Karlsruhe Institute of Technology

# Holistic modeling and optimization of vanadium redox flow batteries

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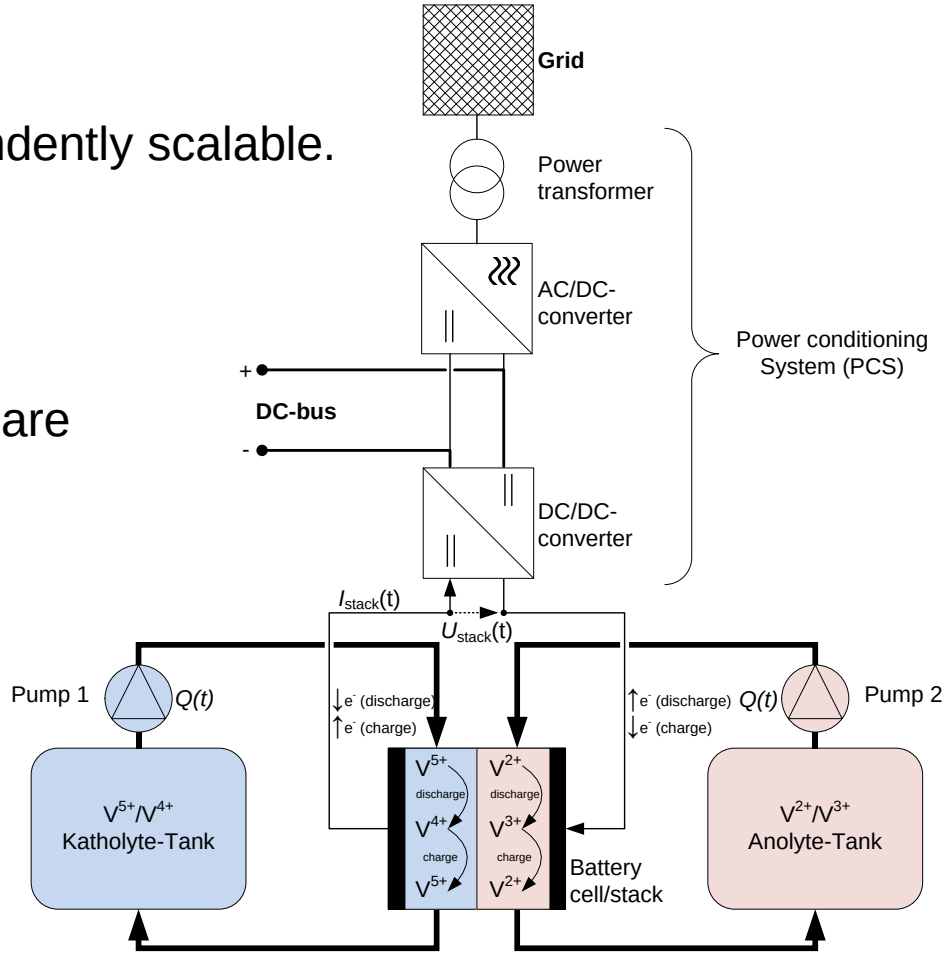
INSTITUTE OF ELECTRICAL POWER SYSTEMS AND HIGH-VOLTAGE TECHNOLOGY (IEH)

# Why model based system analysis?

- Vanadium Redox Flow (VRF) technology is very promising for large energy storage systems
  - Power and energy independently scalable.
  - Excellent cycle stability.
  - No self discharge.
  - **But:** VRF battery systems are very complex.



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# Aims of model based system analysis

