NTNU

Innovation and Creativity

Control of a Fuel-Cell Powered DC Electric Vehicle Motor

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Outline

Currently Available Models and Control Strategies

- Many current models focus on the lab.
  Common assumptions:
  - *Current* is a manipulated variable, *or*
  - *Voltage* is a manipulated variable.
- This is not possible in an autonomous fuel cell system.
  These models are valid in their context, but have to be adapted for control.

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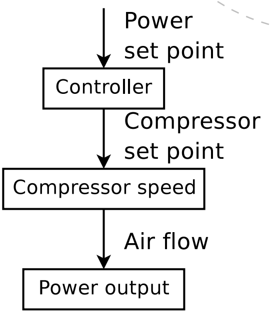
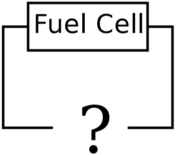
- This is not possible in an autonomous fuel cell system.
  These models are valid in their context, but have to be adapted for control.
- Manipulated variables are sometimes badly chosen:
  - Controlling power with air compressor speed, through oxygen concentration
- The external circuit is often not given its importance

Controlling Power with Air Flow



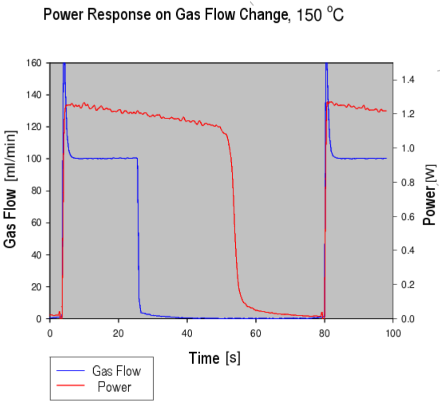
Controlling Power with Air Flow

— The system is only “half”



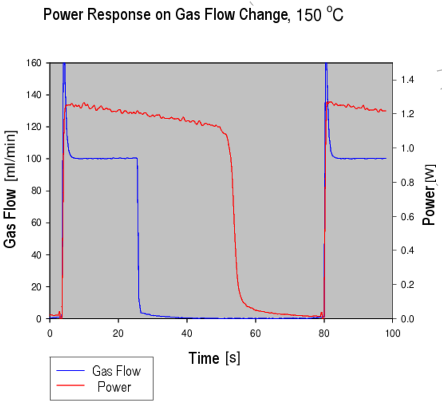
Controlling Power with Air Flow

- The system is only “half”
- The dynamics of oxygen concentration have been studied by Johansen (2003)
- Oxygen has a strong effect, but only at the mass-transport limit; it is non-linear and asymmetric



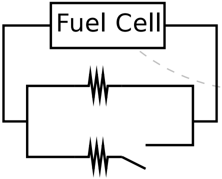
Controlling Power with Air Flow

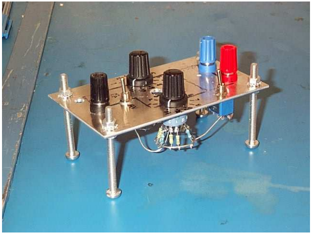
- The system is only “half”
- The dynamics of oxygen concentration have been studied by Johansen (2003)
- Oxygen has a strong effect, but only at the mass-transport limit; it is non-linear and asymmetric
- This approach will not be able to meet performance requirements for PEM fuel cells.



Manipulated Variables

— Types of manipulated variables:
  - Resistances and switches;





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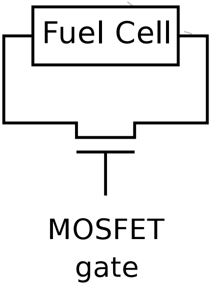
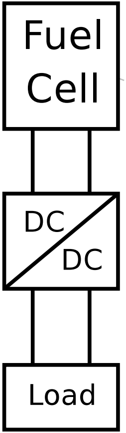


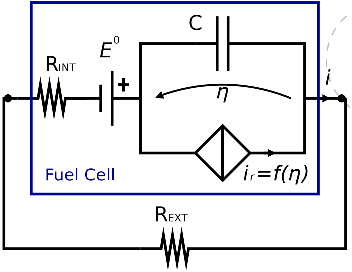
Manipulated Variables

- Types of manipulated variables:
  - Resistances and switches;
  - Rheostat or transistors (e.g. MOSFETS)
- More efficiently:
  - DC/DC converters (buck-boost)
  - Sliding-mode control
  - Pulse-width modulation (PWM)



Proposed Model

- A typical model used for a PEM/PBI fuel cell has cathode, internal resistance, reversible voltage
- Anodic overvoltage is assumed less important, and is discarded. This assumption is not valid with CO.



