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Prioritizing Power demand response for Hydrogen PEMFC-Electric Vehicles using Hybrid Energy Storage

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ABSTRACT

PEMFC powered Hybrid vehicle system is one of an interesting issue for the industry due to its high performances. The PEMFC cannot certainly ensure a sustained required energy in some scenarios. To solve this problem related to PEMFC transient response, a Hybrid Electrical Storage System (HES) is a potential candidate for a solution. The proposed Hybrid Storage system is comprised of the battery (BT) and a Super-Capacitor (SC) components. These components are included to control the hydrogen variations and the fast peak powers scenarios respectively. The SC is used to control PEMFC and the BT slow dynamics at the same times. An accurate Multi-Ways Energy Management System (MW-EMS) is proposed which aims to cooperate with the system components through SC/BT state of charge and a flux calculation. The simulation results are discussed and assessed using MATLAB/ Simulink.

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1. INTRODUCTION

Nowadays, the Hybrid Storage System is considered as an attracting issues and an alternative energy storage [1]. These novel energy storages have been applied in various industrial applications and various fields of research respectively. Indeed, these technological devices aimed to replace the conventional fuels like, natural gas, petroleum, coal, which are being depleted rapidly and posing a fatal danger for the environment. To resolve these problems, hybrid storage system like supercapacitor and battery were treated and deployed [2], [3].

Most applications included FCHEVs hybridization concept are appreciated as an attractive and potentially solution for transport applications [4]. Furthermore, FCHEVs included PEMFC, Lion Battery (BT), and Super-Capacitor (SC) are qualified by its performances and its efficiencies [5]. The PEMFC is characterized by its slow dynamic and its rapidity to manage the quick variations power in the FCHEVs. Indeed, the PEMFC was used especially during transient and startup events to satisfy the power demands and to minimize the hydrogen consumption [6-8].

The lion battery technologies were used especially to increase the power, energy and serve the operating voltage. Furthermore, the batteries can work in parallel with the PEMFC to serve and provide the required power during the permanent phases, the hydrogen lack and the energy braking [9]. However, the Supercapacitor is included to control and incrise the low density power throught the averge PEMFC and Battery density power [10]. The Hybrid Energy Storage aimed to ensure a various of the energy demands.

The most proposed Hybrid storage units were tested and studied through varieties of the energy management strategies.

For example, the authrs in [11] proposed an efficient hybridization storage configuration for Electrical vehicle using a PEMFC and an BT. While, the authors in [12], proposed a hybrid electrical system (PEMFC/BT/SC) for transport application. To cooperate between the included sources an a power management approach was proposed and evaluated through BT and SC state of charges.

This article discusses an efficient hybrid storage system uses SC as an energy storage for a short time and BT as an energy storage for a long time for electric vehicles. The proposed system is simulated and evaluated using a given speed profile. An efficient MW-EMS is developed to improve system performance. Indeed, this article attempts to study the system performance through the various hypotheses.

The prepared document is organized as follows: Section 2 discusses related work; Section 3 assesses a brief review of Hybrid storage systems; Section 4 presents the FCHEV structure; Section 5 presents our MW-energy management system; Section 6 discusses the results achieved and the concluding observations are discussed in section 7.

2. LITERATURE REVIEW AND CONTRIBUTIONS

In the literature, numerous Hybrid storage configurations were evaluated a production power that seems to supply electrical vehicles. For example, in [13] the authors presented a Hybrid system (PEMFC/BT/SC) which aims to control the power demands. The BT device was used to ensure a required power when the PEMFC is switched off. While the SC can control the transient power. To control and to cooperate between the included sources an energy management unit is proposed. While, the authors in [14], an FCHEV system using PEMFC, BT and SC.

The authors in [15], proposed an efficient hybrid system (PEMFC/BT/SC) for a vehicle application, where PEMFC is used as the main power and BT/SC were used as storage devices. A seamless control strategy is treated and discussed in [16], according to a power management unit. To select the best efficient control strategy for electric vehicles the authors proposed a Hybrid (PEMFC/BT/SC) system in [17], in which each power source was connected to a DC/DC converter and a common DC bus voltage, from where the electrical vehicle was supplied. An efficient hybrid (FC/BT/SC) system used to supply a tramway is developed. The author in [18] proposed an energy management system using an intelligent fuzzy logic control to manage the distribution power.

