INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 38 (2013) 5845–5856

Available online at www.sciencedirect.com

SciVerse ScienceDirect

journal homepage: www.elsevier.com/locate/he

Control design and power management of a stationary PEMFC hybrid power system

Fu-Cheng Wang*, Po-Chen Kuo, Hsueh-Ju Chen

Department of Mechanical Engineering, National Taiwan University, No. 1, Roosevelt Road, Sec. 4, Taipei 10617, Taiwan

ARTICLE INFO

Article history:
Received 2 January 2013
Received in revised form
28 February 2013
Accepted 5 March 2013
Available online 1 April 2013

Keywords:
PEMFC
System identification
Robust control
Power management
Uninterruptible power supply

ABSTRACT

This paper develops robust control and power management strategies for a 6 kW stationary proton exchange membrane fuel cell (PEMFC) hybrid power system. The system consists of two 3 kW PEMFC modules, a Li–Fe battery set, and electrical components to form a parallel hybrid power system that is designed to supply uninterruptible power to telecom base stations during power outages. The study comprises three parts: PEMFC control, power management, and system integration. First, we apply robust control to regulate the hydrogen flow rates of the PEMFC modules in order to improve system stability, performance, and efficiency. Second, we design a parallel power train that consists of two PEMFC modules and one Li–Fe battery set for the uninterruptible power supply (UPS) requirement. Lastly, we integrate the system for experimental verification. Based on the results, the proposed robust control and power management are deemed effective at improving the stability, performance, and efficiency of the stationary power system.

1. Introduction

The proton exchange membrane fuel cell (PEMFC) has drawn much research attention as an alternative energy source because of its advantageous properties, such as low operating temperature, high efficiency, and low pollution. Some studies have proposed dynamic models for PEMFC systems; for example, Gorgun [1] described a PEMFC as a dynamic model that included water phenomena, electro-osmotic drag and diffusion, and voltage ancillary. Bao et al. [2] developed a nonlinear PEMFC model and further linearized it for linear control design. Hou et al. [3] proposed a semi-empirical dynamic model for stack voltage on based on experimental investigations. Many researchers have expanded on these dynamic models to apply control methods to improve systems performance. For instance, Woo and Benziger [4] designed a proportional-integral-derivative (PID) controller that regulated the hydrogen flow rate for optimal performance. Vega-Leal et al. [5] developed a multivariable system that controlled the air and hydrogen flow rates to optimize net power. Panos et al. [6] considered the physical constraints and developed an explicit multi-parametric model predictive controller that would control the cell temperature and voltage. Park et al. [7] proposed a sliding mode control that could maintain the pressures of hydrogen and oxygen at the desired values regardless of current changes. Wang et al. [8–13] considered system nonlinearities and variations of PEMFC and applied robust control that regulated the oxygen and hydrogen flow rates to provide steady voltage and to reduce hydrogen consumption.

Stationary power is one of the main PEMFC applications, and includes backup power, auxiliary power units, and the uninterruptible power supply (UPS) [14]. Choi et al. [15] designed a 1 kW fuel cell powered line-interactive UPS system, and verified the possibility of replacing conventional UPS power sources with fuel cells. Corbo et al. [16] analyzed

* *Corresponding author*. Tel.: +886 2 33662680; fax: +886 2 23631755.
E-mail address: fcw@ntu.edu.tw (F.-C. Wang).

