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Regular paper

Optimal Contribution of Energy Management of Electric Vehicles

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An Electrical Vehicle (EV) has the advantage of being friendly with environment but it does not have the same performance as a current conventional vehicle. This work proposes a strategy to improve the EV autonomy. At first, an EV model that combines lead acid batteries and a DC motor is described. The individual mathematical model for each component is developed in MATLAB. Moreover, the control speed strategy using fuzzy logic is applied to the system to produce a maximum speed reference of an EV under different states of charge of the battery and acceleration. Then, a proportional integral control adjusts the speed strategy. When the vehicle is subjected to different scenarios, the simulation realized in MATLAB/Simulink will show good efficiency.

Keywords: Electric vehicle, DC motor, Fuzzy logic, battery SOC, Speed control, Energy management.

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1. Introduction

Tunisia is a developing country. It has excellent geographical conditions which provide renewable energies such as solar energy, wind energy and geothermal energy. Tunisia sets up policies and measurements to reduce using fossil energy [1-4].

Like other countries, Tunisia seeks alternative means of transport. A new generation of vehicles such as the Electrical Vehicle (EV) and the Hybrid Vehicle (HV) have captured the attention of researchers in the environmental sustainable context of [5-8].

A lot of researches [9-10] have been interested in the economic efficiency of integrating EVs. They have presented an overview of the impact of the increasing penetration of the EV into the vehicle market. S. Brown and al. focused on the electricity system and the emergence of vehicle-to-grid technologies, batteries and EV recharge infrastructure. They concluded for the standardization need to facilitate a safe transition with an economical efficiency and an environmental abidance.

J. Kiviluoma and al. estimated the costs of plug-in EVs, and their work showed the advantages of smart EVs compared to the dumb EVs, which mostly would appear in time of charging and discharging EVs.

To improve vehicle performance, various researches have dealt with the optimization of energy management for the new generation. S.Dilmi and al. [12] worked on this axis and developed a new controller flux, a mixed Proportional Integral (PI)-based extension of the Field Orientated Controller (FOC) and a sliding mode observer for the induction motor incorporated into a hybrid EV. B.GASBAOUI [13] and al. presented an EV that had two directly driven wheel induction motors and proposed a speed control design of the EV using a Direct Torque Control (DTC) with an adaptive fuzzy control.

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In [14], the authors developed a new traction control approach to a fault-tolerant performance based on the Maximal Transmissible Torque Estimation (MTTE) scheme which could prevent EVs from skidding.

Energy management and control are usually preceded by others, for modeling EVs and their components [10, 15-16].

In this work, the electric drive consists of two directing wheels and two rear propulsion wheels equipped with only one Direct Control (DC) motor which is widely used in electric traction applications resulted from its technological maturity and control simplicity.

Fuzzy Logic (FL) is employed to control the speed of an EV under different State Of Charge (SOC) of the battery and acceleration. The main originality of the suggested method is that the energy management does not choose between different sources, like many references [17-20], but it is capable to predict the behavior of a good driver using not the couple SOC and speed used in [17-19] but using two SOC and acceleration inputs.

The paper is organized in the following way. First, section 2 presents the control strategies developed for the energy management system of the adopted system. After that, the configuration and modeling of the power train system are given in section 3. Then, the simulation results are evaluated and discussed in section 4. Finally, section 5 establishes the conclusions.

2. Approach synopsis

The approach displayed in fig.1 consists in controlling the speed of only one direct current machine that is installed and operated inside the driving wheels. The control assures information in a real time speed reference (Ωref[rd/s]), which can be generated depending on the battery SOC (SOC[%]) and the acceleration (Acc[%]).

