Journal of Power Sources 272 (2014) 225–232

Contents lists available at ScienceDirect

Journal of Power Sources

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

Validation of a novel method for detecting and stabilizing malfunctioning areas in fuel cell stacks

Martin Müller [a,*], Julian Hirschfeld [b], Rita Lambertz [a], Andreas Schulze Lohoff [a], Hans Lustfeld [b], Heinz Pfeifer [c], Martin Reißel [d]

[a] Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research – Electrochemical Process Engineering (IEK-3), 52425 Jülich, Germany
[b] Forschungszentrum Jülich GmbH, Peter Grünberg Institute – Quantum Theory of Materials (PGI-1/IAS-1), 52425 Jülich, Germany
[c] Forschungszentrum Jülich GmbH, Peter Grünberg Institute – Electronic Properties (PGI-6), 52425 Jülich, Germany
[d] Fachhochschule Aachen, Campus Jülich, 52428 Jülich, Germany

HIGHLIGHTS

- We measured a stack's current distribution without current sensors inside the stack.
- All sensors are outlying the stack, the additional resistance within the stack is negligible.
- The improvement of the setup's conductivity increases the measurands by a factor five.
- We demonstrate the function with a local resolution of 25% of the total cell area.
- We prove an excellent correlation of fuel cell simulation results and our measurements.

ARTICLE INFO

Article history:
Received 10 March 2014
Received in revised form
5 August 2014
Accepted 13 August 2014
Available online 28 August 2014

Keywords:
Current distribution
Validation of simulation
Conductivity of stack materials
Fuel cells
Electrolysis

ABSTRACT

In this paper a setup for detecting malfunctioning areas of MEAs in fuel cell stacks is described. Malfunctioning areas generate electric cross currents inside bipolar plates. To exploit this we suggest bipolar plates consisting not of two but of three layers. The third one is a highly conducting layer and segmented such that the cross currents move along the segments to the surface of the stack where they can be measured by an inductive sensor. With this information a realistic model can be used to detect the malfunctioning area. Furthermore the third layer will prevent any current inhomogeneity of a malfunctioning cell to spread to neighbouring cells in the stack. In this work the results of measurements in a realistic cell setup will be compared with the results obtained in simulation studies with the same configuration. The basis for the comparison is the reliable characterisation of the electrical properties of the cell components and the implication of these results into the simulation model. The experimental studies will also show the limits in the maximum number of segments, which can be used for a reliable detection of cross currents.

1. Introduction

Fuel cells are able to convert chemical energy directly into electricity and heat. The direct conversion makes them to promising candidates for an efficient energy supply in the near future. Fuel cells are typically built up as stacks with the aim of stacking many single fuel cells to increase the voltage to a level that is suitable for electrical converters. The disadvantage is that all cells in a stack are in operation with equal current and the cell with the weakest performance limits the power of the whole stack. Reasons for a poor performance could be deficiencies in the manufacturing process, but also problems occurring during operation like an inhomogeneous distribution of the operating fluids.

To avoid quality loss during the manufacturing process, in particular the catalyst distribution inside the MEAs has to be very homogeneous and the manufacturing tolerances of the flow structure have to be very low as well. Besides these manufacturing related issues, the operating conditions also influence the homogeneity of the stack operation. To achieve the appropriate heat and water management, fuel cell systems like PEFC and DMFC are usually operating at low air stoichiometry, and under this condition liquid water may accumulate in one or more cells of the stack.

---

* Corresponding author. Tel.: +49 2461 61 1859; fax: +49 2461 61 6695.
E-mail address: mar.mueller@fz-juelich.de (M. Müller).

http://dx.doi.org/10.1016/j.jpowsour.2014.08.045
0378-7753/

These water accumulations can hinder the air supply resulting in malfunctioning areas in the MEAs of the concerned cells. To understand the processes involved, and to prevent stacks from an uneven operation, it is essential to know when this uneven operation appears and to measure it. By these measurements it can be identified which parameter has the strongest influence on the current distribution.

Various systems exist for measuring the current distribution in fuel cells [1]. Especially for single cells a lot of available systems are described in the literature [2–4]. Most of these systems need special boards with a lot of sensors [5–8], and work only with single cells that cannot be integrated into fuel cell stacks [9–13]. A technique that can be integrated into a stack to determinate spatially resolved degradation rates is described in Refs. [14,15]. This current distribution measurement tool with an active area between 360 and 400 cm^2 and a maximum local resolution of about 1 cm is integrated into a bipolar plate and the local current is measured by sensing the voltage drop in each of the shunt resistors. Two types of sensor boards with 100 and 200 elements are used in the experiments.

A promising measurement tool for the future is the magneto tomography; an improvement of the resolution of this tool is still necessary, especially in the case of the stack but the advantage is that no intrusion into the cell or stack is necessary [3,16–18].

