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Test of hybrid power system for electrical vehicles using a lithium-ion battery pack and a reformed methanol fuel cell range extender

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ARTICLE INFO

Article history:
Received 12 April 2013
Received in revised form
12 November 2013
Accepted 18 November 2013
Available online 17 December 2013

Keywords:
PEM fuel cell
PBI
Range extender
Electrical vehicle
Methanol reformer

ABSTRACT

This work presents the proof-of-concept of an electric traction power system with a high temperature polymer electrolyte membrane fuel cell range extender, usable for automotive class electrical vehicles. The hybrid system concept examined, consists of a power system where the primary power is delivered by a lithium ion battery pack. In order to increase the run time of the application connected to this battery pack, a high temperature PEM (HTPEM) fuel cell stack acts as an on-board charger able to charge a vehicle during operation as a series hybrid. Because of the high tolerance to carbon monoxide, the HTPEM fuel cell system can efficiently use a liquid methanol/water mixture of 60%/40% by volume, as fuel instead of compressed hydrogen, enabling potentially a higher volumetric energy density.

In order to test the performance of such a system, the experimental validation conducted uses a down-sized version of the battery pack used in the Mitsubishi iMiEV, which is subjected to power cycles derived from simulations of the vehicle undergoing multiple New European Drive Cycles (NEDC).

1. Introduction

Powering automotive vehicles using electric energy enables the use of different types of hybrid electrical configurations for increasing the fuel efficiency and reducing emissions. Pure battery electric vehicles show good well-to-wheel efficiencies, but are still suffering from short driving ranges and long charging times. Fuel cell range extenders are one way of improving the driving range of electric vehicles using series or parallel hybrid configurations, where a fuel cell system efficiently charges the vehicle battery pack. Depending on the desired performance of the vehicle, the power provided by the battery system and fuel cell can be balanced. This work examines a system with a battery pack delivering the primary power, and a fuel cell charger that offers a smaller constant charge on the battery pack during driving and while stationary.

Different fuel cell system design topologies exist, the main differences result from the fuel used and the fuel cell technology. High temperature PEM fuel cells offer the possibility of

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http://dx.doi.org/10.1016/j.ijhydene.2013.11.068

using liquid fuels such as methanol, due to the high operating temperatures (160–180 °C). The typical polymer used in HTPEM fuel cells is polybenzimidazole (PBI), doped with phosphoric acid to increase proton conduction [1–3]. Previous studies have shown promising results using various non-hydrogen fuels together with HTPEM fuel cells [4–6], and [7,8] mentions the increased simplicity, robustness and reliability of the Balance-of-Plant of HTPEM system versus LTPEM systems. The methanol is converted to a hydrogen rich gas with CO_2 and traces of CO, and the increased operating temperatures allow these fuel cells to tolerate much higher CO concentrations than Nafion-based fuel cells. The increased tolerance to CO also enables the use of reformer systems with less hydrogen cleaning steps and requirements for hydrogen purity, reducing the complexity of the reformer systems. Using hydrogen containing CO, affects the steady-state as well as dynamic electrical performance of the fuel cell, but stable operation is still possible with concentrations up to 3% using PBI-based fuel cells [1,9,10]. Using liquid fuels such as methanol removes the high volume demands of compressed hydrogen storages, simplifies refueling, and enables the use of existing fuel distribution systems. Studies have show the possibilities and advantages of using methanol reformer systems together with HTPEM fuel cells [11–16] and the possibilities of using methanol and other synthetic fuels as energy carriers [17–20]. This work demonstrates the use of a methanol fuelled fuel cell range extender in an electric vehicle.

2. Experimental setup

The Mitsubishi iMiEV is taken as an example of a commercially available small city car. The authors did not have the vehicle available for experimental characterization of power consumption versus drive pattern instead it was calculated using a mathematical drive cycle simulation program [21]. The New European Drive Cycle (NEDC) was used as input for these simulations. The details of the drive cycle simulations, the battery pack, and the fuel cell system are given in subsequent sections.

