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Experimental study of energy management of FC/SC hybrid system using the Passivity Based Control

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ABSTRACT

Nowadays, the energy management of the hybrid system is becoming an interesting and the challenging topic for several researchers. The wise choice of the energy management strategy allows not only the best distribution of power between different sources but also reduce system consumption, increase the lifetime of the used sources and ensure the energy demand that involve the autonomy of the electrical vehicle. In this paper, the control and the energy management using the passivity control is adopted to the multi-converters multisources system, in particularly, Fuel Cell/SuperCapacitor (FC/SC) hybrid system. In the proposed system, the FC represents the main source and the SC is used for the transient of power where they can absorb or supply powers peaks. The proposed system is validated by experimental results. The obtained results prove the efficacy and the feasibility of the proposed approach for a real electrical vehicle.

Introduction

The global average temperature of the planet has been rising since the beginning of the industrial era (1880–1899). The greenhouse gases created by the transport sector accelerate this phenomenon. In 50 years, the number of cars will be increased by 160% [1,2]. Cleaner means of transport must be proposed. By using hydrogen, Fuel Cell (FC) vehicles are a promising solution to reduce greenhouse gases. The FC converts the chemical hydrogen energy into electrical energy to supply an electric traction motor. With a full tank of H_2 (generally 5.5 kg of H_2 pressurized at 700 bar) [3]), a driver can expect to travel about 500 km, against 200 km for a regular battery electric (e.g. 2016 Nissan Leaf) car and 1000 km for a conventional thermal vehicle. Moreover, the hydrogen tank is filled up in a few minutes in station whereas a full regular charge of a battery electric vehicle lasts several hours (In France, 350 bars is the standard hydrogen pressure for FC car). However, FCVs have to face some issues.

FC systems offers a limited dynamics. Fast power transients can lead to a gas starvation, which can permanently damage the FC [4]. Furthermore, the energy flow of FC

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systems is unidirectional, which does not allow recovering braking energy [5]. Hybridization of FC with other Energy Storage System (ESS) devices can thus improve the vehicle performances [6]. A battery can be used as a secondary source to handle the power transients, to recover braking energy, to extend its lifetime and to reduce its cost. With their Mirai and Tucson car, Toyota and Hyundai have chosen this technology using Ni-Mh and Li-Poly battery packs, respectively [7]. Hybridization of a FC with SuperCapacitors (SC) as energy/power buffer represents another interesting solution. With its high specific power and power density, SCs can easily assist FC to meet the high power requirements [5,8]. Further, while a cycle life of *1000* can be expected for battery [9], SCs can last from *500,000* to *1,000,000* cycles [10]. With its *2002* FCX, Honda has first chosen this technology to supply addition power to its vehicle. The new *2014* FCX clarity use a FC/battery configuration. Indeed, in recent years, batteries made significant progress. In addition, batteries are well known to manufacturers, as they are used for their hybrid models (e.g. Toyota Prius). Henceforth, industrial applications are taking advantages of both battery and SC to assist FC vehicles.

Depending on technical and financial specifications, direct or indirect FC/SC/battery configurations are possible [11–13]. In this paper, an indirect FC/SC configuration is chosen (see Fig. 1). The secondary ESS is then the SC, which is lighter, more robust and has a higher power density than batteries. The use of two converters allows managing the sources according to a specific energy management strategy. This can be based on fuel consumption or source degradations arguments [13,14].

The control of FC vehicles using SC must take into account the constraints related to this association. First, these sub-systems are strongly coupled. Both sources are indeed connected through a DC bus. For example, the FC or the SC cannot independently meet the requested traction energy and power flows. For that, it is necessary to control and manage the interaction and the coupling between the both sources. Numerous studies have discussed on the control and energy management of FC/SC vehicles using PI controllers [15,16], flatness control [8] and fuzzy logic controllers [17]. However, most of these propositions have been evaluated only in simulation. Secondly, all of the vehicle

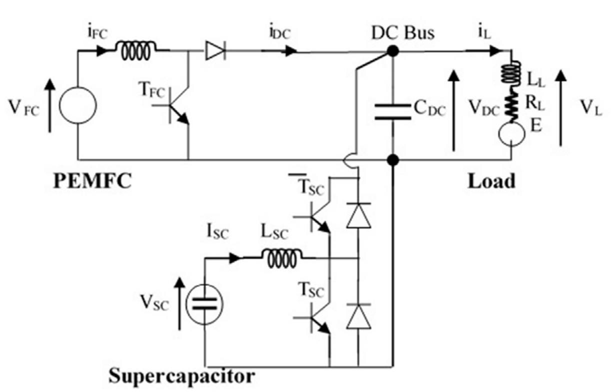

Fig. 1 – FC/SC system structure.

components have nonlinear behaviors [18,19]. These constraints affect the system stability. In this way, the previously mentioned works well managed the FC/SC system, but did not ensure the stability, especially where saturation occurs [15]. It is well established that nonlinear behaviors affect the system stability [18]. Instability can cause energy losses and potentially damage on the vehicle. To solve this issue, several authors have proposed to use energy-based Lyapunov control theory for the controller design [20–25]. In [26], the energy management is proposed for FC/SC system in order to minimize the hydrogen consumption and to limit the current fluctuation for FC. The considered energy management is based on Fuzzy logic controller and filter is used to increase the FC lifetime [26]. Furthermore, the genetic algorithm is used to solve the optimization problems for fuzzy energy management strategy [26]. The simulation results showed a good power distribution and the optimization goals were achieved. However, the stability Proof is not given, the results is limited on simulation and the considered energy management is complex. Another work on energy management proposed by [27] and is achieved as a two levels control structure. One is based on PI controller and is addressed to the inner control loop for FC/SC currents and DC bus voltage. The second level is based on Equivalent Consumption Minimization Strategy (ECMS) in order to regulate the FC power considering the minimization of the hydrogen consumption. The proposed strategies lack the stability proof and validation on real hybrid system [27]. The authors of [16] have proposed to study the hybrid system composed of FC and SC. The considered energy management strategy combines the optimal control and Marcov chain to predict the required power. Two constraints at extreme driving conditions are taken into account namely the high power and high speed. The obtained simulation results have shown that the importance to add the Marcov model in limitation of the problem of slow FC dynamic response and to maintain the SC state of charge. In [28], the authors have used the combination between PBC and Fuzzy logic strategies to control the FC/SC hybrid system. The PBC technic is used to control the power source however the Fuzzy logic method is employed to estimate the desired SC current according to its state of charge and hydrogen level. In [28], the seventh order state space model is studied and the proposed controller is validated using the simulation. The proposed energy management for FC/SC system in [29] is based on a frequency distribution technic. The authors have implemented the experimental data of FC and SOC of SC parameters to emulate the real behavior of the used sources. A dynamical management of the energy required between FC and SC is achieved while operating the sources at their best operating points. In other hand, the undesired phenomena that degrade the FC performance are avoided [29]. The authors of [30] have focused on IDA-PBC energy management strategy of FC/SC hybrid system. The overall studied model in [30] was of a third order. In this work, five scenarios have been proposed according to the SC SOC, hydrogen consumption and braking mode. The validation of the proposed control has been evaluated in Matlab/Simulink software. In [30,31], the studied control strategy for FC/SC hybrid system is based on IDA-PBC. The control design has the objective to