

ELEVES: A NEW SOFTWARE TOOL FOR ELECTRIC VEHICLE MODELING AND SIMULATION

Aiman Nouh*, Mouhcine Chami*, Abdesslem Djerdir**, Mohammed El Bagdouri*

Vehicle simulation software is essential to vehicle design and development. Most current vehicle software simulations, however, require that components be specified prior to running the simulations. Within this context, this paper presents a simulator offering to users flexibility enough to add new component and use different level of accuracy. Thus a first version of a new software tool, in order to assist in developing technologies for Electric Vehicle (EV), is described. The ELEctric VEHICLE Simulator (ELEVES) is currently being developed as a research project in the University of Technology of Belfort-Montbéliard (UTBM) by our laboratory Systems and Transportations (SeT). This simulator is developed on the base of the Component Hybrid Dynamic Nets (CHDN). As application, the proposed software tool has been used to modeling and simulation of four motorized wheels electric vehicle. Finally, a comparison between the results obtained by ELEVES with those obtained by Matlab/Simulink software tool has been included.

Keywords: Electric Drive, Power Electronics, Synchronous Motor, Wheel Motor, Power train, Modeling, Simulation, Component Hybrid Dynamic Nets, EV Simulators.

1. INTRODUCTION

Transportation is a primary source of energy consumption and pollutant emissions worldwide [1]. In response to concerns over environmental degradation, several government agencies, laboratories and the major automotive manufacturers proposed a progressive increasing number of automobiles to be Zero Emission Vehicles (ZEVs). Until now, only electric, low emission hybrid vehicles, and fuel cell powered vehicles are able to response to these regulations [1] - [2]. Historically, during the development of the EV, their power train configurations have been the same as those of the conventional internal combustion engine type vehicle (ICEV), which are merely based on a single motor with a mechanical transmission system. Only in the recent years and due to the progress on electric motors and motor controller technology, alternative modern configurations have been considered. One of the latest configurations is known as motorized wheels, which consists of either two or four motors that are integrated into each drive wheel and can be controlled independently. This configuration was considered one of the best design alternatives to the Ford Ecostar power train. It has also been used by Nissan in their concept vehicle, known as FEV (Future Electric Vehicle). The motorized wheels configuration will be adopted for both the General Motors electric car and the

hybrid electric vehicles in the very near future [3].

The aim of this work is to present a software tool that has been developed in our laboratory especially for simulating the in-wheel electrical vehicles. The adopted methodology in the modeling process allows to our software, to easily include other architectures of EV (hybrid EV, mechanical transmission for example).

We start this paper by displaying the limits of existing EV simulators. Then, a description of the global algorithm of ELEVES is established. A description of the principles and the applied hypotheses, to model the different vehicle units, are explained. So, the paper highlights the modeling and simulation of four motorized wheels EV as a typical application of the tool. Finally, in order to check the validity of the obtained results, a comparison study between ELEVES and Matlab/Simulink software is presented.

2. LIMITS OF EXISTING SIMULATORS

Several software of simulation of the dynamic and energetic performances of the vehicles was carried out since of tens of years in the research centers of manufacturers or in the university laboratories. We count some of the most known as ADAMS/Car, SmartHEV and ADVISOR. Adams is a motion simulation solution for analyzing the complex behavior of mechanical assemblies. So, it allows testing virtual prototypes and optimizes designs for performance, safety, and comfort [4]. The HEV design software, SmartHEV, is a flexible and robust model of steady state HEV operation [5]. These modeling tools focus on

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only a portion of the analysis of the vehicle, and don't treat the transient and unbalanced regimes. For ADVISOR, it was developed as an analysis tool, and not a design tool. Its component models are quasi-static, and should not be used alone to predict phenomena with very small time scales. ADVISOR, however, has been linked with other tools that do perform dynamic analysis capability. Tools like SABER for electrical systems modeling and ADAMS/Car for vehicle dynamics have been linked with ADVISOR [6] - [7]. In spite of the obtained new possibilities, this tool multiplicity penalizes generally the user by adding a supplementary complexity and cost in terms of time and money. So, for these reasons one can say that it's more attractive to have a unique tool entirely dedicated to electric vehicle modeling and simulating problems as well in static studies as in dynamic ones.

3. ELEVES STRUCTURE

ELEVES is an EV component design tool written in Delphi programming language under the environment of Windows. It uses algorithms currently under development at the University of Technology of Belfort Montbéliard (UTBM). This simulator uses the component hybrid dynamic nets (CHDN) [8] - [9] to represent the models and the interaction within them. The main advantage of ELEVES over those mentioned earlier, it is that it allows achieving a high degree of modularity, in order to be able to model new types of component and integrate them easily within the full vehicle model. This modularity includes the vehicle dynamic and its electrical devices (sources, electrical machines and power converters) at different levels of accuracy. Modeling the vehicle by ELEVES involves modeling its different components and the interaction between them. We will study in this article a dynamic model of which we suppose that the vehicle starts of the stop position until it reaches the steady state. During its race, it changes velocity, takes turn and climbs a slope. Moreover, we can treat critical or particular cases like operation in degraded mode and unbalanced regimes. There are also a number of secondary aims, in particular, achieving a good accuracy, providing different levels of modeling for a given type of component and finally, creating a database on EVs.

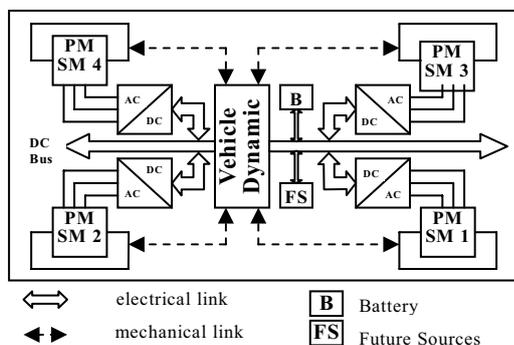


Fig.1 Block diagram of ELEVES

The graphical user interface of ELEVES shown in Fig. 1, allows selecting the vehicle configuration and its type of electrical motorization but also to select them energy supply including the associated converter.

The three types of configurations actually treated by ELEVES are the integral traction, the traction and the propulsion. In the integral traction all wheels are motorized wheels, but only the front wheels are driving in the traction, and only the rear wheels propel the vehicle in the propulsion configuration. In all these cases, the steering applies only on the front wheels. The user has the possibility to select between the DC motor, the induction motor and the Permanent Magnet Synchronous Motor (PMSM). The electric motor is driven by a power electronics component that converts the fixed DC voltage available from a source into a variable voltage. Although the structure of ELEVES is primarily conceived for Battery EV, it regards future energy sources like fuel cell and the associated storage device as for example the ultracapacitors. The principal algorithm of ELEVES is illustrated in Fig. 2. The adopted specification of different components performances are linked to design and to parameters control, on which the user can act in order to get a desired performance.

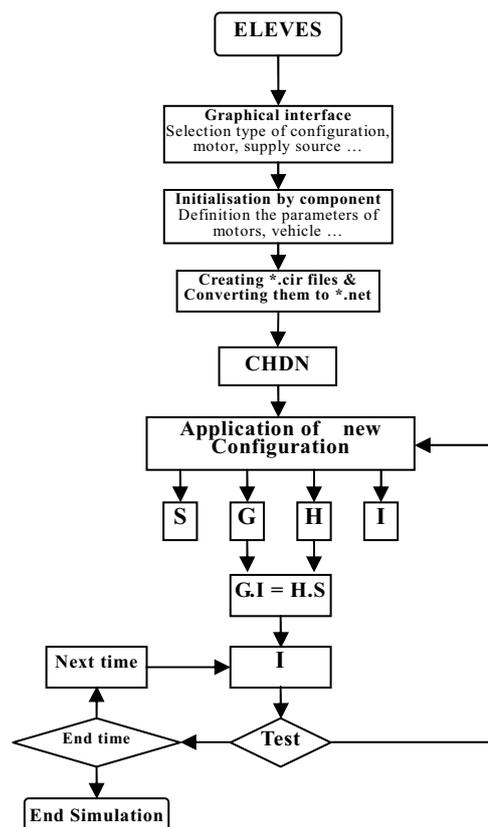


Fig. 2 ELEVES flow chart

The initialization of parameters is done by component. The user can enter or modify the parameters of each component. All vehicle configuration parameters can be saved for future use. Once the user is satisfied with the vehicle input