Compared to the above cited works, our work deals to propose an efficient hybrid power system using Multi-ways energy management approach based on the following enhancements:

a. We offer an efficient management unit based on a multi-ways scenarios than previous works as they use each component to handle the excess and power deficit. The approach envisaged guarantees the possibility of power flows according to an accurate scenario to meet energy demand.
b. We evaluate the proposed energy management based on the following constraints: (1) load demand, (2) BT and SC state of charge, (3) operation of each storage unit, (4) excess power and deficit.

We study the system performance based on a Multi-ways where their study is ignored by certain research works.

3. OVERALL SYSTEM DESCRIPTION

The fuel cell hybrid electric vehicle (FCHEV) showed in the Figure 1 comprises of a hybrid electrical source which is a fuel cell as a primary source connected to a unidirectional converter to provide the permanent exchange power between the DC bus and the load demand. The I-ion-battery as a second power source is connected to a bidirectional converter which deals to replace the PEMFC power in various cases like:

a. When its state of charge is high
b. When the hydrogen quantity is insufficient

Otherwise, the SC is connected directly to a bidirectional converter which aimed to control the fast peak power during BT and SC slow dynamics. The connection between these three sources is ensured by an MW-EMS which makes it possible to serve the distribution power and the hydrogen reduction

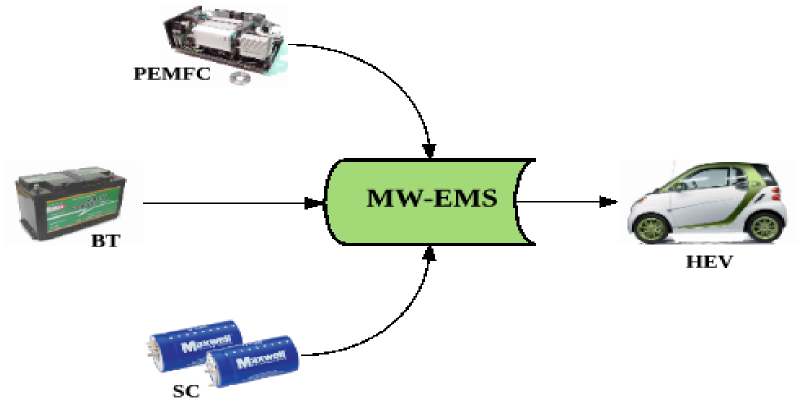

Figure 1 Overall FCHEV structure

4. PEMFC DYNAMIC MODELING

The proposed PEMFC is considered as being an electrochemical energy converter. Indeed, PEMFC is evaluated and discussed through a validated PEMFC stack model presented in [19] which characterized by a constant and an uncontrolled pressure channel. The main PEMFC voltage is presented as the function of the activation overvoltage, the ohmic overvoltage, the concentration overvoltage and the thermodynamic potential. Indeed, the PEMFC stack is composed of the same cells connected in series that operate at the same density current [20]. The total PEMFC voltage is given by the following Equations:

$$\begin{cases} V_{fc\_cell} = E_{Nernst} - V_{act\_cell} - V_{ohm\_cell} - V_{con\_cell} \\ V_{fc} = N_{fc}.V_{fc\_cell} \end{cases} \quad (1)$$

5. SC DYNAMIC MODELING

The SC has included as a storage unit for a short period. Indeed, the SC aims to control the BT and PEMFC slow dynamics respectively. In addition, SC has very high output power densities and high efficient than the battery [21], [22].The SC main voltage is defined by the following Equations:

$$\begin{cases} \dfrac{du_{cell}}{dt} = -\dfrac{1}{C_{cell}R_p}u_{cell} + \dfrac{1}{C_{cell}}i_{sc\_cell} \\ V_{sc\_cell} = u_{cell} + i_{sc\_cell}R_s \\ V_{sc} = N_{sc}.V_{sc\_cell} \\ SOC_{SC} = \dfrac{V_{SC}^2(t)}{V_{SC\_\max}^2(t)} \end{cases} \quad (2)$$

6. BT DYNAMIC MODELING

The BT dynamic model used in this work is treated through the electrical model scheme given in Figure 2. This latter characterized by the Ohmic resistance (**R_0**), the polarization (**R_S ,C_S**) and the concentration (**R_I,C_I**) [23], [24].

