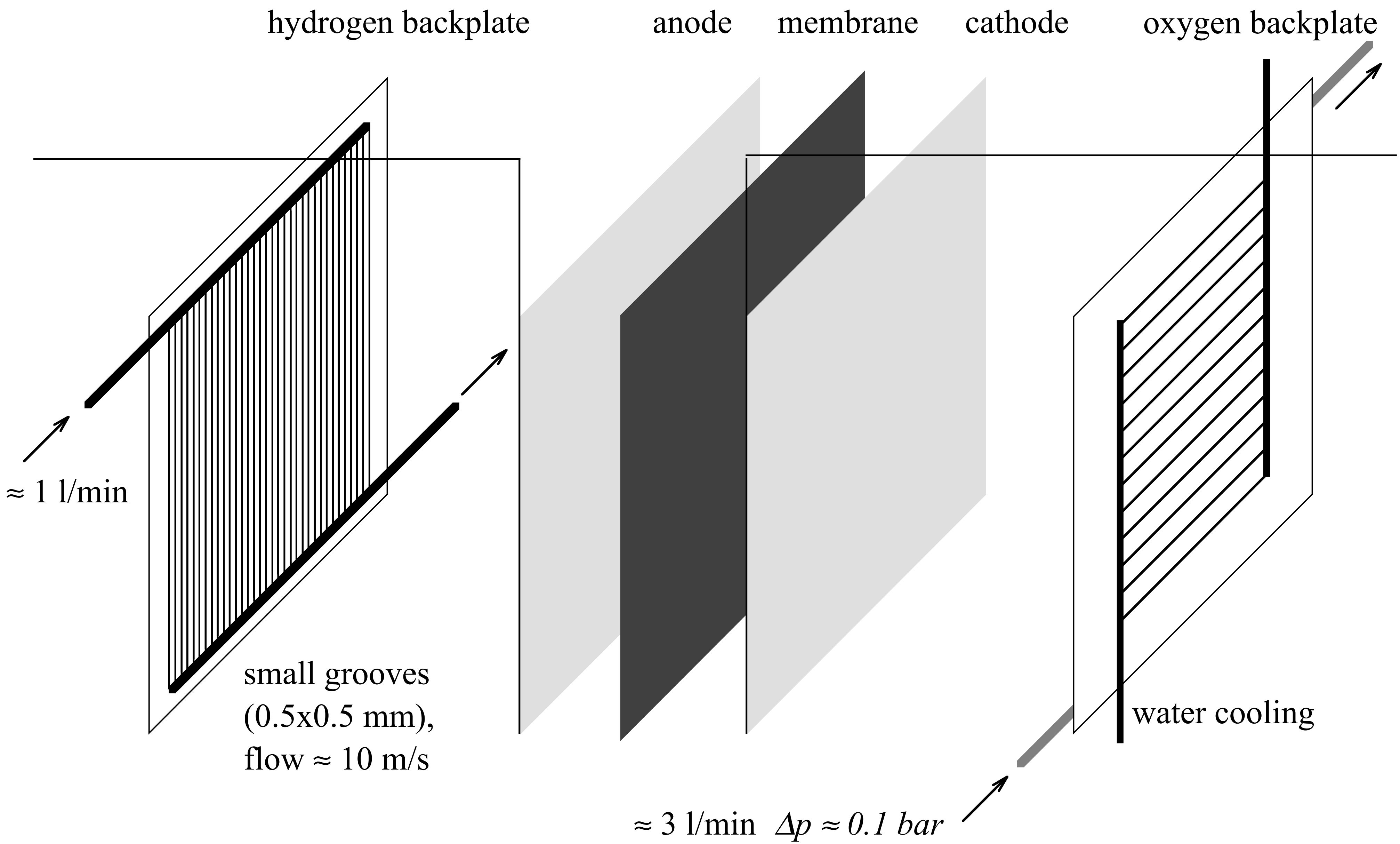
