A simple modular approach to modeling heat propagation and critical temperatures in single-cell and multi-cell battery systems

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Introduction

Challenges in the upcoming integration of battery cells

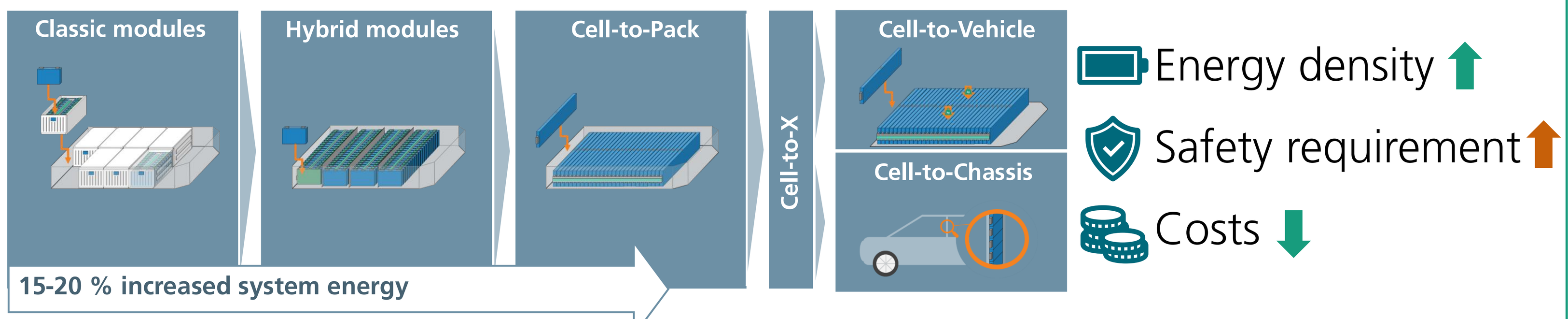

Figure 1: Development of the battery pack design in BEVs. Data basis from [1].

Application of a simple modular approach

- The use of cells with continuously increasing energy densities requires an in-depth analysis of thermal safety, particularly in view of stricter regulatory requirements (e.g. GB 38031-2025)[2]
- Development of a simulation model to describe thermal failure
- The goal is to significantly reduce development time and optimize system integration through suitable propagation protection solutions

Research Questions

1. How can the **critical temperature (T_{crit})** and potential **thermal runaway** in lithium-ion cells be reliably controlled?
2. How can the **propagation** of thermal runaway within a battery system be described and effectively mitigated through **protective measures**?

