Advanced characterization of PEMFCs using a two-phase time-dependent model

Robert Herrendörfer and Jürgen O. Schumacher
Institute of Computational Physics, Zurich University of Applied Sciences, 8401 Winterthur, Switzerland
robert.herrendoerfer@zhaw.ch

Overview

Recently, Vetter and Schumacher (2-3) showed that it is crucial to determine with high precision membrane properties as a function of hydration number. Here we:

• 1. Develop a non-isothermal, two-phase time-dependent PEM fuel cell model
• 2. Conduct classical EIS experiments using small input signals
• 2.1 Analyze the response of current density
• 2.2 Analyze the response inside the membrane and extract from it membrane properties, which is illustrated by the electro-osmotic drag coefficient
• 3. Analyze the non-linear, distorted response from larger input signals

1. Time-dependent PEMFC model

We build upon our previously developed steady-state PEFC model [1-2]:

• 1D through-plane, macro-homogeneous, non-isothermal, two phase
• Electrochemistry: Butler-Volmer equation
• Fully parameterized: Maxwell-Stefan diffusion, adsorption/desorption, condensation/evaporation, temperature/hydration dependence of properties, ...
• Coupled solution of 8 transport equations using COMSOL

• Implementation of transient terms:
  - Electron transport
  - Proton transport
  - Heat conduction
  - Hydrogen diffusion
  - Oxygen diffusion
  - Water vapor diffusion
  - Dissolved water
  - Liquid water transport

• 1D model setup of a PEMFC in through-plane direction. Thickness of the different layers: LGDL = 174.3 μm, CL = 7.3 μm, PEM = 25.4 μm. Boundary temperature is 70 °C and pressure is 1.3 bar. In the CL, ionomer volume fraction is 0.3 and porosity is 1.4. Pure tortuosity/porosity is 2.95/0.7 in GDLs and 1.5-0.18 in CLs. Electron conductivity is 400 S/m. The double layer capacitance is 0.2 F/m².

2. Small-signal response: EIS

• Steady-state operating points:

  - Classical EIS: \( V = V_0 + \Delta V \sin(2\pi f t) \), \( \Delta V = 1 \text{ mV} \)

  - Steady-state polarization curve. Colored circles indicate the operation cell voltage \( V_0 \) for EIS analysis.

• Analysis of the response to input amplitudes from 1 mV to 32 mV
• Calculation of the total harmonic distortion (THD) with \( P \) being the power at the \( i \)-th harmonic of the input signal:

\[
\text{THD} = \frac{\sqrt{\sum_{i=1}^{\infty} P_i}}{P_0}
\]

3. Large-signal response

• Analysis of the response to input amplitudes from 1 mV to 32 mV
• Calculation of the total harmonic distortion (THD) with \( P \) being the power at the \( i \)-th harmonic of the input signal:

\[
\text{THD} = \frac{\sqrt{\sum_{i=1}^{\infty} P_i}}{P_0}
\]

Conclusions

• Classical EIS detects electrical conductivity, polarization resistance and time scales related to double-layer capacitance and membrane hydration.
• Analyzing further the response inside the membrane allows extraction of the electro-osmotic drag coefficient.

Outlook:
• Run models by including liquid water saturation
• Utilize the large-signal response as on-board diagnostics
• Analyse the response from different inputs: temperature, gas pressure, ...

Acknowledgements

We gratefully acknowledge the financial support by the Swiss Federal Office of Energy for the project “Advanced characterization of fuel cell stacks for automotive applications” (SFOE contract number: St/501764-01).

References: