_q i_d + \Phi_f i_q] \quad (4)$$

We add the mechanical equation to these in order to obtain a complete model of a synchronous traction system.

### D. Mechanical part.

The developed modeling is based on the use of data from the Leroy-Somer Society. [4]

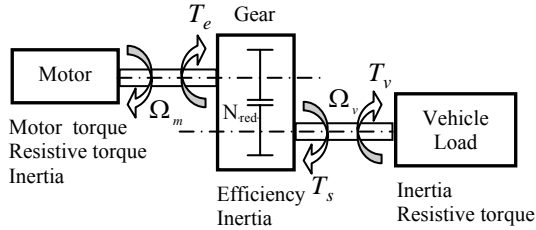


Fig. 2. Electromechanical structure.

#### 1. The vehicle as load.

The vehicle which is considered as a load is characterised by many torques which are mostly considered as the resistive torque [4,5]. The different torques include:

- The vehicle inertia gives a torque defined by the following relationship:

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

- The aerodynamics torque is:

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

- The slope torque is:

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

- The friction torque  $T_{tire}$  is defined as it is shown by figure 3.

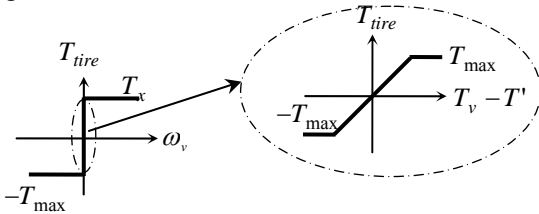


Fig. 3. Definition of the friction torque.

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

$$T_{max} = Mgf_r R_r \quad (8)$$

We obtain finally the total resistive torque :

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

#### 2. Gear.

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

The mechanical equation is given by :

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

With :

$$T_r = \frac{1}{\eta N_{red}} T_v \quad (11)$$

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

The modeling of the traction system allows the implementation of some controls such as the vector control.

### 3. Vector control.

Our aim is to apply the vector control to the permanent magnets synchronous motor (PMSM) as a DC motor. This technique is widely used mostly because of its simplicity. Several types of vector control exist. In this paper we use the direct vector control by stator current orientation. This control strategy consists of maintaining the stator current  $i_d$  equal to zero and regulate the torque with varying the current component  $i_q$ . Once we are able to regulate the torque, we can add a speed control loop called the cascade regulation.

The model of the permanent magnets synchronous motor (PMSM) is given by the following equations [4]:

$$v_d = -L_q \omega_m i_q \quad (13)$$

$$v_q = R_s i_q + L_q \frac{di_q}{dt} + \Phi_f \omega_m \quad (14)$$

$$T_{em} = p\Phi_f i_q \quad (15)$$

While choosing,  $v_d = 0$  we obtain the equivalent block diagram of a separately excited DC Motor.

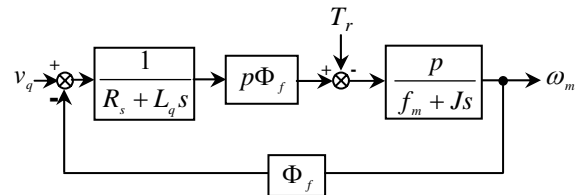


Fig. 4. Voltage model (with  $v_d = 0$ ).

