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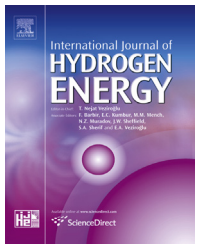

Natural degradation and stimulated recovery of a proton exchange membrane fuel cell

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ABSTRACT

In this paper, the stimulated recovery of a proton exchange membrane (PEM) fuel cells after natural degradation has been investigated. The performance degradation of a 63-cell PEM fuel cell stack over a storage interval of 40,000 h at temperature 24 °C and relative humidity 65% was analyzed by static and dynamical tests. The average cell voltage degradation rate was 309 μV h^{-1}, averaged over a range of currents. The performance was then partially recovered by application of a high frequency pulsing procedure after which the effective average degradation rate (from the commencement of storage to after the recovery) was approximately 170 μV h^{-1}. This indicates the existence of both recoverable and irrecoverable degradations in the fuel cell. Furthermore, the equivalent circuit model and membrane resistance were used to investigate the degradation mechanisms, suggesting that the natural degradation of the fuel cell is mainly caused by the increase of the resistance, which is most likely caused by membrane dehydration.

Introduction

There are two major incentives to developing the use of hydrogen in different types of fuel cells. One is that hydrogen can be made from diverse domestic resources and from renewable energy via electrolysis, and the other is that the hydrogen can be employed to generate electric power with zero or low emissions across a broad range of systems, including stationary power systems, but especially in vehicles and in backup and portable power systems. Among all the kinds of fuel cells, the proton exchange membrane (PEM) fuel cells are the most promising. They are environmentally friendly and have many advantages over conventional energy-conversion devices, including higher efficiency and higher power density. Significant progress in PEM fuel cells has been made over the past few decades, especially in improvement of the power density and the effective material utilization. However, the commercialization of this technology has been limited due to some technical challenges, including the fuel cell system itself, as well as problems of on-board storage and the need for an infrastructure for hydrogen fuel. According to the US Department of Energy (DOE), the lifetime targets of PEM fuel cell in 2015 for transportation applications are 5000 h for cars, 20,000 h for buses, and 40,000 h for stationary systems, and the voltage degradation rate per cell should be 2–10 μV h^{-1} [1]. At present, the fuel cell lifetimes in vehicles and stationary systems are only around 1700 h and 10,000 h, respectively, with degradation rate of

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15–30 μV h^{-1} [2]. Some reviews on the lifetime of fuel cells indicate that the governing factors include the design and assembly of the fuel cell, material degradation, impurities and the operating conditions (in particular temperature, relative humidity, pressure, feed starvation, load change, start-up and shut-down cycling, potential cycling, freezing or thawing). Further research is needed to understand and ameliorate the degradation of PEM fuel cells in order to achieve commercial viability [3].

Studies on storage-induced degradation and methods to stimulated recovery of the components for the PEM fuel cells from such degradation have not been reported. However, many scholars have done a lot of research on the degradation of the fuel cells in other cases. Because the PEM fuel cells are complex electrochemical devices, which contain many components such as catalysts, catalyst supports, gas diffusion layers (GDLs), membranes, bipolar plates, seals and gaskets. Each of these components can degrade or fail due to various causes dependent on the storage and operating conditions, the presence of contaminants, etc. According to reviews on PEMFC degradation, component degradation causes include: the platinum catalyst degradation of Pt agglomeration and particle growth [4–7]; Pt elemental loss [8]; Pt migration [9,10]; Pt catalyst contamination [11]; catalyst support degradation [12–15]; membrane degradation due to chemical causes [16–19] and mechanical causes [20–26]; porous transport layer degradation due to mechanical and thermal physics causes [27–30] and due to chemical and electrochemical causes [31–35]; degradation of graphite composite bipolar plates [36–39] and metal bipolar plates [40]; and degradation of other components such as seals, endplates, and bus plates [41–43].

Long-term durability tests are often required to evaluate the degradation mechanisms. However, it is generally impractical and too costly to operate a fuel cell under its normal conditions for several thousand hours, and hence accelerated stress tests (ASTs) and durability test protocols are often applied [44,45].