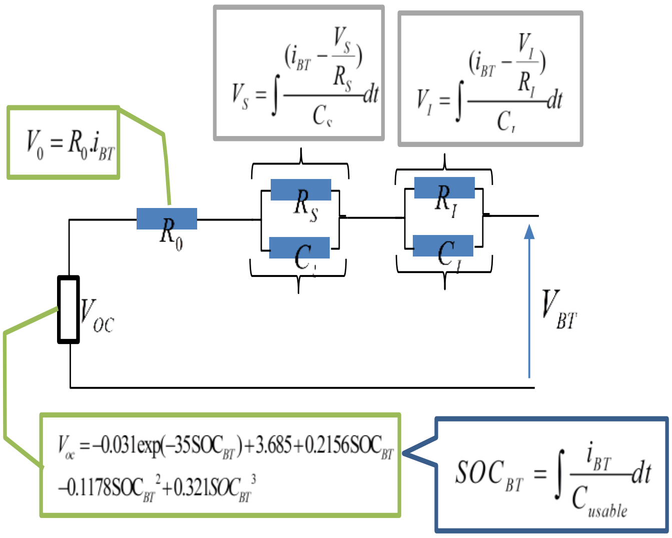

Figure 2. Equivalent circuit of BT model

7. MULTI-WAYS-EMS

This section discusses and evaluates the proposed SM-EMS. This latter deal to control and to supervise the hybrid vehicle system according to the experimental speed, the power demand and the BT and SC statement of charges respectively (Figure 4). Indeed, the MW-EMS is designed to cooperate with the system components and the electrical load based on various ways. These ways are evaluated and discussed in details as:

Way$_1$: When the PEMFC is switched off, the hybrid storage system can ensure the load demand. The BT is enabled to function as the primary source (regardless of the state of the SC) due to its capacity storage. But, the SC can control the fluctuation power.

Way$_2$: if (ϕ>0) The BT cannot satisfy the need demand power, since our approach based on the priority BT operation such as the discharge of the battery is still necessary to aim to reduce the consumption of hydrogen. In this way, the BT delivers its maximum power with a $SOC_{BT} \geq SOC_{BT}^{min}$ .The PEMFC activated in order to satisfy the remaining power needed by the traction vehicle.

Way$_3$: In this way, the state of charge of the two hybrid storage sources operates in the effective range. Therefore, the system must be respected these assumptions:

Respect the primarily to discharge the BT (Until SOC_{BT}^{min}).
Respect the primarily the charge the SC from DC bus (UntilSOC_{sc}^{max}).

Way$_4$: if $SOC_{sc} < SOC_{sc}^{min}$, $SOC_{BT} < SOC_{BT}^{min}$. The PEMFC activated in order to supply the required power needed by traction vehicle. In addition, the hybrid electrical storage sources deactivated. In this way, a deceleration phase in the future will allow the charge of the Hybrid electrical storage sources.

8. OVERALL EFFICIENCY

The proposed strategy for the calculation of the overall vehicle efficiency are based on the priority operation of the source that has the best efficiency, according the state of charge of the two-second sources. Indeed, the total energy efficiency of the hybrid vehicle can be calculated as the energy efficiency of the hybrid vehicle by the sum of energy efficiency of each source [24], [25].

$$\eta_{HEV} = \frac{\int_t P_{HEV} dt}{\int_t P_{FC} dt + \int_t P_{BT} dt + \int_t P_{SC} dt}$$

Where, P_{HEV} is the hybrid vehicle traction power, P_{FC} is the total output power of the PEMFC. Figure 3 shows the MW-EMS algorithm.