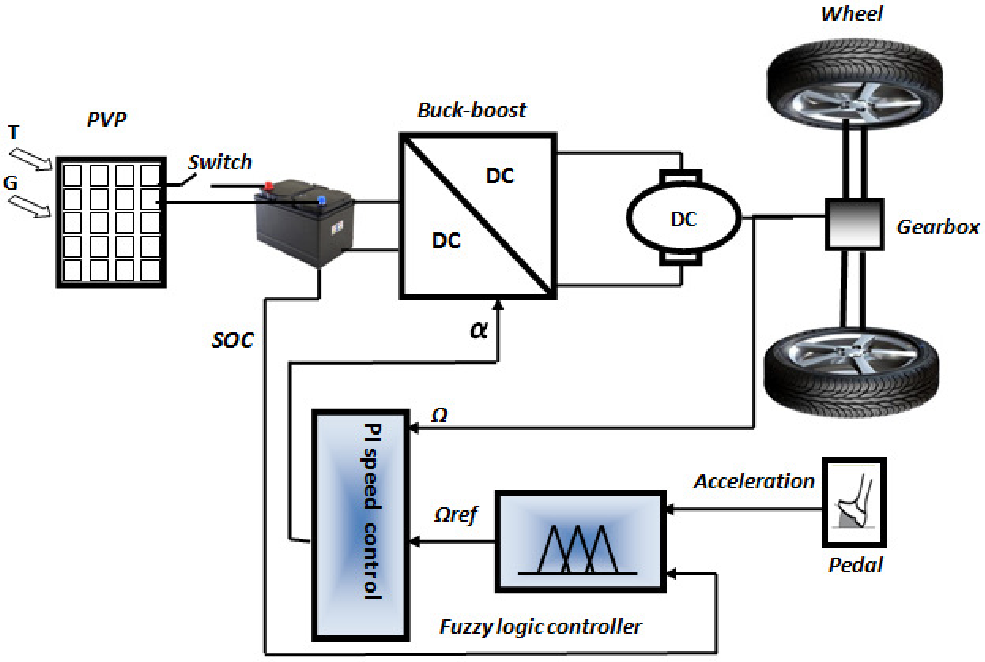

Fig. 1. Synoptic schema of the approach proposed

3. System modeling

3.1 Modeling DC machine

In a vehicle, the DC machine functions like motors in a traction phase and generators in a braking phase. The model of DC motors is reacted by the following electromagnetic equations:

$$V_s = R_s i_s + L_s \frac{di_s}{dt} \tag{1}$$

$$V_r = R_r i_r + L_r \frac{di_r}{dt} - M_{sr} i_s \Omega \tag{2}$$

$$J \frac{d\Omega}{dt} = C_{em} - C_r - f\,\Omega \tag{3}$$

$$C_{em} = -M_{sr} i_s i_r \tag{4}$$

where: V_s and V_r are respectively the stator and the rotor voltage,
i_s and i_r are respectively the stator and the rotor current,
L_s and L_r are respectively the stator and the rotor inductances,
R_s and R_r are respectively the stator and the rotor resistances,
M_{sr} is the mutual inductance,
Ω is the mechanical speed of the machine,
J is the total inertia of the machine,
f is the coefficient of friction,
C_{em} is the electromagnetic torque,
and C_r is the load torque.
The DC motor parameters are given in Table 1:

Table 1. DC machine parameters

Parameters	values
Rotor winding resistance R_r [Ω] (per phase)	1.26
Stator winding resistance R_s[Ω] (per phase)	130
Rotor inductance L_r [H] (per phase)	0.034
Stator inductance L_s [H] (per phase)	0.034
Total inertia J [kg.m^2]	0.002
Viscous friction coefficient Bm [N.m.s]	0.01
Torque constant K [N.m/A]	1.15

3.2 Modeling DC-DC converter

The chosen DC-DC converter is the converter buck boost, bidirectional in current, presented in fig. 2.

"α1" is the duty cycle whose T1transistor is closed in the period T of hashing.

"α2" is the duty cycle whose T2transistor is closed in the period T of hashing.

The relationship between the voltage input (Vint) and voltage output (Vout) in buck converter is:

- In the tracing phase: (T1 ON) and (iout >0); then

$$V_{out} = \alpha_1 V_{in} \tag{5}$$

- In the braking phase: (T2 ON) and (iout <0); then

$$V_{out} = (1 - \alpha_2) V_{in} \tag{6}$$

For this application, we adopt the complementary command summarized by the following equation:

$$\alpha_1 + \alpha_2 = 1 \tag{7}$$

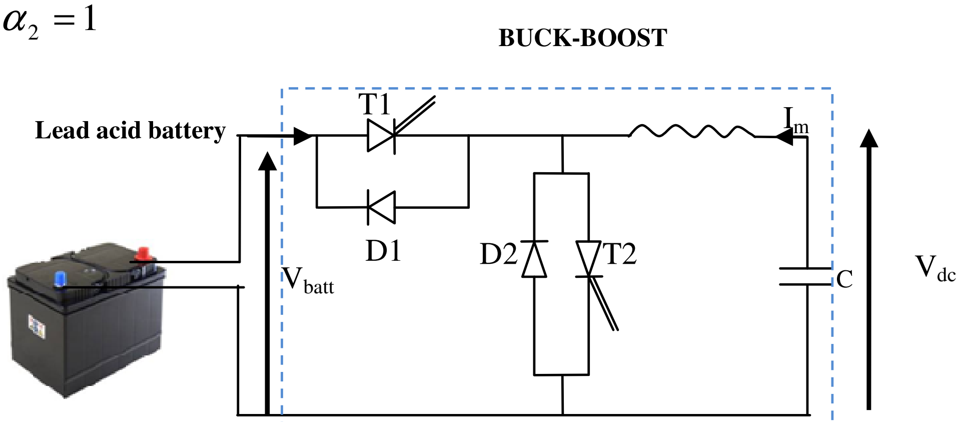

Fig. 2. DC-DC buck converter

3.3 Modeling battery

There are several battery types, which are used in EVs [21-23]. The most known ones are: lead acid (Pb) battery, nickel-cadmium (Ni-Cd) battery, and Lithium-ion (Li-ion) battery. In this study, we use the model of the lead acid battery given by [24] which estimates the SOC battery using the Linear Matrix Inequality (LMI) observer. The model is represented in fig. 3.

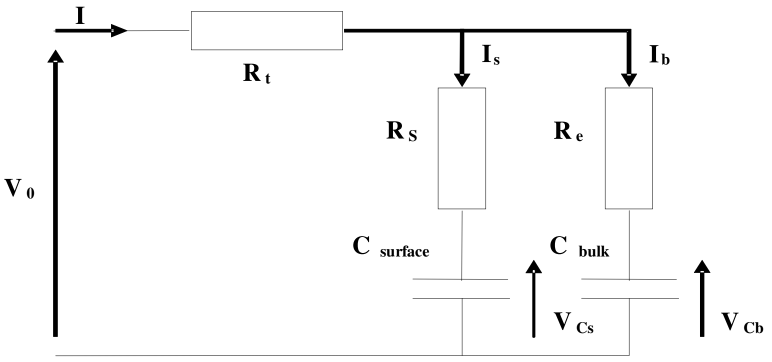

Fig. 3. Battery model diagram

To evaluate the battery voltage V_0, Kirchhoff laws are applied:

$$\begin{cases} V_0 = I R_t + I_b R_e + V_{cb} \\ V_0 = I R_t + I_s R_s + V_{cs} \end{cases} \tag{8}$$

The complete state model is described by:

$$\begin{bmatrix} \dot{V}_{Cb} \\ \dot{V}_{Cs} \\ \dot{V}_0 \end{bmatrix} = \begin{bmatrix} -\dfrac{1}{C_{bulk}(R_e+R_s)} & \dfrac{1}{C_{bulk}(R_e+R_s)} & 0 \\ \dfrac{1}{C_{surface}(R_e+R_s)} & -\dfrac{1}{C_{surface}(R_e+R_s)} & 0 \\ A(3,1) & 0 & A(3,3) \end{bmatrix} \begin{bmatrix} V_{Cb} \\ V_{Cs} \\ V_0 \end{bmatrix} + \begin{bmatrix} \dfrac{R_s}{C_{bulk}(R_e+R_s)} \\ \dfrac{R_e}{C_{surface}(R_e+R_s)} \\ \dfrac{R_e}{C_{surface}(R_e+R_s)^2} - \dfrac{R_s R_t}{C_{bulk} R_e (R_e+R_s)} + \dfrac{R_t}{C_{surface}(R_e+R_s)} + \dfrac{R_e R_s}{C_{surface}(R_e+R_s)^2} \end{bmatrix} I \tag{9}$$

with

$$A(3,1) = -\frac{R_s}{C_{bulk}(R_e+R_s)^2} + \frac{R_e}{C_{surface}(R_e+R_s)^2} - \frac{{R_s}^2}{C_{bulk} R_e (R_e+R_s)^2} + \frac{R_s}{C_{surface}(R_e+R_s)^2}$$

$$A(3,3) = \frac{R_s}{C_{bulk} R_e (R_e+R_s)} - \frac{1}{C_{surface}(R_e+R_s)}$$

Table 2 Initial parameters for battery model

Parametrs	Values
Bulk capacitor C_{bulk} [F]	88372.83 F
Surface capacity $C_{surface}$ [F]	82.11 F
End resistance R_e [Ω]	0.00375Ω
Surface resistance R_s [Ω]	0.00375Ω
Terminal resistance R_t [Ω]	0.002745Ω

