SINTEF GIANTLEAP

Relay feedback excitation for identification of Fuel Cell performance parameters

Ivar J. Halvorsen, Federico Zenith

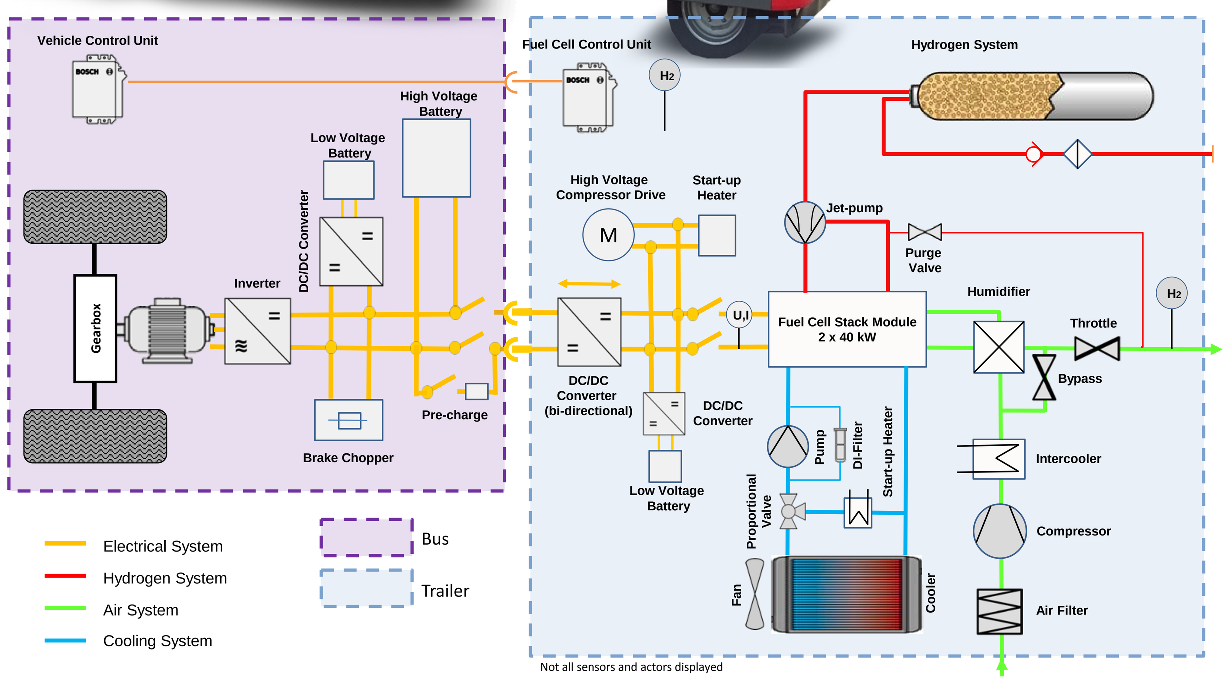
SINTEF Digital, Trondheim, Norway

The GIANTLEAP EU-project:

- Building Hydrogen Fuel Cell range extender for heavy duty transport
- Diagnostic, Control, Performance and health monitoring for fuel cells

Project partners:

elringklinger, VDL, FESB, Bosch Engineering, BOSCH Technik fürs Leben, FC LAB Research, SINTEF

