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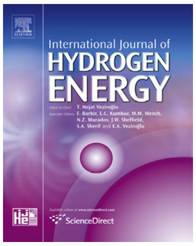

A purge strategy for proton exchange membrane fuel cells under varying-load operations

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ABSTRACT

When a proton exchange membrane fuel cell is operated in a dead-ended anode mode, its performance gradually drops due to impurity accumulation in the anode channel. The performance can be recovered by purging the impurities from the anode channel. Developing a purge strategy for a fuel cell is challenging under varying-load operations because the measured or monitored signals vary with the load demand. To capture the local performance throughout the active area during dead-end operation, the local current density distribution was measured using a specially designed single cell. First, the single cell was operated at three different current density levels for the observation of the variation of the local current density. The ratio of the normalized local current density to the load current density can be employed as a characteristic value for the purge strategy. The purge strategy with different threshold values was applied to a single cell operated under varying-load conditions and was discussed. Finally, a procedure for implementing the purge strategy was presented in detail.

Introduction

Proton exchange membrane fuel cells (PEMFCs) play an important role of clean energy for the future because they have the advantages of quick startup, low emission, low operating temperature, high power density, and high efficiency. Energy efficiency of a PEMFC system depends on hydrogen utilization and control strategy for auxiliary components. In order to increase hydrogen utilization, the anode configuration of a PEMFC is practically either in the recirculation mode or in the dead-end mode [1]. Compared with the recirculation mode, the dead-end mode does not require a recirculation loop, which usually consists of a pump, water separator, humidifier, and a purge valve neither a complicated control algorithm. In a dead-ended anode (DEA) configuration, a pressure regulator is installed at the anode inlet to supply hydrogen at a constant pressure, and a normally closed solenoid valve is employed to block the anode outlet. During the DEA operation, liquid water and nitrogen gradually permeate from the cathode to the anode and accumulate in the anode channel, causing a performance drop of the PEMFC [2–7]. The accumulated impurities can be purged by opening the solenoid valve at the anode outlet of the PEMFC.

The purge parameters, including the purge interval and the purge duration, may affect cell performance and have been investigated by many groups. Hou et al. [8] developed a semi-empirical dynamic voltage model based on a series of experimental data, including constant-current and current step operations. In their experiments, the hydrogen purge frequency was related to the load power. Hou's model captured the transient response of cell voltage under hydrogen purge

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operation but did not provide a purge strategy. Wan et al. [9] investigated the relationship between channel geometry and the wettability of the gas diffusion layer surface of a dead-ended PEMFC. The experimental results suggested that the PEMFC could operate for approximately 1 h with a channel width of 2 mm. In their study, the purge valve was opened periodically throughout the experiments. Strahl et al. [10] experimentally studied the hydrogen purge effects on the performance and efficiency of an open-cathode PEMFC and showed that water accumulation instead of nitrogen within the anode channel caused the voltage drop of the PEMFC. The experimental results suggested that the pressure drop of the anode inlet can be monitored as an indicator for purge strategy. Meyer et al. [11] applied electrochemical impedance spectroscopy, off-gas analysis, and high resolution thermal imaging to investigate the performance decay of an open-cathode PEMFC during DEA operation. The results showed that accumulated liquid water and nitrogen caused the performance drop.

In order to improve energy efficiency, the optimal purge cycle was also intensively investigated. Belvedere et al. [12] measured the slopes of the voltage decrease of a PEMFC with a DEA operated at five different load power levels and developed a purge strategy. The optimum purge period decreased with increasing load power. By measuring the hydrogen flow rate during operation, they also showed that the energy efficiency was improved by the newly developed purge strategy. However, the slope was not easily captured during varying-load operations unless the relationship between the slope and operating conditions was established. In addition, the strategy was not validated for varying-load operations. Chen et al. [13] developed a model that captured liquid water and nitrogen accumulation in the anode channel to study the optimum purge cycle. The results showed that the optimum purge cycle varies with operating conditions. Sasmito et al. [14] employed a full factorial approach to investigate the effects of purging time, purging duration and cathode stoichiometry on the PEMFC with a DEA and revealed that the best purging time was 3 s, the best purging duration was 4 min, and the best cathode stoichiometry was 2. Nikiforow et al. [15] studied the effects of the purge cycle and operating conditions on the PEMFC efficiency and hydrogen utilization. Zhang et al. [16] systematically investigated the effect of the purge parameters, such as the pressure, purging duration and purging interval, for a high-temperature PEMFC.