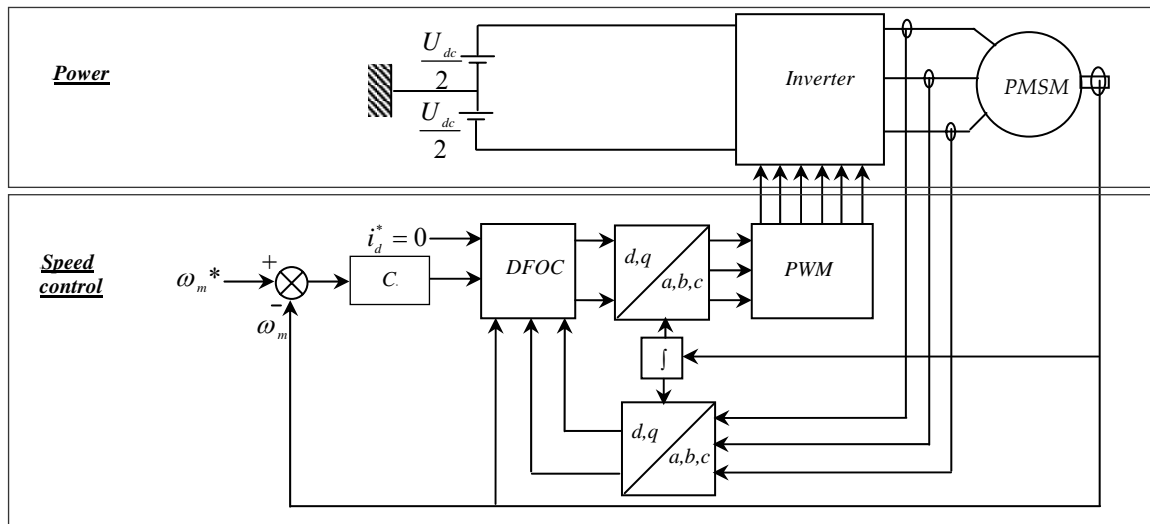


Fig. 5. Speed control system of PMSM with DFOC.

Figure 5 gives the vector control scheme of a permanent magnets synchronous motor (PMSM). It represents the speed control system with  $i_d$  and  $i_q$  currents controls.

These two currents are controlled by two loops where the outputs are  $v_d^*$  and  $v_q^*$  as references in the  $dq$  system.

In order to simplify the control algorithm and improve the control loop robustness, instead of using classical control, we use fuzzy logic control [6]. The advantage of this control is its robustness, its capacity to maintain ideal trajectories independantly of the external disturbances and the parameter variations.

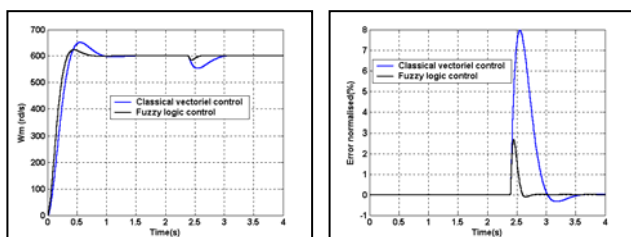


Fig. 6. The load influence.

To compare the effect of disturbances by resistive torque in the cases of two types of control, figure 6 shows the system response in two cases.

This figure shows that the effect of the disturbance is very low in the case of fuzzy logic control.

It appears clearly that the classical control with PI controller is easy to apply. However the control with fuzzy logic controllers offers a better performances in both control and tracking. It, also, presents less sensitivity to these dynamic performances. In addition to these dynamic performances, it respects the imposed constraints by the driving system such as the robustness of parameter variations.

#### 4. Electric vehicle propulsion system.

##### A. Propulsing system structure.

The proposed propulsing system structure is similar to that of multiconverters-multimachines system (MCMMS). [7-9]. It is defined as a system composed by several electric drives mechanically coupled.

Figure 7 represents an electric vehicle (EV) driving wheels system.

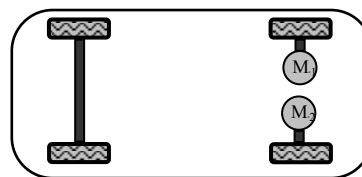


Fig. 7. Driving wheels system of an EV.

The considered propulsing system architecture permits to develop an electronic differential ensuring a speed synchronization of the driving wheels with the motion of the vehicle. The next step is to control electronically the speed of back wheels motors.

One the one hand, this system allows to control independantly with high accuracy the applied torque to the driving wheels, and in the other hand to maximize the regenerative braking capacity.

The multimachine systems are characterized by the coupling of different electromechanical conversion systems.

The system represented by the figure 8 is characterised by only one coupling. It is illustrated by figure 8.

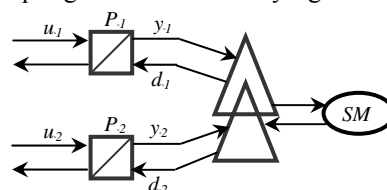


Fig. 8. Studied topology.