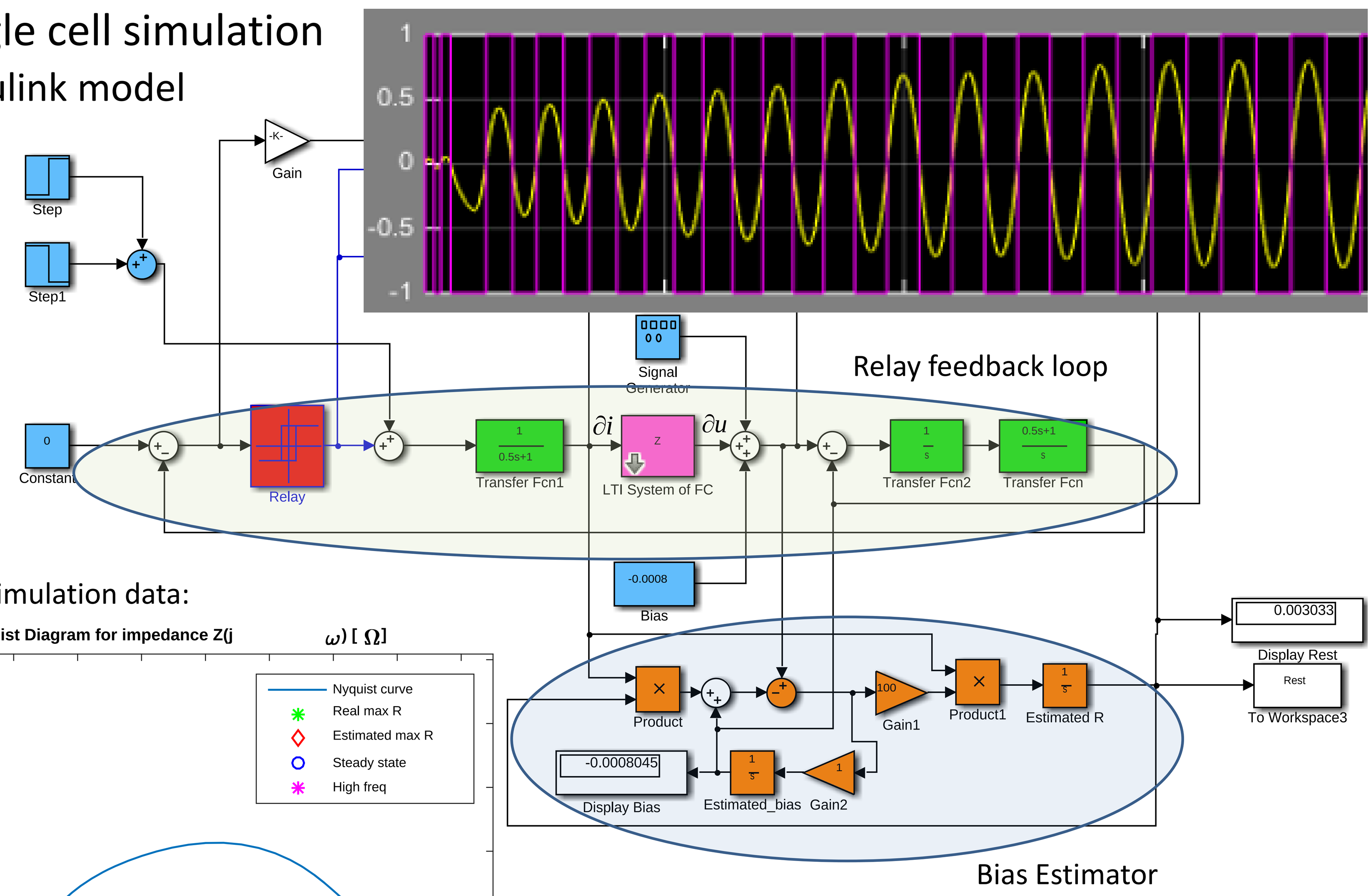


Relay feedback excitation for identification of fuel cell low frequency resistance[3] = impedance at: $\angle Z(j\omega)=0°$

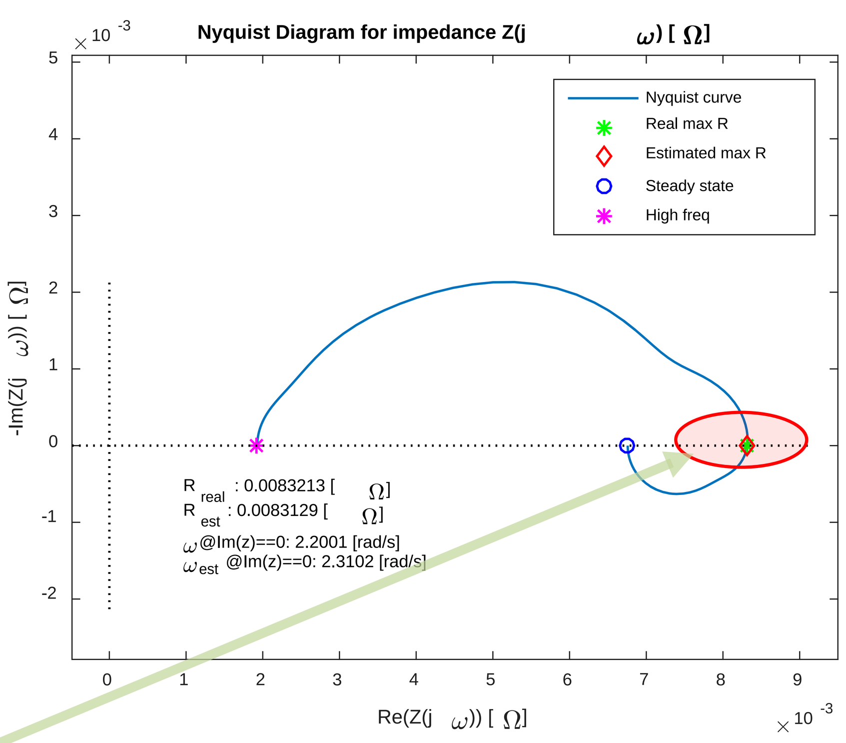
- Add filter d(s) such that $H(s)=Z(s)d(s)$
- Filter $d(s)=1/s^2$ => $\angle Z(j\omega_{H180})=0°$ when $\angle H(j\omega_{H180})=-180°$
- The filter can be partitioned in to pre- and post-filers e.g:

$$d(s)=d_1(s)*d_2(s)=\frac{1}{1+T_1s}*\frac{1+T_1s}{s^2}=\frac{1}{s^2}$$

- Bias estimator for handling of slow voltage drift must be included
- Require access to DC/DC in FC system for setting fuel cell current
- Single cell simulation Simulink model



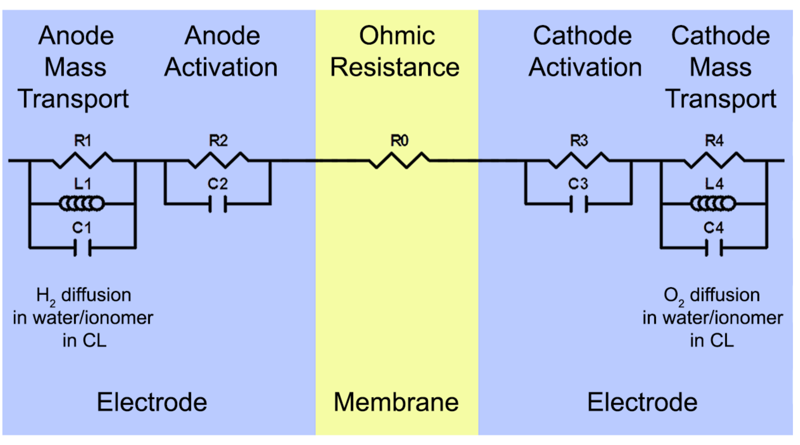
From simulation data:



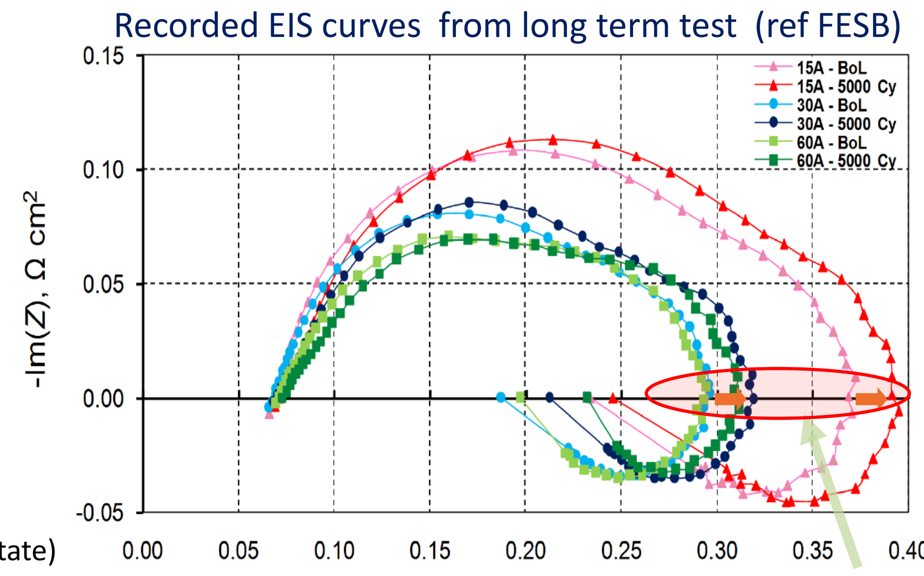
- Bias estimation is based on simple adaption by a gradient method
- Data can be post processed for more detailed analysis