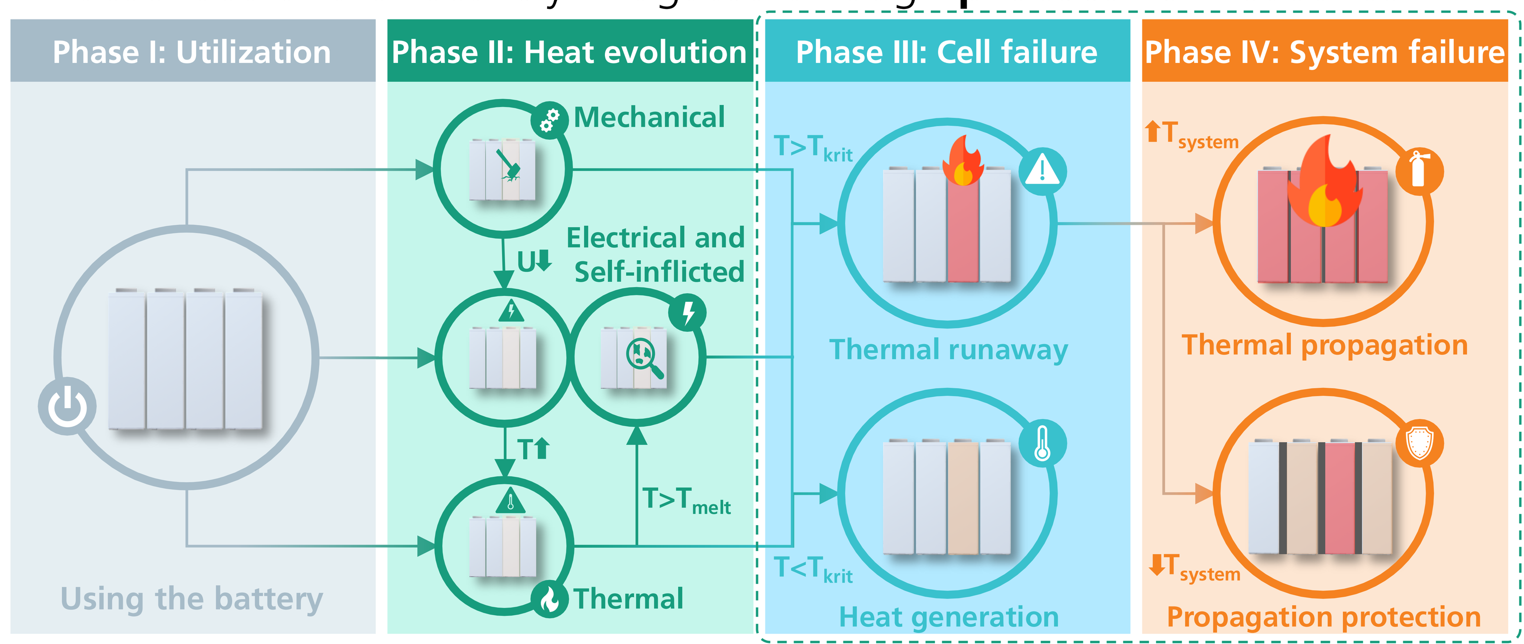

Figure 2: Schematic phases from normal use to potential thermal propagation. The focus of the modeling is indicated by a dashed line.

Modular Approach Using Ansys Fluent

- Development of a 3D heat propagation model with Ansys Fluent
- Thermal abuse model based on Arrhenius equation with four material decompositions
  - Structural destabilization of the primary SEI
  - Balanced reaction of SEI decomposition and regeneration
  - Cathodic decomposition reaction
  - Electrolyte decomposition reaction