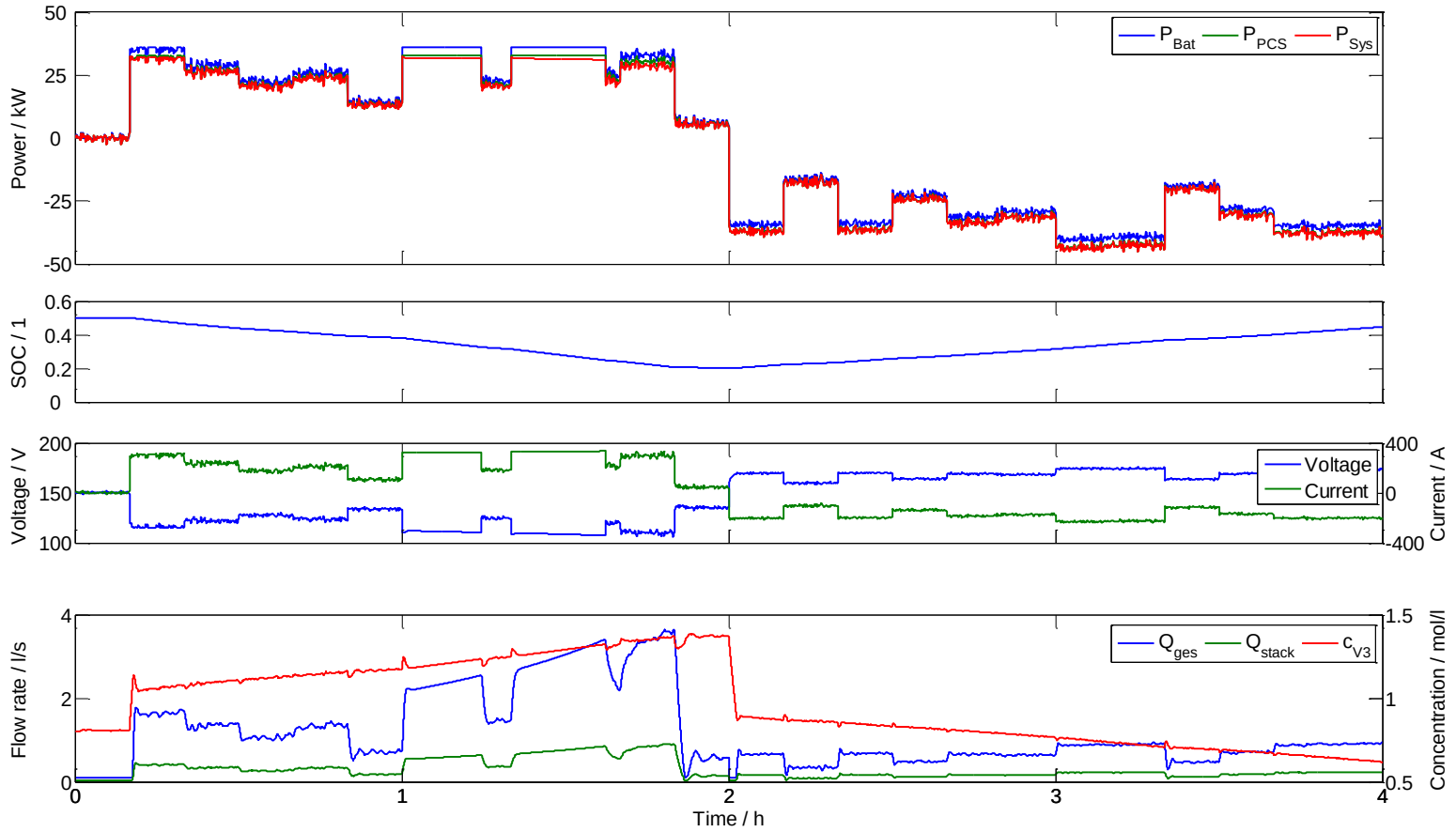
Holistic modeling approach to include influences, the subsystems have on each other.

- Identify optimal hydraulical and electrical system design
- Identify optimal system operation mode
- Suppress shunt currents

# Introduction of holistic modeling approach

- Electrochemical model:
  - Implementation of Nernst equation with Simulink blocks
- Hydraulical model:
  - Implementation with Simscape elements
- Power conditioning system:
  - Separate simulation with high resolution
  - Efficiency considered using look-up tables in holistic model
- Control system:
  - Implementation of charge/discharge controller
  - Implementation of electrolyte flow controller