The system tested in this work includes an HTPEM fuel cell stack. The fuel for the stack is supplied by methanol steam reforming, and a DC/DC converter controls the fuel cell stack charging of the lithium-ion battery pack. In order to ensure safe operation this battery pack is monitored by a Battery Management System (BMS). A diagram of the test system is shown in Fig. 1.

The control and data acquisition of the fuel cell and reformer system is handled by an EtherCAT (Ethernet for control automation technology) from Beckhoff. An EK1100 coupler was connected with a number of I/O terminals for measuring and actuating all sensors and BoP components. The EK1100 was connected to a PC running TwinCat and Labview. The control and data acquisition systems were programmed in a Labview virtual interface (VI). The battery management system logs the data of each battery cell every 1000 ms. The emulation of the drive cycle on the vehicle is handled by a National Instruments USB-6215 and a Labview VI, that produces analog reference signals to the Amrel PLW25K-600-600 water cooled electronic load. The electronic load is only able to sink current, which means that regenerative breaking is disregarded in these experiments and conclusions.

2.1. *Drive cycle emulation*

In order to test the concept of using the proposed HTPEM fuel cell system topology, as a range extender in an electrical automotive applications, the Mitsubishi iMiEV is chosen as a case study. The main parameters used in the simulations can be found in Table 1.

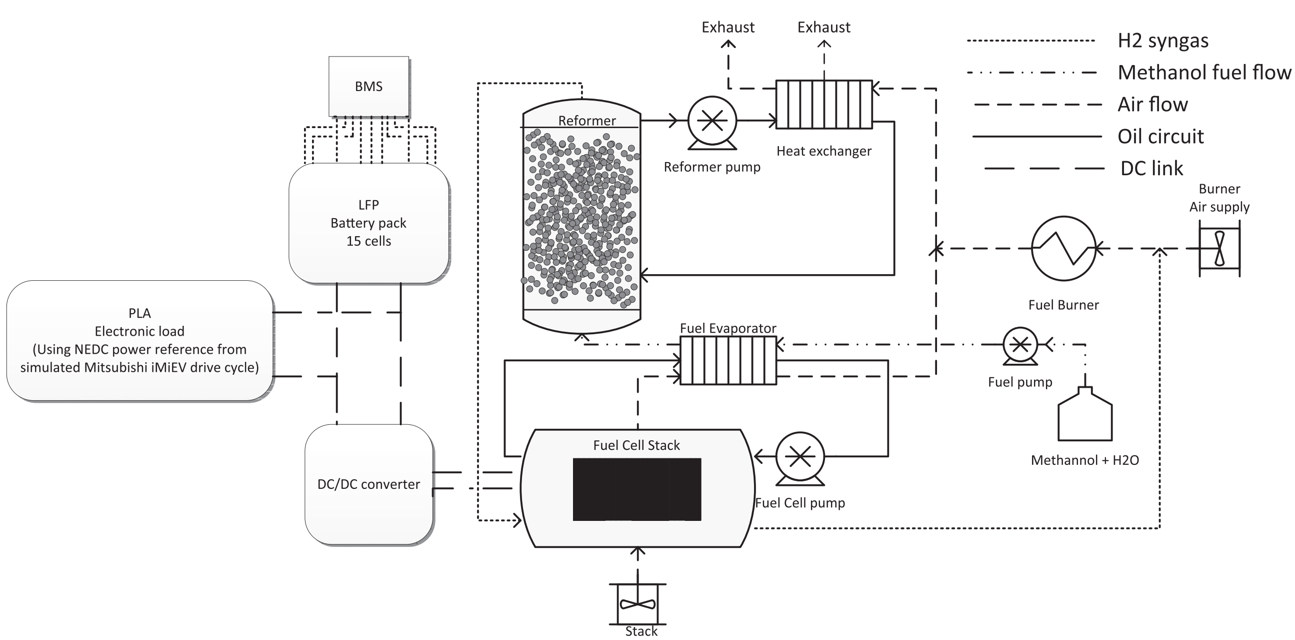

Fig. 1 – Schematic of the system setup including the primary components and connections.