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Dynamic behaviour of 5-W direct methanol fuel cell stack

Jung-Han Yoo [d], Hoo-Gon Choi [a], Jae-Do Nam [b], Youngkwan Lee [d], Chan-Hwa Chung [d], Eun-Sook Lee [c], Jung-Kyu Lee [c], Sung M. Cho [d,*]

[a] *Department of System Management Engineering, Sungkyunkwan University, Suwon 440-746, Korea*
[b] *Department of Polymer Science and Engineering, Sungkyunkwan University, Suwon 440-746, Korea*
[c] *Hyup Jin I&C Co. Ltd., Hwasung, Kyunggi-do 445-970, Korea*
[d] *Department of Chemical Engineering, 300 chunchun-dong Jangan-gu, Sungkyunkwan University, Suwon, Kyunggi-do 440-746, Republic of Korea*

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Abstract

A 5-W direct methanol fuel cell (DMFC) stack has been developed to investigate the dynamic behaviour of the performance. The stack generates the 5-W peak power with 10 cells of 3 cm × 3 cm active area. Upon changing the load conditions, the transient behaviour of the stack voltage is monitored to evaluate the speed at which the stack adapts to the changes. The transient characteristics of the stack current are also studied with continuously changing fuel flow rates of 2 M methanol solution and air. The optimum operating conditions for the stable operation of the 5-W DMFC stacks are reported.

Keywords: Direct methanol fuel cell; Stack; Membrane–electrode assembly; Peak power; Fuel flow rate; Dynamic behaviour

1. Introduction

The dynamic behaviour of fuel cells is of importance to insure stable performance under various operating conditions. In particular, knowledge of the dynamic behaviour is critical to the engineering and design of the cells, stacks and systems. Among the different types of fuel cell, the direct methanol fuel cell (DMFC) offers particular advantages for portable applications [1–3]. For such service, two types of DMFC system have been investigated, namely, the stack system [1] and the flat micro system [2,3]. While a flat micro system utilizes air breathing for the cathode reaction, the stack system normally uses mechanical pumps for fuels and is therefore suitable for rather higher power portable applications than the flat-pack counterpart. For small DMFC systems to be used for portable electronic applications, the transient responses upon abrupt load changes should be well understood for ensuring stable operation. Since the time constants of the transient responses can vary with the load demand, special care should be taken when the DMFC system is operated under conditions with high time constants.

The transient response of the DMFC is inherently slower than that of the hydrogen fuel cell, and hence delivers inferior performance. This is because the electrochemical oxidation kinetics of methanol are slower due to the formation of intermediates during methanol oxidation [4]. In addition, unlike the hydrogen fuel cell, the DMFC utilizes a liquid fuel. Since the methanol solution has to penetrate a diffusion layer before reaching the anode catalyst layer for oxidation, it is inevitable for the DMFC to experience the high mass-transport resistance. The carbon dioxide produced as the result of the oxidation reaction of methanol could also partly block the narrow flow path so that it is more difficult for the methanol to diffuse the catalyst. All these resistances and limitations can alter the cell characteristics and the power output when the cell is operated under variable load conditions. The fluid dynamics inside the fuel cell stack is more complicated and thus the transient stack performance could be more dependent of the variable load conditions [4–7].

This study reports the effect of varying loads on a small-size DMFC stack (10 cells, each with 9 cm^2 active area). The transient responses of the stack voltage have been investigated to obtain information on the dynamic characteristics of the stack. Also, the transient responses of the stack current upon changing fuel flow rates have been monitored to obtain the optimum operating conditions for the stack.

* Corresponding author. Tel.: +82 31 290 7251; fax: +82 31 290 7251.
E-mail address: sungmcho@skku.edu (S.M. Cho).

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2. Experimental

The DMFC was a 10-cell stack with 3 cm × 3 cm active area (i.e., a total active area for the stack of 90 cm^2). The eight middle membrane–electrode assemblies (MEAs) were sandwiched by two graphite bipolar plates and two outside MEAs were sandwiched by a graphite bipolar plate and an end plate. The cells were held together with two plastic insulation sheets and two aluminium backing plates using a set of retaining bolts positioned around the periphery of the stack. In the stack, the fuels of methanol solution and air were introduced through a port for even distribution to 10 separate flow channels. After the fuels flow through the channels of the MEAs, the fuel streams are collected into a single path to leave the stack. In this study, a single serpentine flow-field was used in the active area of 9 cm^2. The flow channel has the dimension of 1 mm width, 1 mm depth, and 1 mm rib-width.

The MEAs used in this study were prepared by the following procedure [8,9]. The diffusion backing layers for the anode and the cathode were Teflon-treated (20 wt.%) carbon paper (Toray 090, E-Tek) of 0.29 mm thickness. For electrode polarities, a thin diffusion layer was formed on top of the backing layer by spreading Vulcan XC-72 (85 wt.%) with PTFE (15 wt.%). After the diffusion layers were sintered at a temperature of 360 °C for 15 min, the catalyst layer was then formed with Pt/Ru (4 mg cm^{-2}) and Nafion (1 mg cm^{-2}) for the anode, and with Pt (4 mg cm^{-2}) and Nafion (1 mg cm^{-2}) for the cathode. The electrodes were placed either side of a pretreated Nafion 115 membrane and the assembly was hot-pressed at 85 kg cm^{-2} for 3 min at 135 °C.

