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Energy control strategies for the Fuel Cell Hybrid Power Source under unknown load profile

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ABSTRACT

Four new energy control strategies are proposed here for the Fuel Cell Hybrid Power Source (FCHPS) used in stationary and mobile FC application (such as the FC backup source for a smart-house and FC vehicle, respectively) based on the Load Following (LF) control and Maximum Efficiency Point Tracking (MEPT) control of the fueling rates. The LF control approach is used to design simple strategies of the Energy Management Unit (EMU) that will assure a charge-sustaining mode for the batteries stack of the Energy Storage System (ESS). If a fueling rate is controlled based on the LF strategy, then the other is controlled based on MEPT strategy in order to maximize the FC net power available. The advantages of the proposed EMU strategies during an unknown load cycle are comparatively shown.

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1. Introduction

In last decade the FC applications try to penetrate into the specific market and the FC issues are extensively revised in Refs. [1,2], as good references to start a FC system implementation. Nevertheless, the EMU (Energy Management Unit) strategies for energy management and optimization are still at an early stage for the FC applications [3,4]. Consequently, it is a challenge for the designers to develop an EMU strategy to optimize the operation of FC stack [2] and increase the lifetime of FCs and batteries [3], these being the main objectives in designing of a FCHPS (Fuel Cell Hybrid Power Source). Thus, several EMU strategies have been proposed based on the power flow balance to control the distribution of power between the two energy sources (FC and ESS (Energy Storage System)) and the load [5], but none based on the LF (Load Following) control that is proposed here to optimize the size of the ESS. An equivalent consumption minimization and a real time optimal EMU strategy based on the dynamic load strategy are presented in Refs. [6,7], but the FC stack doesn't operate close to the MEP. A MEPT (Maximum Efficiency Point Tracking) strategy is put forward here to increase the efficiency of the whole FCHPS. The power profile requested by the equivalent load will be split into three frequency components based on the wavelet or other filtering transformation [8,9], but this cannot be made in real-time, without increasing the control circuit complexity. The idea to use the low frequency power component as the control reference for the FC system (in order to protect it against sharp changes on real load cycles [8]) is very good, but here it will be used in a different manner, which is easier to be implemented.

All strategies mentioned above were tested under standard load cycles, but in general the real load profile is unknown. Thus, more input and state variables must be used in EMU strategy (with expense of increasing the EMU complexity), if the LF control proposed here is not used. For example, if both batteries and ultracapacitors stacks States-Of-Charge (SOC) are considered and the power profile of the load cycle is unknown, then the basic rules of the fuzzy logic control proposed in Refs. [10,11] will became too complex compared to the LF control proposed here. Note that other two EMU strategies based on fuzzy logic controller are proposed in Refs. [10,12] to include the dynamic restrictions of the power sources and regenerative braking power flow based on new input variables considered. The LF control proposed here is based only on the load power, so this has some advantages compared to these proposals. Thus, it is worth to mention the two main advantages obtained based on LF control put forward here: (1) the EMU strategy is very easy to be implemented and (2) the size of battery stack is minimized (because the battery SOC is maintained almost constant during a load cycle).

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A perturbation approach to minimize the hydrogen consumption in Polymer Electrolyte Membrane (PEM) FC systems was introduced in Ref. [2] and the main drawback of this technique (related to the fixed values of the algorithm parameters) is solved here based on the Extremum Seeking (ES) control scheme [13] used for the MEPT algorithm. The hydrogen consumption for a given load current will be used as a performance indicator [14] to compare the use of the ES control-based MEPT algorithm to other control techniques mentioned below.

It is worth mentioning that the energy efficiency of the whole FCHPS (including the power interfaces [15]) depends on HPS architecture and battery charging ratios [16]. So, the series HPS architecture is used here to exploit direct connection of the battery to the DC bus and other advantages shown in Refs. [11,17–19] based on the minimization of the equivalent fuel consumption [11], hysteresis band [17], state machine [18], or fuzzy logic control [19].

The main EMU objective is to efficiently sustain the load demand by controlling the FC power flow. Consequently, the maximum FC power must be higher than the maximum load demand. On the other hand, the control inputs for the LF and MEPT controllers from the fueling rates must be determined: the air flow rate (AirFr) and the fuel flow rate (FuelFr). The LF control based on the average (AV) power flows balance and MEPT control based on the ES control scheme are proposed here to reduce the battery stack at minimum and operate the FC stack efficiently. It will be shown that the hydrogen consumption under an unknown load cycle is reduced with 12% compared to the static feed-forward (sFF) control scheme proposed in Ref. [20].

To conclude, using two controllers and two FC input rates means that four topological combinations must to be tested here. The references for both controllers will be generated by a Single-Input Double-Output (SIDO) ES control scheme. To compare the results obtained, one of the reference will be generated by the Single-Input Single-Output (SISO) ES control scheme and the other will be generated by the sFF control scheme. All four configurations to fuel the FC stack are compared based on the fuel consumption efficiency, which is the fuel consumption per one kW of the FC net power delivered to the load.