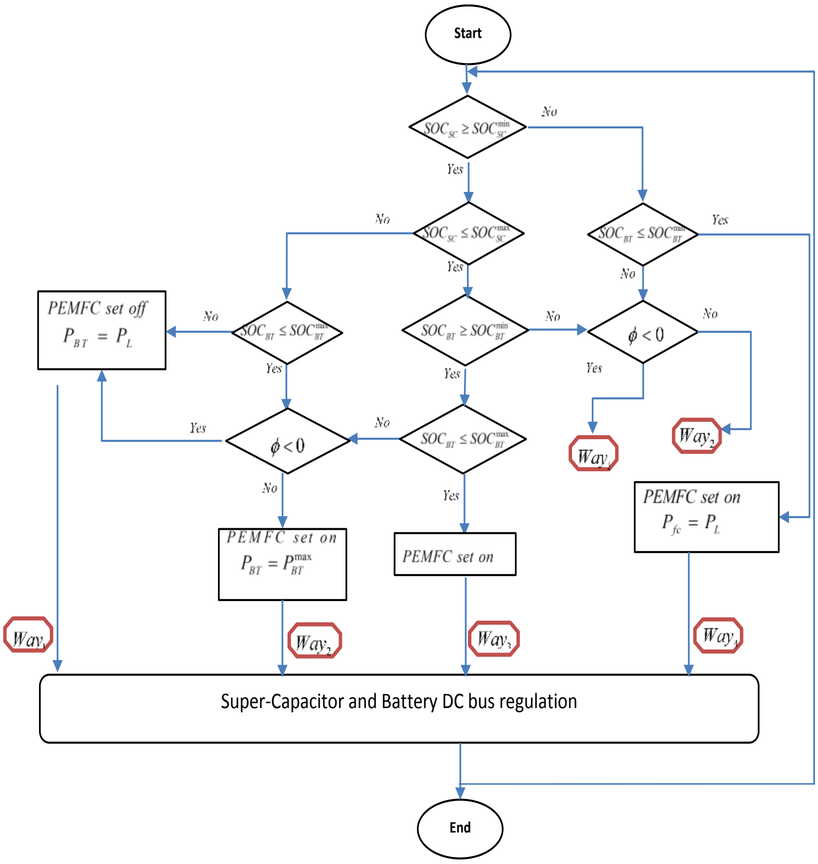

Figure 3. MW-EMS algorithm

9. Findings and Discussion

The MW-EMS proposal is used for more coordination between the system components. To study the MW-EMS performance, an accurate algorithm is developed and discussed using the Matlab environment. The vehicle model is evaluated and simulated for 200s by an ECE cycle drive. Therefore, the obtained simulation results focused on the evaluation of multi-ways states, which is based on the priority operation of the source. Each way acts to select the best efficiency, according to the state of charge of each source (**SOC_{BT} and SOC_{SC}**). These SOCs deals to test the MW-EMS efficiencies. Indeed, the MW-EMS is simulated and discussed through the below profiles, which are illustrated respectively in Figure 5, Figure 6, Figure 7 and Figure 8.

According to the obtained results in Figure 6 and Figure 7), the BT ensures the required energy as a primary source and operated with its maximum state of charge. According to the Fig.7 the SOC_{BT} initial value is greater or equal than **80%**, the system supply energy through the **way-$_1$**. During these ranges (**[15, 23s] [61, 85s] [143, 155s] [162, 175s]**): It is clearly shown that in this period the system operates according to the way-1 (Figure 6). The BT manages the permanent phase of delivering the required power (**$P_{BT} = P_L$**), the SC can satisfy the load demand in the transition phases. **From 32s to 152s** the BT delivers its maximum power and the SC control the required power ensured by the BT (Figure 6). According to this state, the system operates through the way-2. From**165s to 175s** the PEMFC switched off (**P_{FC}=0W**) and the hybrid storage sources **BT/SC** provides the required power together (Figure 6). According to this state, the system operates through the way-3. During these ranges [10, 22s] [50, 82s] [120, 158s], it can be seen that the average vehicle efficiency increases during the BT operation (Figure 8), this justifies that proposed management strategy is based on BT priority operation. Another advantage is attributed to the proposed management strategy for the recovery of all braking energy by the HESS. Moreover, the best response of the continuous bus voltage regulation obtained (**Vbus = 400V**). The synoptic diagram illustrated in Figure 9 describes the system behavior with regard to the activation and deactivation system component blocks. In addition, the parameters used to simulate this work is cited in the below Table 1.

