UNIVERSITY OF APPLIED SCIENCES MUNICH

Institute for Sustainable Energy Systems – ISES

A Modelica-based Simulation Model for Large-Scale Stationary Lithium-Ion Battery Systems

Abstract

Holistic battery system models are a key tools for the design and optimization of stationary battery systems. The objective of this contribution is the development of a Modelica-based system model which can be used for the investigation of operational optimization strategies and predictive maintenance approaches. The model includes a 0D-battery cell model based on an electrical and thermal equivalent circuit. The model has been verified via comparison to a validated Python-based model. A particular focus of the project is the model scaling, which describes the extension of the battery cell model up to system size representing a variable number of cells structured in modules and racks. Therefore a statistical approach for electrical scaling, which calculates the effects of resistance and capacity deviation is presented. It offers lower computational effort and simplified results analysis while retaining a comparable information content. In addition, the thermal influences of scaling are also calculated by an integrated thermal equivalent circuit model, which is expandable for a variable number of cells and a arbitrary two-dimensional geometry. Further work concerning integration of additional system components and validation has to be carried out during consecutive works.

Our Partner

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Contact and Information

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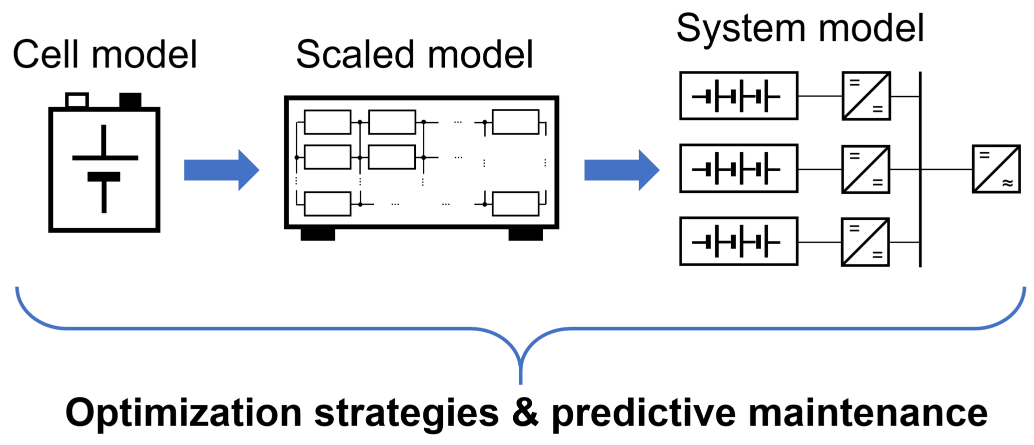
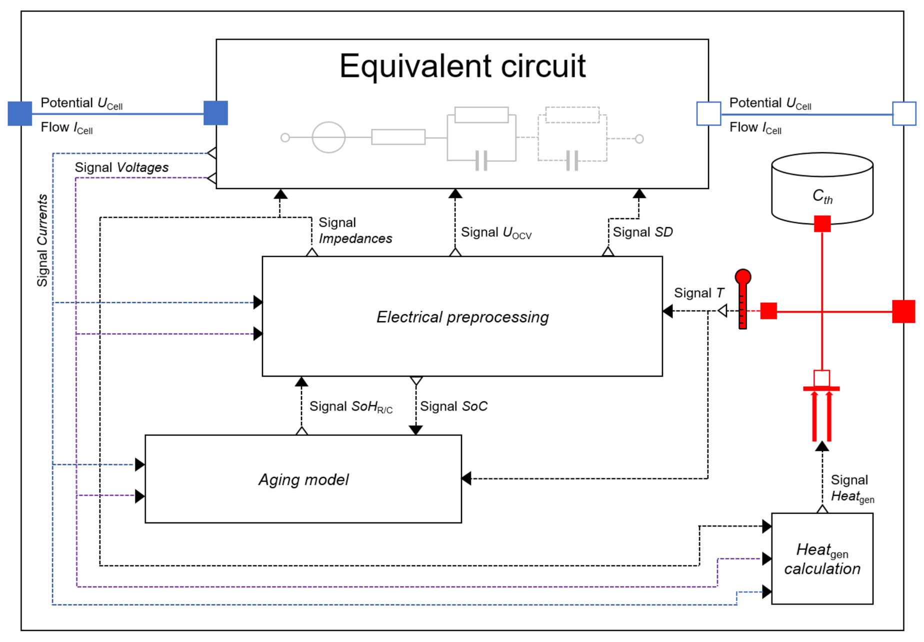
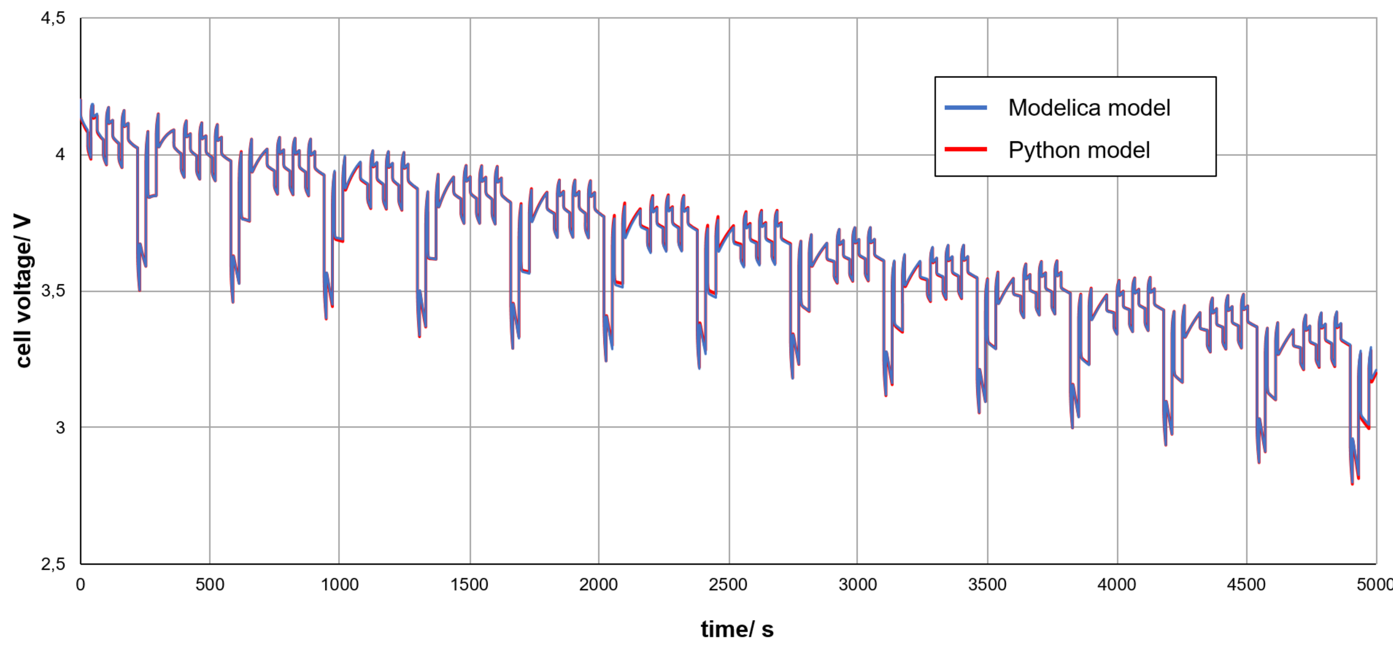
Motivation

Operational optimization and **predictive maintenance** are key challenges during design and operation of stationary battery systems. In order to develop and test strategies and approaches for these tasks, **holistic system models** are required. For this purpose, common cell modelling approaches must be **scaled to system size** and extended by models for **further system components**. The calculations of the scaling effects in the electrical and thermal domain require **smart model reductions** in order to achieve a reasonable computational effort during simulation.



