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Introduction of a Flow Battery Management System (FBMS)

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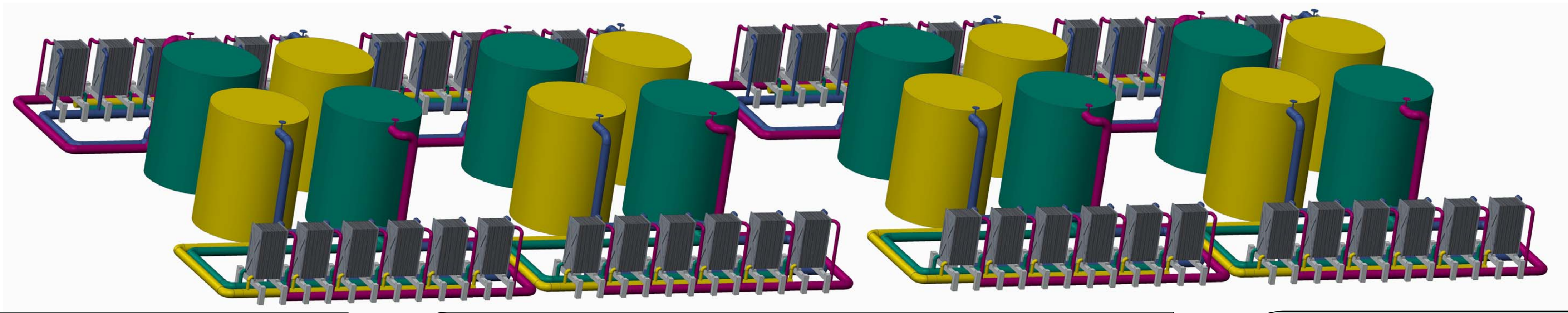
Motivation and objectives

- Flow batteries are a promising but also a complex technology.
  - Power and energy rating are independently scalable.
  - Very low self-discharge in tanks
  - Specific costs decrease with storage capacity.
  - Higher complexity e.g. due to the combination of electric and hydraulic circuits.
- Model-based design and optimization helps to decrease system costs and to increase system efficiency.
- Flow battery management varies from classic battery management:
  - Single cell monitoring and balancing is surplus.
  - Additional tasks like flow rate control and handling of de-activated battery stacks are required.
- In this work, tasks of the FBMS are simulated using an eight module test system:
  - In total -320/+480kW and 1800kWh.
  - Each module consists of two strings with three stacks in series, consisting of 30 cells each.