In this study, the natural degradation, not via an AST, has been observed on a 63-cell 300 W PEM fuel cell stack, purchased on 15 February 2008. After some experiments were conducted from 15 February 2008 to 3 March 2008, the stack had been stored until 17 September 2012, hence for approximately 40,000 h, in the Fuel Cell Lab at the University of Technology Sydney (UTS), Australia. Static and dynamic performance tests have been conducted. To attempt to recover the performance of the stack 40,000 h previously, a stimulated recovery procedure was conducted using high frequency pulse technology and intelligent control methods on the stack. The stack potential curve was measured continuously during the procedure, and the relationships between the stack potential and other parameters, such as current, load change, recovery time and degradation rate are reported below.

Experimental study

Experimental setup

The experimental setup is composed of an improved uninterrupted power supply (UPS) system with stimulated recovery system (SRS), the PEM fuel cell (PEMFC) generating and test system, supercapacitors (SCs), deep cycle lead-acid batteries and a data acquisition system. The UPS system with backup PEMFC and battery/SC provides the AC power source and connects with the linear loads (e.g. a lamp box) and nonlinear loads (e.g. a personal computer PC). The SRS system contains a DC/DC converter with a modulation frequency changing from 1 kHz to 100 kHz and DC/AC inverter with AC output voltage frequency from 10 Hz to 100 Hz. In the PEMFC generating and test system, the mass flow controllers (type: F-201C-GAS-22V and F-112AC-GAS-22V, Bronkhorst) are used to regulate the hydrogen and air. Because the PEMFC stack is self-humidified, the option to humidify the hydrogen is not used in the generating system. The hydrotransmitter (type: HD2008TV1, Delta OHM) and the pressure transmitter (type: AUS EX 1354X, Burkert) between the inlets of the cathode and anode are applied to measure the temperature and humidity of air and hydrogen at the inlet. The data acquisition system includes the analog voltage output devices NI6713, multifunction I/O devices NI6036E, analog multiplexer with temperature sensor AMUX-64T and parallel digital I/O interface PCI-6503. All physical parameters such as the currents and voltages of the SRS, PEMFC stack and battery/SC, relative temperatures of hydrogen and air, pressure drop in the flow fields, and gas mass flow of the reactants are recorded with the data acquisition system [46].

Fig. 1 illustrates schematically the structure of a single-phase high-frequency SRS system, a backup PEMFC and battery power sources. Fig. 2 shows a photo of the experimental setup and storage place of the PEMFC. Fig. 3 indicates the PEMFC generating system with component details, consisting of a PEMFC stack, H_2 humidifying and filtering, water-cooling and air-cooling components, the control and monitoring of temperature, pressure and feed mass flow rate. Hydrogen, nitrogen and air/oxygen are used in the system. A LabVIEW™ software package designed by the authors is used to control the whole process.

PEM Fuel cell parameters

The 63-cell Horizon® H-300 PEMFC stack, made by Horizon Fuel Cell Technologies, Singapore, was tested thoroughly

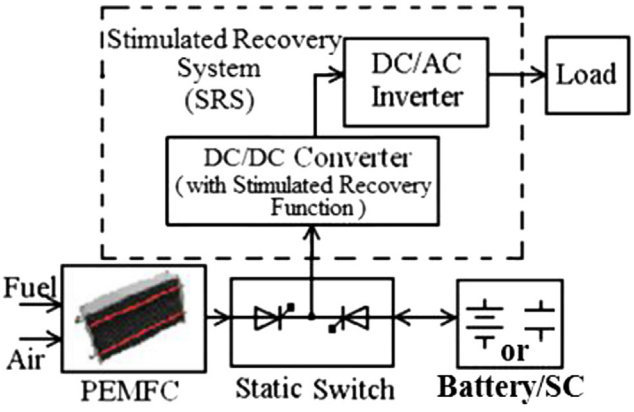

Fig. 1 – Stimulated recovery system (SRS) with backup PEM fuel cell and battery/SC.