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Energy management optimization Based on Fuzzy Logic for a fuel cell electrical vehicle with Battery-Ultracapacitor hybrid storage system

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Abstract— **The management of power exchanges in the driving chain of a multisource hybrid vehicle is a key element in optimizing the vehicle hydrogen consumption. This work aims to develop an energy management optimization method applied for a hybrid vehicle which consists to a fuel cell as the main energy source and storage system, composed by a battery and a supercapacitor, as the secondary energy source. The fuzzy logic technique is used to find the optimal control actions necessary to manage the power between the primary source (Fuel cell) and the secondary source (Energy storage system). Also, we have proposed an algorithm to find the power split, between the two storage elements, based on prior knowledge of the power required of the all of the storage system.**

In this paper, the proposed optimization technique is evaluated for a power profile and for the New European driving cycle (NEDC). Simulation results are presented to prove the effectiveness of the adopted strategy.

***Keywords*— Energy management optimization, Fuel Cell, Battery, Supercapacitor, Hybrid vehicle. Fuzzy Logic Control (FLC).**

I. INTRODUCTION

Because of the fact that the problems of air pollution and energy scarcity become, recently, more and more severe, the interest in automotive power train increases rapidly. In the context of the climate crisis caused principally by an overall dependency on fossil fuels, renewable and clean energy sources can establish a reliable alternative [1]. Hydrogen is one of the most important clean energy vectors. Electricity generation through its utilization in fuel cells can be clean and efficient for the vehicular applications.

As one substitute for traditional known internal combustion engine based vehicular applications, fuel cell powered vehicles have rapidly expanding and there are several different research lines associated with the various sectors such as the stationary application sector, the portable device sector and especially the transport sector [1,2]. For this reason, this new technology has become a research hotspot in the domain of clean vehicle technology.

Among fuel cell types, Proton exchange membrane fuel cell (PEMFC) is the most useful in electrical vehicles because of its several advantages. Indeed, PEMFC is characterized by solid membrane, low operating temperature and pressure, also, its good performance for the slow load dynamic. Besides, the hydrogen, used to generate the electricity, can be produced by electrolysis processes in order to produce near zero total emission electricity [3]. However, when a fuel cell is integrated as stand-alone source into a hybrid vehicle, it can not always satisfy the high load demands [4, 5]. Indeed, despite of its many advantages, there are some limitations on the rate of current drawn from it. Fuel cell is characterized by a slow power transfer rate, particularly, in transient operation because of its slow response which depends on electrochemical reactions. For these reasons, it becomes necessary to associate FC with an auxiliary source such as battery (BAT) or/and supercapacitor (SC) [6].

Hybrid storage systems composed of battery and supercapacitor have recently appeared as an alternative to the conventional single storage system in electrical hybrid vehicles. The high energy and power density of a hybrid storage system allow improving the performance of the vehicle. However, an energy management strategy should be employed to share the energy flow between battery and ultracapacitor [7].

Among the aforementioned control strategies in the literature [6, 7, 8, 9], fuzzy logic was considered as a better controller due to its independence of a complete mathematical model and procedure of training. Thus, this makes it pretty adequate and practicable, especially, for the systems with nonlinear behaviours [10, 11].

In this work, a new control strategy, which is based on a combination of a simple management algorithm and the fuzzy logic control (FLC), is proposed and applied for a hybrid power source, which is composed of FC, BAT and SC, used in electrical hybrid vehicle. The overall system structure adopted is presented in Fig.1 where the FC presents the main source, and the energy storage system (ESS) composed by the BAT and the SC is the secondary source which allows benefiting the aforementioned advantages of a BAT/SC combination used as the auxiliary source in vehicular applications. The most important property of this structure is that the power flow of the system can be managed with the same control algorithm in different vehicle operating modes.

The proposed FLC, which is based on the load power required and the energy of the storage system, can be well

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adapted in the vehicular applications for which the trajectory planning is required. This algorithm is used to control the energy management between the main source and the secondary source. On the other hand, the energy distribution between the two elements of the ESS is obtained by an other energy management algorithm.

