ADVANCED METHOD TO MEASURE CURRENT GRADIENTS IN POLYMER ELECTROLYTE FUEL CELLS

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Polymer electrolyte fuel cells (PEFC) comprise extended areal electrodes where the electrochemical reactions take place. These reactions lead to material conversion and are represented by an electric current. Due to the individual design of electrochemical cells and especially to the type of the flow field an inhomogeneous mass transport of the reactants across the electrode area occurs affecting the performance of the cell as a whole. Measuring the current distribution along the electrode area the design of fuel cell components and the operation modes can be suited to the requirements. Such a technique for measuring lateral current gradients in electrochemical cells working independently from the dynamic cell operation has been developed and applied in a PEFC.

Introduction

Fuel cells are electrochemical devices in which the storage of the chemical energy is separated from the location of the conversion reaction. Consequently, gaseous or liquid reactands have to be supplied adequately to the electrodes and reaction products as well as inert constituents have to be removed from the cell. At the latest this is a problem if the electrode areas increase to commercially relevant dimensions and the thickness of the bipolar plates is reduced. The configuration of inlet and outlet channels and especially the design of the flow-field considerably influence the occurrence of local concentration gradients which strongly affect the local electrochemical reaction rate. Furthermore, the local performance from inlet to outlet is depending on the operating conditions, e.g. reaction gas flow rate or humidification strategy. During operation such inhomogeneities in electrochemical cells cannot be recognized because usually only integral measured values like cell voltage, current and impedances are obtained. In order to resolve the measurement locally a modification of the fuel cell is necessary. This modified cell must ensure sufficient resolution at reasonable expenditure. Furthermore, the steady-state and dynamic operation must not be affected and the design should allow the integration in
a fuel cell stack. Existing approaches do not fulfill the entirety of these requirements (1). Therefore an advanced technique of current mapping measurements has been developed by applying a new approach using a magnetic loop array based on a technique similar to a DC current clamp. In the following first results are being presented.

Experimental

In order to observe distinct effects, a large fuel cell with an active area of 578 cm² (papersize A4 as being considered commercially relevant) has been designed. Disregarding lateral currents in the electrode membrane assembly (EMA) only one flow-field is divided in an array of 5x8 equal area squares. The segmented flow-field comprises straight channels of 1×1 mm² cross section with a spacing of 4.8 mm. First investigations were undertaken with the same flow-field at the counter electrode side. Each segment of the measuring frame has a cylindrical end on the current collector side around which a ferrite ring is placed. The rings are manufactured with a gap where a magnetic field sensor (Hall sensor) is positioned. For insulating and sealing reasons the individual segments are separated by a silicon cast. A schematic cross section of the measuring frame is shown in Fig. 1. Measuring the magnetic fields of the electric currents the Hall sensors generate a voltage output which is proportional to the electric currents crossing the individual segments. Independent of the fuel cell operation the output voltages of the 40 segments are scanned by a multiplexer and measured by a microvoltmeter. Automatic calibration of the Hall voltage offset and online visualization of the current density distribution is done by a PC. Because all sensor wires are connected through the side of the 10 mm thick measuring frame the integration in a fuel cell stack is possible and the temperature control of the cell by water flow could be implemented on the reverse side. Eventually, the whole cell is clamped between two pairs of brackets in the lower and upper third and installed in the test rack.

To simplify the exchange of the air flow field the measuring frame was installed on the hydrogen side of the cell. The EMA with an active area of 578 cm² was produced by hot-pressing two ELAT gas diffusion electrodes with 20 wt.% Pt on Vulcan XC-72 and 4 g Pt/m² on a Nafion® 117-membrane for three minutes at 160 °C and 80 bar pressure.
Results

First measurements demonstrate that the measurement technique is suited to resolve local effects such as dehumidification, changes of partial pressure or contact resistances. Exemplary, a series of measurement with operation under different air flow rates at constant pressure (2 bar$_{abs}$ on both sides), cell potential of 535 mV and 60 °C temperature has been performed. The gases were fed unhumidified and hydrogen flow was dead ended. The cell was held at constant operation conditions for more than twelve hours to achieve steady-state before the air flow rate variation. The total current output during operation is shown in Fig. 2. The main information one can extract from this figure is that the subsequent increase of the air flow rate at first leads to a moderately higher total current output and later on to a decrease at high flow rates. The moderate effect might lead to the assumption of slight changes in the relative spacial conditions of the cell. However, the locally resolved measurements presented in Fig. 3 demonstrate that dramatic changes occur.

In the following we assume that the influence of the hydrogen side on the current distribution can be neglected. With regard to the chosen experimental conditions two distinct phenomena can be observed at low air flow rates which is shown in map (a) of Fig. 3 where each point of intersection represents a measured data point. At first, the depletion of oxygen leads to the decrease of local cell performance toward the air outlet. Furthermore, the special design of the air inlet in combination with the low pressure drop resulting from the low air flow rate might be the reason for a preferential gas flow in the channels on the right side of the cell diminishing the current density on the left side.

The significant decrease of the performance in the upper part of the cell as shown in map (b) of Fig. 3 can be explained by dehumidification of the membrane with increasing flow rate of the dry air. The higher flow rate diminishes the problem of oxygen depletion in the lower part of the cell. Trying to interpret the local peaks in the upper half we cannot exclude differences in the contact pressure due to varying segment thicknesses resulting from manufacturing tolerances. To exclude this influence in future investigations the surface of the mounted segments has been carefully grinded over meanwhile to reduce contact resistance deviation.

With preceeding operation time and further increase of the air flow rate the tendency of membrane dehumidification in combination with the shift of the electrochemical activity towards the outlet as shown in map (c) of Fig. 3 becomes more obvious. Although the total current just starts
to decrease remarkably (Fig. 2) the locally resolved measurement shows that already about half of the cell area is electrochemically inactive.

Outlook

The presented results demonstrate the feasibility of current distribution measurements using the magnetic loop array technique. Future investigations will concentrate on systematic study of different flow field designs under varying operation conditions in the PEFC and DMFC, e.g. flow rates and water management. Another interesting topic for this kind of measurement will be the consideration of effects on the anode with the focus on catalyst poisoning and regeneration for example by carbon monoxide. Besides these relatively slow phenomena fast transients such as load changes and sudden flushing of the cell will be considered.

References

1. S.J.C.Cleghorn, C.R. Derouin, M.S. Wilson and S. Gottesfeld, J. Appl. Electrochem., 28,1 (1998) and references therein

Figure 1: Schematic cross section of the fuel cell assembly including a segment of the measuring frame. Beneath the elements of the magnetic loop are shown separately in the top view (not to scale).
Figure 2: Total current depending on gas flow rate with time including the points in time of flow rate changes.

Figure 3: Current mapping at three selected times (points a, b, c of Fig. 2) normalized to segment area of 14.5 cm² in a non-humidified hydrogen/air PEFC.