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Advanced Power Systems and Controls Laboratory

Dynamic Thermal Model of Polymer Electrolyte Membrane (PEM) Fuel Cell

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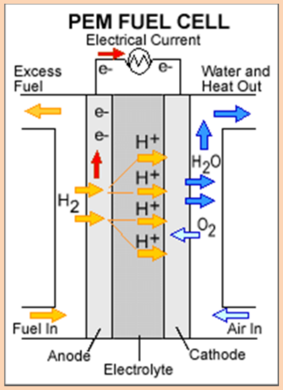
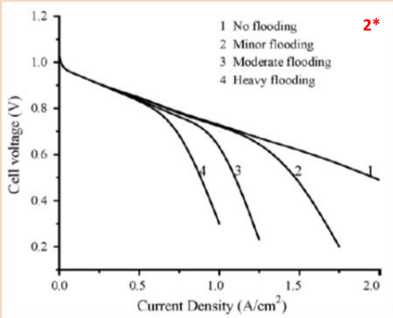




$$H_2 \rightarrow 2H^+ + 2e^-$$ [1*]

$$4H^+ + 4e^- + O_2 \rightarrow 2H_2O$$

Motivation:

To mitigate flooding issue by thermal and water management to improve the performance of a PEM fuel cell

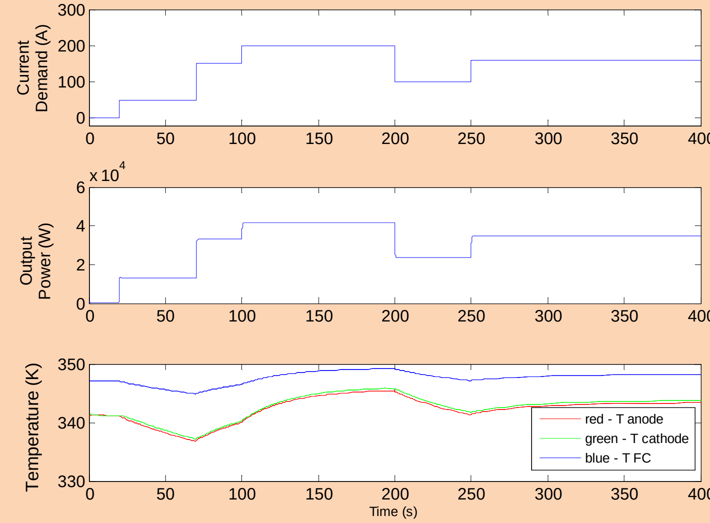
Objectives:

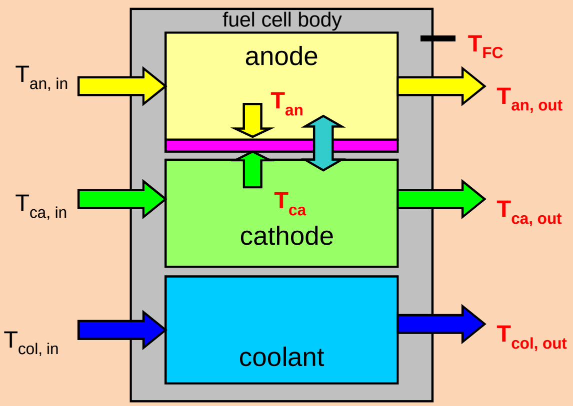
- Develop a fuel cell stack model that includes dynamic thermal and two phase water transport phenomena for control design
- Use decentralized SISO control for MIMO system

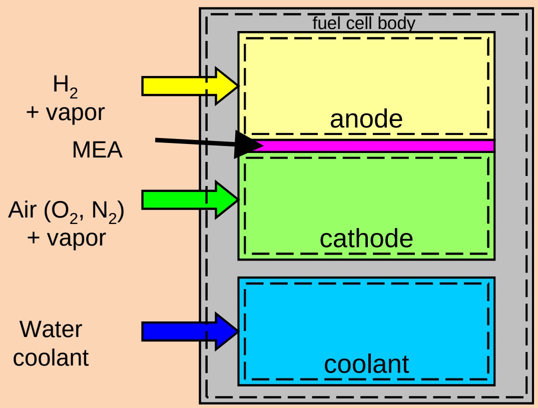
Methodology:

- First law of thermodynamics: conservation of energy
- Four lumped control volumes
- RGA analysis for decentralized SISO control

Simulation Results







CV 1: fuel cell body + MEA

CV 2: anode gasses

CV 3: cathode gasses + liquid water

CV 4: water coolant

RGA Analysis

$$\begin{bmatrix} P_{net} \\ T_{stack} \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_{cmpr} \\ \dot m_{coolant} \end{bmatrix}$$

- The decentralized SISO control can be applied to control the MIMO system under high coolant temperatures and high current operations
- RGA suggests pairing T_{stack} and $m_{coolant}$, and P_{net} and V_{cmpr}

1st Law Thermodynamics:

$$\frac{dE}{dt} = Q_{net} + W_{net} + \sum(\dot m_{in} h_{in}) - \sum(\dot m_{out} h_{out})$$

CV 1: $$m_{FC}\, Cp_{FC} \frac{dT_{FC}}{dt} = Q_{produced} - Q_{An,conv} - Q_{Ca,conv} - Q_{Cl,conv}$$

CV 2: $$\frac{dE_{An}}{dt} = Q_{An,conv} + h_{An,in} - h_{An,out}$$

CV 3: $$\frac{dE_{Ca}}{dt} = Q_{Ca,conv} + h_{Ca,in} - h_{Ca,out}$$

CV 4: $$Q_{conv,cl} = \dot m_{cl}\left[(T_s - T_{m,i}) - (T_s - T_{m,o})\right]$$

$$T_{m,o} = T_s - \left[\exp\left(-\frac{h_{Cl} A_{Cl}}{\dot m_{Cl} C_{Cl}}\right)\right](T_s - T_{m,o})$$

Contribution:

- Dynamic thermal model for control application
- Decentralized SISO controller

Future Work:

- Design and analysis gas diffusion layer (GDL) to reduce water saturation
- Model water transport in PEM fuel cell

1*. http://www.eoearth.org/article/Fuel_cells

2*. H. Kim, T. Ha, S. Park, K. Min, M. Kim, Visualization study of cathode flooding with different operating conditions in a PEM unit fuel cell, Procceedings Fuel Cell 2005, Ypsilanti, Michigan

3*. B. Hadisujoto, R. Refai, D. Chen, T. J. Moon, Dynamic Thermal Model of PEM Fuel Cells for MIMO Control Design, Dynamic Systems and Control Conference, Cambridge, MA, 2010.