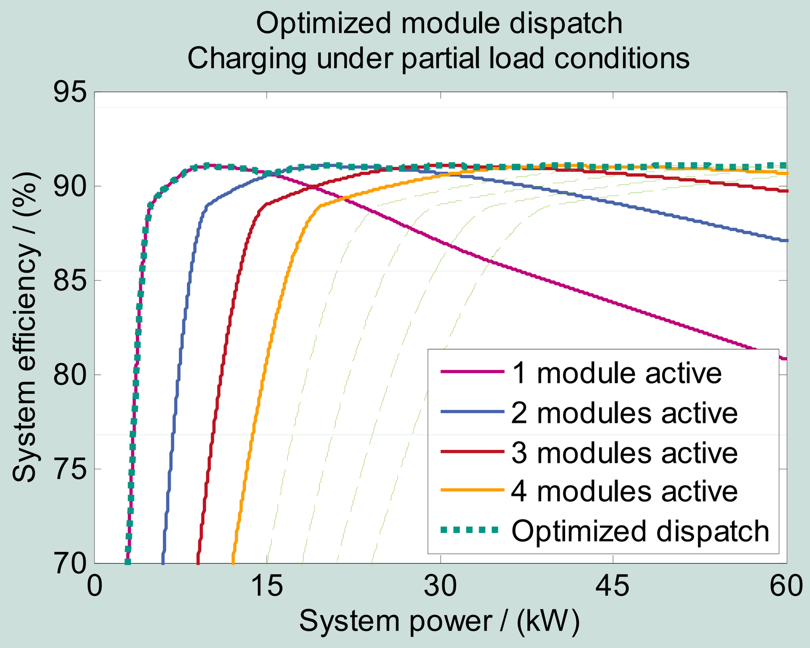
Module dispatch

- Optimization problem with

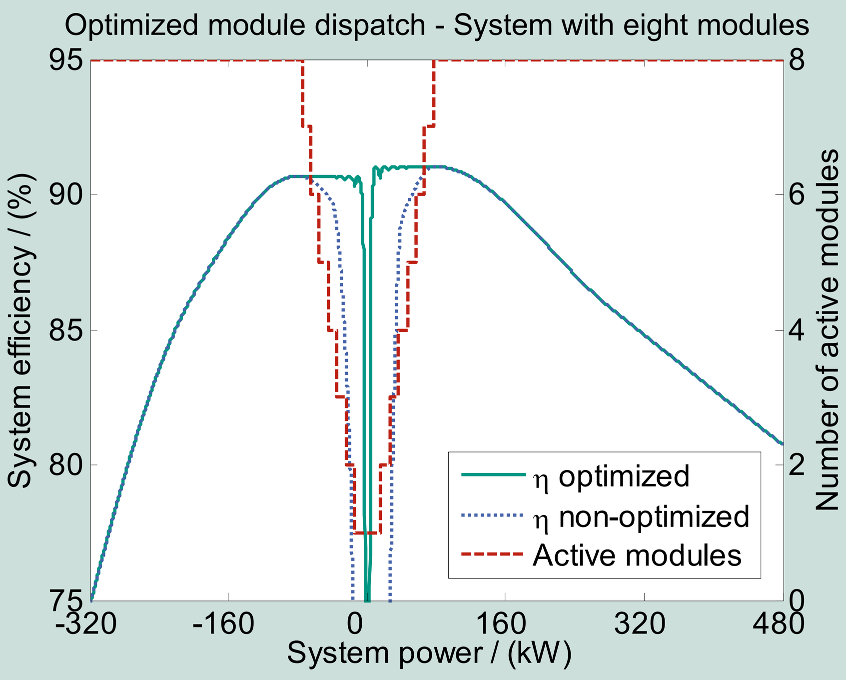
$$\eta_{System}(P_1, P_2, \ldots, P_N) = \frac{\sum_i^N P_i \cdot \eta_{Module}(P_i)}{\sum_i^N P_i}$$

as objective function.

- Optimal solution hard to obtain.
- **Simplification:** Active modules share load equally.
- „Stretch" module efficiency with number of active modules.