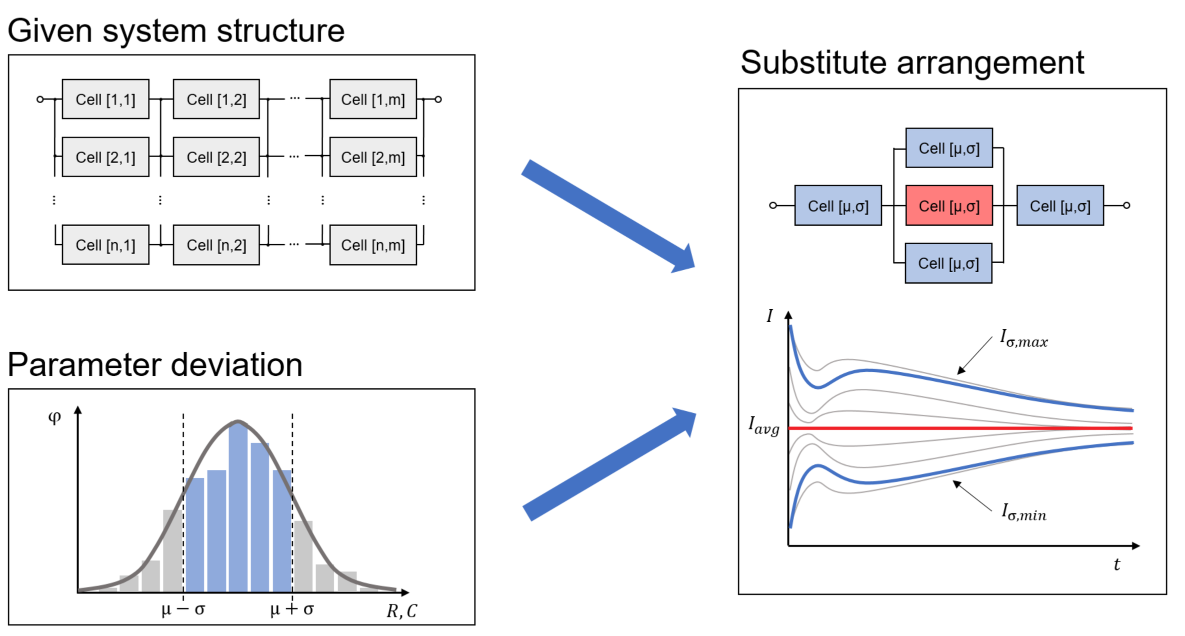
Battery Cell Model



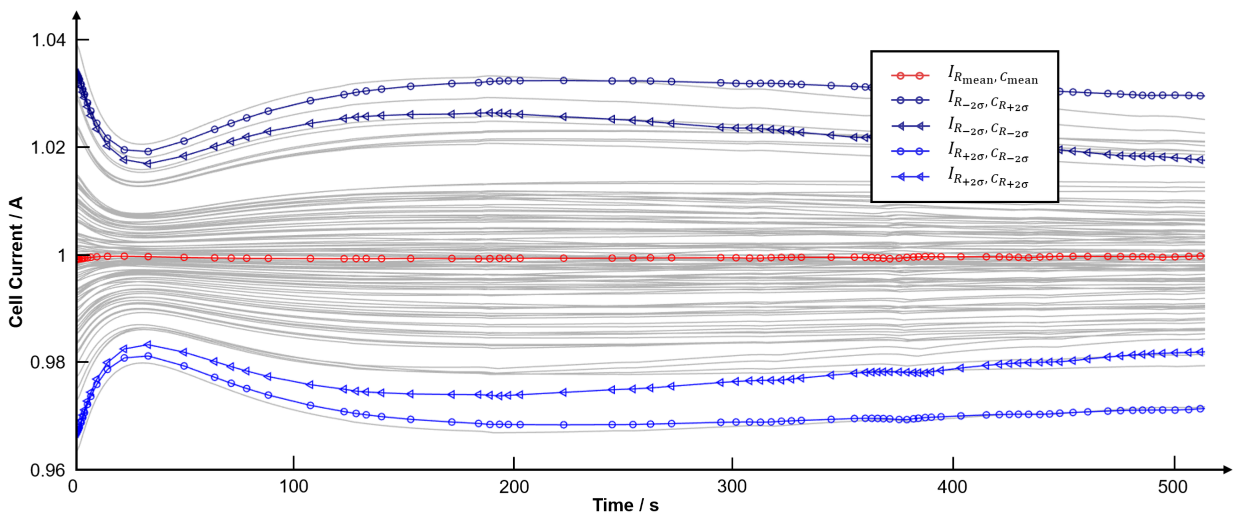


The proposed battery cell model is a **0D model** based on an **electrical and thermal equivalent circuit**. It considers the electrical and thermal behavior as well as the **effects of aging** [1,2]. The model behavior was **verified via comparison** to a validated linear standard model implemented in Python. The deviations from the measurement are due to still unconsidered long term processes and incomplete parameterization of the cell capacity. It is shown, that the Modelica model can almost exactly mimic the Python model. Minimal deviations occur due to the different calculation approaches of the RC-elements.

