Analysis of conventionally controlled PEMFC based on a distributed parameter model

M.L. Sarmiento-Carnevali[1] msarmiento@iri.upc.edu

M. Serra[1] maserra@iri.upc.edu

C. Batlle[2] carles.batlle@upc.edu

[1]Institut de Robòtica i Informàtica Industrial (CSIC-UPC), C/ Llorens i Artigas 4-6, 08028 Barcelona (Spain)

[2]Departament de MA IV & IOC, Universitat Politècnica de Catalunya, EPSEVG, Av. V. Balaguer s/n, 08800 VnG Barcelona (Spain)

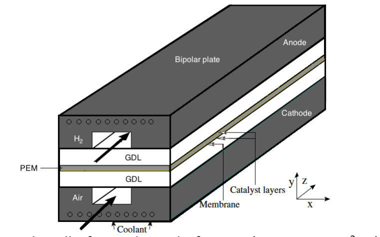
Motivation

- Variations in the concentrations of reactants, as well as temperature, have significant effects on the performance and durability of PEMFC.
- All these variables exhibit spatial dependence along the channel.
- A controlled PEM fuel cell study is done through a distributed parameter simulation model.
- A conventional stoichiometry control objective is considered in order to analyze the behavior of spatial profiles of some important variables.
- Importance of considering distributed parameter models in control design is shown.

Simulation scenarios

- **Scenario 1:** oxygen and hydrogen stoichiometry references are set at 2 and 1.7, respectively. Voltage is set at 0.8 V and, at time t = 110 s, system undergoes a series of step changes in humidification of gasses on cathode side.
- **Scenario 2:** oxygen and hydrogen stoichiometry references are set at 2 and 1.7, respectively. Voltage is set at 0.8 V and, at time t = 110 s, the setpoint for hydrogen stoichiometry is changed down to 1.4.

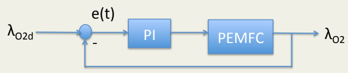
System description



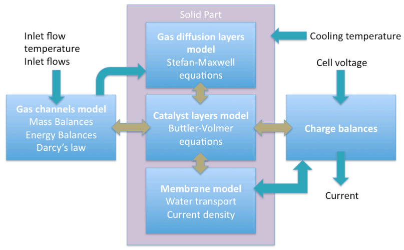
- Single cell of one channel of 0.4 m (area 0.4 x 10^{-3} m) with Nafion 117 membrane.
- The model is 1+1D, based on the work by Mangold et al. [1].

Control description

- Two simple PI feedback controllers are chosen to obtain a closed-loop system.
- The control objectives are to maintain oxygen and hydrogen stoichiometry at a certain reference value.

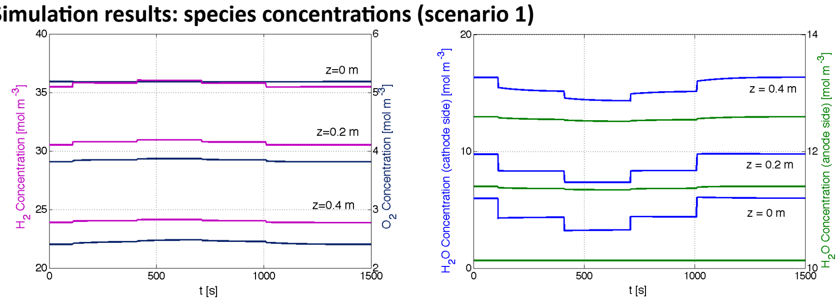


Model structure and implementation

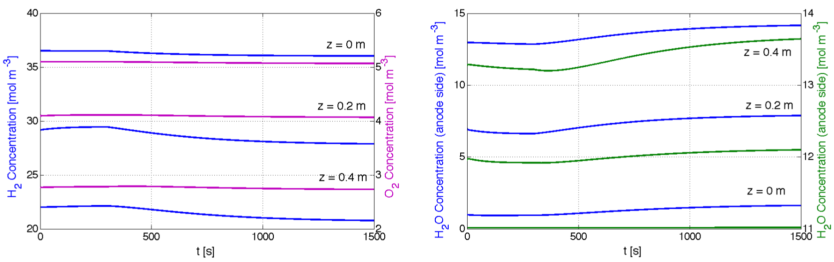


- Six submodels that are coupled by internal variables.
- **1. GC module:** reactant concentrations, flow velocity, pressure and temperature in the gas channels.
- **2. GDL module:** diffusion in a multicomponent mix of species.
- **3. CL submodel:** the electrochemical reactions and mass fluxes are modeled in the.
- **4. Membrane module:** detailed protonic exchange membrane model.
- **5. Solid part module:** energy balance to determine the solid part temperature.
- **6. Charge balances module:** Cell current and voltage.
- The inputs are inlet flows for anode side and cathode side, inlet flows temperatures, cooling temperature and cell voltage. The main output is cell current.

