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Electric power system for a Chinese fuel cell city bus

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Abstract

A state-of-the-art Chinese fuel cell city bus, using a hybrid power system is proposed. This comprises a proton exchange membrane fuel cell and Ni/MH batteries to combine the high energy density of fuel cells with the high power density of batteries. A dc/dc converter is placed between the fuel cell and the battery to control the electric power flow. This paper presents a novel control strategy for efficiency of the fuel cell operation and optimization of the hybrid power system for the bus. The control strategy is able to regulate the output current of the fuel cell and the charging current or voltage for the battery while limiting the discharge current of the battery. It can achieve a higher efficiency, longer fuel cell lifetime, and higher drive performance. The hybrid fuel cell power system and the proposed control strategy were verified by using dynamometer and road test experiments. The experimental results demonstrated that the control strategy has great flexibility and generality, and also validated that the peak power capacity of the active hybrid power source and the vehicle drive performance can be significantly enhanced.

Keywords: Electric vehicle; Fuel cell; Hybrid power system

1. Introduction

There are two types of power system configuration in a fuel cell vehicle, a direct one and a hybrid one. The direct fuel cell drivetrain system is used in the Citaro fuel cell bus made by DaimlerChrysler, and more than 30 of these fuel cell buses have been demonstrated in the CUTE project and the CaFC project [1,2]. Due to the higher price and lower durability of a fuel cell system, there is a trend to use the hybrid power system. The hybrid mode is similar to that used in the ICE/battery hybrid electric vehicle, but using the fuel cell system to replace the internal combustion engine (ICE). This kind fuel cell vehicle includes a fuel cell unit and a secondary battery unit. The other reasons for applying a hybrid configuration includes the ease of using the same platform for regeneration of the brake energy.

For the hybrid electric vehicle, including the fuel cell hybrid vehicle, there are different power system configurations and thus different control strategies. The proper power control strategy will result in extending the fuel cell lifetime, increasing of energy efficiency, and an improvement in the vehicle performance.

Some control strategies has been published by other researchers for different kinds of power system components and the corresponding power system configurations. Ohkawa used a voltage and current control unit to control the power from the fuel cell system in a fuel cell hybrid vehicle while employing the electric double-layer capacitor as the back up power source [3]. Jeanneret and Markel developed an adaptive control strategy to adjust the power ratio between the fuel cell and battery in fuel cell/battery hybrid vehicle [4]. But both of these control strategies do not include the optimization of fuel cell operation. Jiang et al. proposed a multi-objective control method to regulate the current output of the fuel cell and the charging/discharging current or voltage of the battery. They used a bi-directional dc/dc converter to complete this control strategy [5]. Yokoyama et al. increased the efficiency through the power distribution algorithm according to the efficiency characteristics of the fuel cell and battery. The improvement in power efficiency was about 66% better than that of the base diesel engine power bus [6].

For a hybrid fuel cell vehicle power system, besides power system configuration, three other important aspects must been considered, they are the power system efficiency, the vehicle drive performance and the fuel cell lifetime. With the present technology, the fuel cell lifetime is about 4000 h with stable operating conditions, but under the variable operating conditions,

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such as in the vehicle operating environment, fuel cell lifetime is reduced to about 2000 h. The shortened fuel cell lifetime is partly due to the unstable fuel cell operation mode. Besides increasing the power system efficiency, peak output power, acceleration response, the perfect control system or algorithm should include some strategy to decrease the in-stability for the fuel cell to increase the fuel cell lifetime.

This paper proposes a new control strategy for the fuel cell hybrid city bus with an enhancement in the reliability.

The organization of the rest of the paper is described as follows. In Section 2, the components, the configuration of hybrid fuel cell power system and parameter of fuel cell city bus are described according to state-of-the-art in China. In Section 3, the proposed power system and control algorithm are analyzed and its corresponding control algorithm is presented. In Section 4, the dynamometer and road test results are obtained and the performance of first Chinese fuel cell city bus is also presented.

2. Configuration of hybrid fuel cell power system

2.1. Chinese fuel cell city bus

The first Chinese fuel cell city bus was developed in 2004 by Tsinghua University and partners. It is a hybrid vehicle combined the fuel cell as main power and a battery as the auxiliary power unit. The major parameters are shown in Table 1.

2.2. The main components of power system

The main components of the power system include a fuel cell unit, a battery unit and the motor drive unit.