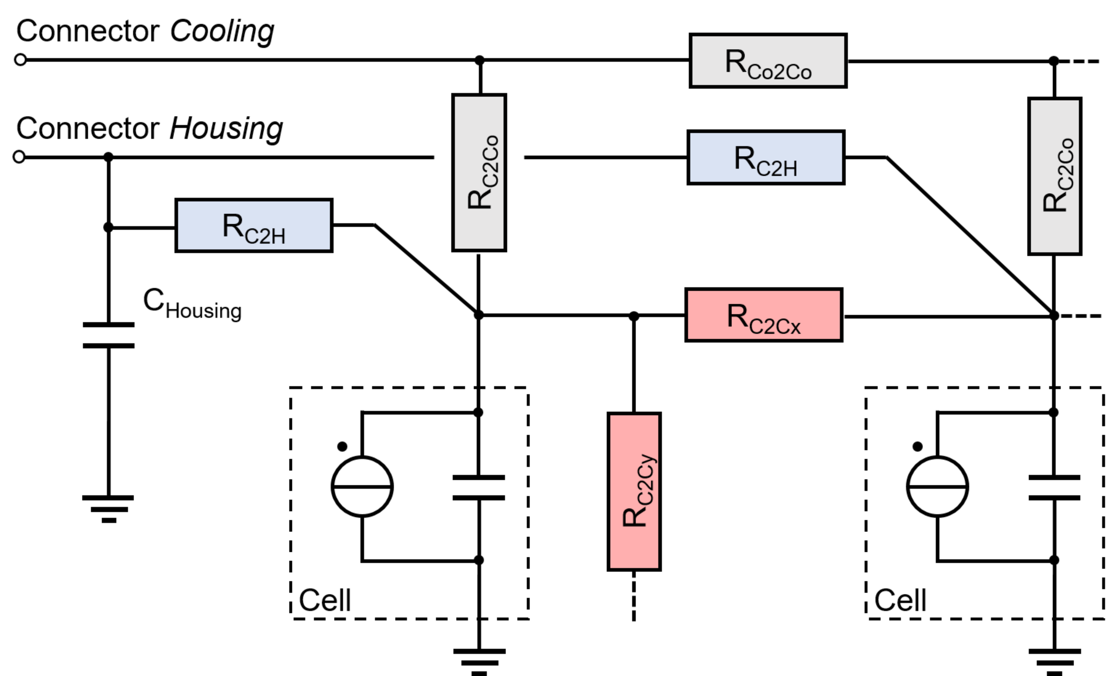
Electrical Scaling



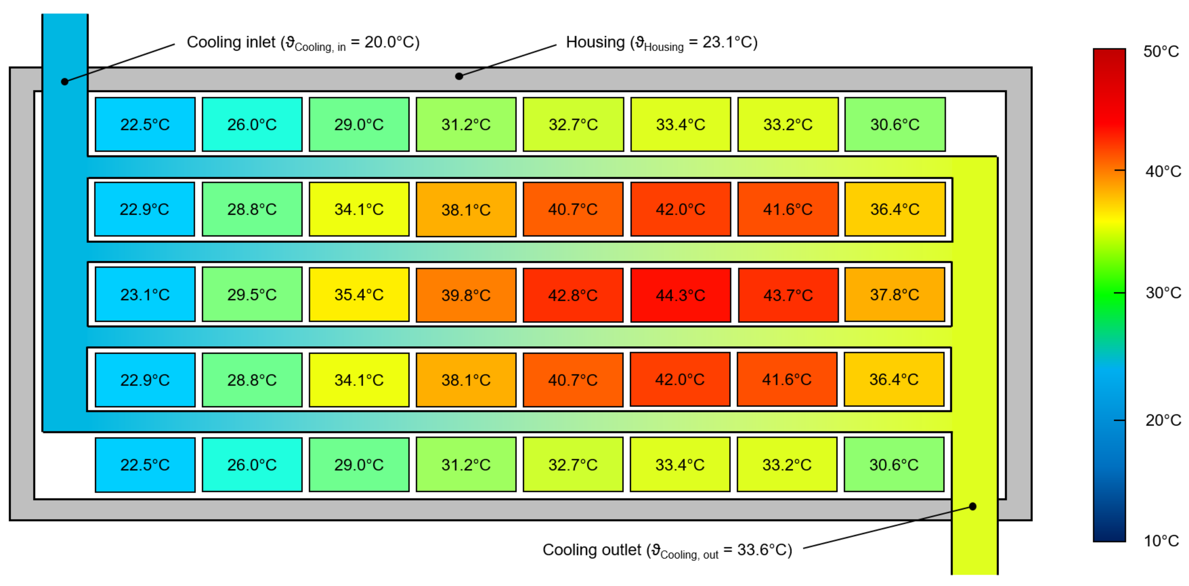
In large battery systems, the **cell characteristics** such as capacity and internal resistance of the individual cells are not uniform but **approximately normally distributed** [3]. This distribution causes **uneven cell currents and voltages** and as a consequence uneven SoC and temperature developments. In order to simulate these derivations with a reasonable effort, a **statistical approach** is proposed. It replaces the given cell structure by a **defined substitute arrangement** with statistical parameters, which represent a certain probability.



Thermal Scaling



Besides the electrical effects of scaling, there are also **thermal influences** on the individual cells by its surroundings. In this work, the **resulting temperature distribution** is approximated by a **thermal equivalent circuit** [4]. Heat transfer between cells, between cell and housing and between cell and cooling structure are taken into account. The thermal equivalent circuit can be represented a **variable number of cells** in a two-dimensional geometry.



Outlook

The **validation of the model** is a key task for consecutive works. For this purpose, a commercial battery module for stationary applications will be investigated. Initially, the generated data will be used for **parameterization and validation of the battery cell model**. In the following, the **thermal and electrical scaling model will be validated**. For this purpose a process for parameter generation has to be developed. Furthermore, smart **model reductions for the thermal scaling model** must also be developed in order to ensure a reasonable application of the model. After validation of the scaled battery model, it has to be extended by further system components to complete the step from cell to system model. Subsequently, the system model is to be used for development and testing of optimization strategies and predictive maintenance approaches.

[1] Z. Gao et al., "Integrated Equivalent Circuit and Thermal Model for Simulation of Temperature-Dependent $LiFePO_4$ Battery in Actual Embedded Application", *Energies*, 2017
[2] J. Schmalstieg et al., "A holistic aging model for $Li(NiMnCo)O_2$ based 18650 lithium-ion batteries", *Journal of Power Sources*, 2014
[3] K. Rumpf et al., "Experimental investigation of parametric cell-to-cell variation and correlation based on 1100 commercial lithium-ion cells", *Journal of Energy Storage*, 2017
[4] Y. Gan et al., "Development of thermal equivalent circuit model of heat pipe-based thermal management system for a battery module with cylindrical cells" *Applied Thermal Engineering*, 2020