Case introduction:

Fuel Cell Impedance – electrical equivalent model *Z(s)*:



Recorded EIS curves from long term test (ref FESB)



$\partial u(s)=Z(s)\partial i(s)$ u: voltage, i: current, (deviations from steady-state)

Region of interest $\angle Z(j\omega)=0°$ $\text{Im}(Z(j\omega))=0$

LFR - A dynamic parameter for ageing indication[1]:

- The low frequency resistance (LFR) at the intercept where $\text{Im}(Z(j\omega))=0$ increases with ageing.
- Challenge: How to identify LFR in a running FC application!

Alternatives for on-line identification:

- Electrochemical impedance spectroscopy (EIS) – use in lab only
- Fixed frequency excitation in relevant range - feasible, tested
- Phase locked loop - feasible
- Relay feedback excitation – studied here

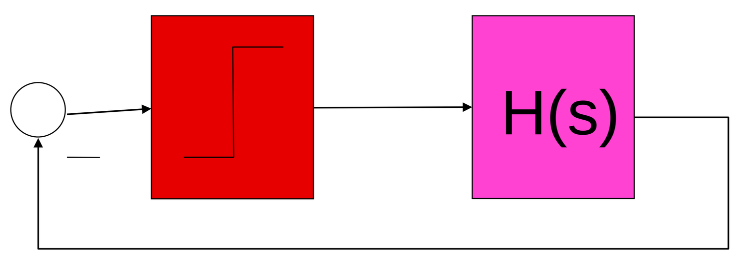
Relay feedback excitation[2]

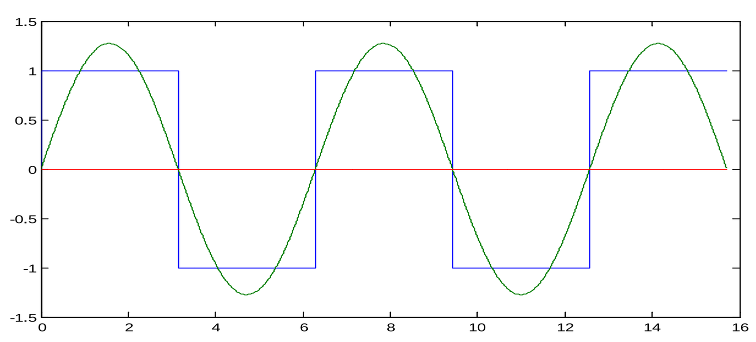
Relay feedback creates quickly a stable limit cycle at critical frequency of H(s)

