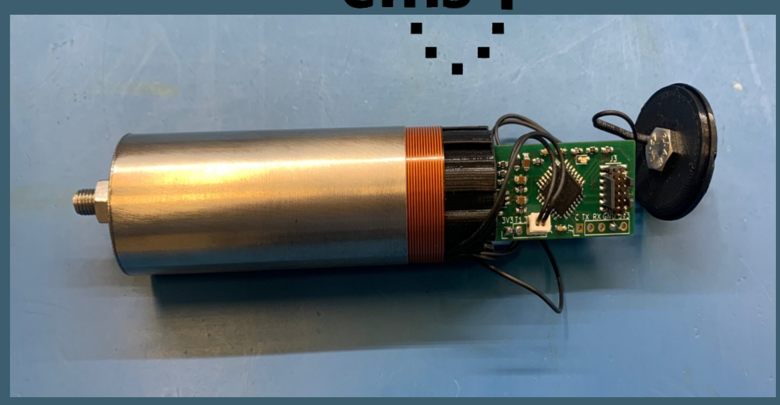
BATTERY CELL LEVEL

Dummy prototype and communication

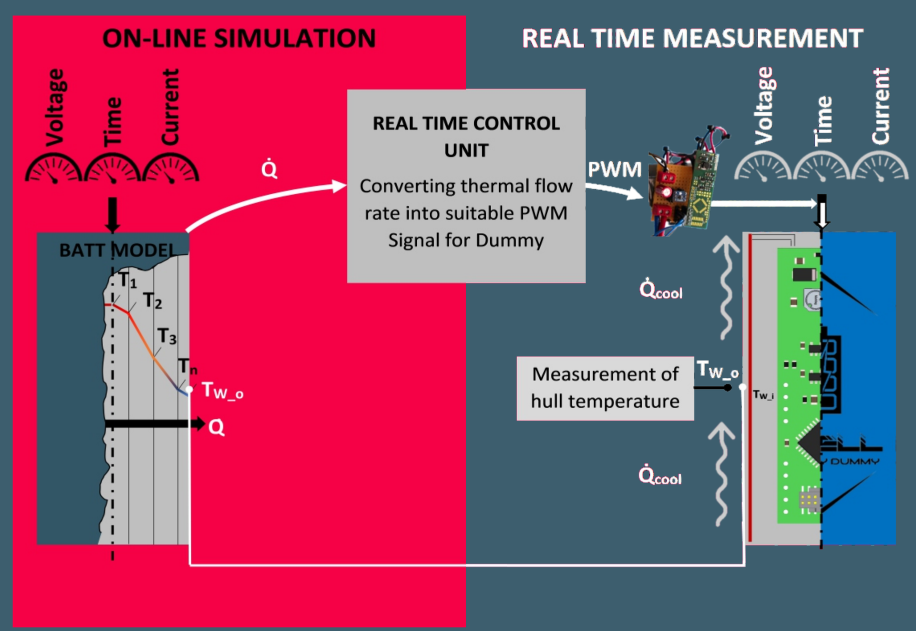
In cooperation with ems



The **T-Cell substitution cell** was developed and prototyped. It consists of the **following main components:**

- 0.2 mm stainless steel hull
- Heating flex print
- Printed plastic sleeve
- Electronics with power line communication via UART protocol
- Top cap

Testbed coupling and SiL



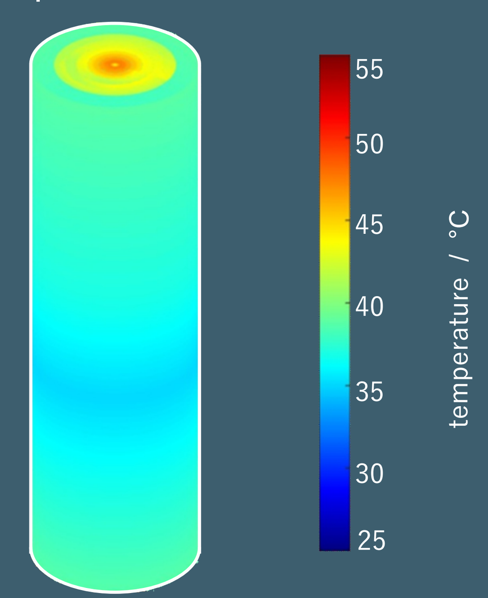
In the **SiL approach,** the measured **wall temperature** of the substitution cell is used **as a boundary condition in the simulation.**

