Vehicle Propulsion Systems
Lecture 09

Fuel Cell Modeling – Some More Details

Lars Eriksson
Associate Professor (Docent)

Vehicular Systems
Linköping University

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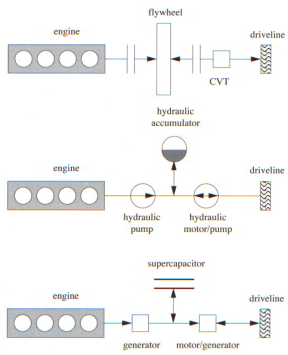
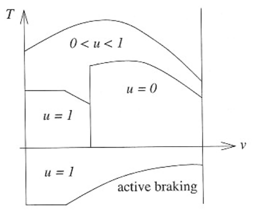
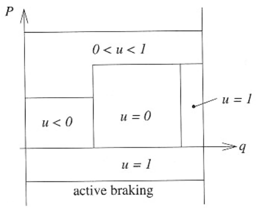
Short Term Storage Systems



Heuristic Control Approaches

- Parallel hybrid vehicle (electric assist)

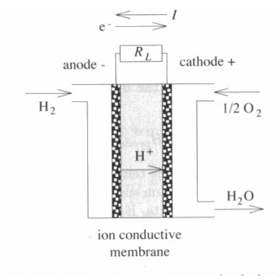


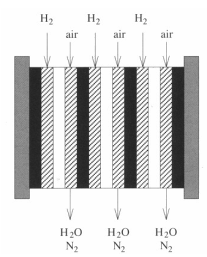


- Determine control output as function of some selected state variables:
  vehicle speed, engine speed, state of charge, power demand, motor speed, temperature, vehicle acceleration, torque demand

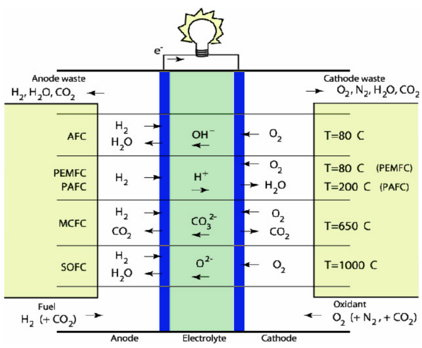
Fuel Cell Basic Principles

- Convert fuel directly to electrical energy
- Let an ion pass from an anode to a cathode
- Take out electrical work from the electrons
- Fuel cells are stacked ($U_{cell} \leq 1$V)





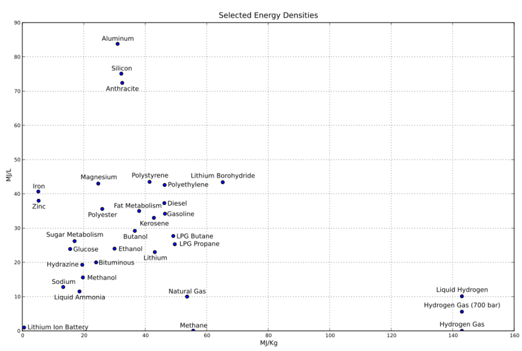
Overview of Different Fuel Cell Technologies



Hydrogen Fuel Storage

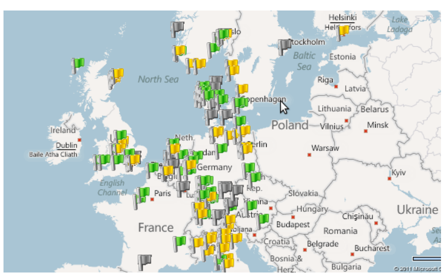
- Hydrogen storage is a challenging task.
- Some examples of different options.
  - High pressure bottles – 700 bar
  - Liquid phase – Cryogenic storage, -253°C.
  - Metal hydride
  - Sodium borohydride $NaBH_4$

Energy Contents – Hydrogen and others



Towards the Hydrogen Society

- Hydrogen filling stations in Europe. in operation planned out of operation



Oslo is pushing for H_2 development in Scandinavia

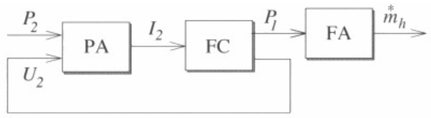
Towards the Hydrogen Society

- November 21, 2011: Oslo's third H_2 refueling station.
- Refueling time 3 min, pressure 70 bar.
- Electrolysis of H_2 from water. 50/5 cars per day/hour.

- H2moves Scandinavia cars:
  - 10 Mercedes-Benz B-class F-CELL from Daimler, range 380 km
  - 2 Hyundai ix35 FCEV, range 525 km
  - 5 Think city cars. Originally a battery electric car, now equipped with a fuel cell range extender, allowing a 250 km range

Quasistatic Modeling of a Fuel Cell

- Causality diagram



- Power amplifier (Current controller)
- Fuel amplifier (Fuel controller)
- Standard modeling approach

Fuel Cell Thermodynamics

- Starting point reaction equation

$$H_2 + \frac{1}{2} O_2 \Rightarrow 2\, H_2 0$$

- Open system energy – Enthalpy H

$$H = U + pV$$

- Reversible energy – Gibbs free energy G

$$G = H + TS$$

- Open circuit cell voltages

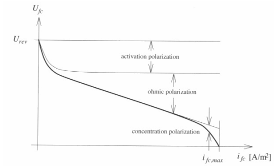
$$U_{rev} = -\frac{\Delta G}{n_e\, F}, \qquad U_{id} = -\frac{\Delta H}{n_e\, F}, \qquad U_{rev} = \eta_{id}\, U_{id}$$

  F – Faradays constant ($F = q\, N_0$)
- Under load

$$P_l = I_{fc}(t)\,(U_{id} - U_{fc}(t))$$

Fuel Cell Performance – Polarization curve

- Polarization curve of a fuel cell
  Relating current density $i_{fc}(t) = I_{fc}(t)/A_{fc}$, and cell voltage $U_{fc}(t)$



  Curve for one operating condition
- Fundamentally different compared to combustion engine/electrical motor
- Excellent part load behavior
  –When considering only the cell

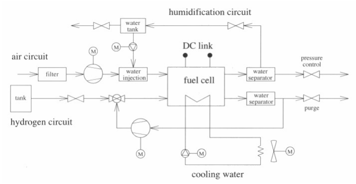
Fuel Cell System Modeling

- Describe all subsystems with models

$$P_2(t) = P_{st}(t) - P_{aux}(t)$$

$$P_{aux} = P_0 + P_{em}(t) + P_{ahp}(t) + p_{hp}(t) + P_{cl}(t) + p_{cf}(t)$$

  em–electric motor, ahp – humidifier pump, hp – hydrogen recirculation pump, cl – coolant pump, cf – cooling fan.



- Submodels for:
  Hydrogen circuit, air circuit, water circuit, and coolant circuit

Modeling of fuel cells from first principles

Modeling is done on the white board.