3.4 Speed control

Separately excited, the stator current is constant and is equal to i_{sn}. Therefore, the model of DC motor becomes:

$$V_r = R_r i_r + L_r \frac{di_r}{dt} - M_{sr} i_s \Omega \tag{10}$$

$$J \frac{d\Omega}{dt} = C_{em} - C_r - f\,\Omega \tag{11}$$

$$C_{em} = -M_{sr} i_s i_r \tag{12}$$

The precedent model involves two variable states (i_r and Ω) which should be converged to the desired values ($i_{r,ref}$ and Ω_{ref}). That is why the speed control must contain two loop controls relative to the speed and to the rotor current.

The speed control structure uses two PI correctors presented in fig. 3.

The PI corrector is known for its robustness, simplicity and stability for several real world applications [13, 25].

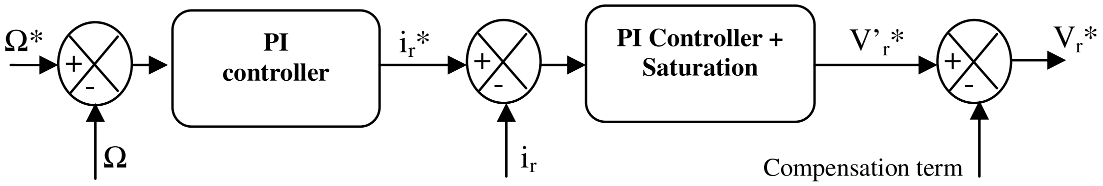

Fig. 4. Speed control

4. Fuzzy logic controller

Classical logic needs a deep comprehension of a system, exact equations and accurate numeric values to allow modeling the system, contrary to FL which uses the highest level of abstraction results of our knowledge and experience to establish a model for a complex system.

In this study, FL is utilized to estimate the reference speed (Ω_{ref}) adequate to the given couple of acceleration, ACC and SOC. Fuzzy partitions are necessary in order to permit a multi-criteria resolution.

Battery SOC: The fuzzy partition of the SOC is composed of an Ns = 6 fuzzy membership function speed (A_l= very very low (VVL), very low (VL), low (L), medium (M), high (H), and very high (VH)) (fig. 5.a),where l= {1, 2, 3, 4, 5, 6} is the fuzzy subset number which covers the fuzzy domain SOC= [0.2, 1] and verifies $\forall$ x= v$\in$ SOC.

$\sum_{l=1}^{Ns} \mu_{A_l}(x) = 1$ where μ_{A_l} is the membership function.

Acceleration (ACC): The fuzzy partition of acceleration is composed of an Ns = 6 fuzzy membership function speed (B_l= very very low (VVL), very low (VL), low (L), Medium (M), high (H), and very high (VH)) (fig. 5.b).

where l= {1, 2, 3, 4, 5, 6} is the fuzzy subset number that covers the fuzzy domain ACC= [0, 1] and verifies $\forall$ y= Q$\in$ ACC.

$\sum_{l=1}^{Ns} \mu_{B_l}(x) = 1$ where μ_{B_l} is the membership function.

Speed reference (Ω_{ref}): The fuzzy partition of the speed reference is composed of an Ns = 6 fuzzy membership function speed (C_l= very very low (VVL), very low (VL), low (L), Medium (M), high (H), and very high (VH)) (figure 5.c).

where l= {1, 2, 3, 4, 5, 6} is the fuzzy subset number which covers the fuzzy domain Sest= [0,145] and verifies $\forall$ z= d$\in$ VREF.

$\sum_{l=1}^{Ns} \mu_{C_l}(z) = 1$ where μ_{C_l} is the membership function.