3. Results and discussion

The polarization curve of the fabricated 5-W stack at a temperature of 50 °C is shown in Fig. 1. Since the total active area of the stack is 90 cm^2, the average power density of the stack is 55.6 mW cm^{-2}, which is close to that for a unit cell at the same temperature. The flow rates of the methanol solution and air were

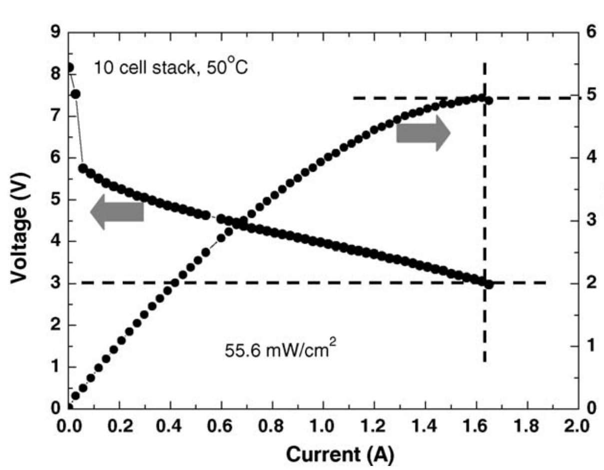

Fig. 1. Performance curves of 5-W DMFC stack, in terms of stack voltage and power. The stack is operated with 2 M methanol solution and air at 50 °C. Flow rates of methanol and air are 8 ml min^{-1} and 5 l min^{-1}, respectively.

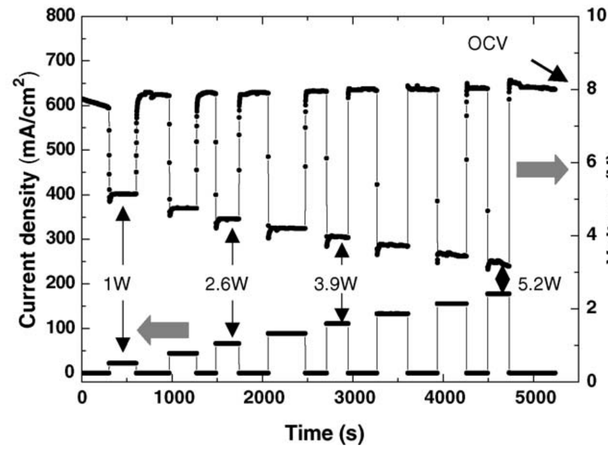

Fig. 2. Stack voltage response under increasing current load with pulses up to 178 mA cm^{-2}. The stack is operated with 2 M methanol solution and air at 50 °C. Flow rates of methanol and air are 8 ml min^{-1} and 5 l min^{-1}, respectively.

set to be in excess (i.e., 8 ml min^{-1} of 2 M methanol solution; 5 l min^{-1} of air) to ensure maximum performance of the stack. No back-pressure was applied to either the anode or the cathode. For unit cell operation, the optimum flow rates of 2 M methanol solution and air are 0.3 and 200 ml min^{-1}, respectively, although the results are not given shown in this paper. Excessive supply of fuels has little effect on the stack performance.

When a square pulse with a fixed current density is loaded to the stack, the open-circuit voltage (OCVs) is expected to drop rapidly to a value that corresponds to the current load. The voltage should then recover to the OCVs when the pulse ends. For current loads of 0–1.6 A applied to the stack as consecutive pulses, the voltage response as a function of time is shown in Fig. 2. As the current load increases, the voltage drop increases correspondingly. For a load step change from zero to a fixed current, the voltage falls instantaneously to below the steady-state value for a fixed current, and then returns relatively slowly to the steady-state value. This behaviour is observed for current densities from low to high values. When a load step change occurs from a fixed current to zero current, however, the voltage response gradually approaches the steady-state value at relatively low current densities, but tends to show a sharp rise at higher current densities that results in an overshoot and slow relaxation back to the steady-state value.

The typical transient responses of the stack voltage are shown in Fig. 3 for two different current load changes. When a current load changes from 0 to 44 mA cm^{-2} abruptly, the stack voltage drops for about 5 s from the OCVs and reaches a value below the steady-state voltage (Fig. 3(a)). Then, the voltage slowly increases back to the steady-state value that corresponds to the current density of 44 mA cm^{-2}. When the current load is decreased from 44 to 0 mA cm^{-2}, the measured voltage increases monotonically to the OCVs (Fig. 3(b)). Meanwhile, for a current load change from 0 to 178 mA cm^{-2}, (Fig. 3(c)), the stack voltage response is much faster and has similar behaviour to that shown in Fig. 3(a). For a current load decrease from 178 to 0 mA cm^{-2}, (Fig. 3(d)), the response is also very fast but it exhibits an overshoot and slow relaxation, unlike the case