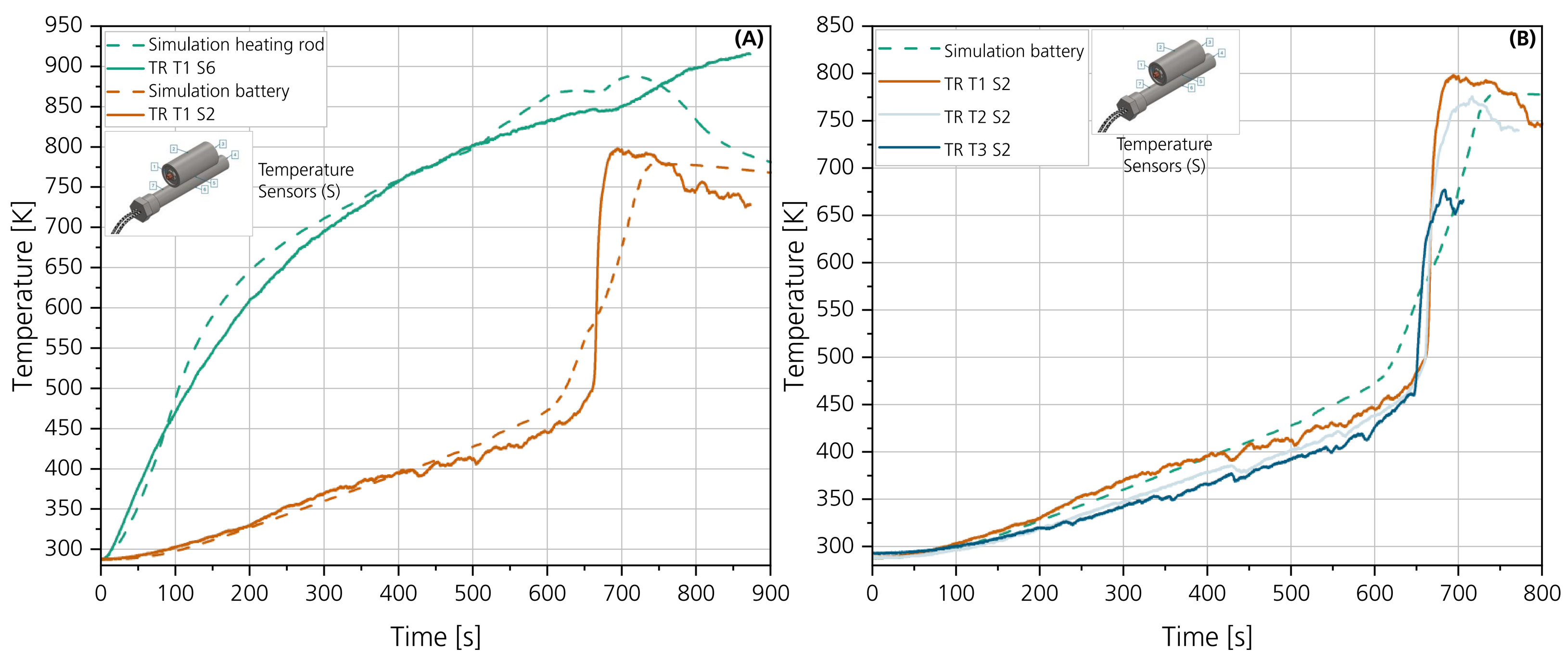

Figure 3: Comparison of TR simulation and experiment on a cylindrical 32650 LFP cell with a heating rod. (A) Average heating rod and cell temperatures from the simulation, as well as measured values from sensors 2 and 6. (B) Average cell temperature from the simulation compared to sensor 2 for all three validation experiments. Arrhenius parameters used based on [3,4].

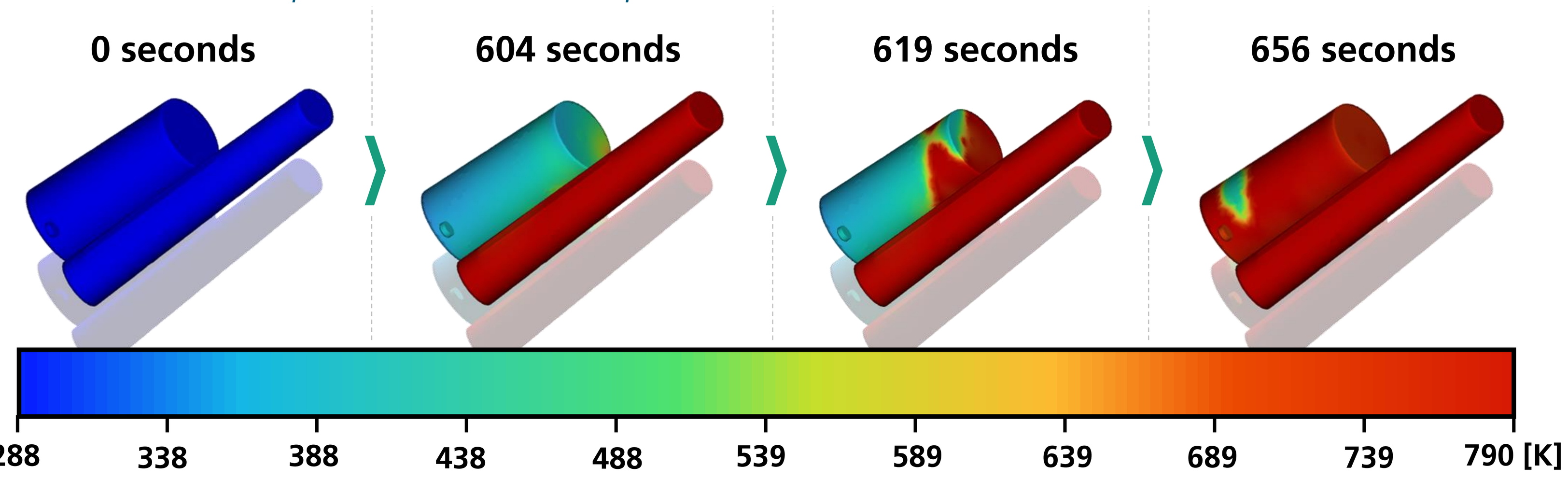

Figure 4: TR simulation of a cylindrical 32650 LFP cell using a heating rod

- The model enables a high-resolution, three-dimensional representation of heat distribution and energy release
- However, the numerical calculation requires a significant amount of time and computational resources, particularly in the TR region
- In addition, realistically modeling the heating element within the simulation poses a methodological challenge

Development of a Simple Modular Approach

- Development of a simplified model with Python based on the Heat and Arrhenius equation
- Use of experimental data to determine an optimal fit for heating element and cell temperatures
- Parameter variation to simulate and analyze the TR curve
- Division of the overall curve into three phases (see Figure 5)