# Simulation results



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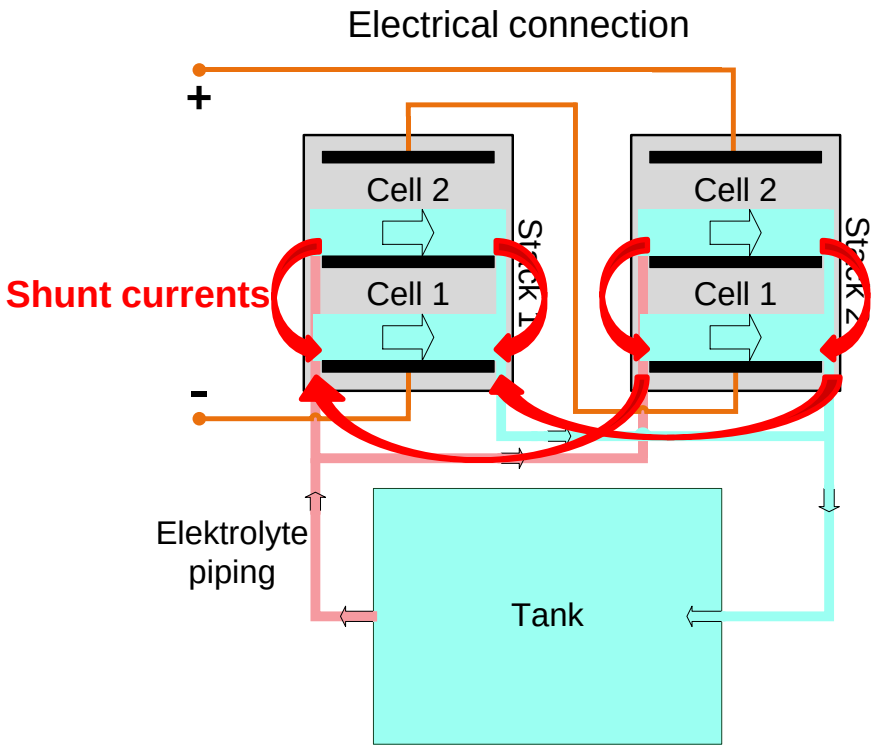
# Model based optimization: PCS

- **Question:** How many battery stacks should be connected in series?
- More stacks in series:
  - Higher system voltage → Higher efficiency of PCS
  - **But:** Higher losses caused by shunt currents.

# Excursion: Shunt currents

- All battery electrodes are connected by the liquid electrolyte
  - Electrolyte is a bad insulator  (approx. 50 S/m)
  - Shunt currents between different cells and stacks