characteristics, ELEVES will create the *.cir files and will convert them to *.net. This last is necessary to build the global CHDN. The *.cir file is composed in its first line of the component number and the number of flow lines between elements of component. It contains also a series of parameters specific to the component. ELEVES uses an original approach to generate a global model of the system based on CHDN which compose of two parts, the Component Continuous Dynamic Net (CCDN) which allows a representation at the component level of continuous dynamic system. As Bond Graph [10] - [11], it has an analogous presentation of continuous Petri Net [12] (Places, Transitions, weighted arcs). The second part is the Petri net which allows to modeling the discrete part of the component with variable topology. The algorithm shows the methodology of simulation. The equations of global model are numerically solved by a trapezoidal algorithm with a fixed step. The vector *S* represents the vector of source (effort and flow), while the vector *I* represents all validated Place variables and Transition variable of global models. The matrix *G* and *H* represent the weight associated to all places and the weight of all arcs incoming and outgoing of all places.

4. FOUR MOTORIZED EV MODEL

In this section, the governing differential equations of motion, the analytical expression for the kinematics and dynamics of the vehicle model have been derived. The analyses, which are presented separately, have been carried out for both dynamic and electric components to clarify the understanding of the vehicle performance. We show also the CHDN model for both electrical and dynamic components of our system in order to achieve the needed simulation.

4.1 Dynamic Model

With reference to the model, illustrated in Fig. 3, and by neglecting the effect of roll angle of the sprung mass about the roll axis and the effect of camber angle, the equations of motion of the vehicle are [13]:

$$\begin{aligned}
 M_v \ddot{X} &= F_X \\
 M_v \ddot{Y} &= F_Y \\
 J_v \ddot{\psi} &= M_z
 \end{aligned}
 \tag{1}$$

Where F_X , F_Y and M_z are respectively the total forces acting in X and Y directions and the total yawing moment. M_v , J_v are the vehicle mass and the inertia of vehicle respectively. Let v_x , v_y and r be the longitudinal, lateral and angular velocities of vehicle in its own frame. They are clearly linked with the velocities in reference frame by the obvious relationship:

$$\begin{pmatrix} \dot{X} \\ \dot{Y} \\ \dot{\psi} \end{pmatrix} = \begin{pmatrix} \cos(\psi) & -\sin(\psi) & 0 \\ \sin(\psi) & \cos(\psi) & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} v_x \\ v_y \\ r \end{pmatrix}
 \tag{2}$$

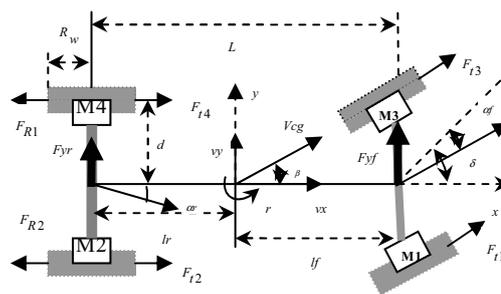
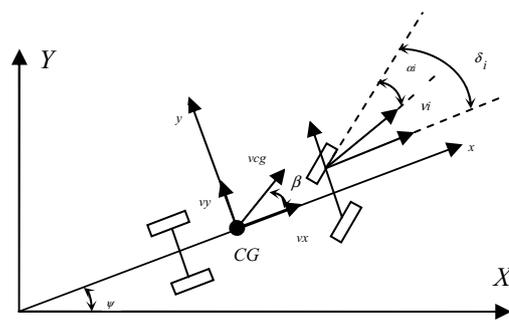


Fig. 3 Vehicle model

Although there are many ways to obtain the mathematical model, a procedure based on Lagrange equations will be followed here. Neglecting the rotational kinetic energy of the wheels the kinetic energy of the vehicle is as follows:

$$T = 0.5M_v(\dot{X}^2 + \dot{Y}^2) + 0.5J_v\dot{\psi}^2
 \tag{3}$$

and the equations of motion can be obtained by the relation:

$$\frac{d}{dt} \left(\frac{\partial T}{\partial \dot{q}_i} \right) - \frac{\partial T}{\partial q_i} = Q_i
 \tag{4}$$

where the coordinates q_i are X , Y and ψ , and Q_i are the corresponding forces F_X , F_Y and M_z . Performing the relevant derivatives with respect to time and introducing forces F_x and F_y written with reference to vehicle frame, we obtain:

$$\begin{aligned}
 M_v(\dot{v}_x - rv_y) &= F_x \\
 M_v(\dot{v}_y + rv_x) &= F_y \\
 J_v \dot{r} &= M_z
 \end{aligned}
 \tag{5}$$