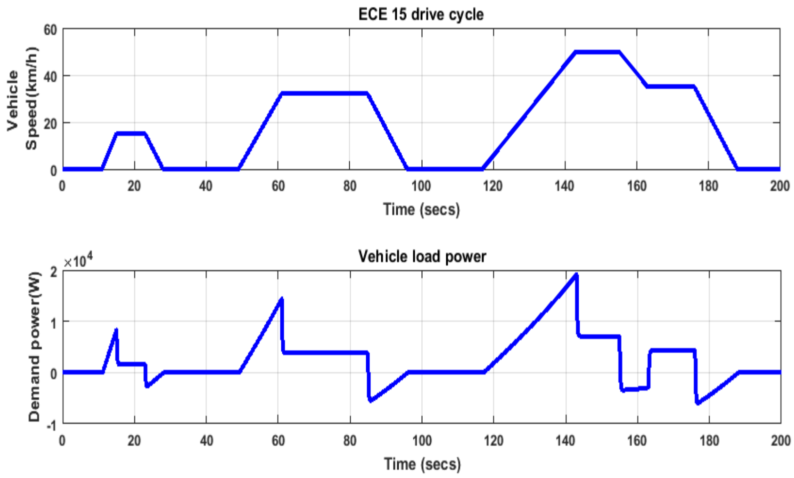

Figure 4: FCHEV: Speed and Power demand profile

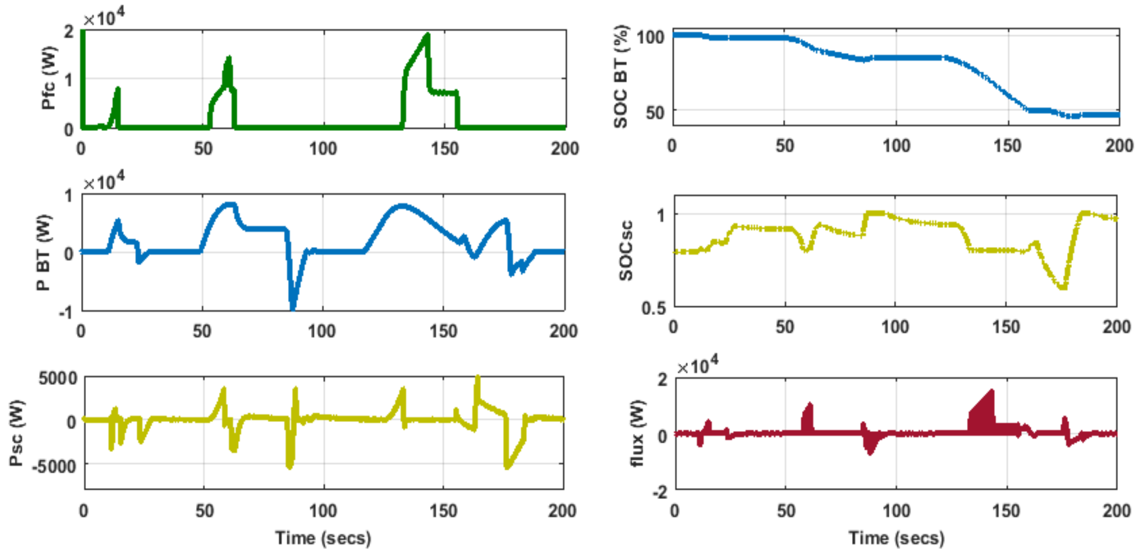

Figure 5. PEMFC/BT/SC power profile/ and SOC_{BT}/SOC_{SC}/ϕ profile

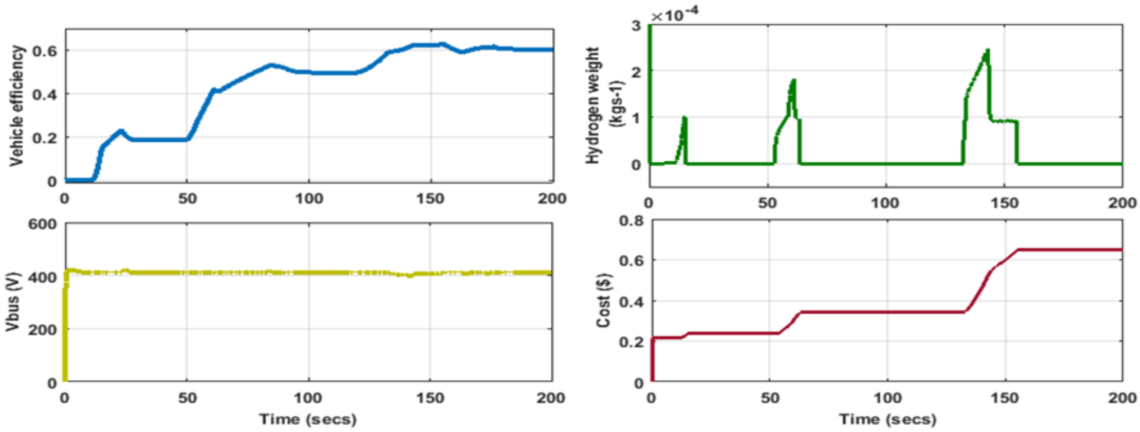

Figure 6. Overall efficiency / DC bus voltage profile and hydrogen weight / fuel cost

10. CONCLUSION

This study presented an MW-EMS that can be performed in FCHEV supervisory structure. This proposed MW-EMS determines the PEMFC, BT and SC power commands. In this study, the hybrid electric vehicle structure based on the fuel cell, the BT and the SC is designed for an urban electric vehicle. The PEMFC deeds as the main primary energy source of the vehicle, the BT and the SC are used as the monitoring system to complete the PEMFC power during vehicle permanent phases and acceleration. This hybrid storage source is also utilized for braking energy from DC bus. The SC is able to supply and can store the peak power because of its elevated specific power and elevated dynamic response. Hence, in order to ensure the supplied power during quick variation, and distribute the required power demands appropriately to power sources. A proposed MW-EMS based on the hybrid storage sources, state of charge allows a priority operating off the battery for aim to improve the system efficiency in the first side and to increase the PEMFC lifetime on the other side. The main results show that the fuel cell cannot treat with the all of the positive parties during high frequency of power demand. In this state, the SC has satisfied all of the quick power demand, which can keep the PEMFC against damage. The BT can absorb the slow variation of negative powers. Moreover, it helps the PEMFC during permanent phases. Thus, the proposed MW-EMS can guarantee a reliable operation with the liberate transient for the PEMFC and improve the lifetime of every power source.

