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A review on energy management system for fuel cell hybrid electric vehicle: Issues and challenges

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ABSTRACT

Emerging issues on fuel price and greenhouse gas emissions have attracted attention on the alternative energy sources, especially in transportation sector. The transportation sector accounts for 40% of total fuel consumption. Thus, an increasing number of studies have been conducted on hybrid electric vehicles (HEVs) and their energy management system (EMS). This paper focuses on reviews of EMSs for fuel cell (FC) based HEV in combination with battery and super-capacitor, respectively. Various aspects and classifications of fuel cell–HEV EMS are explained in this paper. Different types of FC–HEV control models and algorithms derived from simulation and experiment are explained in details for an analytical justification for the most optimal control strategy. The performances of the various combinations of FC–HEV system are summarized in the table along with relevant references. This paper provides comprehensive survey of FC–HEV on their source combination, models, energy management system (EMS) etc. developed by various researchers. From the rigorous review, it is observed that the existing technologies more or less are capable to perform well; however, the reliability and the intelligent systems are still not up to the mark. Accordingly, current issues and challenges on the FC–HEV technologies are highlighted with a brief suggestions and discussion for the progress of future FC–HEV vehicle research. This review will hopefully lead to increasing efforts towards the development of economic, longer lifetime, hydrogen viable, efficient electronic interface and well performed EMS for future FC–HEV.

Contents

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1. Introduction

Hybrid electric vehicles (HEVs) have become a phenomenon since the Toyota Prius and Honda Insight were introduced to the automotive industry in 1997 and 1999 [1], respectively. An electric motor power rating of 33 kW was achieved by the first-generation Prius, with the third generation having a 60 kW power rating as compared with the 10 kW power rating of Insight [2]. Honda hybrids only use one electric motor and one inverter, whereas Toyota hybrids embed two electric motors and two inverters with split power. The configuration of Honda is simple but has limitations in power flow and system optimization. Meanwhile, the Toyota design is more complex because power can be fed to the motor by the battery alone, gasoline alone, or a combination of both battery and gasoline [3]. Such design provides continuously variable transmission and a larger room for electric motors because clutches are not used [1]. However, more than 25% of complaints are made against the Prius [4].

The idea of HEV started way back in early 1900s when the electric vehicle failed to succeed in the market due to costly battery technology and limited driving range. Differences between electric vehicles and hybrid electric vehicles may appear rather small. However, the difference in terms of impact of each vehicle and their controls are massively huge. An electric vehicle (EV) operates on electric drives; consisting of batteries, electric motors and electric generators, such as Honda EV Plus, GM EV1, and Toyota RAV4 EV. On the other hand, a HEV operates using one electric motor and an internal combustion engine (ICE) due to its energy source consisting of battery and fuel, respectively [5]. The HEV reduces fossil fuel consumption due to its operation of running on battery during low power demand and runs on fuel only during acceleration or high load power. Among HEV models that made its way into mass production are Honda Insight, Toyota Prius, and recently Honda Civic Hybrid. However, issues of pollution, global warming, and drastic rise of fuel price, have forced automotive manufacturers to introduce fuel cell vehicles.

Fuel cells have been attracting considerable attention for their zero emission of greenhouse gases. Furthermore, the energy from a fuel cell is drawn from the chemical reaction of hydrogen and oxygen from air, which is an abundant resource. Fuel cells directly transform chemical energy into electrical energy through an electrochemical process [6]. A fuel cell comprises two electrodes immersed in electrolytes and sandwiched together. Seven types of fuel cells are available in the market: proton exchange membrane fuel cell (PEMFC), direct methanol fuel cell, alkaline fuel cell, phosphoric acid fuel cell, molten carbonate fuel cell, solid oxide fuel cell, and microbial fuel cell [7]. These types of fuel cells are either used commercially or in research. Selecting the appropriate fuel cell is essential because of the different operating temperatures and power levels produced. Cost and efficiency are important considerations in selecting the best fuel cell.