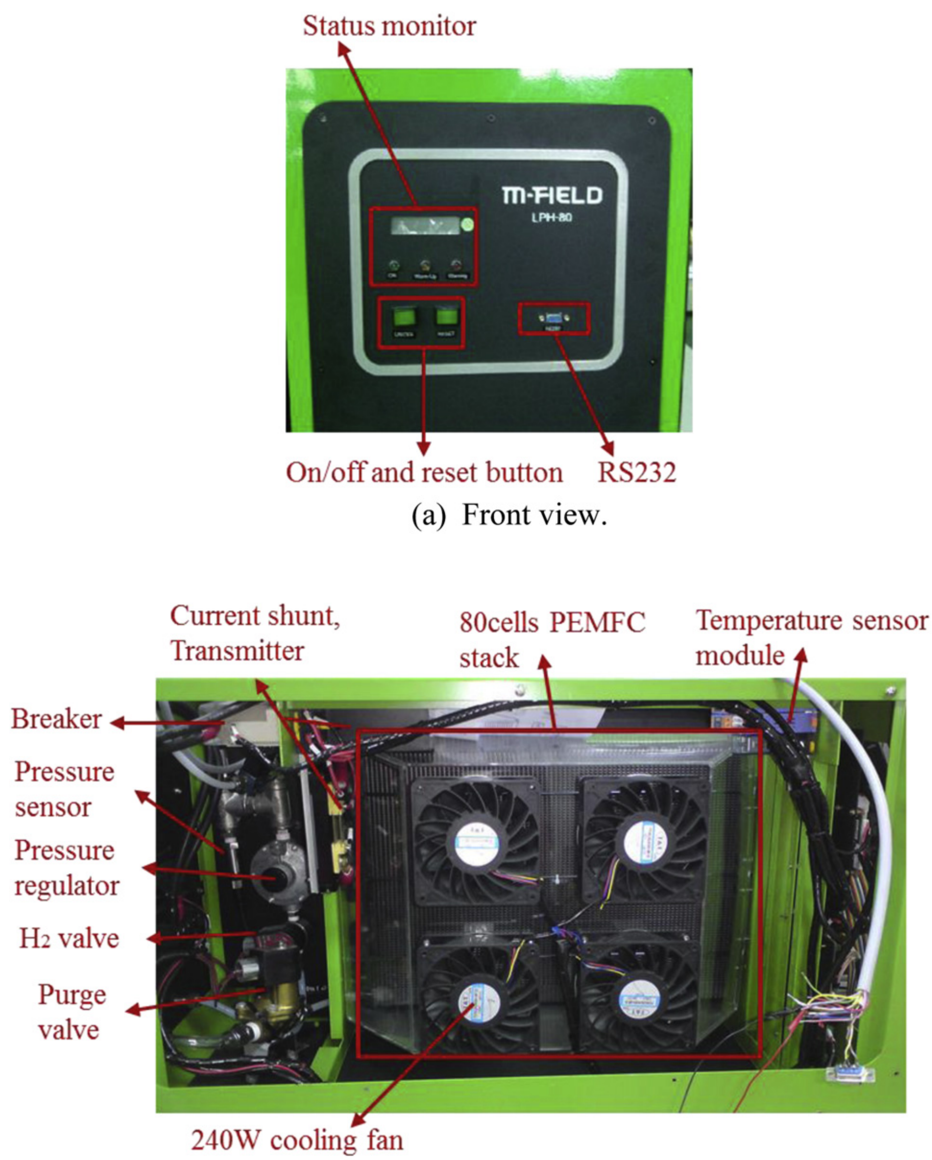
http://dx.doi.org/10.1016/j.ijhydene.2013.03.021

the application of a 20 kW PEMFC stack to both stationary power and automotive systems. Zhan et al. [17] developed a hybrid intelligent UPS system that comprises a PEMFC and a battery. Tao et al. [18] proposed a line-interactive fuel cell powered UPS system that consisted of a three-port bidirectional converter, a fuel cell, a super-capacitor, and a grid-interfacing inverter. This paper discusses the application of a 6 kW PEMFC hybrid power system for the UPS for telecom base stations, where unexpected power failure might result in serious business disruption, data loss, and machine breakdown. Compared to the traditional UPS that uses combustion engines, a battery-based UPS can improve system performance and is environmentally friendly. However, the operating time is limited because of the battery capacities. Therefore, in this study, we combine the merits of PEMFC and battery-based UPS by integrating a PEMFC hybrid power system for sustainable UPS.

Table 1 – Stack specifications of an M-Field™ 3 kW PEMFC [18].

Number of cells	80
Maximum power	DC 3.2 kW (at DC75 A)
Input voltage	24 VDC
Output voltage	42–80 VDC
Size	80 × 46 × 40 cm^3
Weight	40 kg
Fuel inlet temperature	−15→55 °C
Fuel inlet pressure	136 kpa (0.36 bar)
Air inlet temperature	10–50 °C

This paper is organized as follows: Section 2 discusses the dynamics of a 3 kW PEMFC modules. Section 3 applies H_∞ robust control to regulate the hydrogen flow rate of the PEMFC to improve system performance. Section 4 designs a parallel



(a) Front view.

(b) Side view.

Fig. 1 – The M-Field 3 kW PEMFC module.