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Monitoring a commercial μ-CHP SOFC-Stack by electrochemical impedance spectroscopy

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Advanced use cases for SO(F)Cs

Advanced use cases of SO(F)Cs incorporate for example reversible operation for energy storage or the application of wood gas as fuel. On the one hand those use cases might greatly enhance market penetration of SOFCs but on the other hand reliable and safe stack operation is even more challenging. Therefore novel approaches for comprehensive stack monitoring and controlling are necessary.

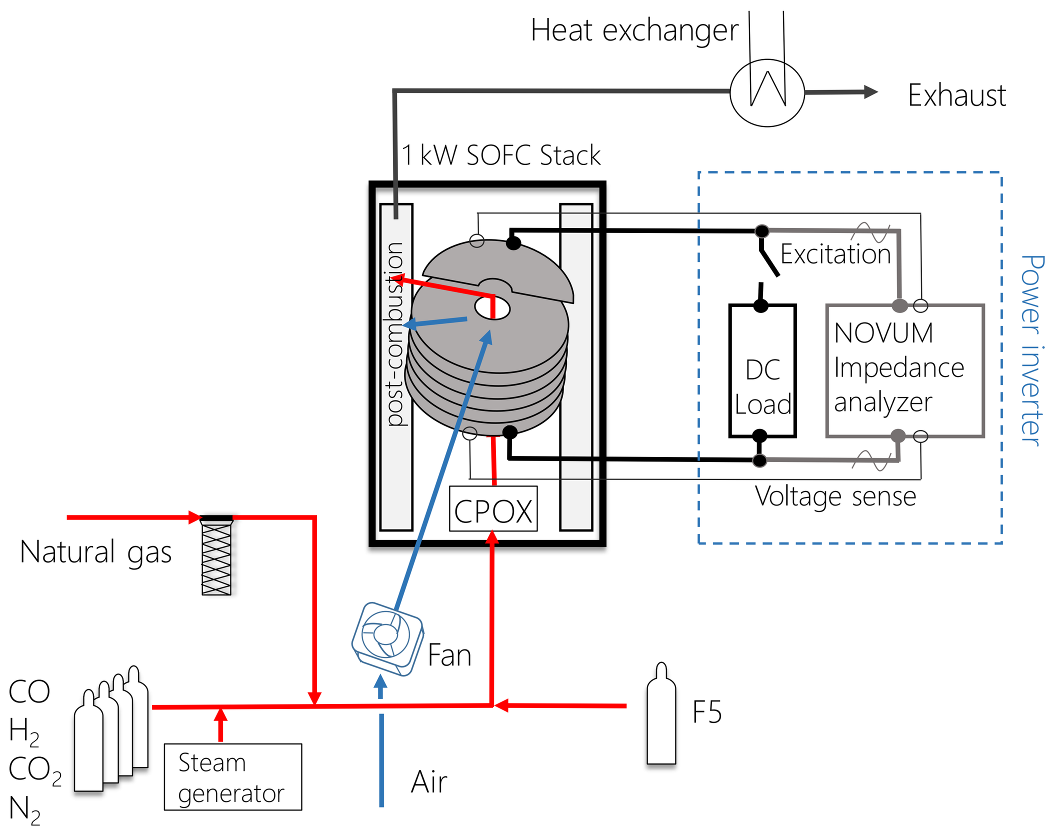

Figure 1: Experimental setup featuring a commercial 1 kW SOFC stack operated from either natural gas or a gas mixing station. Electrical instrumentation is realized by a four-wire connection of the parallel-connected frequency response analyzer (FRA by NOVUM engineering GmbH) and a DC load.

Monitoring approach

The aim of this work is the establishment of an online monitoring scheme for a commercial μ-CHP SOFC stack, based on electrochemical impedance spectroscopy (EIS). The experimental setup is sketched in Figure 1. The implementation of EIS is beneficial, because it involves a relatively simple electrical measurement, which can be integrated in the power inverter. Continuous measurements deliver intrinsic information within a short measurement time. EIS measurements assess processes at different time scales and implicate their contribution to the electrochemical system. Regarding solid oxide fuel cells, EIS can for example identify and evaluate diffusion processes, charge transfer or the conduction of ions.

Electrochemical impedance spectra at stack scale

Figure 2 shows a typically measured electrochemical impedance spectrum at open clamp conditions. The Nyquist representation reveals three different arcs. In our experimental setup the low frequency and the high frequency arc are not fully closed, meaning that the measured frequency range (0.1 Hz – 10 kHz) is not sufficient to expose all processes in detail. Meanwhile, literature has roughly identified the underlying processes:

1. Low-frequency arc (< 1 Hz): gas conversion impedance and gas diffusion.
2. Electrode arc (1 Hz – 1 kHz): charge transfer, catalyst activity at the triple-phase boundaries.
3. Electrolyte arc (> 1 kHz): grain boundary impedance of the electrolyte.