2.2.1. Fuel cell unit

The fuel cell unit uses a PEM stack which is mostly used to drive the vehicle, and a high pressure system is employed [7]. Fig. 1 is its *V–I* curve, which shows that the output voltage lower limit is 262 V and the open circuit voltage is 350 V. The maximum stack current is 405 A. The maximum output power is 100 kW. As shown in Fig. 2, the fuel cell stack has a relatively normal response to the load variation. The power response time from about 10% load (11.3 kW) to near 70% load (67 kW) is about 3 s.

The fuel cell stack has a higher efficiency compared with a conventional internal combustion engine. As Fig. 3 shows,

Table 1
Specifications of the Chinese fuel cell city bus

Parameters	Value
Empty loaded mass (kg)	11600
Fully loaded mass (kg)	15000
Main reducing gear ratio	1:6.83
First shift ratio	1:3.002
Second shift ratio	1:1.862
Wheel radius (m)	0.502
Wind faced area (m^2)	7.5
Windage coefficient	0.7
Rolling resistance coefficient	0.018

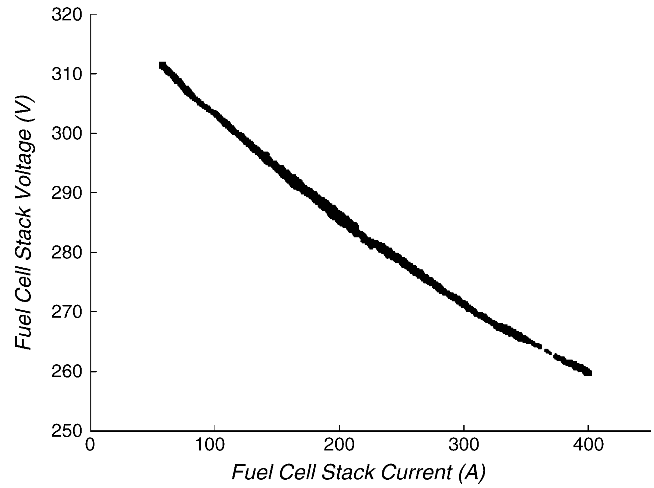

Fig. 1. The fuel cell *V–I* curve.

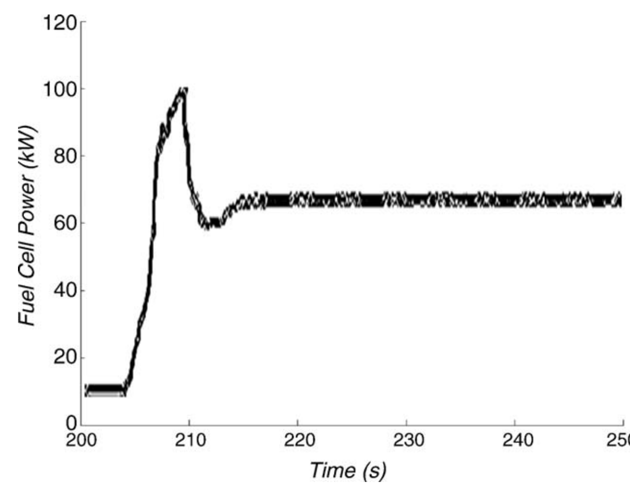

Fig. 2. Fuel cell power response.

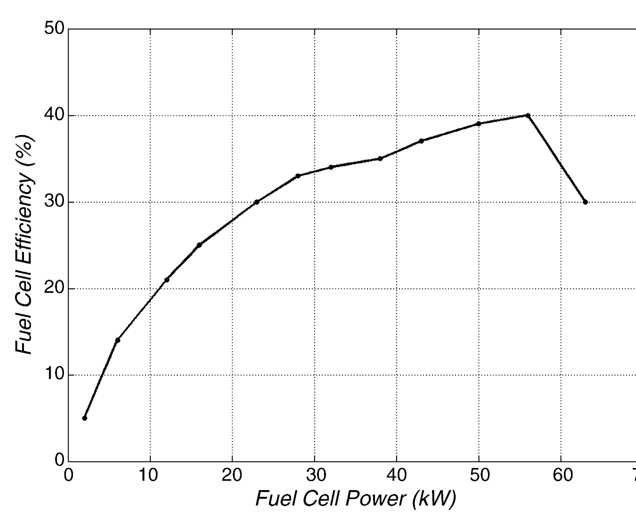

Fig. 3. Fuel cell efficiency curve.