The control strategy of multiconverters- multimachines systems is applied to our electric vehicle, i.e to the driving wheels.

In order to realise the electronic differential, the control structure "independant machines" is applied to the propulsing system of two driving wheels, by a speed control. In order to realise the electronic differential, "independent machine" control structure is applied to the propulsing system of the back wheels motors speed.

### B. Independent machine control structure.

This structure is composed of two machines controlled independantly as two single machine structures. For every machine we can impose different speed reference ( $\Omega_{1ref} \neq \Omega_{2ref}$ ) by using two static converters. These machines are uncoupled through the control structure and reject all disturbances like single machine control. [6]. The principle of this control is illustrated by figure 9.

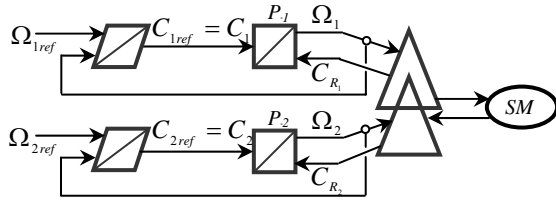


Fig. 9. Independent machine structure.

Speed control of each machine is necessary in order to control wheel torques. This allows an electronic differential.

### C. Macroscopic energetic representation of electronic differential.

A macroscopic energetic representation (MER) of the propulsing system was proposed to obtain a global view of an electronic differential. [10]

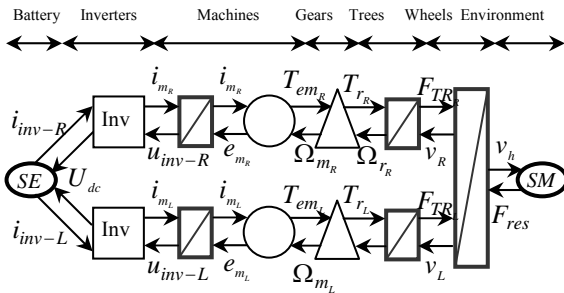


Fig. 10. MER of the electronic differential.

This investigation proposes the control of the driving wheels speeds  $\Omega_{rR}$  and  $\Omega_{rL}$  by the 'independant machines' control structure. This structure permits to impose two speed references  $\Omega_{rR} \neq \Omega_{rL}$  (i.e in a curve), the applied torque on each wheel is different  $T_{rR} \neq T_{rL}$ , the two wheel control system does not receive the same torque reference. Thus, it is not possible to impose the same speed reference.

In order to have identical machines, an appropriate distribution of electric power is necessary. This is done by an adequate control based on the distribution of mechanical power where each motor develops half of the electric power.

### D. Structure of the studied system.

The general scheme of the driving wheels control is represented by figure 11. It is an electric vehicle, the wheels of which are controlled independently by two PMSM.

The reference blocks must provide the speed references of each motor taking into consideration information from the different sensors.

#### 1. Speed references computation.

It is possible to determine the speed references versus the requirements of the driver.

When the vehicle arrives at the beginning of a curve, the driver applies a curve angle on its wheel. 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 outside the curve.

The driving wheels angular speeds are:

$$\omega_{rR} = \frac{V_h}{R_r} + k_b \cdot \Delta\omega \quad (16)$$

$$\omega_{rL} = \frac{V_h}{R_r} - k_b \cdot \Delta\omega \quad (17)$$

with  $k_b = \pm 1$  corresponding to a choice of the direction of the wheel, (-1) for the right turn, and (+1) for the left turn. The driving wheels speed variation is imposed by the trajectory desired by the driver and is given by:

$$\Delta\omega = \frac{d_w \sin(\delta + \beta)}{2 l_w \cos \delta} \cdot \frac{V_h}{R_r} \quad (18)$$

The relation between  $\alpha$  which is the curve angle given by the driver wheel and  $\delta$  of the real curve angle of the wheels is given by:

$$\delta = \frac{\alpha}{k_d} \quad (19)$$

where  $k_d$  is the gear ratio.