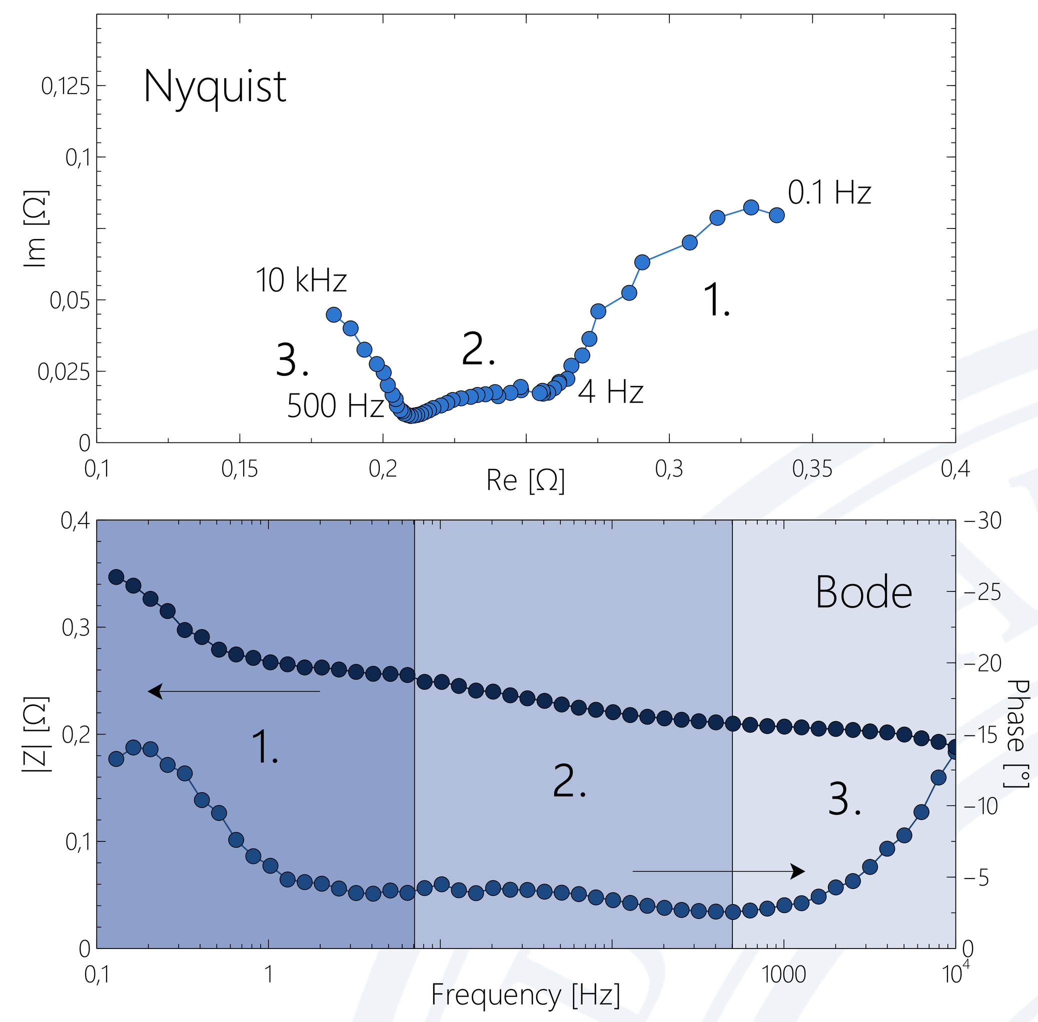

Figure 2: a) Nyquist plot and b) Bode plot of a SOFC stack at OCV conditions. The stack was operated at 850 °C with 1.8 kW partially oxidized natural gas. (50 EIS measurements 0.1 Hz to 10 kHz with three sine periods, 0.12 A amplitude, 0.1 A offset)

Measurement series

Online monitoring and controlling of a SOFC stack, based on EIS, requires continuous impedance measurements. Here the relative change of the impedance spectra over time and within altered operation conditions are of interest.