The control roles are indicated in Table 3 and the general rules format is:

IF (SOC are **A**) and (ACC are **B**) **THEN** (Ω_{ref} are **C**)

This paper uses the Min-Max fuzzy inference method suggested by Lotfi Zadeh [26] used in [27-28].

In this work, the Bisector method is used for defuzzification.

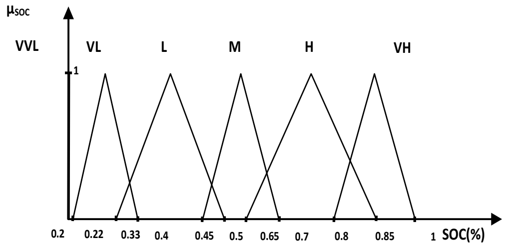

Fig. 5 (a). Input SOC

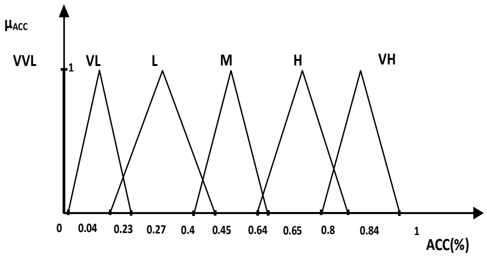

Fig. 5 (b). Input ACC

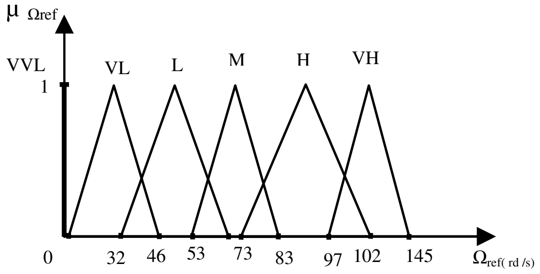

Fig. 5 (c). Output Ωref

Table 3. Control roles

SOC / ACC	VVL	VL	L	M	H	VH
VVL	VVL	VVL	VVL	VVL	VVL	VVL
VL	VL	VL	VL	VL	VL	VL
L	VL	VL	L	L	L	L
M	VL	L	L	M	M	M
H	VL	VL	L	M	H	H
VH	VL	VL	L	M	H	VH

5. Simulation results

To demonstrate the effectiveness of the Proposed Approach (PA), a vehicular system is simulated by a MATLAB Simulink software using a different couple of input SOC and acceleration (ACC).

For all tests, any arbitrary value of an input is supplied by the function random in MATLAB Simulink.

5.1. SOC = 0.95 and ACC = random [0 1]

In the first test, during a maximal SOC (SOC=0.95 %) and an arbitrary ACC (fig. 6), the vehicle speed follows the reference speed generated by the PA, as shown in the figure below with a small error proven by zooming in fig. 7.