A proportionality coefficient between  $\delta$  and  $\beta$  which is the vehicle slip angle is defined by:

$$\beta = k \cdot \delta \quad (20)$$

The speeds references of the two motors are:

$$\omega_{mR}^* = N_{red} \cdot \omega_{rR} \quad (21)$$

$$\omega_{mL}^* = N_{red} \cdot \omega_{rL} \quad (22)$$

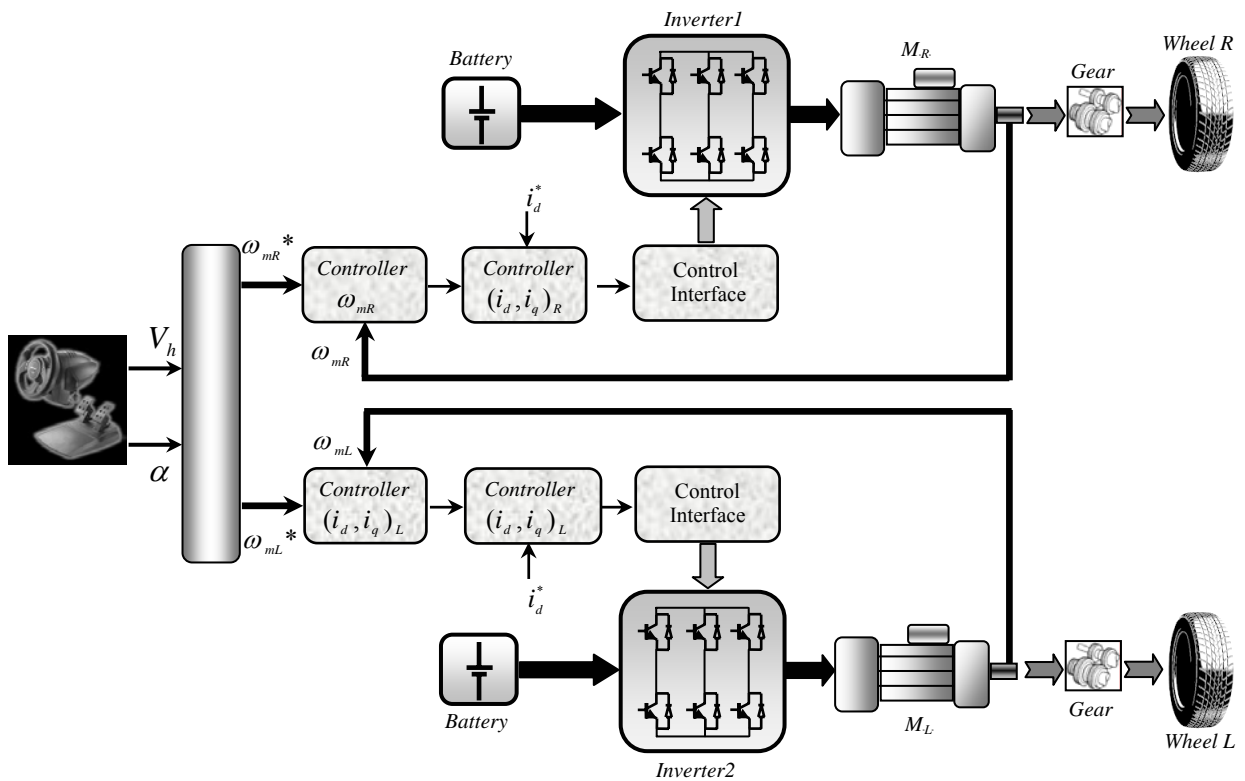


Fig. 11. The driving wheels control system.

## 5. Simulation results.

In order to characterise the driving wheel system behaviour, simulations were carried using the model of figure 11. They show motor current and the variation of speed for each motor.

### A. Case of straight way.

*Case1: Flat road with constant speed 80km/h.*

A 80km/h speed step is applied to our system. A good tracking of the speed step can be observed (fig. 12 (1)). In this case the driving wheels speeds are almost identical, and the speed difference is zero. These speeds are illustrated by figure 12 (2).

The behaviour of traction forces is illustrated by figure 12 (4). They are identical as the same conditions of environment are assumed.