In this paper the validation of a new technique for the detection of malfunctioning areas in MEAs is described. No high-tech sensor boards are needed. Only highly conductive metallic sheets have to be integrated into the stack [19]. During operation, malfunctioning areas can be detected by measuring the equalizing cross currents which move along the segments of the third layer in the bipolar plates and pass the surface of the stack [20,21].

This technique is not developed for high resolution imaging of the current density in one cell, but it is easy to integrate into fuel cell stacks and it can be used to identify areas with a low and inhomogeneous fluid supply in certain cell areas. In stacks it will help to detect operating condition where larger areas of the cells do not work in a proper manner and that lead to an increased MEA degradation. A further advantage is the reduced influence malfunctioning cells have on neighbouring cells.

1.1. Current density inside a stack

If a fuel cell stack is operating in a homogeneous manner, current will only flow vertically through the bipolar plates with no in-plane currents. This is the ideal case; but due to a local limited reactant supply and other reasons like surface defects and contact problems or problems in the fluid supply a stack usually operates inhomogeneously. Possible failures are that the channels in the bipolar plate maybe blocked by particles or in the case of a two phase flow water accumulation can occur and hinder the air supply; an imperfect moulding of the channels or an imperfect assembly could also influence the flow distribution negatively. Cells inside a stack with the described problems will have malfunctioning areas and will begin operating inhomogeneously thus forming cross currents in the adjacent bipolar plates. This is schematically shown in Fig. 1.

If it is possible to measure these cross currents, the malfunctioning areas of a MEA can be calculated by using a realistic stack model that includes the electrical properties of all components. The methods that are used for calculating and simulating malfunctioning areas are developed and described in Refs. [20,21]. If in addition to the cross currents in a fuel cell stack the current distribution inside the end plates is monitored, it is possible to reconstruct the current distribution inside the whole stack by using the simulation tool.

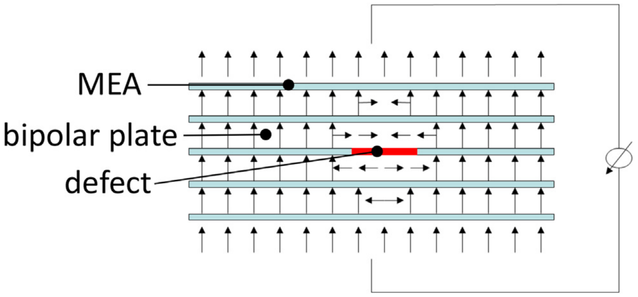

Fig. 1. Currents in the different layers of a fuel cell stack across an area (red) without electrochemical activity. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

The obvious impact of a local defect is, that the rest of the cell has to compensate for the lack of performance and this may lead to an increased degradation rate in the properly working cell areas around a defect [22]. Another possible effect is that a malfunction in one cell has an influence on neighbouring cells. To reduce the influence on neighbouring cells the in-plane conductivity of the bipolar plates should be increased. This can be done by the integration of highly conductive metal plates into the bipolar unit, see the yellow plate in Fig. 2. At the same time these highly conductive plates can be used to detect equalising cross currents. The segmentation of the plates forces these currents to pass the surface of the stack where they are measured by a current sensor. It is clear that along the paths of these cross currents the resistance must be as small as possible. This is necessary in particular for the electrical bridges between the segments.

In this work, a stack consisting of graphite bipolar plates is used for the analysis. Special in the stack's construction is that the bipolar units are consisting of two “half” plates, indicated by light grey and light blue colour in Fig. 2. One half-plate is used for the anodic flow field and the other for the cathodic flow field. The construction and assembly of the stack components is described in greater detail in Ref. [3]. It is also possible to integrate an additional sealing or an extra flow structure between the flow field plates for the supply of a coolant.

1.2. Integration of the technique into a stack

Between the graphite flow field plates a metallic layer is added (Figs. 2 and 3). The idea is that cross currents in the bipolar plate will mainly flow in the path lowest resistance and that is through the metallic layer with its low resistance. As already mentioned, the

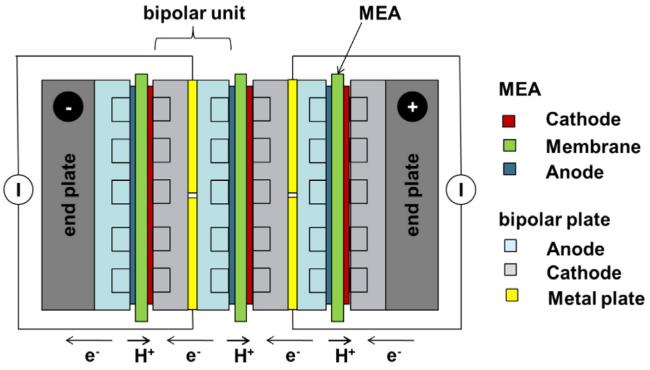

Fig. 2. Principle of the stack concept. Bipolar units are divided into two half plates and a high conductive plate in the middle.