Using a linear tire model, the front and rear cornering forces can be expressed as the product of the cornering stiffness (C_f, C_r) by the sideslip angle (α_f, α_r)

$$\begin{aligned}
 F_{yf} &= -C_f \alpha_f \\
 F_{yr} &= -C_r \alpha_r
 \end{aligned}
 \tag{6}$$

The sideslip angles of the wheels can be expressed easily in terms of the longitudinal, lateral, angular velocities and the steering angle δ . The explicit expressions of the sideslip angles for the front and rear axels are represented in (Eq.7).

$$\begin{aligned} \alpha_f &= \tan^{-1}((v_y + rl_f)/v_x) - \delta \\ \alpha_r &= \tan^{-1}((v_y - rl_r)/v_x) \end{aligned} \quad (7)$$

We can obtain the three governing equations of motion by finding the resultant of forces acting on vehicle in x, y directions and the total yawing moment about the Center of gravity CG , then substituting in the system of equations (Eq. 5) with taken in consideration the cornering forces and the sideslip angles. The longitudinal, lateral and angular accelerations of vehicle are represented as follow.

$$\begin{aligned} \dot{v}_x &= v_y r + \frac{F_{t1} + F_{t2} + F_{t3} + F_{t4} - F_{res}}{M_v} \\ &+ \frac{C_f \delta}{M_v} \left(\frac{v_y + rl_r}{v_x} - \delta \right) \\ \dot{v}_y &= \left(-\frac{C_r + C_f}{M_v v_x} \right) v_y + \left(\frac{C_r l_r - C_f l_f}{M_v v_x} - v_x \right) r + \left(\frac{C_f}{M_v} \delta \right) \\ \dot{r} &= \left(\frac{C_r l_r - C_f l_f}{J_v v_x} \right) v_y - \left(\frac{C_r l_r^2 + C_f l_f^2}{J_v v_x} \right) r + \frac{C_f l_f}{J_v} \delta \\ &+ \frac{d}{J_v} (F_{t1} + F_{t2} - F_{t3} - F_{t4}) \end{aligned} \quad (8)$$

Where $F_{t1}, F_{t2}, F_{t3}, F_{t4}$ are the tractive forces of motors, F_{res} is the resistant forces which including the aerodynamic drag force F_a , climbing force F_c and rolling force F_r . They have the following expressions:

$$\begin{aligned} F_a &= 0.5 \rho C_{px} A_f V_{cg}^2 \\ F_c &= M_v g \sin(\alpha_p) \\ F_r &= C_{rr} M_v g \end{aligned} \quad (9)$$

In the set of equations (9) C_{px} is drag coefficient, A_f is the cross section area, ρ is air density, V_{cg} is vehicle velocity at the CG, g is the acceleration gravity, α_p is the grade angle of the road and C_{rr} is the rolling resistance coefficient.

By applying a driving force to a tire which has a certain slip (s), the longitudinal coefficient (μ) is influenced by the wheel sideslip angle (α_f, α_r). With reference to Fig. 4, we can see that the peak value of longitudinal characteristic decreases with the increasing of the sideslip angle.

Moreover, the longitudinal slip can be defined for the four wheels as:

$$s_i = \frac{R_w \omega_i - u_{ii}}{\max(R_w \omega_i, u_{ii})}, i \in [1, \dots, 4] \quad (10)$$

Where R_w is the wheel radius, ω is the angular velocity of the in-wheel motor and u_i is the linear speed at which the contact zone moves on the ground and can be written for the four wheels as [3]:

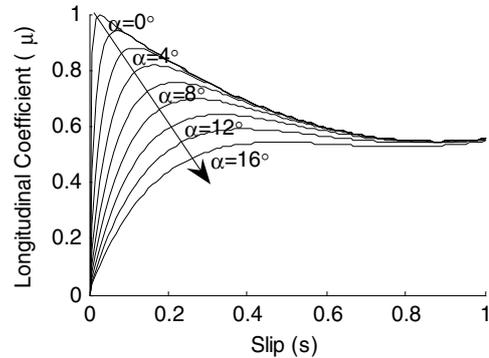


Fig. 4 Longitudinal force coefficient as function of slip for a given values of the sideslip angle

$$\begin{aligned} u_{i1} &= (v_x + dr) \cos \delta + (v_y + l_f r) \sin \delta \\ u_{i2} &= v_x + dr \\ u_{i3} &= (v_x - dr) \cos \delta + (v_y + l_f r) \sin \delta \\ u_{i4} &= v_x - dr \end{aligned} \quad (11)$$

The longitudinal force for the four in-wheel motors can be calculated by the next equation:

$$F_{ii} = (M_v g / 4) \mu_i \cos(\alpha_p), i \in [1, \dots, 4] \quad (12)$$

Finally, from the mathematical equations represented in this part, we can realize the CHDN model for the dynamics vehicle component that it is showed on Fig. 5.

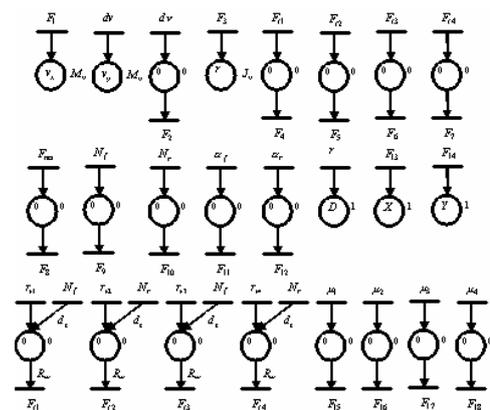


Fig. 5 The CHDN model for vehicle dynamics component

4.2 Electric Motor

For the wheel direct drive, especially with in wheel motors, the Permanent Magnet Synchronous Motor (PMSP) is the reasonably, if not only possible solution, due to its relatively low mass which contribute to

reduction of unsprung mass and to better drive comfort [14]. The PMSM is supplied by a battery E_b through a DC/AC converter developed in [8] - [9]. The drive system model can be described by the following electrical and mechanical equations:

$$\begin{aligned} L_s \dot{I}_a &= V_a - R_s I_a + K \omega \sin(\theta_e) \\ L_s \dot{I}_b &= V_b - R_s I_b + K \omega \sin(\theta_e - 2\pi/3) \\ L_s \dot{I}_c &= V_c - R_s I_c + K \omega \sin(\theta_e - 4\pi/3) \end{aligned} \quad (13)$$

$$\begin{aligned} \Gamma_m &= -K I_a \sin(\theta_e) - K I_b \sin(\theta_e - 2\pi/3) - K I_c \sin(\theta_e - 4\pi/3) \\ (J_w + J_m) \dot{\omega}_i &= \Gamma_{mi} - \Gamma_{ri}, i \in [1, \dots, 4] \\ \dot{\theta}_e &= p \omega \end{aligned} \quad (14)$$

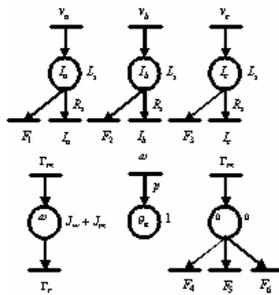
with,

$$\begin{aligned} \Gamma_{ri} &= F_{fi} R_w - N_f d_z, i \in [1, 3] \\ \Gamma_{ri} &= F_{ri} R_w - N_r d_z, i \in [2, 4] \end{aligned} \quad (15)$$

Where, I_a, I_b, I_c are stator currents, V_a, V_b, V_c are stator voltages, L_s, R_s, K, J_m, p the motor parameters, ω_i rotor speed of motor (i), θ_e electric angle of rotor, Γ_{mi}, Γ_{ri} motor torque and resistant torque respectively, J_w is the wheel inertia, d_z distance from wheel center to normal force, N_f, N_r are the front and rear normal force which have the following expressions:

$$\begin{aligned} N_f &= \frac{M_v g}{2} \left(\frac{l_r}{L} - \frac{h_{cg}}{Lg} \frac{dV_{cg}}{dt} \alpha p - \frac{h_{cg}}{L} \alpha p \right) \\ N_r &= \frac{M_v g}{2} \left(\frac{l_f}{L} + \frac{h_{cg}}{Lg} \frac{dV_{cg}}{dt} \alpha p + \frac{h_{cg}}{L} \alpha p \right) \end{aligned} \quad (16)$$

The Fig. 6 illustrates the developed CHDN model for electrical motor component.



