Physics-based Modeling of PEM Fuel Cell Systems using Modelica

Master Project (30 ECTS)/Semester Project (10 ECTS)

Administrative

Supervision: Dr. Du Wen, Prof. J. Van Herle
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Location: Sion or remotely (travel allowance offered)
Remarks: If interested, please send your CV, with a short motivation letter, to Du Wen.

Project description:

Proton Exchange Membrane Fuel Cells (PEMFCs) are among the most promising clean energy conversion technologies due to their high efficiency, high power density, and fast dynamic response. They are widely considered for applications ranging from transportation and mobile power systems to stationary and hybrid energy systems. However, the design and operation of PEM fuel cell systems remain challenging due to their strong coupling between electrochemical, thermal, fluid, and control domains.

To accelerate system design and reduce reliance on costly experimental test benches, physics-based dynamic modeling plays a crucial role. In particular, equation-based, multi-domain modeling frameworks such as Modelica / OpenModelica enable modular, transparent, and computationally efficient representations of PEMFC stacks and their Balance of Plant (BoP).

Recent work has demonstrated the feasibility of building modular PEMFC system models in OpenModelica, including fuel cell stacks, anode and cathode subsystems, cooling loops, and feedback control, with validation against manufacturer data and experimental polarization curves. Building upon this foundation, further development, extension, and validation of PEMFC models are required to support advanced system studies, control design, and integration into larger energy system simulations.

This project will address these challenges from system level modeling and optimization and will be done in collaboration with GEM and IPESE.

This project aims to develop and further refine a dynamic PEM fuel cell system model using Modelica, with a focus on physical consistency, modularity, and applicability to energy system studies:

- Physics-based stack voltage modeling (activation, ohmic losses)
- Gas utilization and partial pressure calculation
- Balance of Plant (air supply, hydrogen supply, cooling)
- Feedback control (e.g., PI-based current and flow control)
- Validation against manufacturer data and load profiles

The student will extend, adapt, or improve this model depending on their background and project scope.

Your tasks:

- Understanding the physical principles and system-level operation of PEM fuel cell systems
- Studying and reproducing an existing OpenModelica PEMFC system model

- Further developing or extending PEMFC stack and BoP sub-models (e.g. thermal, flow, or control aspects)
- Validating model behavior against reference polarization curves or operating scenarios
- Documenting modeling assumptions, limitations, and results in a structured technical report

Skills:

- Background in energy systems, fuel cells, thermodynamics, or control
- Interest in model-based system simulation
- Programming experience (Modelica, MATLAB/Simulink, Python)
- Ability to interpret technical literature and write clear reports