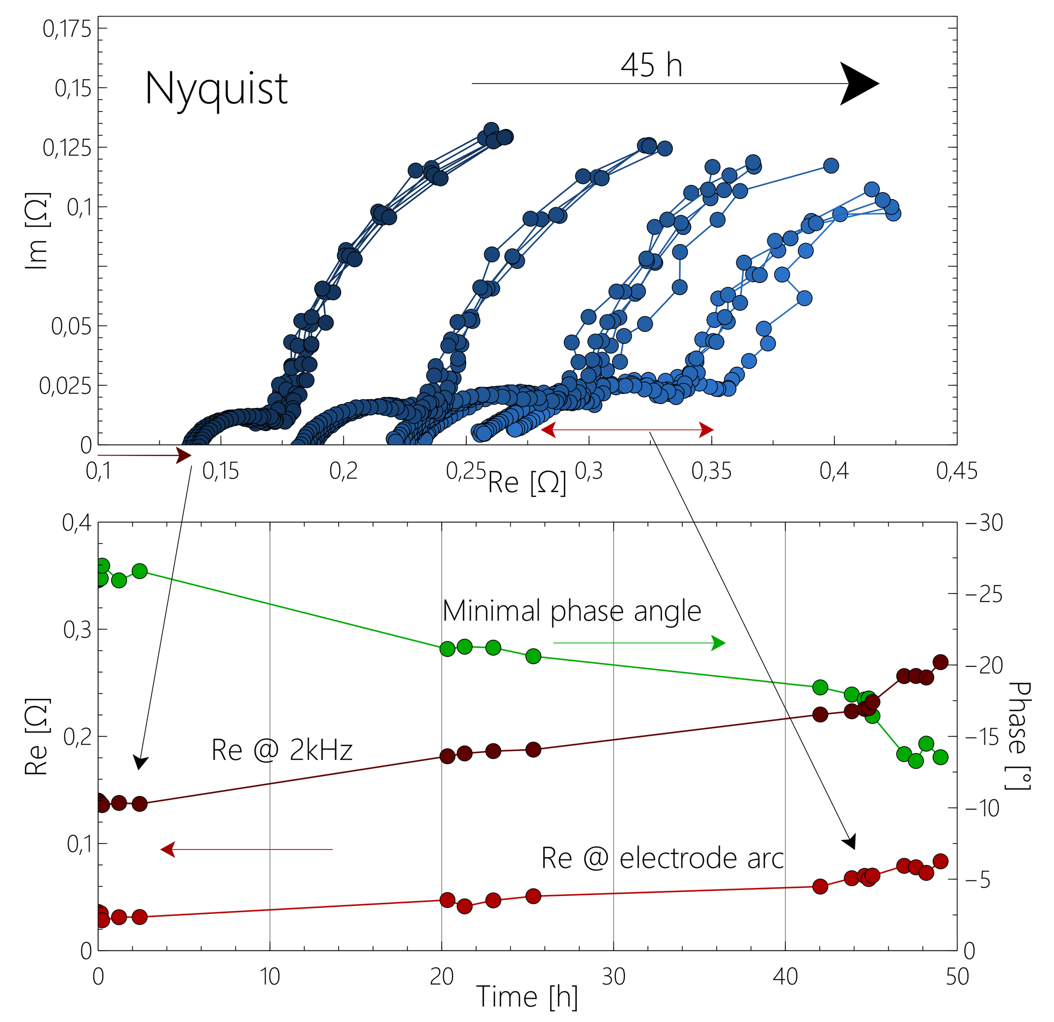

Figure 3: a) Evolution of impedance spectra in the Nyquist plot during 50 h stack operation (OCV, 850 °C, 1.9 kW partially oxidized natural gas, 40 EIS measurements 0.1 Hz to 2 kHz with two sine periods, 0.1 A amplitude, 0.2 A offset) b) Changes in minimal phase angle and selected Real values

Figure 3 depicts an example for a measurement series at open clamp conditions, where no external parameters were altered. Throughout the measurement period, the dry fuel gas increases the Ohmic resistance, the electrode resistance and finally decreases the minimal phase angle in the low frequencies. This indicates a deactivation of the triple-phase and may result from carbon deposition.

Project: "FlexSOFC"

The goal of the research project FlexSOFC is the EIS-based online identification of faulty operation states and a subsequent controlling scheme of a commercial μ-CHP SOFC stack. Especially the effect of unstable fuel gas supply, provided from a wood gasifier and the resulting hazard of fuel starvation is under investigation.

Acknowledgements

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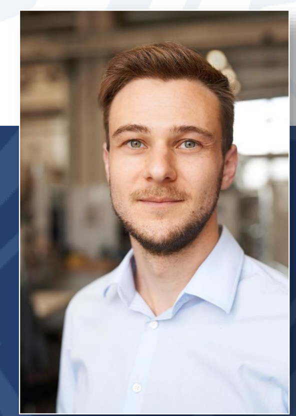

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