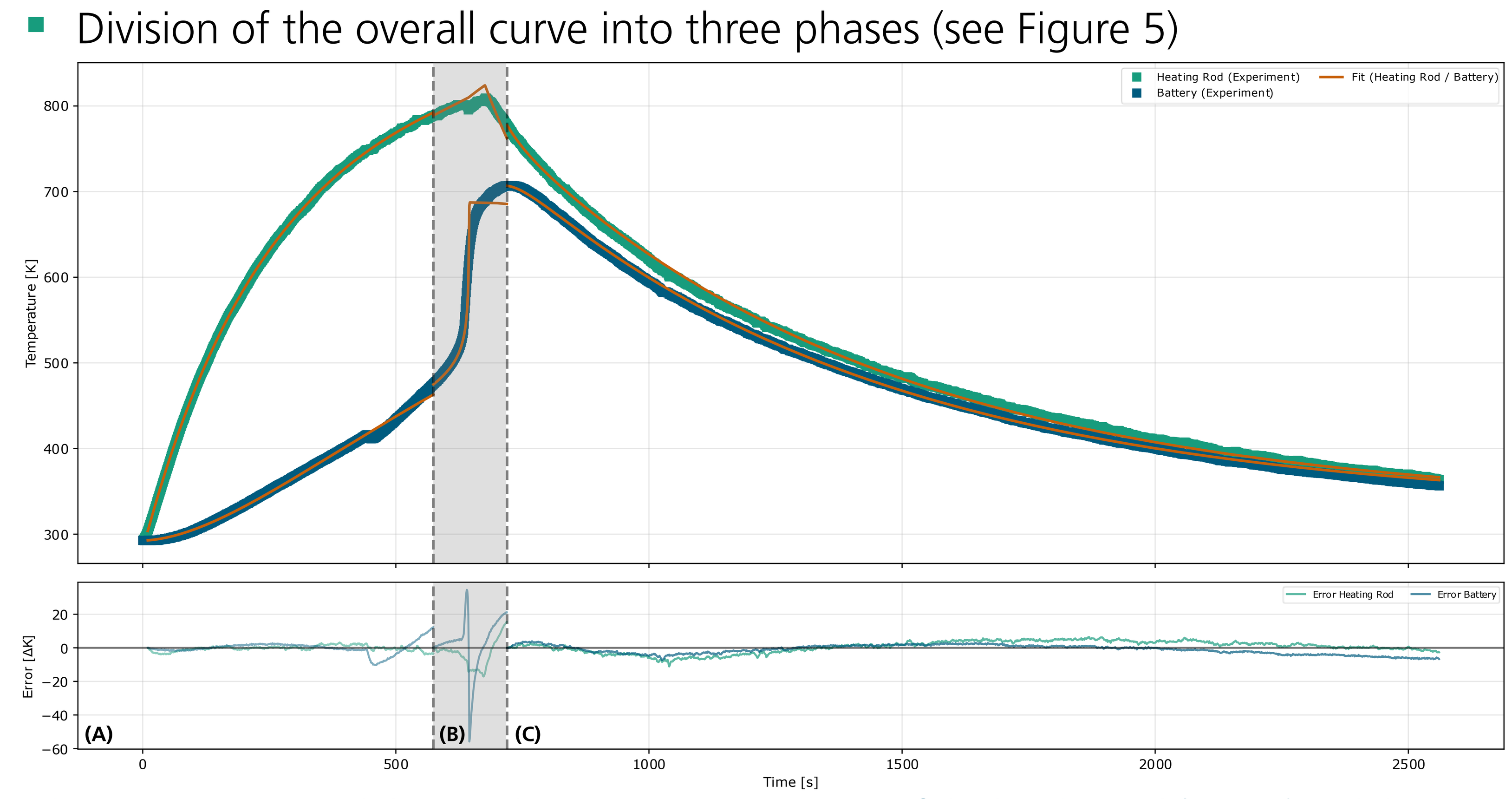

Figure 5: Experimental data on the average temperatures of the heating rod (200 W) and the cylindrical cell (26650; LFP) during the TR, as well as the fit of a Python model. The deviations between the model and the experimental data are visualized in an additional graph shown below. The datasets were segmented by phase and fitted separately: (A) heating phase, (B) TR phase (gray-shaded area; initial results; the model requires further refinement), (C) cooling phase.

- No three-dimensional representation of the processes
- For different geometries, a new experimental validation is required

Next Steps and Contact Details

- Integration of additional reactions and implementation in a TP model
- Focus on modularity and simplicity
- Coupling with ANSYS Fluent
- Further development and validation of the model

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