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A direct borohydride–peroxide fuel cell–LiPO battery hybrid motorcycle prototype – II

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ABSTRACT

In this study, a direct borohydride–peroxide fuel cell (DBPFC)–LiPo battery hybrid motorcycle, called HYBROTO, was developed. The hybrid system was designed using a 10-cell DBPFC stack with 120 W of maximum power as the main power source, a 12 LiPo battery pack with 6300 mAh and 65 C for energy storage and as auxiliary power source, and a brushless DC (BLDC) motor. In addition, a voltage-monitoring integrated circuit for fuel cells, a battery management unit, and a motor control circuit were developed to command the DBPFC, LiPo battery, and BLDC motor, respectively. The hybrid system was managed and synchronized by a main control unit (MCU) containing a synchronous bidirectional buck–boost converter and a boost converter. For performance tests, the DBPFC–battery system and BLDC motor were installed in an electric motorcycle body. Performance tests were carried out in the hybrid system under a constant load of 60 W. The hybrid system showed a satisfactory performance under the constant load with an efficiency of 67%. However, the MCU requires further improvement to provide more stable power output. The motorcycle prototype was tested at the 2016 International Symposium on Sustainable Aviation organized by the Sustainable Aviation Research Society.

Introduction

Li-ion batteries are important components of electric vehicles as energy storage units. They are attractive for automotive applications given their high energy density and efficiency. Recently, fuel cell (FC)-based electric vehicles are gaining attention given their lower fuel consumption and emissions compared to more conventional types of electric vehicles. FCs are considered as suitable alternatives for future transportation applications, and prototypes of FC-powered vehicles are being developed by automobile companies worldwide [1]. In hybrid electric vehicles, FCs and batteries present both benefits and drawbacks. However, if FCs and batteries are used together along with a proper power management strategy, they can balance the shortcomings of each other. For instance, FC systems increase the driving distance by providing the necessary power and deliver the peak power to speed the battery start time, whereas batteries can store regenerative breaking energy. In addition, an FC can reduce the costs associated to vehicles operated with battery, which is their main disadvantage, and increase both the power transfer performance and energy efficiency [2–4].

FC–battery hybrid systems consist of an FC as power supply and a battery for energy storage and to power the electronic control units. The voltage levels and dynamics of the units in the hybrid system are different. Therefore, an optimization is required to improve the performance of the

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units by using a power management system (PMS). By controlling the energy conversion in the hybrid system, researchers expect to achieve maximum fuel economy and high driving performance [5]. In fact, Hwang et al. reached a 30% increase in conversion efficiency by using an FC system instead of an internal combustion system [6].

Although PEM Fuel cells (proton exchange membrane fuel cell) have been widely considered as power sources for mobile applications, they have some disadvantages due to the hydrogen limitations. Liquid fuels with higher energy densities have been used instead of hydrogen to overcome its limitation. Hydrogen carrying liquid fuels such as alcohols (methanol, ethanol, ethylene glycol, diethyl ether and propanol) and metal hydrides have been considered as direct fuels for fuel cells. Comparing the other liquids, the borohydride has taken a lot of attention because of its unique features of chemical stability, high energy density, easy storage and distribution, non-toxic oxidation products and recyclability [7,8]. Recently direct borohydride-peroxide fuel cells are being investigated as an advanced technology of space mission [9,10]. They have high energy density (DBFC: 1000 Wh kg^{-1}, 2850 Wh l^{-1}, PEMFC: 690 Wh kg^{-1}, 2070 Wh l^{-1}) and provide compact fuel cell systems. Therefore, they offer higher cell voltage and current than those of the PEM fuel cells.

Integration of the DBPFC into the hybrid system is a complex issue. A balance of Plant (BoP) including microprocessor and electronics such as sensors and pumps must be a significant part of the stack system. The DBPFC with minimum size and little maintains is expected to operate more efficiently at low temperatures. Furthermore, they are being considered to provide high power for automobile applications. The DPFCs, however, don't generate enough voltage and power to fast starting up and needs the power electronics system especially as a DC/DC converter. The DBPFCs rely on a complex controlling system and stack management like the other liquid fuel cell types such as DMFCs [11]. Designing the BoP system for the DBPFC is a new topic and little information is addressed. A DC/DC converter was designed by Hwang et al. for a 20 W DBFC with air cathode. An analysis approach and control scheme were proposed for its improved speed and stability [12].

In the present study, we aimed to adopt an approximately 120 W DBPFC stack system into an electrical motorbike as an energy source along with a LiPO battery and to execute the hybrid performance. The stack system used in the hybrid system was described in our previous article (A Direct Borohydride–Peroxide Fuel Cell–LiPO Battery Hybrid Motorcycle Prototype I). Powertrain structures are described according to hybridization rate and have influences on vehicle performances [13]. We designed “power hybrid structure” based on the voltage control method to be able to meet the power requirements when it increases suddenly. The DBPFC voltage was boosted to the bus by ignoring its polarization curve. A LiPO battery was charged and discharged by a bi-directional DC/DC converter.

Some of the FC-Battery hybrid systems addressed in the literature were summarized in terms of their electronic controls. Differences of control equipments between a liquid phase and a gas phase fuel cells were compared below because of its importance for our study.

FC–battery hybrid system

In a hybrid system, besides the differences between FCs and batteries, the energy flow and losses from the power converters, storage systems, and controllers should be considered. To minimize losses and improve efficiency, the power control units and management systems are essential given that they regulate the energy flow between the FC and the battery. Thus, these units can extend the autonomy of electric vehicles [14,15].

In addition, several elements of a hybrid system should be considered. Power electronics devices play important roles in controlling, transferring, and converting the energy that flows through the system. They can be considered as the core of the PMS, which is directly related to the overall efficiency in a hybrid system.

The DC–DC converter is one of the most important components in an FC-powered system and influences the hybrid stack performance. In general, FCs generate a low voltage, even if combined in series into a stack. The energy flow in FCs must then pass through a high-power unidirectional DC–DC converter. This converter both converts the direct borohydride–peroxide FC (DBPFC) voltage to a constant DC-bus voltage and regulates the output voltage fluctuation. Therefore, the converter provides reliable, robust, and efficient automotive applications [16,17].

Recently, bidirectional DC–DC converters have gained importance in the development of battery systems for the automotive industry. Hence, battery management configurations now require unidirectional and bidirectional DC–DC converters. Buck–boost bidirectional converters are adopted for high-power electric vehicle applications. This type of converters manages the power flow between the high-voltage (HV)/low-voltage (LV) energy sources and the motor. The buck part is placed on the HV side to charge the LV battery [18]. An increase in the number of converters and electronic devices is usually required to deliver the DC power demand. However, instead of using more converters, the bidirectional DC–DC converters can interconnect the system, supply higher flexibility, stability, and efficiency, and reduce the system size and weight [19,20].

In a hybrid system, the power required by the motor is divided according to the energy source through a process known as hybridization. The hybridization level highly depends on the energy management strategy (EMS). The EMS should offer low cost and high efficiency while employing current manufacturing methods. A high control level of the hybrid components can be achieved by more intelligent control algorithms. Different EMSs have been reported for the polymer electrolyte membrane (PEM) FC–battery hybrid systems such as rule-based strategies and optimization approaches [21–23]. From literature surveys, fuzzy logic control is the most commonly used method for FC–battery hybrid applications. This control approach results in the optimal load sharing based on the battery state of charge (SOC) and load demand [14].

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