This paper is organized as follows. Section 2 presents the FCHPS system and briefly explains the control loops of the EMU. The experimental work performed in this study is shown in Section 3, as follows: the four possible EMU configurations are detailed in Section 3.1 based on the power flow balance; all the models used in simulation are briefly shown in Section 3.2; the implementation of the EMU control loops is detailed in Section 3.3. The results obtained are discussed and compared to other EMU strategies in Section 4. Section 5 concludes the paper.

2. FCHPS system

In this paper, a new FC fueling control strategy based on LF and MEPT control loops is presented for the FCHPS system. It is clearly that PEMFC, due to their advantages compared to other FC technologies (such as reduced size and weight, ease of implementation and so on [1,21]), is the best candidate to be used in electric vehicles as a range extender [22]. Also, it is known that the use of the FC stack under dynamic loads, as in the case of FC backup source for a smart home, can destroy the FC stack. Consequently, the FCHPS system must include at least one energy storage device [21,23], which will improve the FCHPS system performance under sharp power profile obtained when high levels are requested on the DC bus [24].

Usually, the hybrid batteries/ultracapacitors ESS topology is used [25]. The batteries used in FCHPS have a higher specific energy than the ultracapacitors, and can sustain an extra power for a period [24,25]. Thus, the semi-active hybrid ESS topology based on bidirectional power convertor to the ultracapacitors stack is usually used due to the compromise of high performance obtained (the ultracapacitors stack SOC can have the maximum available range to dynamically compensate the power flow balance) at reduced cost (only a power converter is used) [15]. So, this semi-active hybrid ESS topology is chosen in this paper, too.

Fig. 1 shows the architecture of the FCHPS system which is composed of: (1) FC stack; (2) ESS (only the battery stack is shown in this Figure); (3) equivalent load; (4) boost converter; (5) ES controllers which form the SIDO ES control scheme; (6) LF control block; and (7) auxiliary services and control modules. For example, in mobile FC application (Fig. 1), the traction motor drives and the braking system are modeled by the equivalent load. If the FCHPS is used as a backup source for a smart home (grid connected), then the equivalent load will also have an unknown power profile. A sharp power profile will be set to test the FCHPS under all EMU strategies proposed.

The EMU is partially shown in Fig. 1 through the LF and MEPT control loops. If the switch is on the sFF position, then the FuelFr input is classically controlled based on the sFF control scheme [20].

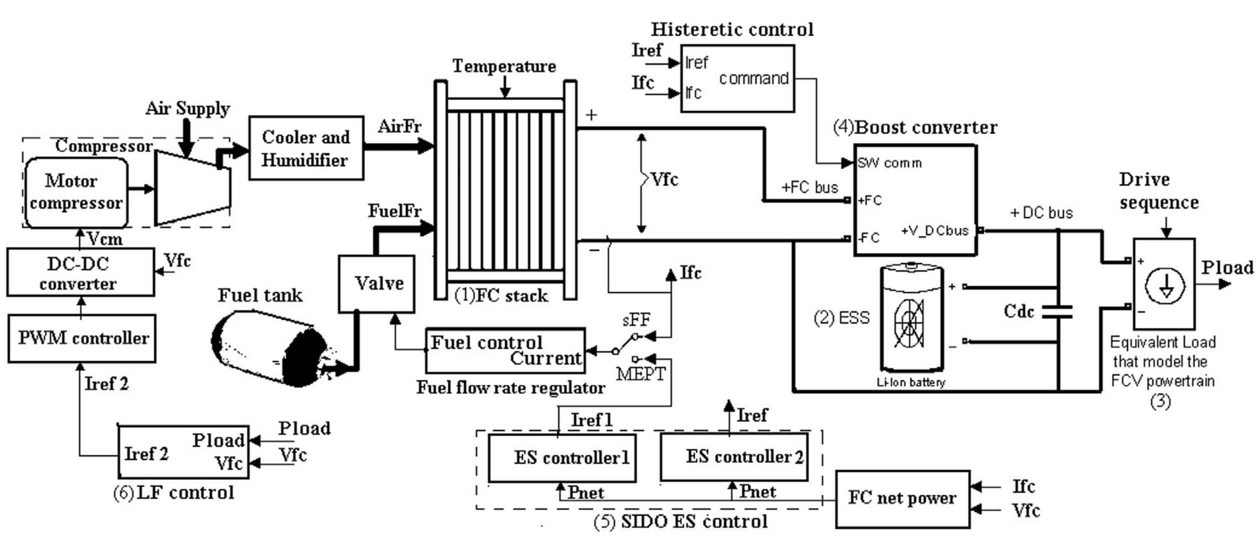

Fig. 1. The FCHPS system.

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