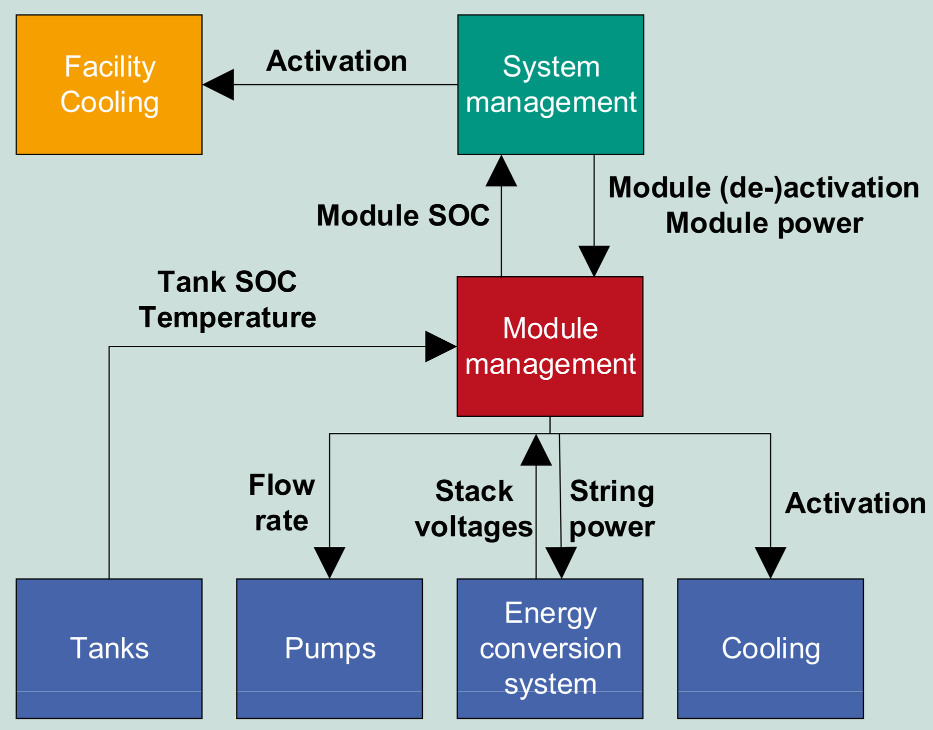


- Strong increase in efficiency especially under partial load conditions.



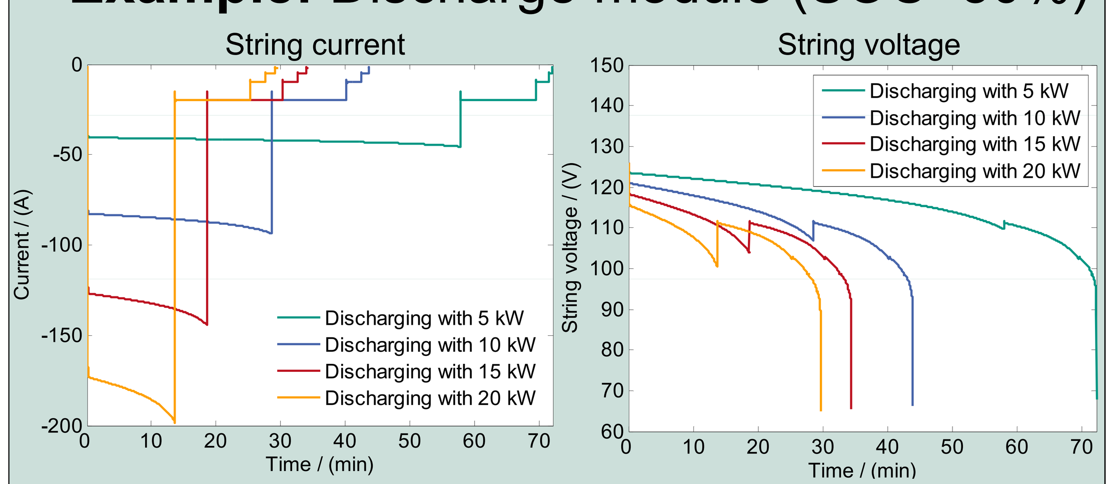
- Proper idle management is required to prevent self-discharge losses in de-activated modules.

FBMS Structure



Idle management

- De-activated modules still contain energy
  → Discharging without pumping.
  → No cooling anymore.
- Determine optimal discharging rate to minimize self-discharge, over-potential losses and thermal problems.
- **Strategy:** Constant power / constant current discharge.
- **Example:** Discharge module (SOC=50%)



$P_{Discharge}$	$W_{Discharge}$	η_{DC}	Duration	ΔT_{Max}
Ideal	5,53 kWh	100 %	N/A	0,00 °C
5 kW	5,28 kWh	95,6 %	72,5 min	0,61 °C
10 kW	5,23 kWh	94,6 %	44,2 min	0,74 °C
15 kW	5,13 kWh	92,9 %	34,8 min	0,98 °C
20 kW	5,02 kWh	90,9 %	30,0 min	1,26 °C
Max.	4,59 kWh	83,0 %	23,6 min	2,32 °C

- Fast discharging of modules is possible without significant more losses or significant temperature inclination.