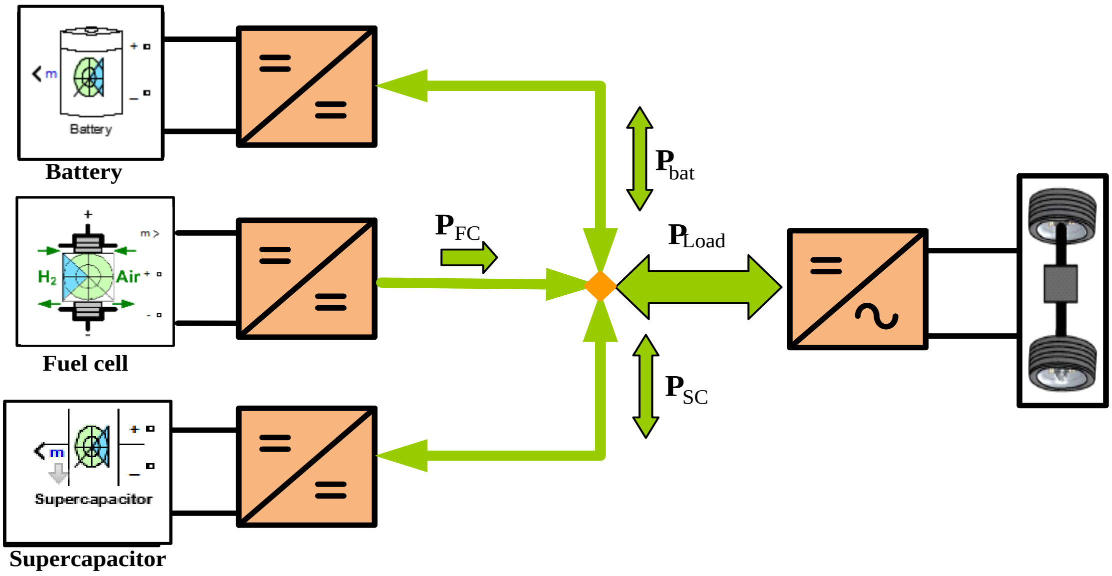

Fig. 1. Electrical vehicle structure

II. Modelling of Electrical Sources

The proposed hybrid vehicle presents a fuel cell as the main energy source and the storage system, composed by a battery and a supercapacitor, as the secondary energy source. The main source must produce the necessary energy to the electrical vehicle. The secondary energy source produces the lacking power in acceleration and absorbs excess power in braking operation.

A. Main Source: Fuel Cell

A fuel cell, presented in Fig.2, is composed of two electrodes, anode and cathode, which are separated by an electrolyte membrane interposed between them. The operation of PEM fuel cells is based on using pressurized hydrogen and oxygen as a fuel in order to produce electricity.

Hydrogen existing in anode side is dissociated into protons and electrons. The electrons flow from anode to cathode through external circuit producing electrical current. For the protons, they flow from anode to cathode through the electrolyte membrane. On the other hand, in the cathode side, oxygen reacts with electrons and protons allowing producing water and heat. Described reactions can be expressed using the following equations:

$$H_2 \rightarrow 2H^+ + 2e^- \qquad (Anode) \qquad (1)$$

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \rightarrow H_2O \qquad (Cathode) \qquad (2)$$

So, the operating principle of a fuel cell is described by a chemical reaction given by equation (3), which reacted hydrogen and oxygen to produce electricity, heat and water.

$$2H_2 + O_2 \rightarrow H_2O + electricity + heat \qquad (3)$$

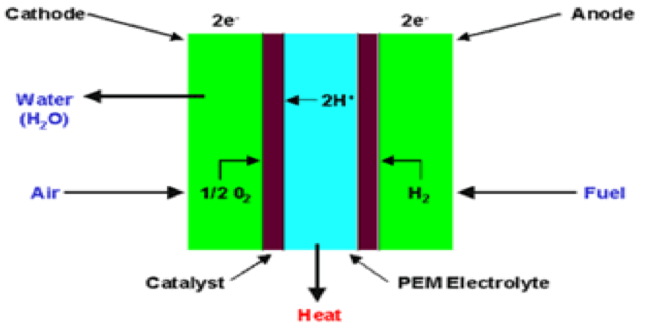

Fig. 2. Fuel cell structure

The cell voltage should be expressed as the difference between the ideal Nernst voltage and the sum of voltage losses in the fuel cell such as described by the following equation:

$$V_{FC} = E_{Nernst} - \sum \Delta V \qquad (4)$$

Where E_{Nernst} presents the average thermodynamic potential of each unit cell.