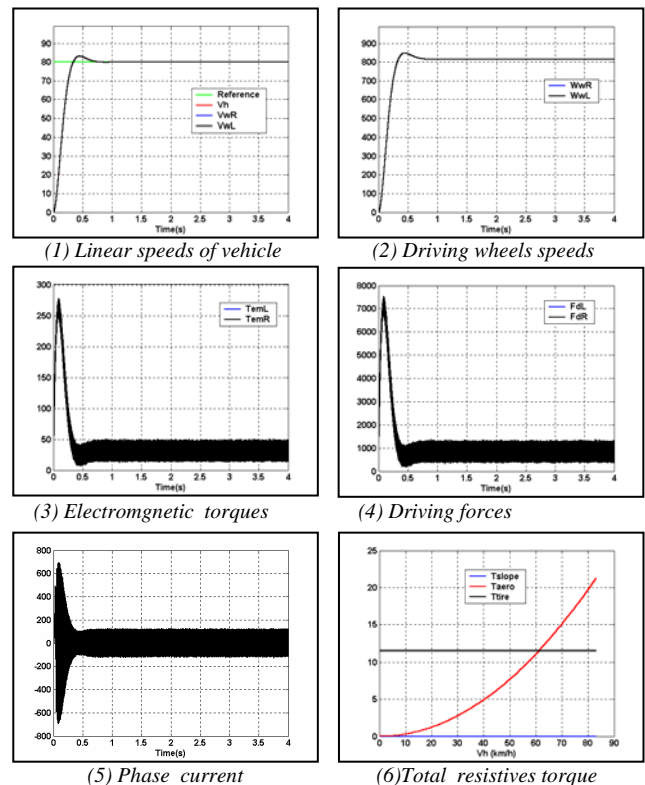


Fig. 12. Simulation results for case 1.

**Case 2: Flat road with 10% slope at 80km/h speed.**

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. Only a change of the developed motor torque is noticed. The slope effect results in a high increase in the phase current of each motor. The system behaviour is illustrated by figures 13(1), 13(2), 13(3), 13(4). The resistive torques are shown in figures 13(5), 13(6) and 13(8).

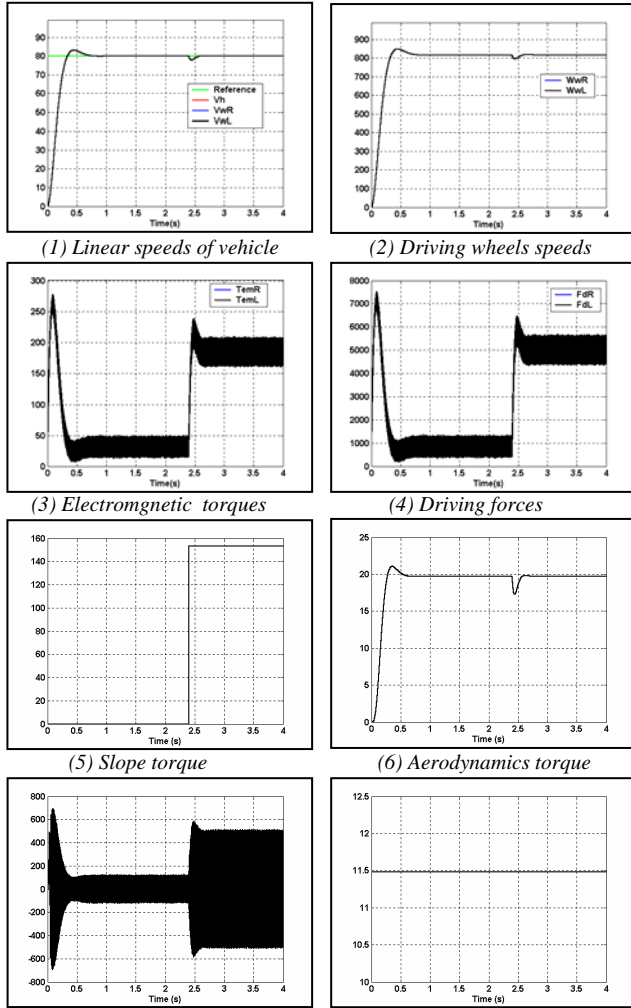


Fig.13. Simulation results for case 2.