$$\angle H(j\omega_{H180})=-180°$$

Gain $|H(j\omega_{H180})|$ can be obtained from data

Result can be used e.g. for PID tuning

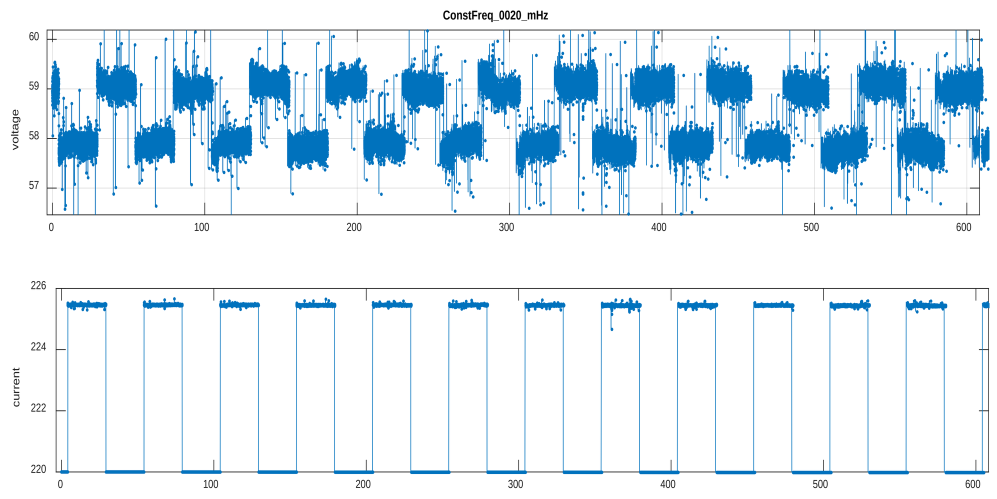




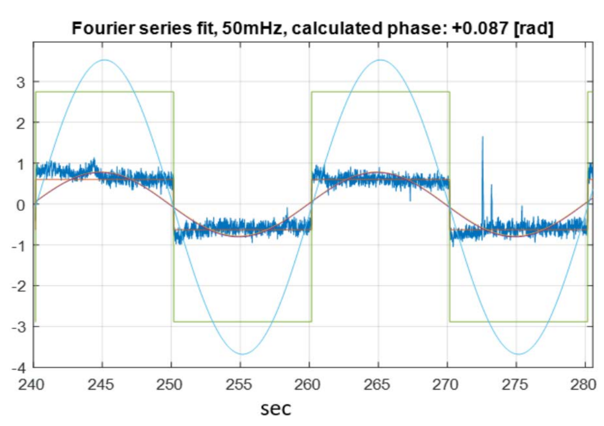
Testing on a full stack:

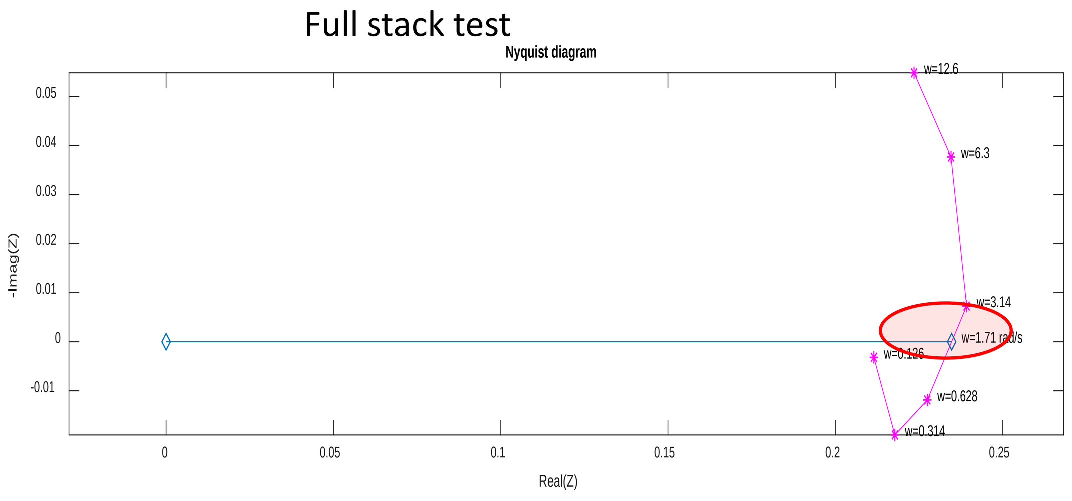
(ElringKlinger)

- Tests have been carried out at a set of fixed frequencies and with the relay excitation.
- The key parameters can be estimated from data
- Post treatment by Fourier series analysis



Full stack test





Conclusion:

- Relay feedback excitation can be applied in common FC control systems
- Simple to implement, robust to noise, quick convergence

References: 1. Ivan Pivac, Dario Bezmalinović, Frano Barbir, Catalyst degradation diagnostics of proton exchange membrane fuel cells using electrochemical impedance spectroscopy, International Journal of Hydrogen Energy, Volume 43, Issue 29, 2018, Pages 13512-13520, https://doi.org/10.1016/j.ijhydene.2018.05.095

2. Aström, Karl Johan, Hägglund ,Tore. PID controllers: Theory, design, and tuning, vol. 2. , NC: Instrument society of America Research Triangle Park; 1995

3. Ivar J. Halvorsen, Ivan Pivac, Dario Bezmalinović, Frano Barbir, Federico Zenith, Electrochemical low-frequency impedance spectroscopy algorithm for diagnostics of PEM fuel cell degradation, International Journal of Hydrogen Energy, 2019, In Press, https://doi.org/10.1016/j.ijhydene.2019.04.004.

Nordic Process Control Workshop NPCW-2019, DTU, Copenhagen 22-23 >August 2019

This project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 700101. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation programme and Hydrogen Europe and N.ERGHY.