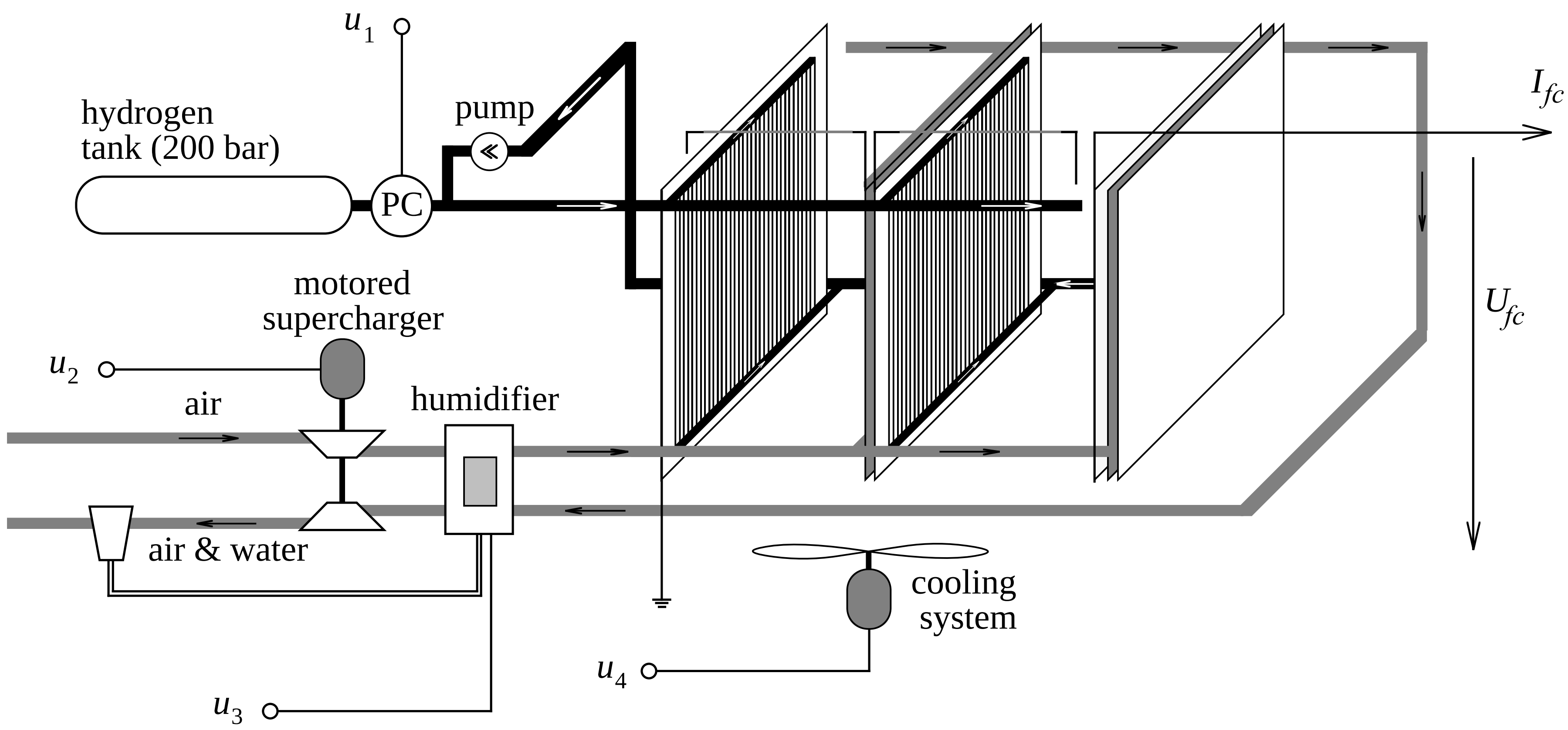
Modeling and Control of FC Systems