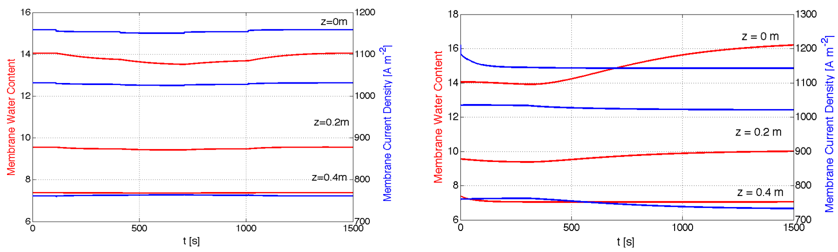
Simulation results: species concentrations (scenario 1)



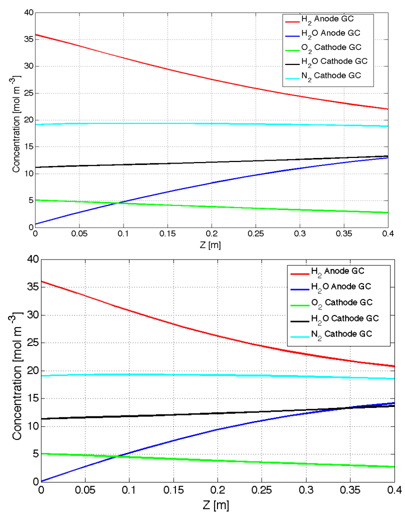
Simulation results: species concentrations (scenario 2)



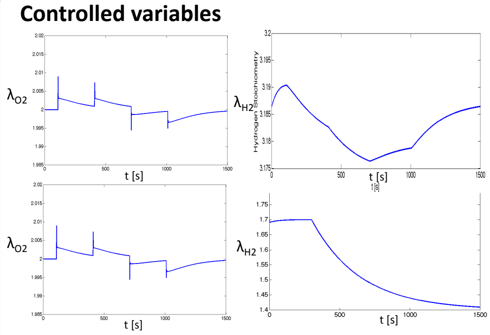
Simulation results: membrane water content and current density (scenarios 1 & 2)



Along-the-channel results (steady-state)



Controlled variables



Conclusions and ongoing research work

- Notice how concentrations of reactants have an important variation along the channel. These profiles need to be taken into account, regarding fuel starvation or membrane humidity, for example. Therefore control design considering spatial profile seems appropriate.
- Differences in behaviour for three points along the channel are appreciated. Results for scenario 1 show how the step changes have immediate effects at the beginning of the channel, while these effects get attenuated towards channel end due to different time constants. Different behaviours suggest the interest of designing controllers for specific points along the channel by means of reduced order models, in order to avoid zones of operating conditions that can be harmful to the membrane, catalyst layer or other elements of the fuel cell vulnerable to degradation or low performance. The ongoing research is aimed at finding interesting control objectives that consider spatial variations.

References

[1] Mangold M., Bück A., Hanke-Rauschenbach R., Passivity based control of a distributed PEMFC Model J. Proc. Control, 20, pp. 292-313, 2010.

[2] M. L. Sarmiento-Carnevali, M. Serra, C. Batlle, Distributed parameter model simulation tool for PEM fuel cells. *V CONAPPICE*, Madrid, 2012.

[3] W. Neubrand, Modellbildung und Simulation von Elektromembranverfahren, Logos-Verlag, 1999.

[4] M. Sarmiento-Carnevali, M. Serra, C. Batlle, Distributed parameter model simulation tool for PEM fuel cells, International Journal of Hydrogen Energy (2013). DOI:10.1016/j.ijhydene.2013.04.015