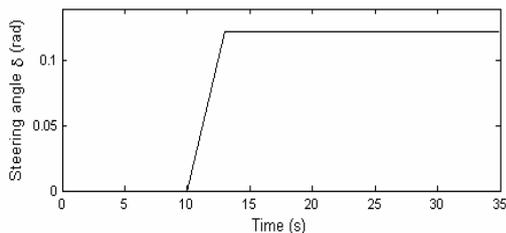


Fig. 8 Steering angle

The resulting output for the vehicle body velocities is shown in Fig. 9 and Fig. 10. It may be seen that the longitudinal speed of vehicle remains at the steady state until the turn begins and the friction starts to dissipate energy, resulting in a lower speed at the completion of the turn. The lateral vehicle body velocity increasing with the steering as does the angular velocity.

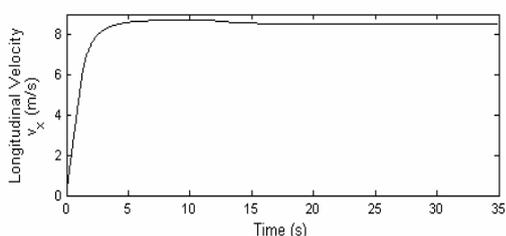


Fig. 9 Longitudinal velocity

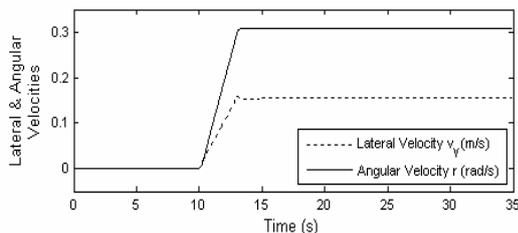


Fig. 10 Lateral and angular velocities

We have the same behaviors for the three motions or velocities obtained by Matlab/Simulink as shown in the next figure (Fig. 11.).

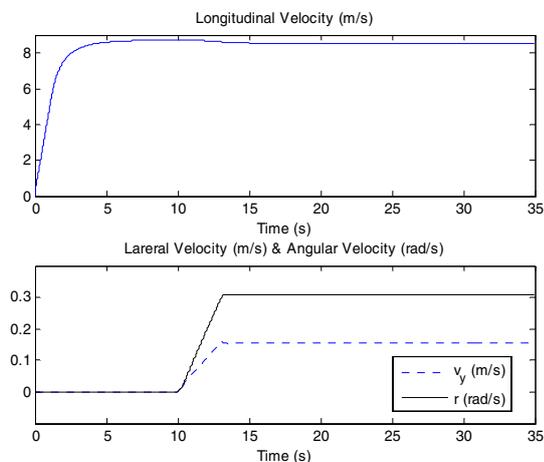


Fig. 11 Longitudinal, lateral & angular velocities obtained by Matlab/Simulink

The Fig. 12 shows the difference in the tractive forces of motors during the completion of turn. This also clearly seen on the speed of motors (Fig. 13) and on the resistant torque of motors (Fig. 14). Where the speeds of motors on the left side and the right side diverge as the left wheels slow down and the right wheels speed up to traverse the turn.

