Simulations and Experiments on Critical Operating Conditions with Total Harmonic Distortion

Kurt Mayer, Viktor Hacker
Institute of Chemical Engineering and Environmental Technologies, Graz University of Technology
Inffeldgasse 25C, 8010 Graz, Austria
kurt.mayer@tugraz.at

Online monitoring systems for polymer electrolyte fuel cells in vehicles are used to increase the reliability and service life of fuel cell systems. Currently, cell voltage monitoring (CVM) and electrochemical impedance spectroscopy (EIS) are primarily used for this purpose. However, CVM requires extensive wiring and often cannot distinguish between the causes of sudden voltage changes caused by critical conditions. EIS is slow and can preferably be used in the high frequency range for online monitoring of membrane resistance. Another challenge arises from the time invariance and linearity of the transfer function, so that it cannot be applied for transient studies.

In this talk, new developments of the innovative online monitoring technique based on Total Harmonic Distortion (THD), will be presented. In THD, the fuel cell is excited with a sinusoidal current at a certain frequency and the voltage response is evaluated. The harmonic distortions caused by the nonlinearity of the polarization curve are interpreted [1] and the frequency with the highest harmonic content is chosen in order to identify a certain critical condition. Discussed is the distinction of different critical operating states (flooding, drying of the membrane, and degradation of the catalyst layer) in models and in experiments. Recent experiments showed that not only in the low frequency region high harmonic content can be detected for flooding and drying events, but also at frequencies above 1 kHz for catalyst degradation.

In a Dynamic Large Signal Equivalent Circuit (DLSEC) (Figure 1), all losses of a fuel cell are described by voltage or current sources that follow the Butler-Volmer Equation ($j_{ct,anode}$, $\eta_{ct,cathode}$, $\eta_{PtO,formation}$) or a combination of the Nernst-Equation and Fick's Law (η_{mt}). DLSEC is parameterized based on impedance measurements and data from operating points [2] by using an evolutionary fitting algorithm in Python. The actual simulations are performed in the software LTSPICE (Analog Devices). DLSECs can simulate polarization curves, impedance spectra and THD. The new platinum oxide formation part has been added to the existing models. This new feature describes the induction loop at very low frequencies in the impedance spectra, completing the fuel cell characterization.

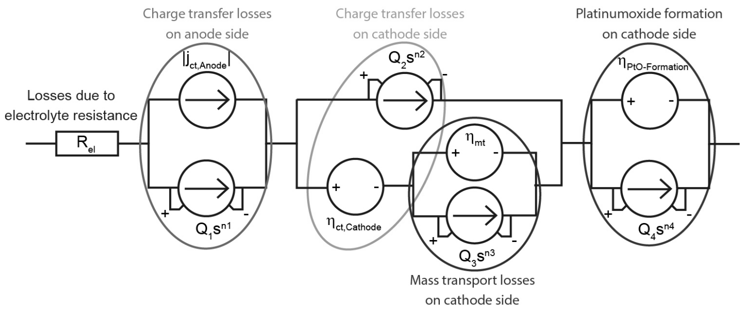

Figure 1: Dynamic Large Signal Equivalent Circuit with possible loss mechanisms.

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References:

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