$\sum \Delta V$ is given as follows:

$$\sum \Delta V = V_{act} + V_{ohmic} + V_{con} \qquad (5)$$

V_{act} : Activation voltage drop.

V_{ohmic} : Ohmic voltage drop.

V_{con} : Concentration voltage drop.

B. Secondary Source: Hybrid Storage System

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Hybridization of energy storage elements with different characteristics allows obtaining efficient energy management and power share control of the hybrid energy storage system.

- **Battery**

Batteries have been adopted, generally, in electrical vehicles because of their characteristics in terms of safety, reliability, high energy density, and compact size.

The battery model used in this work is presented as a simple controlled voltage source V_{bat} which is described by Equation (6), in series with a constant resistance.

$$V_{bat} = E - R_{bat} I_{bat} \quad (6)$$

Where

R_{bat}: is the internal resistance (Ω)

I_{bat}: is the battery current (A)

For the controlled voltage source, it is given by equation (7).

$$E = E_0 - K \frac{Q}{Q_0 - \int i.dt} + A.\exp(-B\int i.dt) \quad (7)$$

- **Supercapacitor**

Supercapacitor is characterized by a power density which is significantly higher than that of the battery. Besides, low internal resistance value of supercapacitor makes it high energy efficiency. Also, because of its special characteristics, supercapacitor is taking placed in-between lead acid battery and conventional capacitor.

Equation (8) gives the SC voltage expression V_{sc}, as function of SC current I_{sc} and ultracapacitor resistance R_{sc}.

$$V_{sc} = V_1 - R_{sc} * I_{sc} = \frac{Q_{sc}}{C_{sc}} - R_{sc} * I_{sc} \quad (8)$$

Q_{sc} is the electricity quantity stored in a cell.

III. Control Strategy Description

In this work, the control strategy proposed is based on a combination of a fuzzy logic controller (FLC) and a management algorithm which is based on the limitation of the battery current. The FLC is used to control the energy flow between the fuel cell and the storage system. On the other hand, the energy management algorithm is proposed to share the energy between the two elements of the storage system: the SC and the BAT.

A balance equation can naturally be established, since the sum of power from both sources (main and secondary) has to be equal to the required power P_{Load} at all times [12] as given by Equation (9).

$$P_{Load} = P_{FC} + P_{BAT} + P_{SC} \quad (9)$$

A. Energy Management Between Fuel Cell and Storage system

In this paper, we propose an energy management strategy based on the fuzzy logic to control the distribution of the energy flow between the main energy source (FC) and the secondary energy source (ESS).

This FLC has two input variables:

1) The power of the load P_{Load};

2) The energy of the storage system E_{ss}.

As output, the FLC allows to give the power required from to the Fuel cell.

The proposed energy management algorithm based on fuzzy logic is determined by the membership functions shape and number of different fuzzy variables. Besides, this algorithm is based on the selection of rules, which are necessary for increasing efficiency of the fuel cell by optimizing its delivered current. The selection of the FLC rules depends, especially, on the dynamic behavior of electrical vehicle in order to ensure the process reliability and robustness [13].

For the proposed FLC, the membership functions of the input variables (the required power and the storage system energy), which are presented in Fig. 3, are listed as follows:

N: Negative.