**B. Case of curved way.**

**Case1: Curved road at right side with speed of 80km/h .**

The vehicle is driving on a curved road on the right side with 80km/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 behaviour of these speeds is given by figure 15(1) and 15(2).

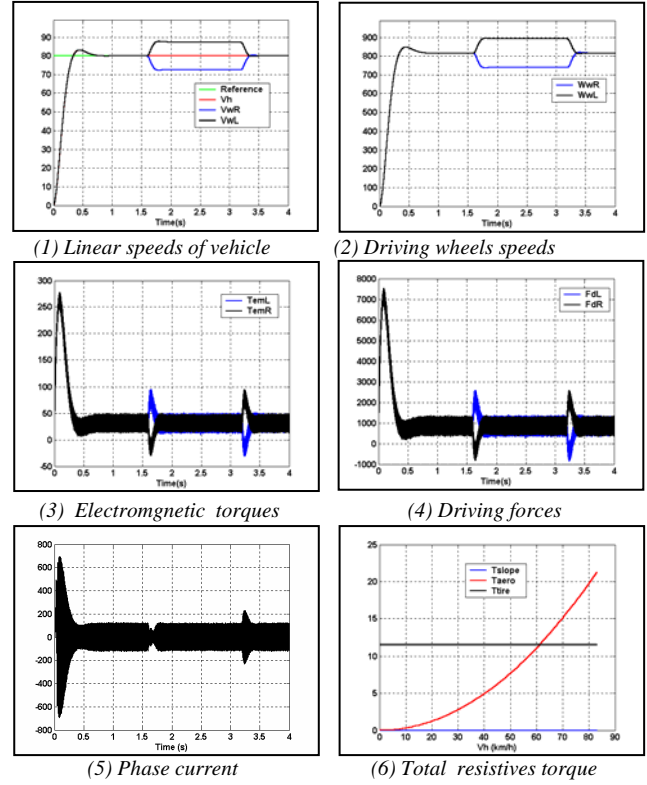
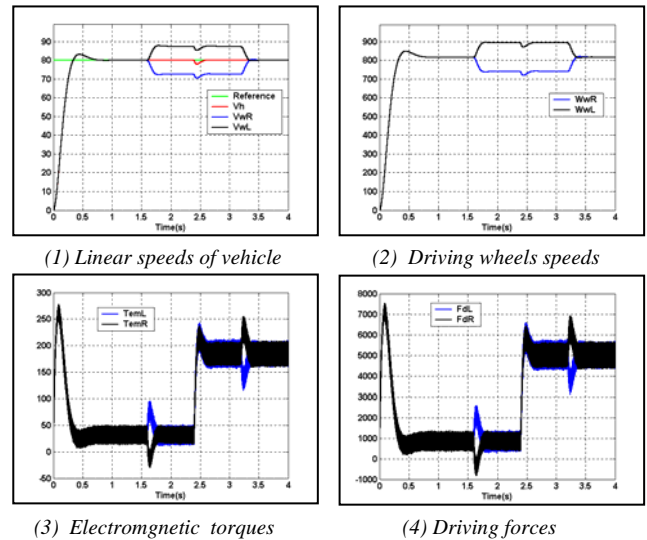


Fig. 14. Simulation results for case 1.

**Case 2: Curved road with 10% slope with right turn.**

This test shows the influence of the road slope on the vehicle moving in curved road. Figure 16 shows the effect of the slope and the curved road on the motor parameters. The driving wheels speeds are controlled and the errors created by the disturbances are quickly compensated.



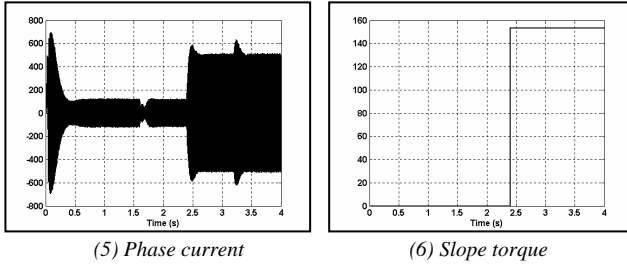


Fig. 15. Simulation results for case 2.