Print PIC2_CAD


u1
hydrogen
tank (200 bar)
PC
pump
Ifc
Ufc
motored
supercharger
u2
air
humidifier
air & water
cooling
system
u4
u3

Solve implicit loops using affine approximation for the cell voltage and noting that the auxiliary power is typically linear in the cell current

Cell voltage

$$U_{fc} = f(I_{fc}) \cdot N$$

Cell current

$$I_{fc} = \frac{P_{el} + P_{aux}}{U_{fc} \cdot N}$$

$P_{el} =$ input (desired net power)

Auxiliaries

$$P_{aux} = g(\dot{m}_{air}, \dot{m}_{H2})$$

e.g. $$P_{aux,air} = \dot{m}_{air} \cdot c_{p,air}\, T_1 \,(\pi^{(\kappa_{air}-1)/\kappa_{air}} - 1)\frac{1}{\eta_C\, \eta_{EM}}$$

Massflows

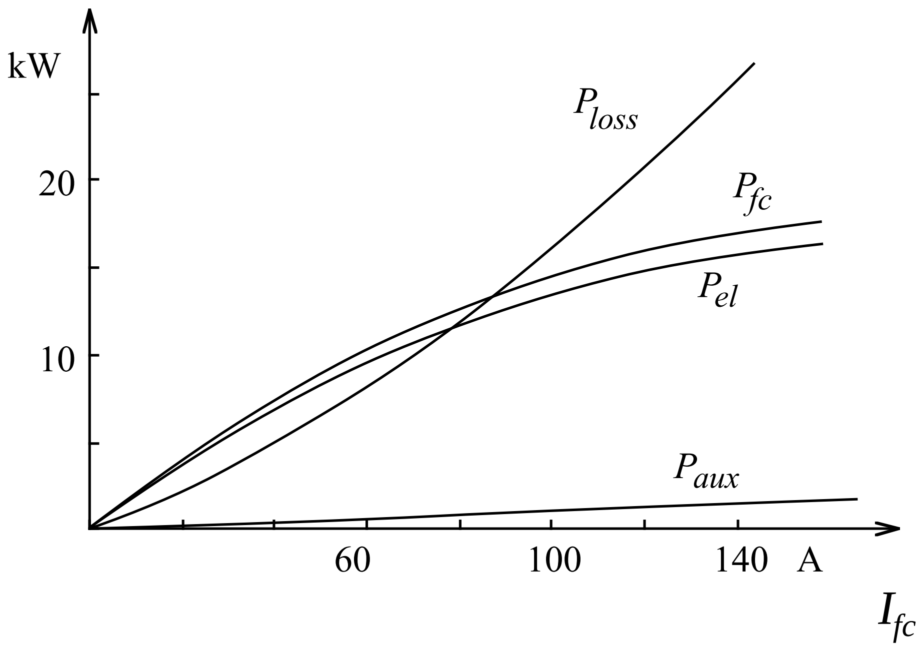
$$\dot{m}_{air} = \lambda_{air} \cdot N \cdot \frac{M_{air}/0.21}{4 \cdot F} \cdot I_{fc}$$

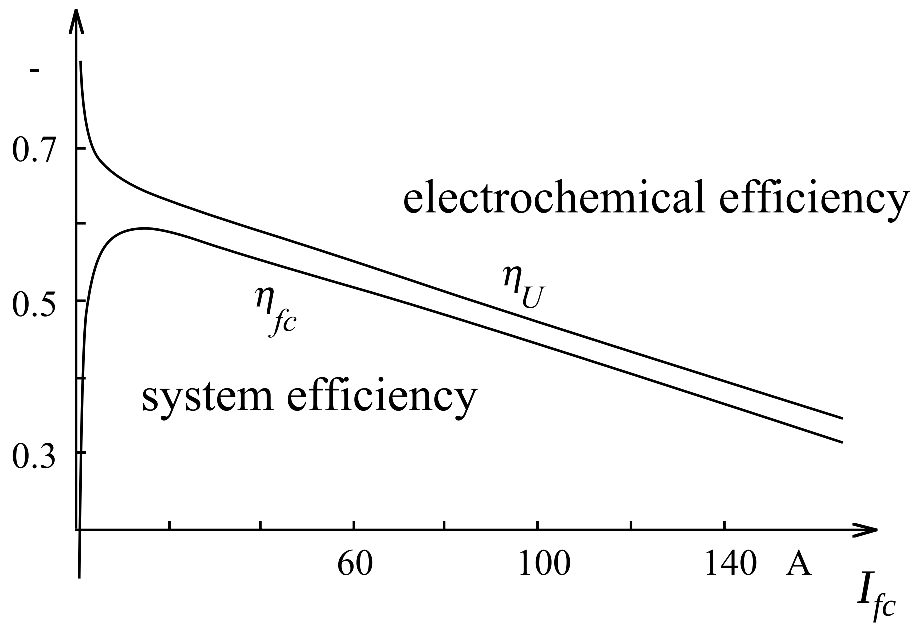
$\lambda_{air} \geq 1$ (typically 1.5 … 2)

$$\dot{m}_{H2} = \lambda_{H2} \cdot N \cdot \frac{M_{H2}}{2 \cdot F} \cdot I_{fc}$$

$\lambda_{H2} \geq 1$ (typically 1.1 … 1.2)

Result: $$I_{fc} = \frac{N\,(U_0 - k_{aux}) - \sqrt{N^2\,(U_0 - k_{aux})^2 - 4\,N\,R_{fc}\,P_{el}}}{2\,N\,R_{fc}}$$





Remarks:
- Cooling not trivial (several 10 kW at rated loads), water-cooling requires de-ionized water
- FC efficiency at low loads very poor due to auxiliaries

Dynamic effects (estimates of the time constants or delays)

O(10^{-9}*s*) electrochemistry (dissociation and recombination kinetics)

O(10^{-9}*s*) RC-element (electrode/membrane system)

O(10^{-1}*s*) hydrogen and air manifolds (mass storages)