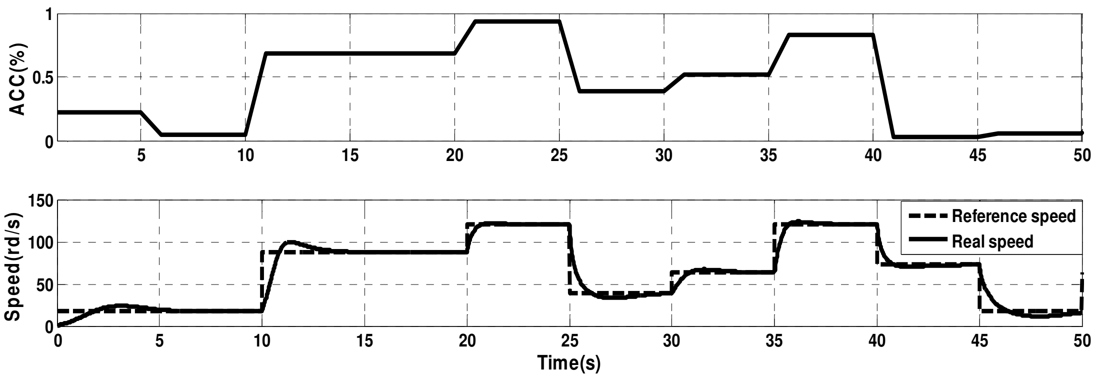

Fig.6. Results of test1

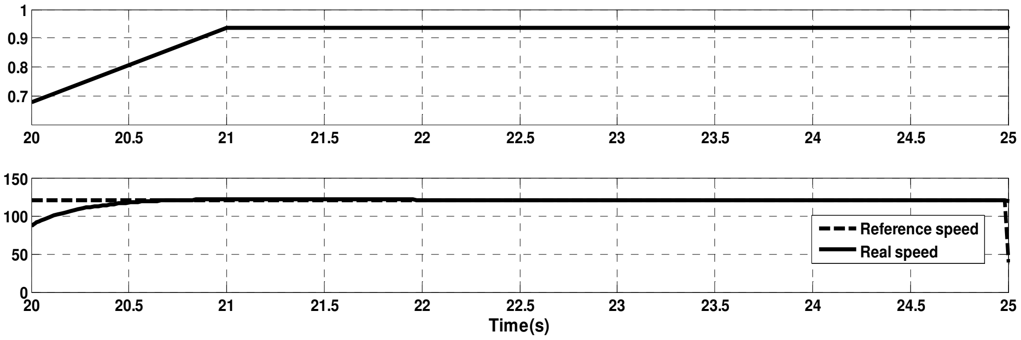

Fig.7. Zoom results of test1

5.2. SOC from battery and ACC=0.95

In the second test, the acceleration is fixed to 0 .95% and the SOC is given by the model of battery, seen in fig. 8. Fig. 9 illustrates the measured speed and the reference speed in test 2, which are closed.

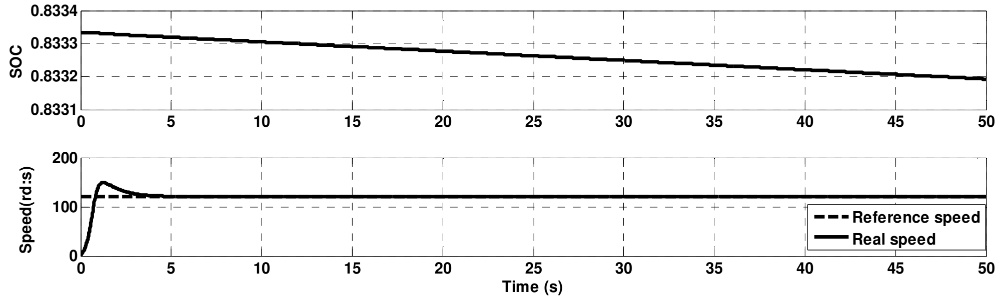

Fig.8. Results test2

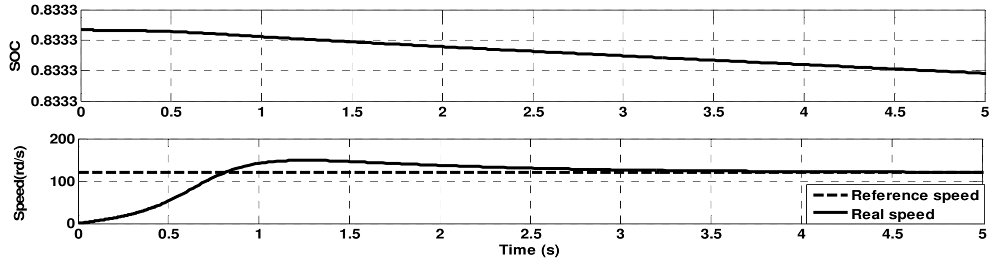

Fig. 9. Zoom results of test2

5.3. SOC from battery and ACC=0.2 %

As in the third test, the SOC is given by the model of battery (fig. 10) and the acceleration chosen is of a low value of 0.2%.

The wave forms of the measured speed and reference speeds are drawn in Fig. 10. A small error between these two speeds is indicated in the zoom in Fig. 11.