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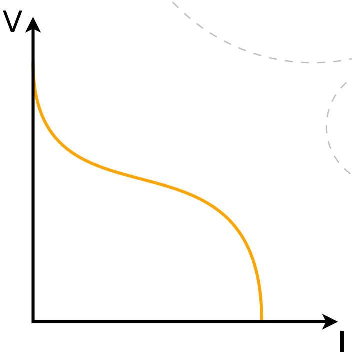

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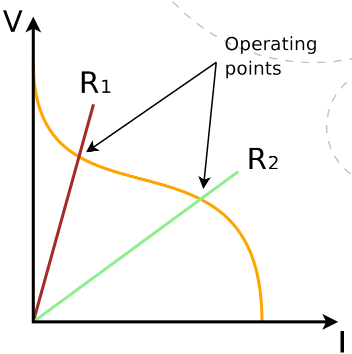

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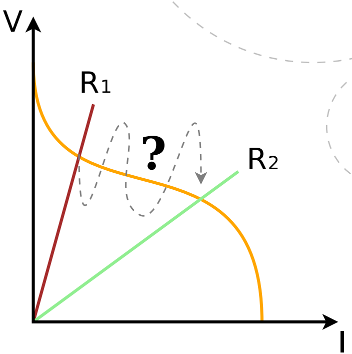

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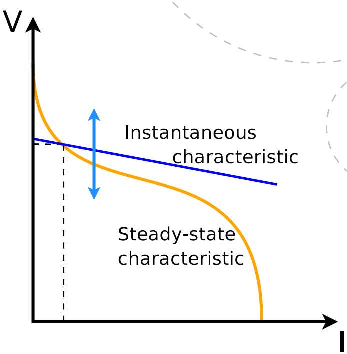

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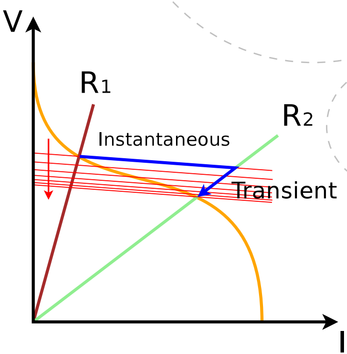

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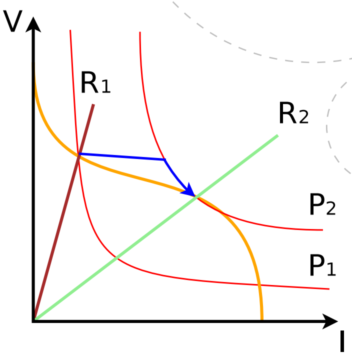
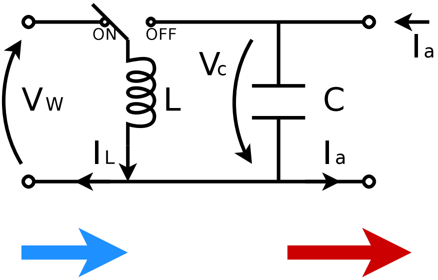
- Steady-state polarisation curve and instantaneous characteristic: path of transients
- *Perfect power control of fuel cells* is in theory always possible!



DC/DC Converters

- Convert power in the right voltage/current ratio
- Over 500 topologies
- *Buck-boost* converters are sufficient for us



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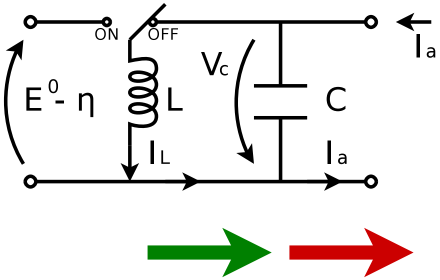
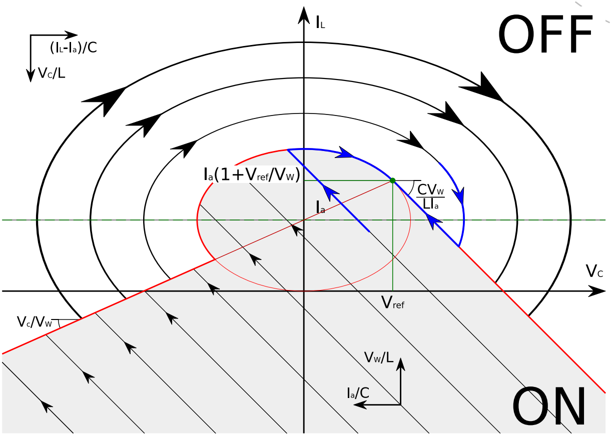