O(10^{0}*s*) membrane water content

O(10^{0}*s*) flow control/supercharging devices

O(10^{2}*s*) cell and stack temperatures

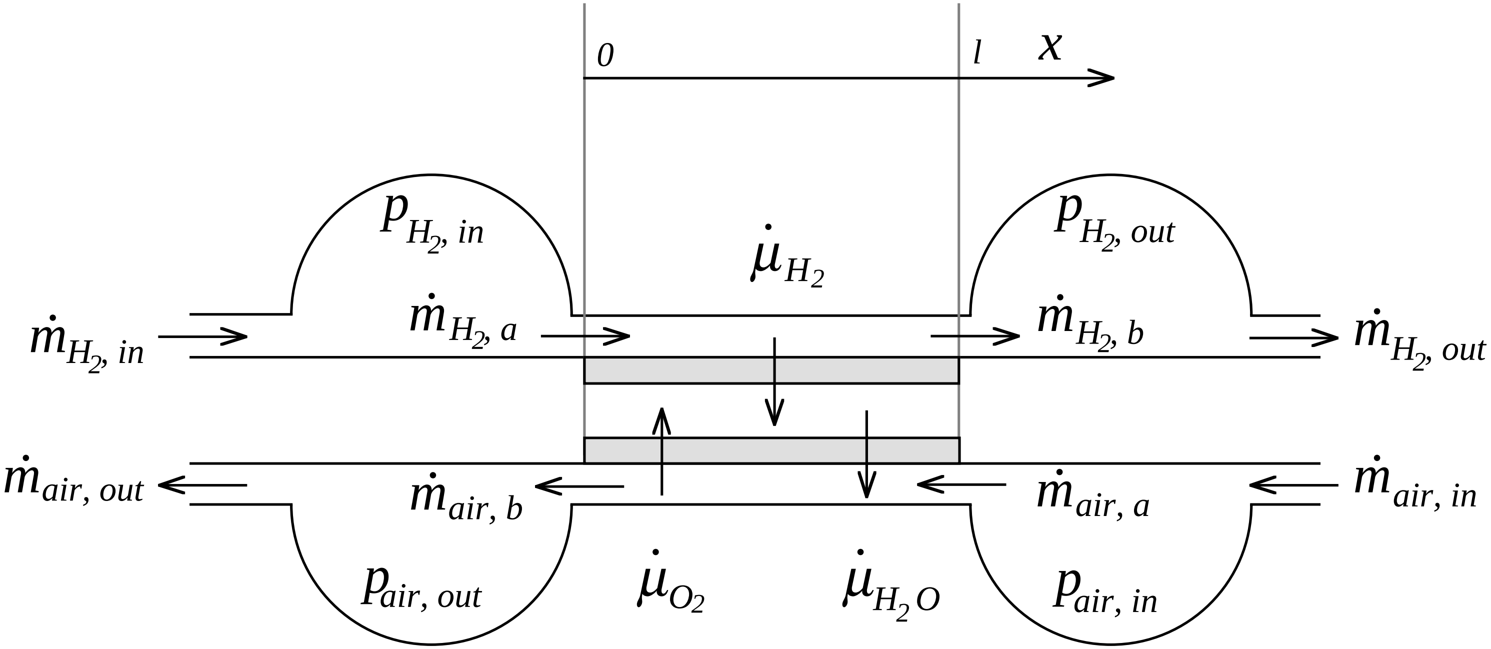
Consequence:

static function — dynamically varying parameters

$$U_{fc}(t) = f(i_{fc}(t), T_{fc}(t), p_{O_2}(t), p_{H_2}(t), x_{H_2O}(t), \ldots)$$

output — input

- Manifolds described by classical "empty-and-filling" dynamics
- Between the manifolds *laminar flow* takes place in the many narrow grooves
- Massflow not constant along the x-direction (diffusion into/from the membrane)



$$\dot{\mu}_{H_2} = M_{H_2} I(t)/(2 \cdot F) \quad \text{etc.}$$

- Laminar flow-law

$$\dot{m}_{H_2}(x,t) = -k_{H_2} \cdot \frac{\partial p_{H_2}(x,t)}{\partial x}$$

- Flow incompressible but not constant due to the electrochemistry; assume uniform reaction intensity $\dot{\mu}_{\dots}$ along x

$$\dot{m}_{H_2}(x,t) = \dot{m}_{H_2,a}(t) - \frac{x}{l} \cdot \dot{\mu}_{H_2}(t)$$

- Resulting pressure profile

$$p_{H_2}(x,t) = p_{H_2,in}(t) - \frac{x}{k_{H_2}} \cdot \dot{m}_{H_2,a}(t) + \frac{x^2}{2\,k_{H_2}\,l}\,\dot{\mu}_{H_2}$$

- Resulting mass-flows

$$\dot{m}_{H_2,a}(t) = \frac{k_{H_2}}{l}\left(p_{H_2,in}(t) - p_{H_2,out}(t)\right) + \frac{1}{2} \cdot \dot{\mu}_{H_2}(t)$$

$$\dot{m}_{H_2,b}(t) = \frac{k_{H_2}}{l}\left(p_{H_2,in}(t) - p_{H_2,out}(t)\right) - \frac{1}{2} \cdot \dot{\mu}_{H_2}(t)$$