Hydrogen can be supplied by methanol and propane from the reformation of hydrocarbon and biological processes. This gas can also be drawn from the electrolysis process by using an electrolyzer, which breaks the chemical bond in water into hydrogen and oxygen and then collects hydrogen in a gas tank [8]. Implementing renewable energy resources, such as fuel cells, can give rise to such concerns as efficiency, cost, and limitations. Efficiency depends on system configuration, design, and component selection. Moreover, the cost of a system strongly relies on its efficiency [9]. Other limitations, such as the relation of vehicle speed with the power required to achieve a certain speed also need to be considered. Thus, the idea of a hybrid fuel cell electric vehicle emerged.

HEVs have more than one power source [10], which serves an important function in determining which power source should be activated or drawn [11]. An energy management system (EMS) controls the energy source to feed the electric motor. In other words, the developed system serves as the power splitter of the energy between the main source and auxiliary sources [12]. This study considers fuel cell as the main source, with the battery and supercapacitor (SC) as the auxiliary sources of HEVs. A battery is an electrochemical device that consists of electrodes separated by electrolyte to convert chemical energy into electrical energy. Several types of batteries are available in the market. These types include lead acid, lithium ion (Li-ion), nickel metal hydride (NiMH), alkaline nickel cadmium, and so on. Among them, NiMH and Li-ion are the most commonly used in electric vehicles [7].

SC is an electrochemical capacitor used to provide peak power for short durations. The electrical characteristic of SC is similar to that of capacitors and consists of either electrical double-layer capacitors made of non-porous materials, such as activated carbon [13], or pseudo-capacitors containing transition metal oxides, nitrides, and polymers possessing relatively high surface areas. The power electronic interface is the interconnection or integration between the energy source and the motor and usually consists of power converters. Power converters can be a plain inverter or DC–DC converter (also known as chopper) with an inverter [10].

However, the main concerns on EMSs are how efficient the used strategy or control method. Apart from that, EMS in FC–HEVs faces some issues or challenges in its development and application. This paper analyzes and discusses the previous methods of EMS for FC–HEV in order to suggest the most efficient EMS for FC–HEV. The issues and challenges of developing FC–HEV are also discussed to provide knowledge and information to the community as a whole. This is important for research involving future development of new EMS or improvement of previous EMS for FC–HEV.

2. FC–HEV classifications

The FC–HEV are reviewed in terms of multiple sources of energy that have to be managed accordingly to ensure that the energy fed to the electric motor is sufficient as per the demand or load power. This is because under certain conditions, energy could be drawn from the battery or from the fuel cell or from both energy sources. In other instances, the energy is drawn from both the fuel cell and battery, and at certain points, the battery and SC are charged [14]. The FC–HEV operating conditions can be related to energy required or motor operation, such as starting, cruising, accelerating, and braking [15]. However, this study thoroughly reviews the EMS for current or previous fuel cell HEVs and then summarizes and proposes recommendations for future research or improvement.

A fuel cell vehicle fed with fuel cell alone, usually PEMFC, appears to have constraints, such as slow dynamic properties [16]. Furthermore, the membrane electrode assembly of the PEMFC is open to failures, such as membrane breaks, internal gas leakage, and cell flooding/drying [17]. Moreover, PEMFCs have slow dynamic response with respect to load changes, which shortens the service life of the fuel cell [18]. Performance, reliability, durability, cost, fuel availability, public satisfaction, and performance during transients [19] are essential factors in developing fuel cell electric vehicles that can compete with the ICE vehicles that are monopolizing the streets. Thus, automotive manufacturers started to produce fuel cell HEVs. Toyota has produced Toyota FCHV, whereas Honda produced Honda FCX-V4 and FCX Clarity [20]. Meanwhile, Hyundai has also produced its own fuel cell vehicle, that is, TUCSON FCEV, which embeds a fuel cell and battery [21]. General Motors, on the other hand, released its Chevrolet Equinox Fuel Cell Vehicle which feeds on hydrogen and battery in 2008 [22,23]. Daimler released its F-CELL B-CLASS in 2005 where else Volkswagen released its Passat Lingyu FCEV in 2008 [24]. These FCEV of fuel cell and battery hybrid face the limitations in battery lifetime though, of which is the reason supercapacitors are now being considered by many automotive manufacturers [7].