QL: Quite Low

L: Low

M: Medium

H: High

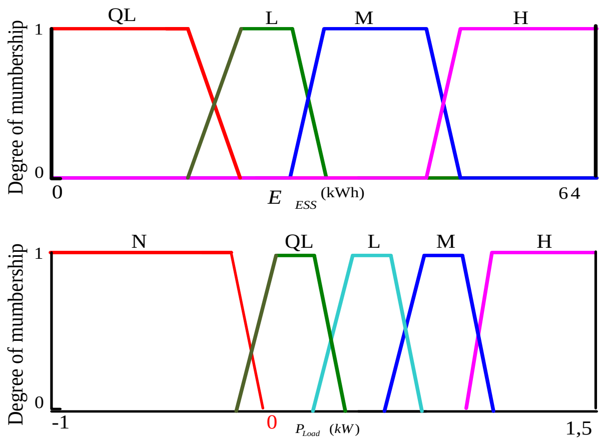

Fig. 3 Membership functions of input variables

Using the data available from the two inputs, the FLC determines the power value to be requested from the primary energy source (P_{FC}). This power is used to calculate the current required from the converter associated to the fuel cell (I_{FC-cv}) and, consequently, the current required from the all of the storage system (I_{ESS}).

For the membership functions of the output variable, there are presented in Fig. 4. The membership functions for the fuel cell power are listed as follows:

Z: Zero.

QL: Quite Low

L: Low.

M: Medium.

H: High

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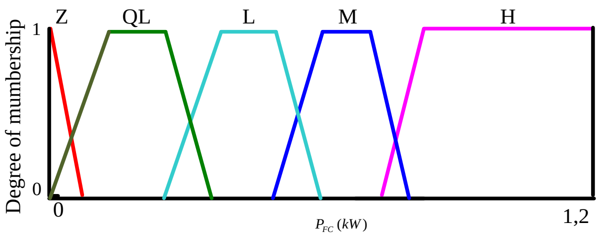

Fig. 4 Membership functions of output variable

B. Energy Management Between battery and Supercapacitor

The energy storage system must be controlled by an energy management system in order to split the electrical power flow between the two elements. The rules on which we are based lie in the limitation of the battery current and the supercapacitor voltage.

After the battery gives a determined current, the ultracapacitor supplies, then, the difference between the current demanded to the overall storage system and the current provided by the battery which is limited to an imposed value. In this case, the adjustment variable is the voltage value of the supercapacitor. The energy management algorithm for the storage system is presented in Fig.5. This algorithm allows giving, for a required current of the overall storage system, the current values supplied from the two converters associated to the battery and ultracapacitor (I_{Bat-cv}) and (I_{SC-cv}).

