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Energy management of a hybrid system based on a fuel cell and a Lithium Ion battery: Experimental tests and integrated optimal design

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Abstract

The optimal design of multisource systems, hybrid systems in particular, requires an adequate choice of the energy management strategy. This latter usually impacts source sizing and lifetime. The present paper deals with an energy management approach based on a frequency sharing of the mission. Firstly, the limits of a symmetric frequency energy management are presented in the case of a hybrid system associating a fuel cell with a Li-Ion battery. Subsequently, an original energy "asymmetric" management strategy for the optimal sizing of this association is presented. This strategy is then tested on the "Hydrogen" platform at the LAPLACE research laboratory. Finally, the two energy management strategies are compared in the context of an integrated design by optimization; the asymmetric strategy offers significant gains in terms of system weight, which is important for embedded applications.

Keywords: Fuel cell; Battery; Lithium Ion; Energy management strategy; Optimal design

1. Introduction

Considering major energy challenges of this new century and in the context of fossil fuel depletion and greenhouse gas emissions, hydrogen is a promising solution for the storage of renewable energies and can be seen as "a potential energy vector for the future" [28]. Its transformation into electrical energy is ensured by a Fuel Cell (FC). Unlike storage components (batteries, ultra-capacitors, flywheels) where energy and power are closely linked in the same component, FCs offer energy/power decoupling. FC system can then be considered as an energy source (with a high specific energy range with respect to the batteries) whose autonomy is related to the hydrogen tank size. As a consequence, the delivered power only depends on FC stack sizing.

Therefore, fuel cells are utilized in a wide range of applications, particularly in transport or embedded systems [7,10] where weight and volume constraints are the key drivers, but also in stationary field [18] for which cost and efficiency are more concerned. In all these fields of application, the lifetime of such devices is also questioned and may

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Nomenclature

FC: Fuel Cell
BAT: Battery
SFEM: Symmetric Frequency Energy Management
AFEM: Asymmetric Frequency Energy Management
F_g: Cutoff frequency of the low pass filter (used for SFEM)
W_g: Cutoff pulsation of the low pass filter
$Fg1$: Cutoff frequency used during the positive current gradient phases.
$Fg2$: Cutoff frequency used during the negative current gradient phases.
I_BAT: Battery current
I_FC: Fuel cell current
I_load: Load current
Ich_BAT: Battery charge current
Ich_nom: Nominal battery charge current
SOC: Battery state of charge
I_HF: High frequency part of the load current
η_{act}: Fuel cell activation losses
η_{diff}: Fuel cell diffusion losses
R_{elec}: Fuel cell internal resistance (ohmic losses)
E_{rev}: Fuel cell reversible potential
N_{PBAT}: Number of battery blocks in parallel
N_{SBAT}: Number of battery cells in series
r_{BAT}: Battery resistance
e_{BAT}: Battery electromotive force
v_{BAT}: Battery cell voltage
q_{BAT}: Battery cell charge quantity
C: Battery nominal capacity
i_{BAT}: Battery cell current
$N_{b//\text{-}BAT}$: Number of interleaved battery converter branches
$F_{d\text{-}BAT}$: Battery converter switching frequency
$V_{stack\text{-}min}$: Fuel cell stack minimum voltage
$J_{FC\text{-}max}$: Fuel cell maximum current density
$F_{d\text{-}FC}$: Fuel cell stack converter switching frequency
$N_{b//\text{-}FC}$: Number of interleaved fuel cell stack converter branches
$P_{disch\_BAT\_max}$: Maximum discharge power that the battery can provide
$P_{disch\_profileBAT\_max}$: Maximum discharge power of the battery profile
$P_{ch\_BAT\_max}$: Maximum charge power authorized by the battery
$P_{ch\_profileBAT\_max}$: Maximum charge power of the battery profile
E_{tot}: Stored energy in the battery
E_u: Energy required to fulfill the battery profile
DOD_{max}: Maximum battery depth of discharge
N_{FC}: *Number of fuel cells in series*
F_1: System weight
F_2: Total losses energy

be greater than 10,000 h for constant operation. However, as soon as the electrical power draw becomes intermittent, the FC lifetime is significantly reduced. To overcome this difficulty, major applications rely on the hybridization of sources associating the FC with storage devices, while also defining an energy management strategy which optimizes power sharing between the FC and storage devices. In [6,23,14,12], authors have studied FC based hybrid structures with management strategies for electric vehicle applications; a double hybridization of FC source with ultra-capacitors