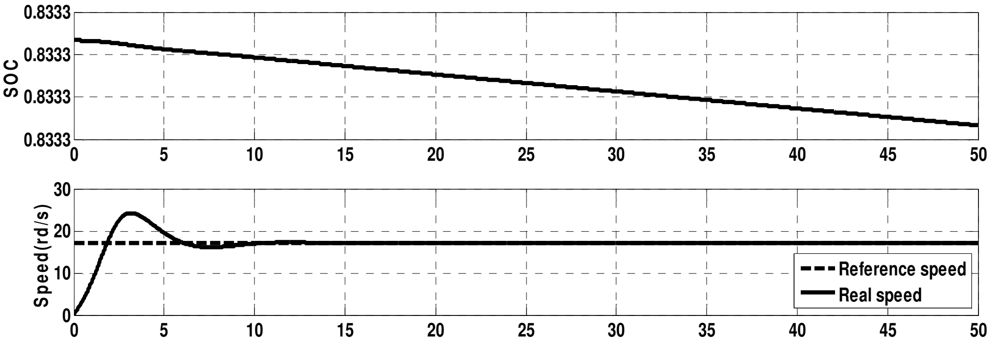

Fig. 10. Results of test3

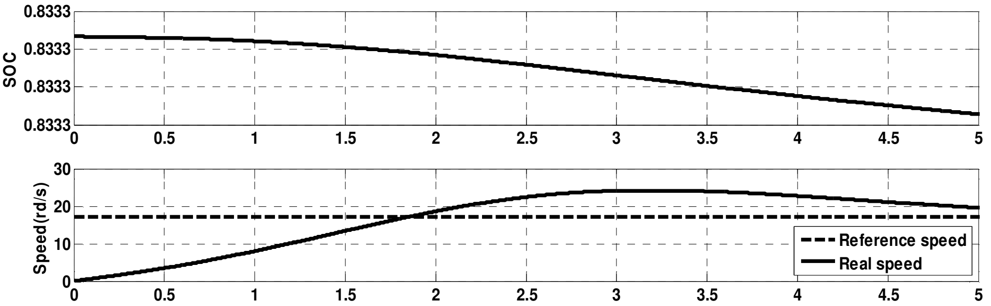

Fig.11. Zoom results of test3

5.4. SOC from battery and ACC = random [0 1]

In the fourth test we enter the SOC provided by the battery, and the arbitrary accelerations are plotted in fig. 12. We present a zoom for the curves of measured speed and reference speed in fig.13.

The figure with zoom indicates that the measured and reference speeds are quite indistinguishable.