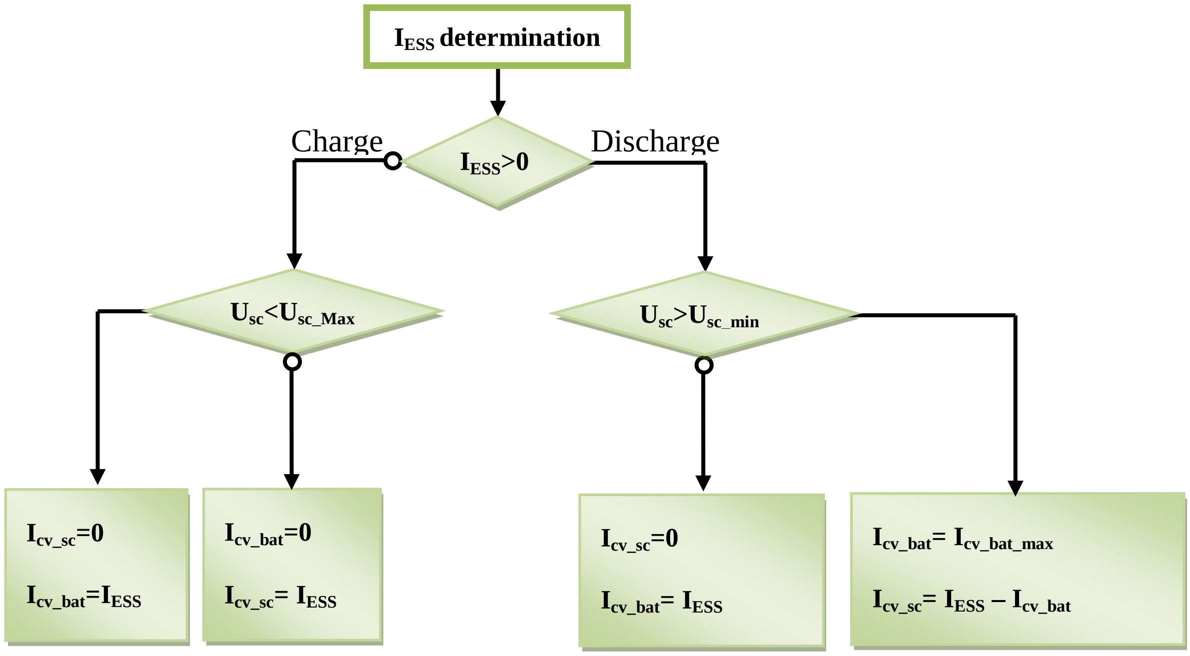

Fig. 5. Electrical vehicle structure with energy management optimization

IV. Simulation Results

In order to improve the effectiveness of the proposed strategy, the overall system is simulated in the environment Matlab-Simulink using mathematical models of the described system elements.

Simulation results are presented for two cases: Profile of power and the driving cycle NEDC. The overall diagram of the controlled system id given by Fig.6.

The FLC ensure the optimum energy management between the FC and the ESS in terms of the power land and the state of the storage system. The power required by the load and by these two elements, for the two load profiles, is given by Fig.7 and Fig.8.

By exploiting different simulation results, we can approve the effectiveness of the proposed control strategy which allows an optimization of the power given by the fuel cell, so, the minimization of hydrogen consumption.

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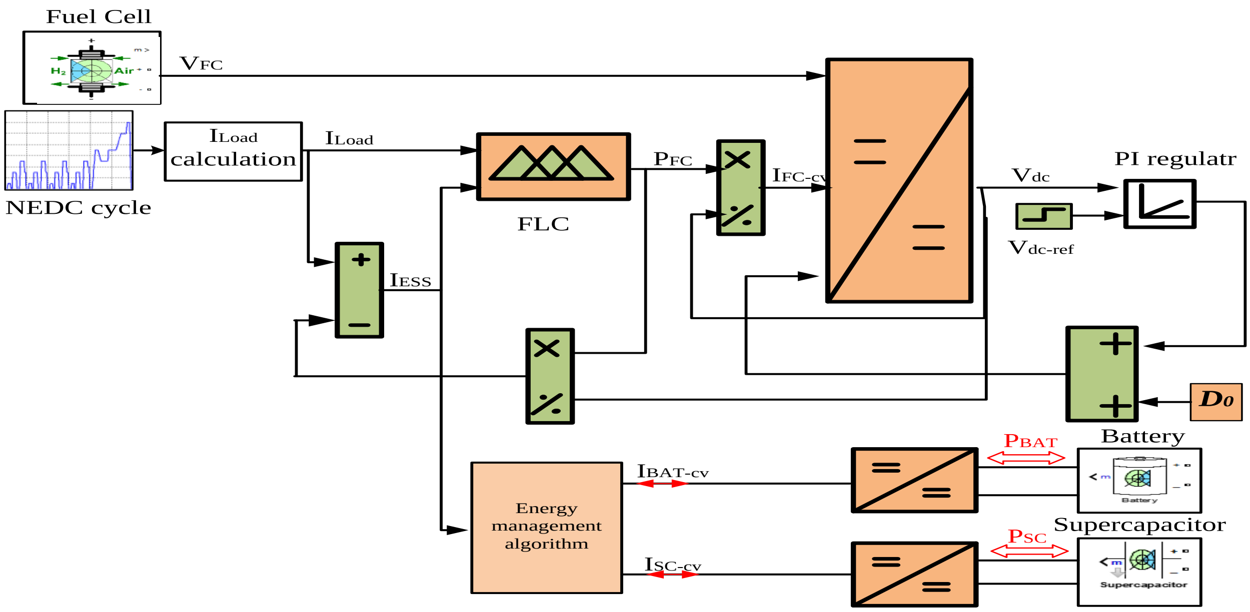