NOMENCLATURE

V_{fc_cell} : The PEMFC cell voltage, V
E_{Nernst} : The open circuit voltage, V
V_{act} : The activation losses,V
V_{con} : The concentration losses,V
V_{ohmic} : The ohmic losses,V
V_{fc} : The PEMFC voltage, V
I_{fc} : The PEMFC current, A
N_{fc} : The PEMFC cells number in series
T_{fc} : The PEMFC temperature, Kelvin
SOC_{BT}^{max} : BT maximum state of charge, %
SOC_{SC}^{min} : SC minimum state of charge, %
SOC_{SC}^{max} : SC Maximum state of charge, %
P_{BT}^{max} : BT Maximum power, W
R_S : SC series resistance, Ω
R_P : SC parallel resistance, Ω
N_{sc} : SC cell number in series
SOC_{sc} : SC State Of Charge, %
SOC_{BT} : BT State Of Charge, %
P_L : Vehicle demand power, W
F_R : The rolling resistance forces, N
m : Vehicle mass, Kg
g : the gravitational acceleration, 9.81 m s^{-2}
F_0 : The road fiction coefficient, N.m.s/rd
F_A : The aerodynamic resistance, N
C_x : The aerodynamic resistance coefficient
S : The car frontal surface, m^2
V_{hev} : The vehicle velocity, Km/h
F_S : the resistance of mounted side, N
α : The road slope
L_{fc} : PEMFC converter inductance, H
C_{bus} : DC bus filtering capacity, F
L_{sc} : SC converter inductance, H
η_{HEV} : Overall vehicle efficiency, %
P_{FCC} : PEMFC command power, W
P_{SCC} : SC command power, W
P_{BTC} : BT command power, W
P_{fc} : The PEMFC power, W
P_{SC} : The SC power, W

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