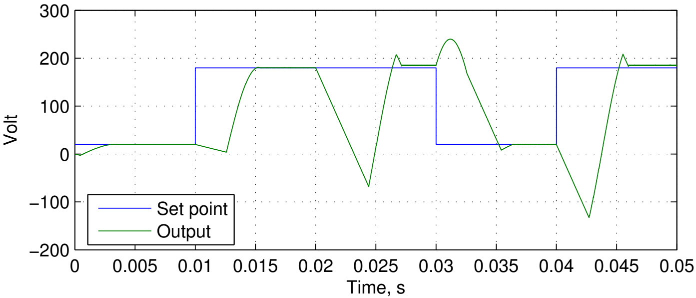
Controlling the Converter

- Switching rules based on measurements: I_L, V_C, V_W, I_a
- Calculations should be finished in at most 0.1 ms.



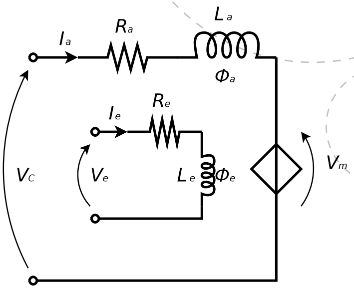
Simulation

- Features an *inverse response* for steps in reference
- External current I_a stepped from 20 to 180 A at time 0.02 s
- Overshoots can be reduced with higher computational speed



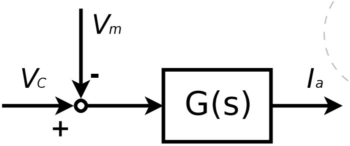
DC Motors

- We manipulate the input voltage to control the armature current
- Permanent magnets (constant magnetic field)



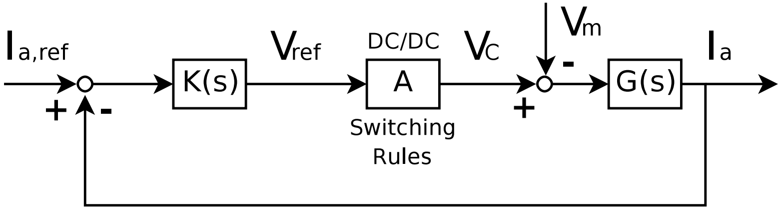
DC Motors

- We manipulate the input voltage to control the armature current
- Permanent magnets (constant magnetic field)
- Main disturbance: the induced voltage *e*, proportional with speed, on the input
- $G(s) = \frac{1}{L_a s + R_a}$



Cascade Control Layout

- I_a is proportional to the motor's output torque
- I_a is controlled by manipulating the converter's output voltage in a cascade control structure
- $K(s)$ is a PI controller tuned with Skogestad's rules

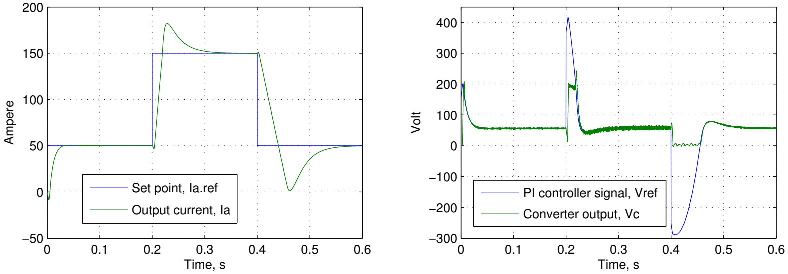


Cascade Control Simulation

— Transients are over by 0.2 seconds

— Input is limited between 0 and 200 volt

— Slow: needs about 200 seconds to calculate this transient



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Conclusions

- It is possible to *instantaneously step the power output* of a fuel cell across its whole nominal range under very general conditions
- A set of *switching rules* can provide a good control strategy for a DC/DC converter connected with a fuel cell
- Using the converter controller as an actuator, it is possible to *control the torque output* of an electric motor
- Simulation time is however slow. *Pulse-width modulation* seems to provide an improvement, allowing simulation of standard *driving cycles*.

Acknowledgements

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STATOIL

Norges forskningsråd

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Thank you for your attention!