Improving fuel economy and performance of a fuel-cell hybrid electric vehicle (fuel-cell, battery, and ultra-capacitor) using optimized energy management strategy

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A B S T R A C T

Fuel-Cell System (FCS) is the primary energy supply of a Fuel-Cell Vehicle (FCV). Battery or Ultra-Capacitor (UC), as a secondary power source, is used along the FCS to improve the FCV's power response. Battery and UC composition, as a hybrid power source presenting the term of Fuel-Cell Hybrid Electric Vehicle (FCHEV), provides the FCV with the advantages of high energy density and high dynamic response. The supervisory system of the FCHEV could be managed efficiently to exploit the benefits of battery and UC at the same time. As a matter of fact, in such a combination, the performance of the hybrid powertrain largely depends on how to distribute the requested power through different types of energy sources.

In this paper, we design the powertrain elements of an FCHEV in advance, with FCS/Battery/UC considerations. The energy management strategy (EMS) is achieved by presenting a novel power sharing method and by implementing an intelligent control technique constructed based on Fuzzy Logic Control (FLC). The control parameters are accurately adjusted by the genetic algorithm (GA) while considering targets and restrictions within a multi-objective optimization function over a combined city/highway driving cycle. This optimized supervisory system is examined by Advanced Vehicle Simulator (ADVISOR) to evaluate the performance of the proposed EMS over 22 different driving cycles and some specific performance tests. The results of simulation show that the presented strategy progressively affects the vehicle characteristics. Fuel economy enhancement, vehicle performance improvement, battery charge-sustaining capability, and optimal energy distribution are some of the significant outcomes achieved by the optimized FLC-based EMS.

1. Introduction

Fuel-Cell Vehicle (FCV) is known as an electric vehicle equipped with FCS [1]. Integrating FCS with battery or UC is a well-known method to mitigate FCS limitations. Battery/UC composition as a hybrid power source which presents the term of Fuel-Cell Hybrid Electric Vehicle (FCHEV), provides the FCV with the advantages of high energy density and high dynamic response. In such a combination, designing an optimal energy management strategy (EMS) plays a vital role in the success of the FCHEV supervisory system [2,3].

There are various EMSs designed and optimized for the hybrid supervisory system [3–7]. Linear programming and PID controller [8–10], state flow algorithms and multiple operation mode control [11–15], dynamic programming techniques [16–18], fuzzy logic control (FLC) [14,19–21], convex programming [22], model predictive control [23,24], and optimal control theory [25,26] are some of the applied strategies. To have an optimal EMS, we need both of control methods and optimization techniques. The EMS deals with hybrid power sources to meet commanded power whereas optimization procedure tries to have a more efficient power balance. In other words, considering powertrain condition, the requested power should be distributed by the EMS while achieving the best fuel economy and vehicle performance [14].

In the FCHEV configuration, the battery is a well-known secondary power source. In the recent studies, Ettihir et al. [26] proposed two adaptive EMSs to be used in the FCS/Battery supervisory system: hysteresis and optimal power splitting. The first strategy tried to keep the battery charge level around its reference value while the second one uses the FCS current as a control variable to distribute power between FCS and battery pack. These strategies were compared based on consumed hydrogen energy and battery energy in a sample cycle. In Ref. [27] three operation modes, including traction/braking/stopping, were presented with an FCS/Battery hybrid vehicle. Ensuring the feasibility of FCV power production, their proposed EMS limited the battery load...
while the battery charge occurred under traction and braking modes.

UC is another type of power source used in the hybrid configuration mainly due to its high power density [4]. UC plays a vital role in providing instantaneous power, particularly in acceleration and regenerative braking. In fact, its power density, durability, and efficiency in charge/discharge cycles give more advantages in comparison with battery and FCS [28,29]. In the recent studies, Sami et al. [10] presented an EMS based on two main modes for an FCV integrated with UC. Based on their experimental results, UC can meet load requirements in a complex, and correspondingly it needs an advanced EMS. In Ref. [30], the author presented an operation mode control for a typical FCHEV. Battery and UC charging and discharging modes occurred with a simple coordination between UC and UC battery [28,29]. In the current studies to distribute the power demand to the FCS/Battery/UC hybrid tramway, a multi-mode strategy has been proposed by the authors in Ref. [31] and Ref. [32]. Odeim et al. in Ref. [33] presented an algorithm evaluated in a drive cycle to control the FCS/Battery/UC hybrid vehicle. On the other hand, considering the vehicle’s main targets, an optimization method should be employed to ensure the optimality of the proposed strategy during an indexed drive cycle. Having an optimized EMS, authors in Ref. [34] and Ref. [35] employed Multi-objective optimization method to minimize the defined cost functions while considering fuel economy and system durability. Moreover, in Ref. [35], GA was employed by the authors to find the best values for FCHEV control parameters, which led to improvement in the battery lifetime.
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