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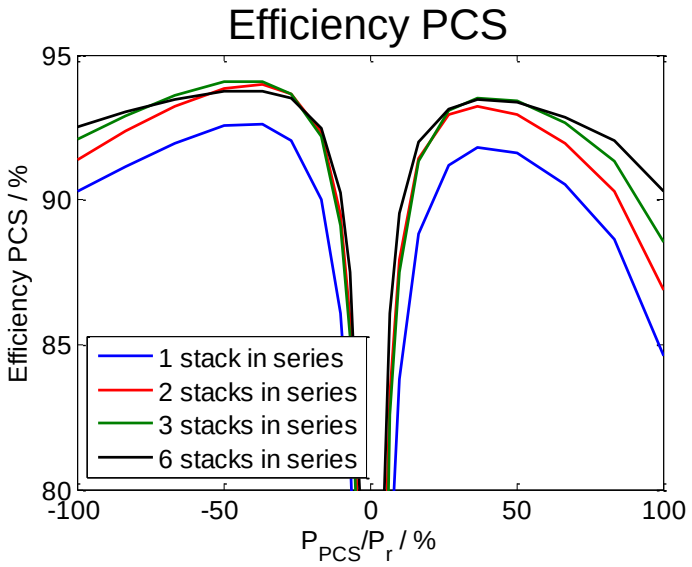
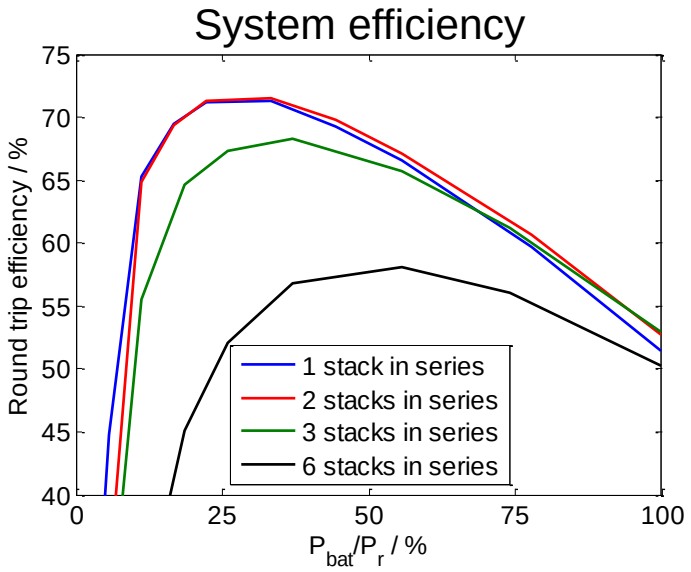
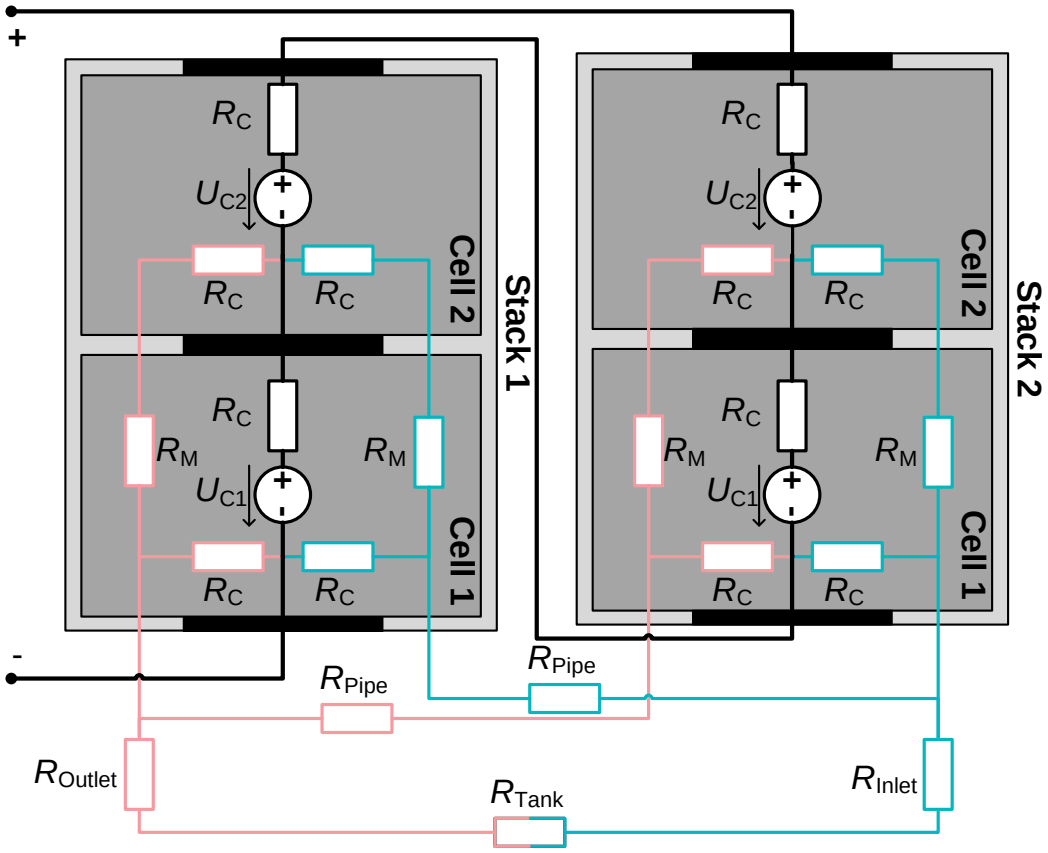



- **In this case:** Series connection of two stacks is optimal.

# Model based optimization: Shunt currents

- **Question:** How can system design variations lower shunt currents?
- Shunt current model:



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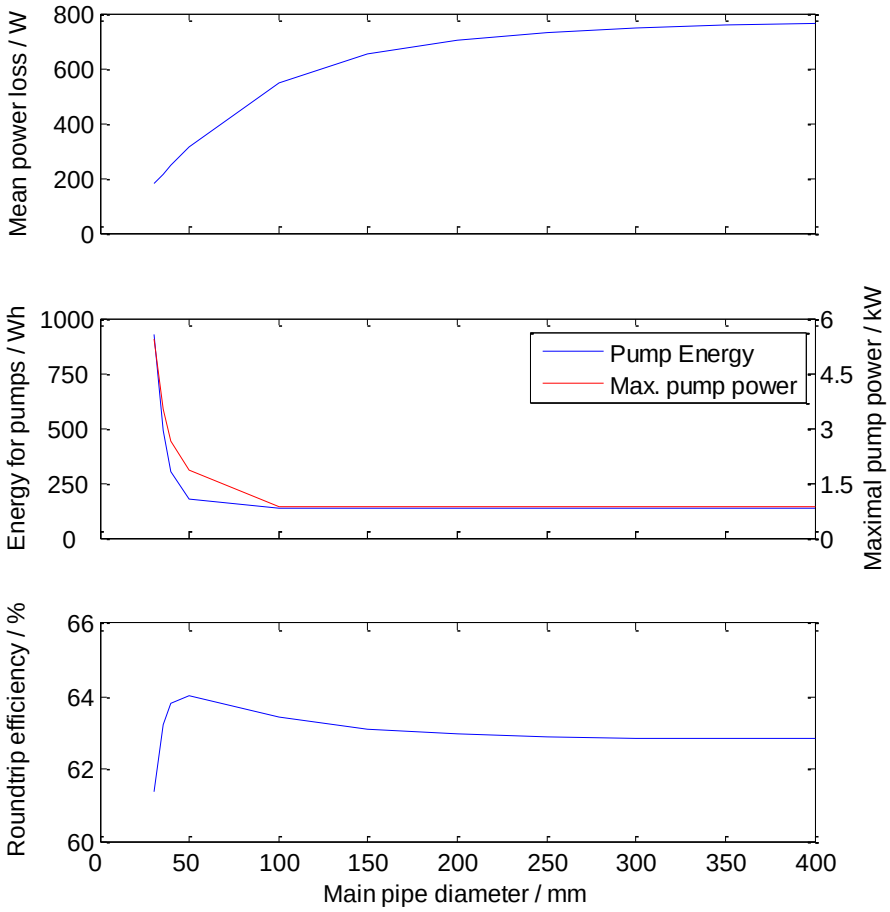
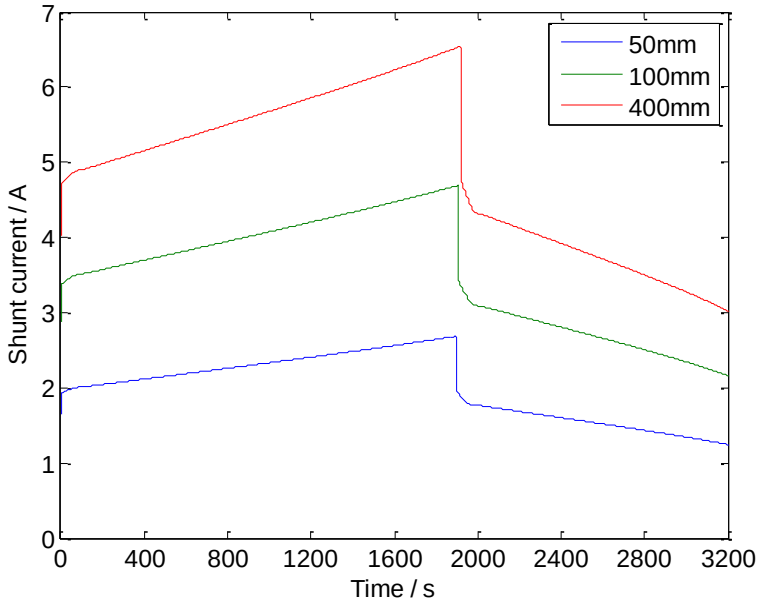
# Shunt currents: Possible approaches

- Design variations in hydraulic circuitry
  - Narrower pipes reduce shunt currents but increase pump losses
- Assignment of stacks to different tanks
  - More complicated piping, higher pump losses
- Bigger cell membrane area
  - Problems regarding manufacturing
- Hydraulical series connection of cells and/or stacks
  - Proper control of electrolyte flow more difficult

# Optimization results for main pipe diameter




- **Optimal main pipe diameter:**

  $d_{\mathrm{Main}} = 50$ mm



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# Summary

- Model based system analysis can help to decrease the costs of VRF-batteries by predicting the optimal system design.
- Shunt currents are a technical issue that prevent higher system voltages and therefore require more expensive special PCS.

# Outlook

- Presented approaches for shunt currents suppression are currently evaluated.
- Model validation using a prototype would be desirable.