Fig. 6 Electrical vehicle structure with energy management optimization

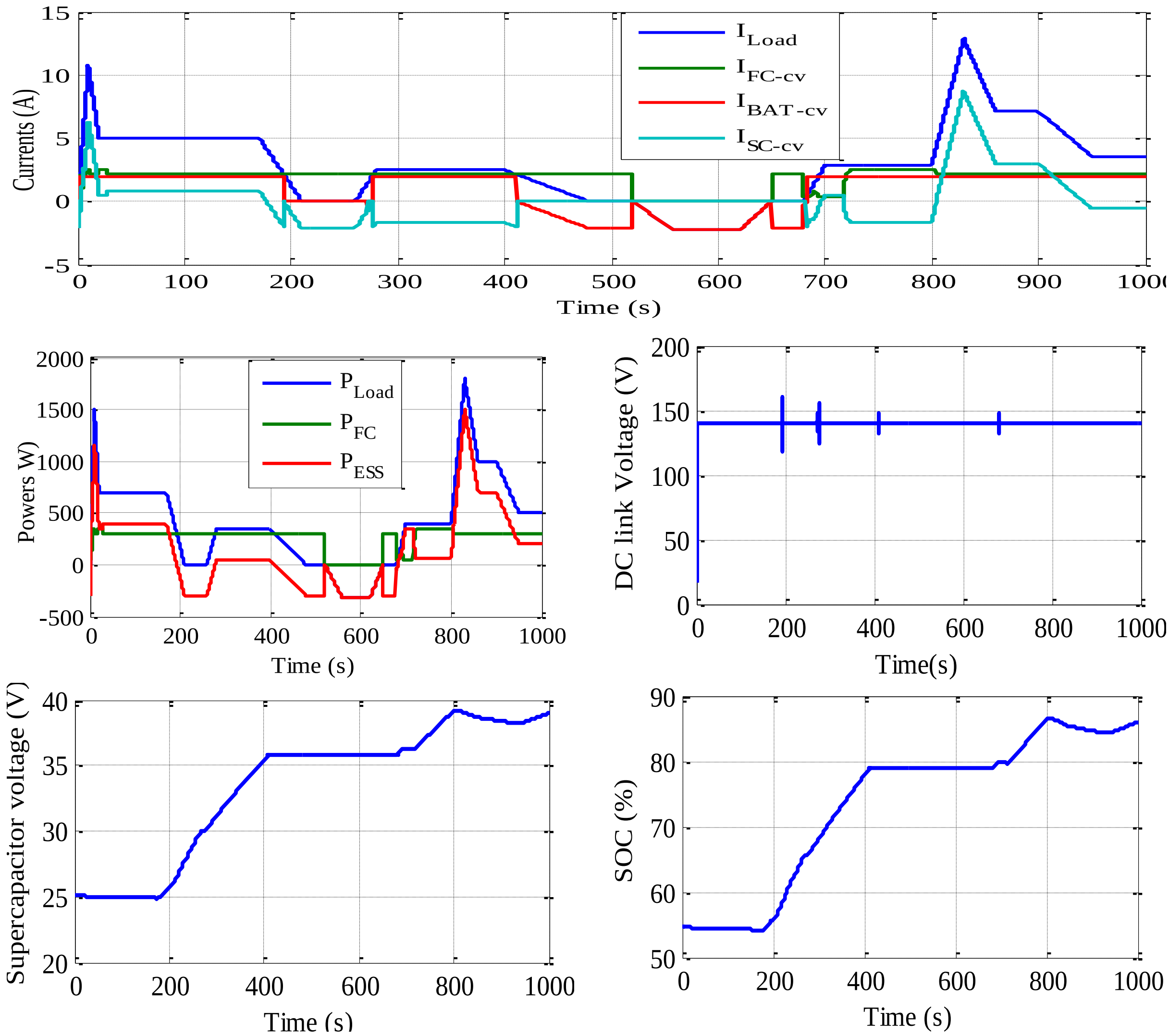

Fig. 7. Simulation results for a profile of power

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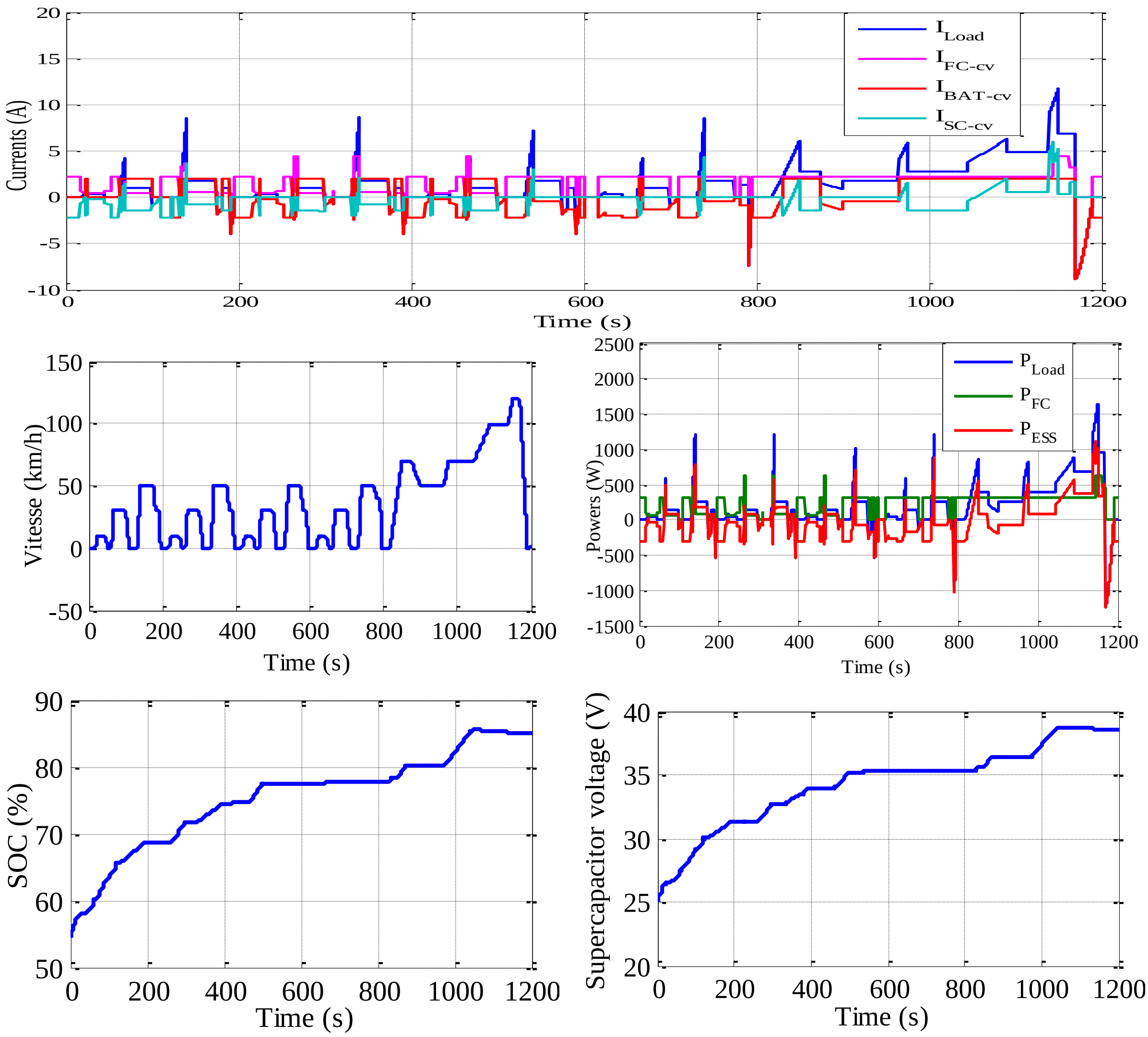

Fig. 8. Simulation results for NEDC cycle

V. Conclusion

In this work, we have presented a combination of two algorithms in order to manage the power flow between the electrical hybrid power source elements in vehicular applications. This hybrid energy source is composed of three elements, fuel cell, system, battery and ultracapacitor. The first algorithm, which is based on fuzzy logic, is used to control the energy flow split between the main source (FC), the secondary source (ESS) and the load. The power management depends on the required load power and the storage system energy. On the other hand, the second algorithm, which is based on the limitation of the battery current and the supercapacitor voltage, ensures the power division between the battery and the supercapacitor.