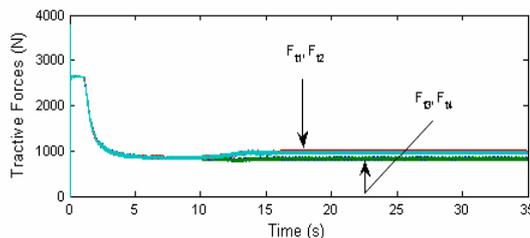


Fig. 12 Tractive forces

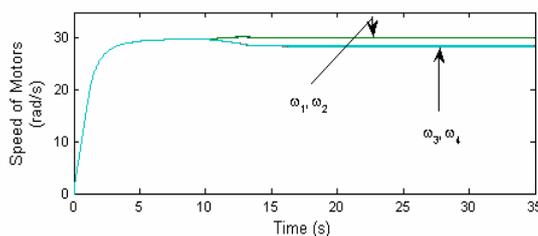


Fig. 13 Speed of motors

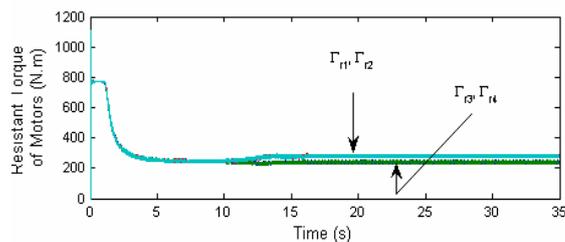


Fig. 14 Resistant torque of motors

The forces of traction, the speeds of PMSMs and the resistive torques to the movement of the vehicle obtained, using the Matlab/Simulink software, are presented on the figure (15). In the same way, we see that these three variables are similar to those obtained by ELEVES.

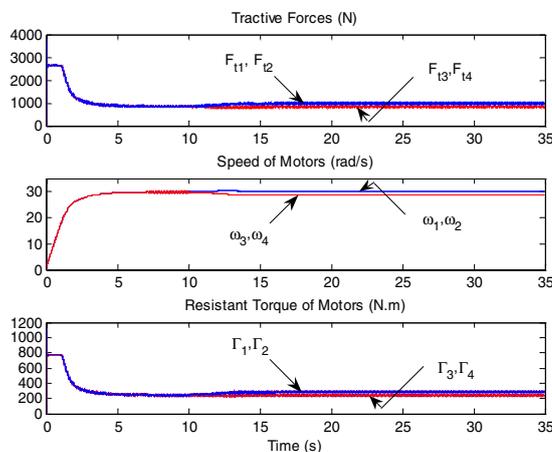


Fig. 15 Tractive forces, speed of motors & resistant torques obtained by Matlab/Simulink

The vehicle body states may be integrated to obtain the absolute vehicle position for simulation output. Since the vehicle body states are measured in the vehicle coordinate frame, a transformation is necessary prior to integration. By integrating the system mentioned in (Eq. 2), we have the absolute position of vehicle. The Fig. 16 illustrates the distance traveled by the vehicle in inertial reference frame (X, Y). It is identical with that obtained by Matlab/Simulink as shown in Fig. 17.

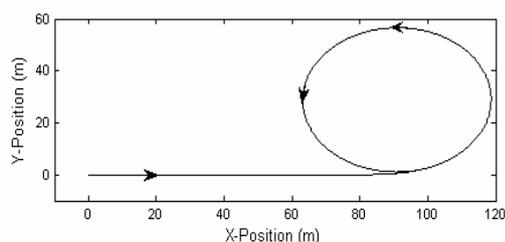


Fig. 16 Vehicle path

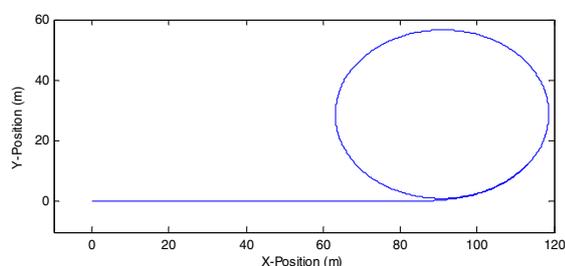


Fig. 17 Vehicle path obtained by Matlab/Simulink

5. CONCLUSION

In this paper, we have presented the first version of a developed simulation tool for predicting the dynamic and energetic performances of electric vehicles. This tool, which is called ELEVES, has a high degree of modularity, in order to be able to model by component the vehicle system whose architecture is becoming increasingly complex. It has also several degrees of accuracy regarding to the modeling level. The simulation results of a four motorized wheels EV have been compared with those obtained with Matlab/Simulink software. This study shows a good agreement between the two software tools. However, knowing that ELEVES is dedicated entirely to electrical vehicles and it offers a graphical programming more practice than that of Matlab/Simulink, one can say that it is better in the area of dynamic electrical vehicles simulating for both design and control targets.

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BIOGRAPHIES



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