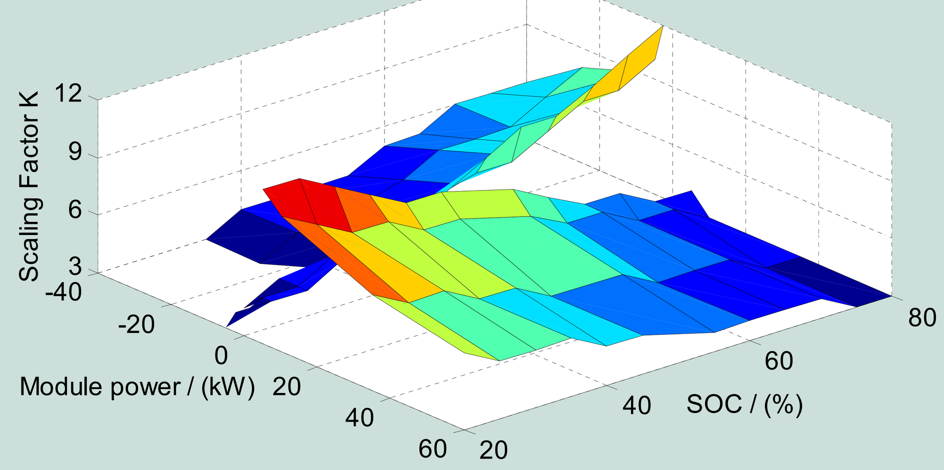
Flow rate control

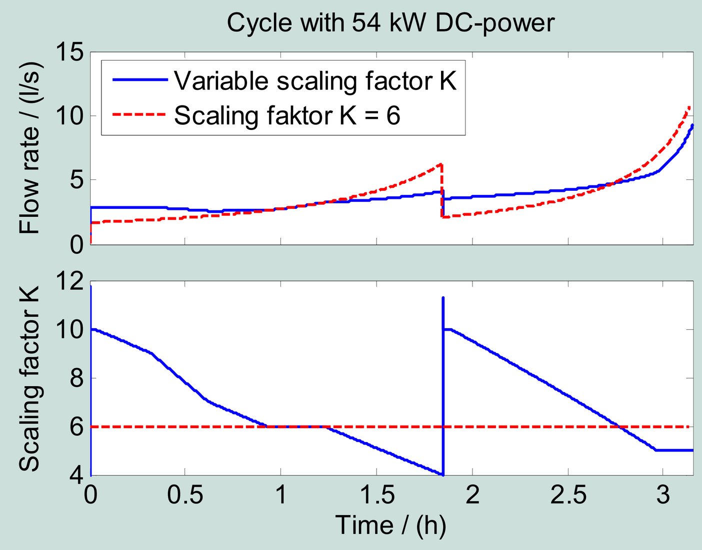
- Model-based optimization to find break-even between additional pump losses and prevented concentration over-potential.
- Concentration over-potential caused
  - by cell SOC deviating from tank SOC.
  - by diffusion layer around porous electrodes.
- Scaled stoichiometric flow rate given by Faraday's first law of electrolysis:

$$Q_{Stack,Charge} = K(SOC, I_{Cell}) \frac{N_{Cell} \cdot I_{Cell}}{F \cdot (1 - SOC) \cdot c_V}$$

$$Q_{Stack,Discharge} = K(SOC, I_{Cell}) \cdot \frac{N_{Cell} \cdot I_{Cell}}{F \cdot SOC \cdot c_V}$$

- Optimal scaling factor *K* ("Flow Factor") depending on *SOC* and load current *I* is derived using model-based optimization.
- Simulation of operation points defined by system power, tank SOC and scaling factor *K*.





- Optimized solution delivers better efficiency and allows for a downsizing of pumps and pipe diameters.