The major advantage of the proposed control strategy is that allows the split of the energy in the hybrid power system without predicting beforehand the system behavior variations, even in transient states.

References

[1] L. Ji-Yong Lee, K.H. Cha, T.W. Lim, T.Hur "Eco-efficiency of H2 and fuel cell buses", International Journal of Hydrogen Energy 2011, 36, pp1754–1765.

[2] Hwang, J.J.; Chang, W.R. "Life-cycle analysis of greenhouse gas emission and energy efficiency of hydrogen fuel cell scooters". International Journal of Hydrogene Energy 2010, 35, 11947–11956.

[3] Sharaf OZ, and Orhan MF, "An overview of fuel cell technology:fundamentals and applications," Renewable and Sustainable Energy Review 2014, vol. 32, pp. 810–53.

[4] Qi Li, Weirong Chen, Yankun Li, Shukui Liu, Jin Huang, "Energy management strategy for fuel cell/battery/ultracapacitor hybrid vehicle based on fuzzy logic", J. Electr. Power Energy Syst 2012, 43, pp 514-525.

[5] P.Thounthong, P.Tricoli, B.Davat, "Performance investigation of linear and nonlinear controls for a fuel cell/supercapacitor hybrid power plant", J. Electr. Power Energy Syst. 2014, 54, pp 454-464.

[1] [6] H. Marzougui, M. Amari, A. Kadri, F. Bacha, J. Ghouili, "Energy management of fuel cell/ battery/ultracapacitor in electrical hybrid vehicle", International Journal of Hydrogen Energy 2016.

[7] M. Ansarey, M. S. Panahi, H. Ziarati and M. Mahjoob, "Optimal energy management in a dual-storage fuel-cell hybrid vehicle using multi-

ISSN 2356-5608

dimensional dynamic programming", International Journal of Hydrogen Energy 2014, 250, pp 359e371

[8] M. Zandi, A. Payman, J. P. Martin , S. Pierfederici and B. Davat "Energy Management of a Fuel Cell/Supercapacitor/Battery Power Source for Electric Vehicular Applications''IEEE Trans Veh. Technol. Feb. 2011, vol. 60, no.2, pp. 433–443.

[9] M. C. Kisacikoglu, M. Uzunoglu, andM. S. Alam, "Fuzzy logic control of a fuel cell/battery/ultracapacitor hybrid vehicular power system," in Proc. IEEE Vehicle Power and Propulsion Conference 2007, pp 591–596,

[10] O. Erdinc, O. Elma, M. Uzunoglu, U. S. Selamogullari, B. Vural, E. Ugur, et al., "Experimental performance assesment of an online energy management strategy for varying renewable power production suppression," International Journal of Hydrogen Energy, vol. 37, no. 6, pp. 4737–4748, Mar. 2012.

[11] B. Vural, S. Dusmez, M.Uzunoglu, E. Ugur, and B. Akin, "Fuel Consumption Comparison of Different Battery/Ultracapacitor Hybridization Topologies for Fuel-Cell Vehicles on a Test Bench" IEEE Journal Of Emerging And Selected Topics In Power Electronics, pp 552-561. Vol. 2, No. 3, September 2014

[12] L. V. Pérez, G. R. Bossio, D. Moitre and G. O. García, "Optimization of power management in an hybrid electric vehicle using dynamic programming", International Journal of Mathematics and Computers in Simulation, 73 (2006) , pp 244–254.

[13] A. A. Ferreira, J. A. Pomilio, G. Spiazzi, and L. de Araujo Silva, "Energy management fuzzy logic supervisory for electric vehicle power supplies system," IEEE Trans. Power Electron., vol. 23, no. 1, pp. 107–115, Jan. 2008.

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