Karlsruhe Institute of Technology

Institute of Electrical Engineering (ETI)
Battery Technology Center
Hermann-von-Helmholtz-Platz 1, Bldg. 420
76344 Eggenstein-Leopoldshafen, Germany
www.batterietechnikum.kit.edu

Elektrotechnisches Institut

Advanced Characterization of a Commercial Scale Vanadium Redox Flow Battery at Controlled Temperature Levels

Felix Schofer[1], Lakshimi Narayanan Palaniswamy[1], Nina Munzke[1], Christian Kupper[1], Frank Säuberlich[2], Marc Hiller[1]
[1]Karlsruhe Institute of Technology, [2]1st Flow Energy Solutions GmbH

01 Motivation

- The efficiency of Vanadium Redox Flow Batteries (VFB) is low when compared to Lithium Ion Batteries
- Higher electrolyte temperatures of a VFB could lead to higher efficiencies [1]
- In the BiFlow project, the electrolyte temperature of a VFB can be controlled using a newly developed Thermal Coupling Module (TCM) [2]
- Developing a control strategy that takes temperature into account requires precise knowledge of the electrical behavior of the VFB at different temperature levels

Fig 1. Installation in Bruchsal, Germany with the VFB (left) and TCM (right)

02 Characterization Methods

- Electrolyte temperature is controlled during tests using the TCM
- Stack resistance R_{Stack} is determined by executing a step profile for the AC-power (Fig. 2)

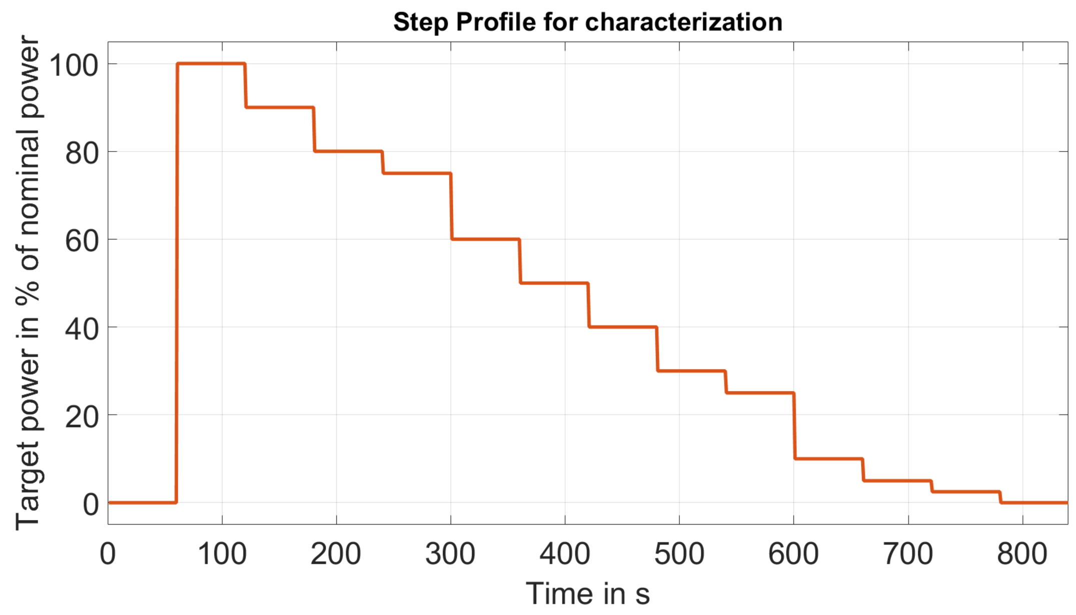

Fig 2. Step profile used to determine internal resistance of the VFB

- Measurements are performed with all permutations of three factors
  - Nominal power: -21 kW / 21 kW
  - SoC Range: 10 % intervals from 0 to 100 % (e.g. 30-40 %)
  - Temperature: 15-20 °C (cold), 30-35 °C (warm), 45-50 °C (hot)
- To determine system efficiency, the VFB was subjected to round trips from 0 to 100 % SoC at 7, 14 and 21 kW target power and the temperature levels mentioned above

03 Round trip analyses

- System is characterized using different efficiencies [3]:
  - Coulomb Efficiency (CE): $\frac{\int I_{\text{Stacks,discharge}}}{\int I_{\text{Stacks,charge}}}$
  - DC Energy Efficiency (DE): $\frac{\int P_{\text{DC,discharge}}}{\int P_{\text{DC,charge}}}$
  - Voltage Efficiency (VE): DE/CE
  - System Efficiency (SE): $\frac{\int P_{\text{AC,discharge}}}{\int P_{\text{AC,charge}} + P_{\text{Aux,charge}} + P_{\text{Aux,discharge}}}$

- CE appears to be lower at higher temperatures, which can be explained with a higher conductivity of the electrolyte
- VE increases with temperature, which is most likely also due to the higher conductivity of the electrolyte
- SE increases significantly with temperature, due to a decrease in pump losses at high temperatures

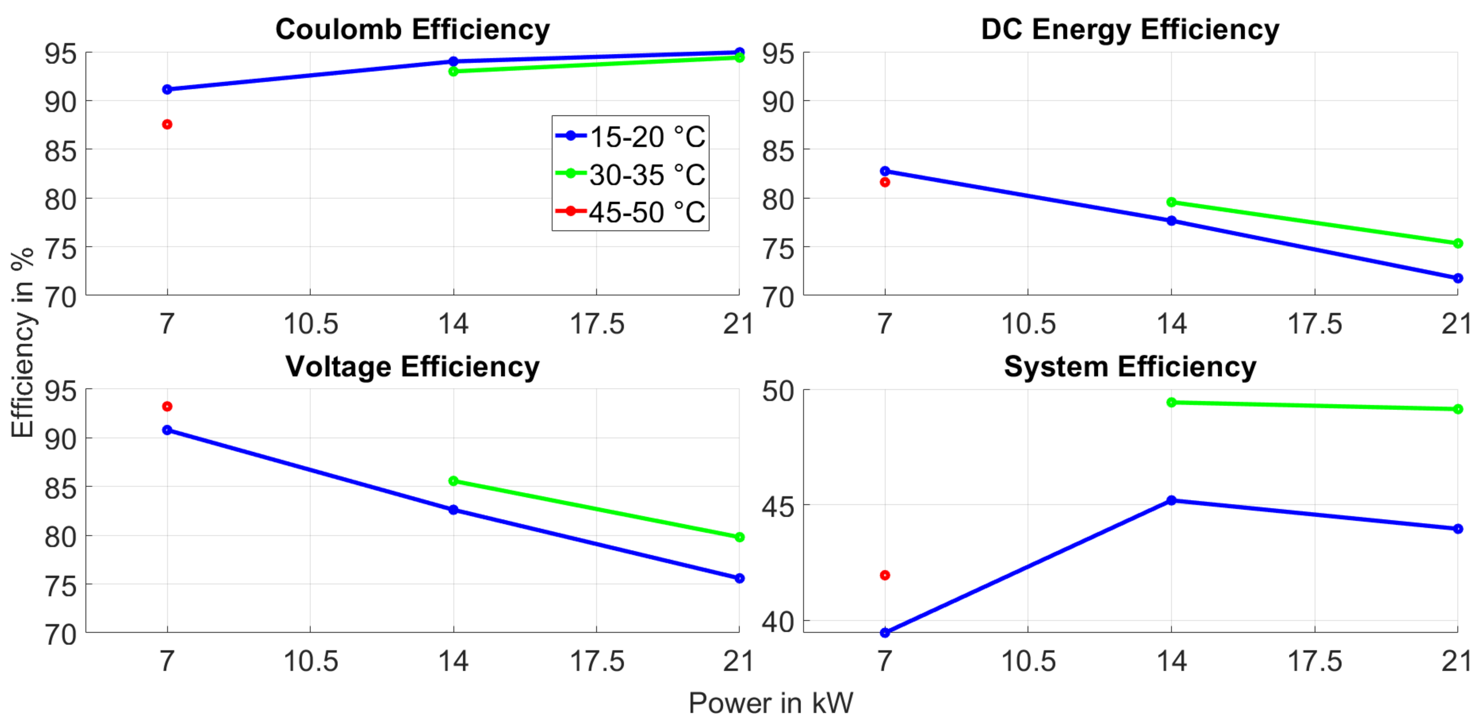

Fig 3. Efficiencies of the VFB system measured at different temperatures and round-trip powers

04 Cell internal resistance

- The characterization allows the determination of the internal resistance of the three stacks at different values of AC power, SoC and temperature
- Stack resistance is calculated using:

$$R_{\text{Stack}} = (U_{\text{Stack}} - OCV\ x\ n_{\text{Cells}})\ /\ I_{\text{Stack}}$$

- R_{Stack} is lower at higher temperatures

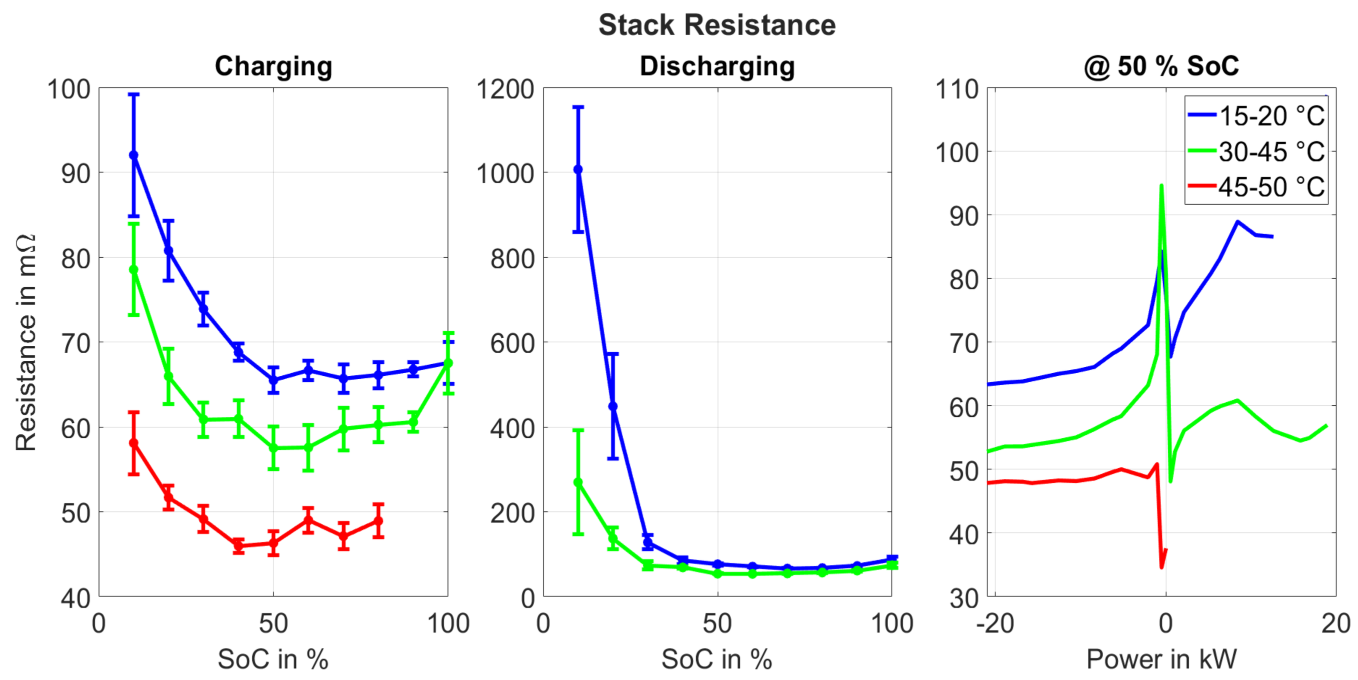

Fig 4. Stack resistances measured at different SoC intervals and AC powers. Left and middle plot include error bars to show standard deviation of the measurements.

06 Conclusion and outlook

- Temperature of electrolyte impacts the system efficiency by:
  - Increasing Voltage Efficiency
  - Decreasing Coulomb Efficiency
  - Lowering pump power consumption
- Losses in the VFB are lower at high temperatures

Outlook:
- System efficiency of the VFB will be improved using the TCM
- The effects of high temperature operation on the electrolyte will be analysed
- The TCM will be integrated in an energy management to optimize combined operation with the VFB

References

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Contact: Felix Schofer, felix.schofer@kit.edu

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