*Case3: Curved road with left turn without slope at a speed of 80km/h.*

The vehicle is moving on a curved road with left turn at a speed of 80km/h. It is assumed that the two motors are not disturbed. In this case the driving wheels follow different paths. They turn in the same direction but with different speeds. The left driving wheels turns at a speed of less than that of the right.

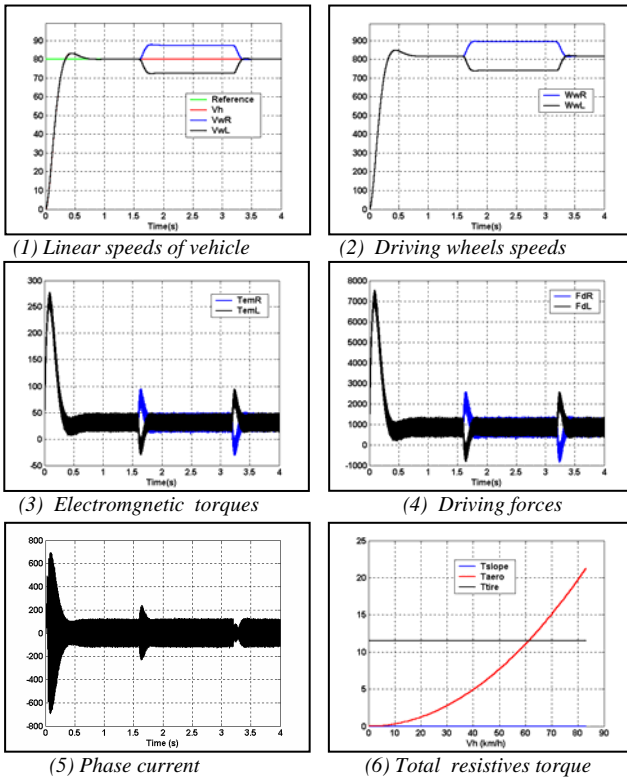


Fig. 16. Simulation results for case 3.

## 6. Conclusion.

In the field of electric drives with variable speed, an application of an electric vehicle controlled by an electronic differential is presented. This paper proposes an 'independant machine' control structure applied to a propulsing system by a speed control. The results obtained by simulation show that this structure permits the realisation of an electronic differential and ensures good dynamic and static performances. The electronic

differential controls the driving wheels speeds with high accuracy either in flat roads or curved ones. The disturbances do not affect the performances of the driving motors.

## Appendix

Vehicle mass	:1200kg
Distance between two wheels and axes	:2,5 m
Distance between the back and the front wheel	:1,5 m
Ray of the wheel	:0,26m
Report of speed reduction	:7,2
Transmission efficiency	:98 %

Table 1: Parameters of the electric vehicle.

Resistance	: 0,34 $\Omega$
$d$ -axis inductance	: 0,2 mH
$q$ -axis inductance	: 0,2 mH
Permanent magnet flux	: 0,08 Wb
Pole pairs	: 4

Table 2: Parameters of electric machines.

## Nomenclature

$L_d, L_q$  :  $d$  and  $q$  axis inductance

$i_d, i_q$  :  $d$  and  $q$  axis currents

$v_d, v_q$  :  $d$  and  $q$  axis voltage

$R_s$  : Resistance

$p$  : Pole pairs

$\theta$  : Electric position

$\Phi_f$  : Permanent magnet flux

$J$  : Rotor inertia

$J_v$  : Vehicle inertia

$C_{em}$  : Electromagnetic torque

$C_r$  : Load torque

$M$  : Vehicle mass

$R_r$  : Wheel radius

$N_{red}$  : Report of speed gear

$\eta$  : Transmission efficiency

$l_w$  : Distance between two wheels and axes

$d_w$  : Distance between the back and the front wheel

$\rho$  : Air density

$S$  : Front area of vehicle

$C_x$  : Aerodynamic coefficient

$g$  : Acceleration of gravity

$f_r$  : Friction coefficient

$\alpha$  : Angle of the slope

$v_h$  : Linear speed of vehicle

$U_{dc}$  : Battery voltage

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