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Influence of secondary source technologies and energy management strategies on Energy Storage System sizing for fuel cell electric vehicles

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ABSTRACT

Fuel cell electric vehicles (FCEVs) have some limitation which make them less competitor to thermal ones and delay their commercialization. The most important problems as the range, the durability and the cost depend directly on the energy storage problematic issues. In this context, this work presents an optimal sizing methodology for an Energy Storage System (ESS) composed by a fuel cell and an assistant source to supply a lightweight vehicle with 700 km driving range. Firstly, a comparative study between single and hybrid source is carried out to show the benefits of hybridization according to the range in terms of weight, cost and fuel consumption. Moreover, in order to improve the hybrid source characteristics, three technologies of the secondary source are tested and evaluated to be chosen for hybridization with fuel cell system purposes. Furthermore, the influence of three Energy Management Strategies (EMSs) on ESS sizing is studied where an optimal strategy provides the most favorable dimensions of the hybrid system. Simulation results give us the best technology needed for hybridization and allow us adopting the optimal management strategy to design the hybrid source. Finally, in order to show the influence of the driving cycles on the ESS design, a comparison study using the New European Driving Cycle "NEDC" and the Assessment and Reliability of Transport Emission Models Inventory Systems (ARTEMIS) confirms that there is a slow influence of the driving cycle on the ESS sizes.

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Introduction

Electric vehicles have some limitations concerning several factors as cost, range and charging time. These barriers depend directly on the Energy Storage System which can be composed by several components as batteries, fuel cells and super-capacitors. Recently, Fuel Cell Electric Vehicles (FCEVs) have attracted many research centers as a promised alternative form of conventional transportation [1–4]. Nevertheless, further applications of FCEVs possess some research challenges as drive range, Energy Storage System (ESS) aging and H_2 storage [5–7]. Moreover, the ESS cost is a major drawback because Fuel Cell (FC) costs approximately between 280 and 800 dollars/kW and 40 dollars/cell for batteries [8,9]. The lifetime of vehicular fuel cells is evaluated only to 3900 h in 2015 according to the US Department Of Energy (DOE) report [10]. For this reason, there is a need for minimizing source's cost, applied stresses and fuel consumption through ESS design process. Consequently, the hybridization of FC system with batteries or supercapacitors seems an adequate solution to take into account the automotive requirements.

Recently, several research papers focus on sizing of FC based hybrid sources with different objectives [11]. In Ref. [8], a Pontryagin's Minimum Principle (PMP)-based sizing-design methodology for the development of a hybrid fuel cell power system. The simulation results confirm the approach optimality but it has some limitation such as tacking into account the hydrogen tank weight and the whole system aging problem. Otherwise, the authors in [12] propose in future study to consider the FC characteristics as temperature, loading ratio and the relevant efficiency, etc. A Range Extender architecture used for a city bus is presented in [13], where the design of a hybrid source achieves an optimal synergy. Also, they do not consider the auxiliaries of FC and efficiency map which can greatly affect the results. A new hydrogen fuel-cell-based range extender system is presented in [14], when the range is extended but without any consideration of ESS added weight and hydrogen tank weight which make the research incomplete at this time. Generally, few literature related research has focused on single objectives as fuel economy, cost minimization or only extending battery lifetime, but has largely neglected addressing the challenge of improving the whole system lifetime and fuel consumption, simultaneously. In this context, several questions are asked as which technology using to assist the FC system?, which management strategy is using to optimize the ESS design? etc.

In this context, this paper aims addressing the interest to response to these questions by an ESS optimal sizing for a FCEV application with 700 km drive range. Firstly, in the objective to show benefits of hybridization according to the range in terms of weight, cost and fuel consumption, a comparative study is carried out between single (FC only, battery only) and hybrid source. Then, three different technologies of battery (High Power HP and Ultra High Power UHP) and supercapacitors are tested to reveal the optimal choice regarding several criteria as hydrogen consumption, ESS weight, cost and ESS volume. Furthermore, the influence of three Energy Management Strategies (EMSs) on ESS sizing is studied by using optimal strategy which provides the most favorable dimensions of the hybrid system with improved H2 consumption and ESS lifespan. This study gives us the best technology needed for hybridization and allows us adopting the optimal management strategy to design the hybrid source. Finally, in the objective to show the influence of the driving cycles on the ESS design, a comparison study using the New European Driving Cycle “NEDC” and the Assessment and Reliability of Transport Emission Models Inventory Systems (ARTEMIS) shows that there is a slight influence of the driving cycle on the ESS sizes.

Technical specifications

As presented in Fig. 1, the electric vehicle structure is composed by an ESS connected to a DC/AC inverter which drives an electric motor. This later drives the vehicle wheels via a transmission device. In the objective to design the ESS, this section is devoted to define the technical specification in terms of vehicle parameters, mission and ESS characteristics.

Vehicle dynamic model

The profiles of both power and energy of the electric vehicle are needed for the sizing process. These profiles can be obtained via the vehicle dynamic simulation and the mission driving cycle. A dynamic model of the vehicle is used at ESTACALAB under Matlab-Simulink software [15]. The parameters of the Bollore vehicle are shown in Table 1.

The vehicle dynamics are modeled as a mass that can move forward and a set of propulsion and resistance forces acting on it [16]. This model is developed taking into account the road and velocity profiles, which includes aerodynamic resistance, rolling resistance, gravitational resistance by the slope in the road and acceleration force [17–19]. Different forces acting upon the vehicle can be described by the following expressions:

$$\begin{cases} F_{aero} = 0.5\rho\, S\, C_x\, V_{veh}^2 \\ F_{roll} = M\, g\left(C_0 + C_1\, V_{veh}^2\right) \\ F_{gx} = M\, g\, \sin\alpha \\ F_{acc} = M\dfrac{dV_{veh}}{dt} \end{cases} \tag{1}$$

where: F_{aero} is the aerodynamic drag force, F_{roll} is the rolling resistance force, F_{gx} is the gravitational force, F_{acc} is the

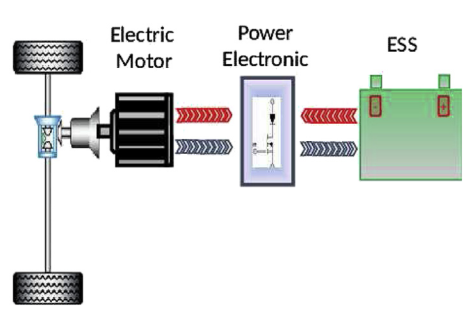

Fig. 1 – Electric vehicle structure.

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