During DEA operation, the local performance throughout the active area is not uniform. It can be observed using a segmented PEMFC [17]. Yu et al. [18] designed a segmented single cell to measure the local current density (LCD) distribution, the local potential, and the micro-structure of the catalyst layers of the cell under the DEA operation. Their results showed that the current density first decreased at the segment near the anode outlet and proceeded to the area near the anode inlet. Ichikawa et al. [19] installed a pressure control valve at the anode inlet to intermittently supply hydrogen to the anode, which is called pressure swing supply. The nitrogen concentration distribution in the anode channel was more uniform under the pressure swing supply operation than under constant pressure operation because the oscillatory flow generated by the pressure swing supply periodically sweeps out nitrogen from the active area, causing stable power generation of the PEMFC.

However, the purge strategies in most of the aforementioned studies were demonstrated for a PEMFC under constant-load operations and not under varying-load conditions. In actual cells, the current of a PEMFC varies with load demand; therefore, a purge strategy for a PEMFC under varying-load operations is required. For this perspective, the current-integration method has been introduced to control the purge valve of a PEMFC under varying-load operation [20]. In our previous study [21,22], a lumped model was developed to predict nitrogen accumulation within the anode channel. Although the PEMFC with a DEA can stably operate using the current-integration or nitrogen-accumulation strategy, the local performance of the PEMFC cannot be monitored.

In this study, experiments with a specially designed single cell were conducted to develop an anode gas management strategy for PEMFCs under DEA operation, especially for varying-load operations. First, the effect of the load current density on the distribution and variation of the LCD of the single cell was studied. An anode purge strategy was proposed and discussed. Finally, the purge strategy was verified at various dynamic load operations.

Experimental

Experimental setup

Fig. 1 shows the experimental setup used in this study. A single cell with an active area of 25 × 5 cm^2 was designed and manufactured. The membrane electrode assembly was a catalyst-coated membrane (Nafion XL, DuPont, USA) sandwiched between two carbon papers (N1S1007, CeTech, Taiwan). The catalyst loadings on the anode and cathode sides of the membrane were 0.1 and 0.5 mg Pt cm^{-2}, respectively. Flow field plates machined with 18 nearly straight channels were used in the study, as shown in Fig. 1(c). The dimensions of the rib width, channel width, and channel depth were 1.3, 1.4, and 1.9 mm, respectively. Both the anode and the cathode flow patterns were identical. The flow directions of the anode and the cathode were counter-flow to humidify the membrane close to the anode inlet. To measure the LCD of the single cell, the outer side of the anode flow field plate was connected with 20 leads using electrically conductive adhesive (FP-5100FA, FeedPool, Taiwan), as shown in Fig. 1(d). Each adhesive-covered area was 1 × 5 cm^2. Each lead was connected to a current shunt (10 A/50 mV), and then all current shunts were connected to the negative side of the electronic load (PLZ 664, Kikusui, Japan). The cathode current collector was gold-coated copper, as in the traditional design. A heating pad was placed on the cathode end plate to heat the PEMFC to the operating temperature of 65 °C. The assembled single cell is shown in Fig. 1(e).

A pressure regulator (R06-221-NNEA, Norgren, UK) was placed at the anode inlet to reduce the hydrogen pressure to 0.2 barg, and a pressure transmitter (A-10, Wika, Germany) was installed to monitor the inlet pressure for safety. The anode outlet was blocked with a normally closed solenoid valve (Type 6126, Burkert, Germany), which was controlled by