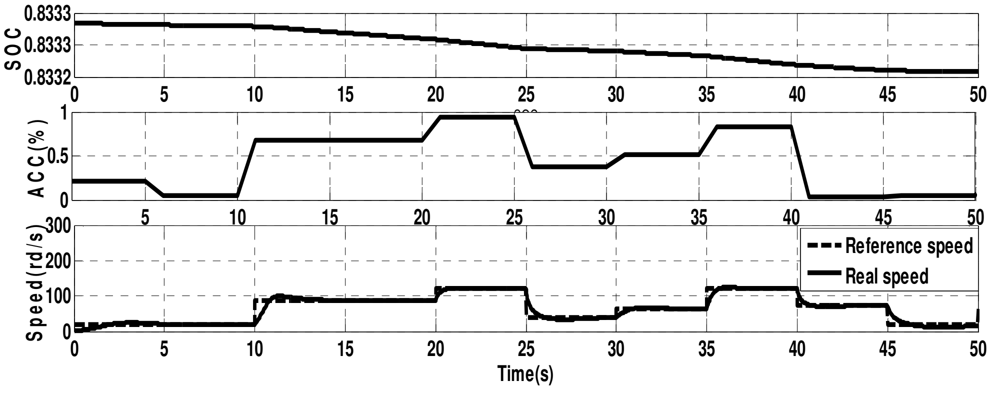

Fig.12. Results of test4

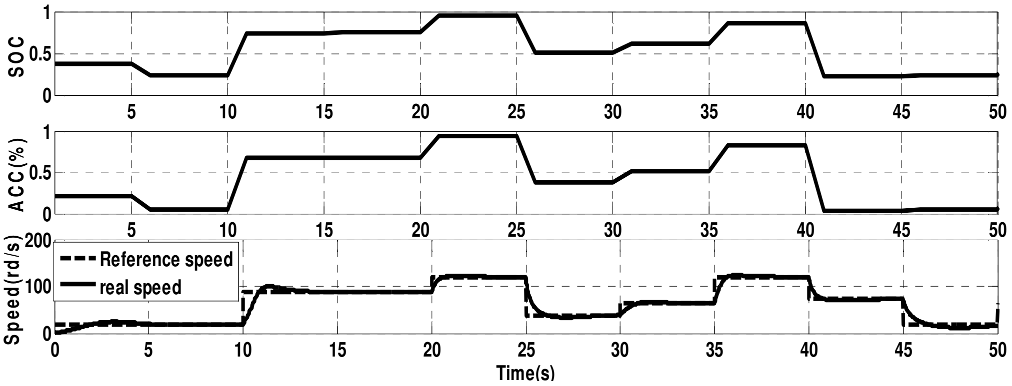

Fig.13. Zoom results of test4

5.5. SOC = random [0.2 1] and ACC = random [0 1]

Fig. 14 draws the measured speed and the reference speed for the arbitrary inputs. We generate the same remarks made in the previous tests.

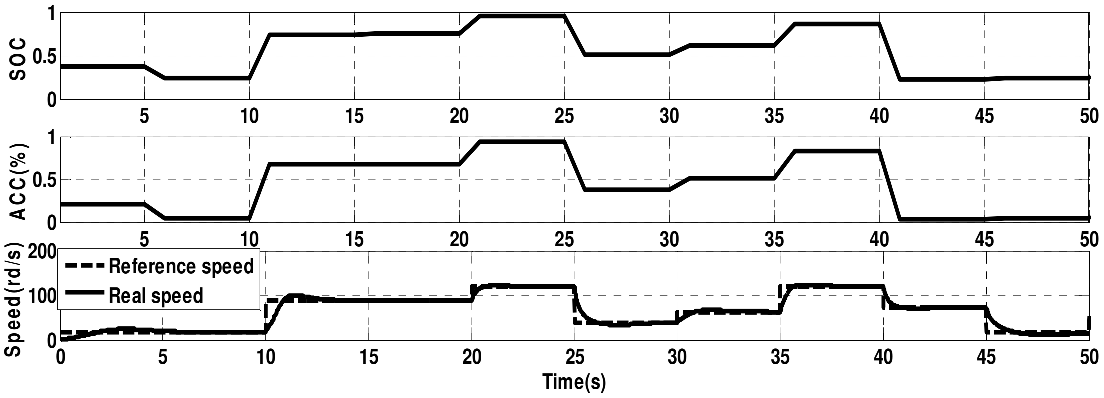

Fig.14. Results of test5

We present a zoom for the curves of measured speed and reference speed in fig.15.

The figure with zoom indicates that the measured and reference speeds are quite indistinguishable.

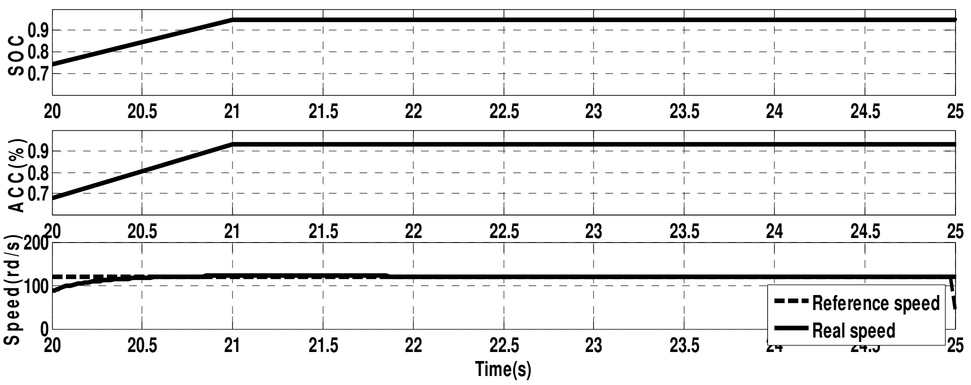

Fig.15. Zoom results of test5

5. Conclusion

Many researchers have investigated the energy management and control strategies of EVs. Most of them have studied the component sizes, and some also have designed linear controllers. However, due to the nonlinear behaviour of EV and converters' structure, a FC controller will be the best choice for simultaneous control of system components.

This paper presents a model of an EV associated with the new control strategy of speed taking into account the battery SOC and the acceleration. The strategy uses FL to generate the reference speed.

To evaluate the performance of the proposed strategy, some tests have been made using MATLAB/Simulink. The simulation results show the effectiveness of the suggested strategy under different inputs.

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