Investigation of localized hydrogen starvation in PEMFC with dynamic electrochemical impedance spectroscopy

Tuan Anh Dao[a,b,c,z], Thomas Kadyk[b], Olav Finkenwirth[a], Michael Eikerling[b,c]

[a]BMW Group, D-80788 Munich, Germany
[b]Forschungszentrum Jülich GmbH, Institute of Energy and Climate Research, Theory and Computation of Energy Materials (IEK-13), Jülich, 52428, Germany
[c]RWTH Aachen University, Faculty of Georesources and Materials Engineering, Chair of Theory and Computation of Energy Materials, Aachen, 52062, Germany

[z]Corresponding author: tuan-anh.dao@bmw.de

Hydrogen fuel utilization is one of the significant factors for the commercialization of PEMFC in automotive applications. Too low fuel utilisation decreases the driving range and fuel economy. However, too high utilization might lead to localized hydrogen starvation, which significantly reduces the lifetime and performance of the fuel cell system [1]. Hence, advanced diagnostics are needed to detect hydrogen starvation early and during operation [2].

In this paper, a commercial MEA is tested under low hydrogen stoichiometry to simulate the spatial anode starvation condition. A newly developed electrochemical impedance spectroscopy (EIS) setup, which could measure up to 1000 impedance values in 1 second, is run in parallel for online characterization. The single cell stack is equipped with a current distribution measurement plate to confirm the starvation condition by the presence of a current deficit area in the anode outlet (Fig. 1). In addition, a novel localized CO stripping method is employed to validate the degradation on the cathode catalyst layer by measuring the localized distribution of the electrochemical active surface area (dECSA).

This study shows that EIS spectra are non-sensitive towards hydrogen stoichiometry in the range of sufficient hydrogen supply, $\lambda > 1$. However, when stoichiometry drops close to $\lambda \approx 1$ and the localized anode starvation starts to occur, the EIS spectra broaden remarkably, even though the cell performance does not yet indicate starvation. Furthermore, the EIS curves exhibit an oscillation in the middle and high-frequency range in both phase and magnitude when the cell is in the localized anode starvation condition (Fig. 2). The oscillation becomes more apparent when the starvation area is bigger. Meanwhile, the low-frequency regime exhibits inductive behavior, becoming more dominant with a more substantial effect of localized starvation. The dynamic current density measurement observes the hydrogen concentration oscillation in the anode outlet area. The localized CO Stripping reveals a significant drop of the dECSA on the cathode side in the same location, indicating cathode carbon corrosion under localized anode starvation conditions (Fig. 3).

This work is a first step towards an onboard diagnosis method, which could detect the presence of localized anode starvation conditions early and take control measures to prevent degradation.

References:
[1] H. Chen et al., Energy Convers. Manag.182, 282-298 (2019).
[2] Z. Tang et al. J. Power Sources 468, 228361 (2020).

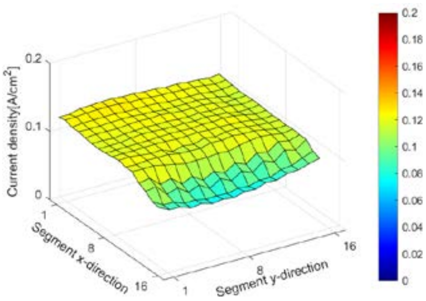

Figure 1: Current density measurement at the exact moment the EIS spectrum has been taken

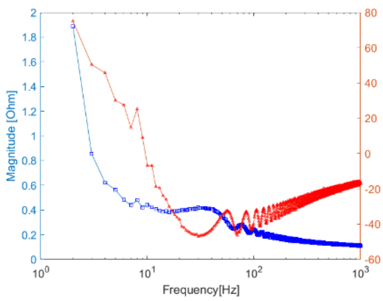

Figure 2: Dynamic EIS spectrum under spatial hydrogen starvation

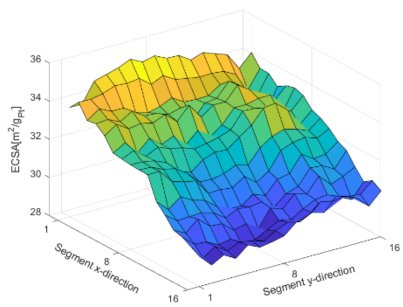

Figure 3: dECSA result after several hours of localized hydrogen starvation