The simulation model **calculates a new thermal field** and **returns the wall heat flow** to the dummy **as a setpoint for the heating.**

With this SiL methodology, **testbed cooling mechanisms can be coupled with real time battery simulation.**

Simulation

temperature distribution at cell surface

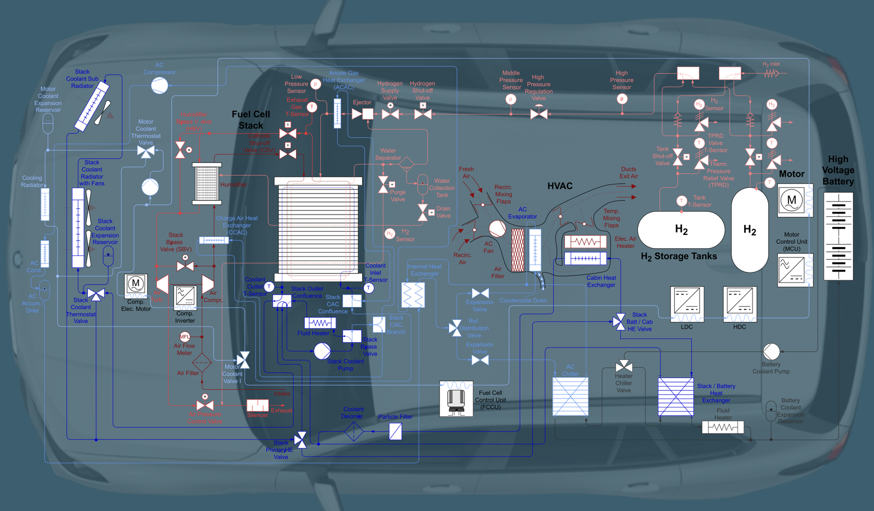


A simulation environment was established **to reflect the behaviour of a real cell** with the highest possible degree of abstraction while **maintaining good reliability.**

Therefore, a **hybrid simulation model,** which consists of an **electrochemical** (EC) model with an equivalent circuit and a thermal network (TN) was utilized.

VEHICLE THERMAL MANAGEMENT LEVEL

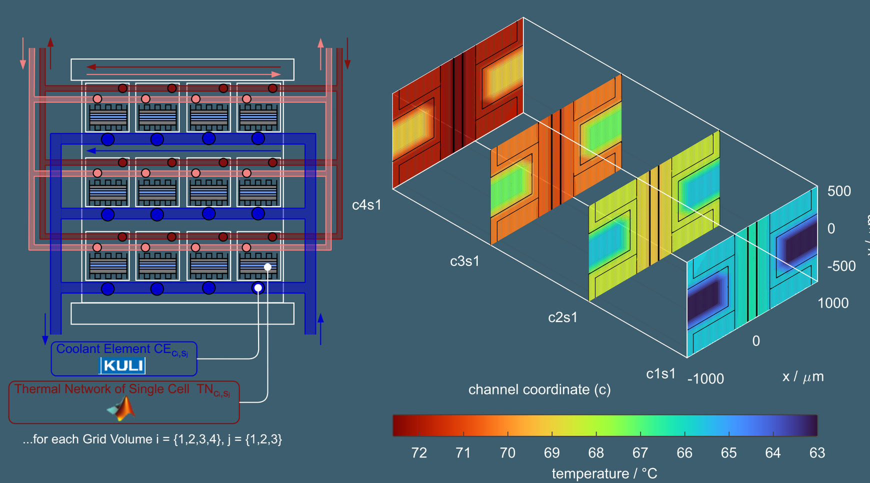
Advanced VTMS Co-Simulation



KULI Software

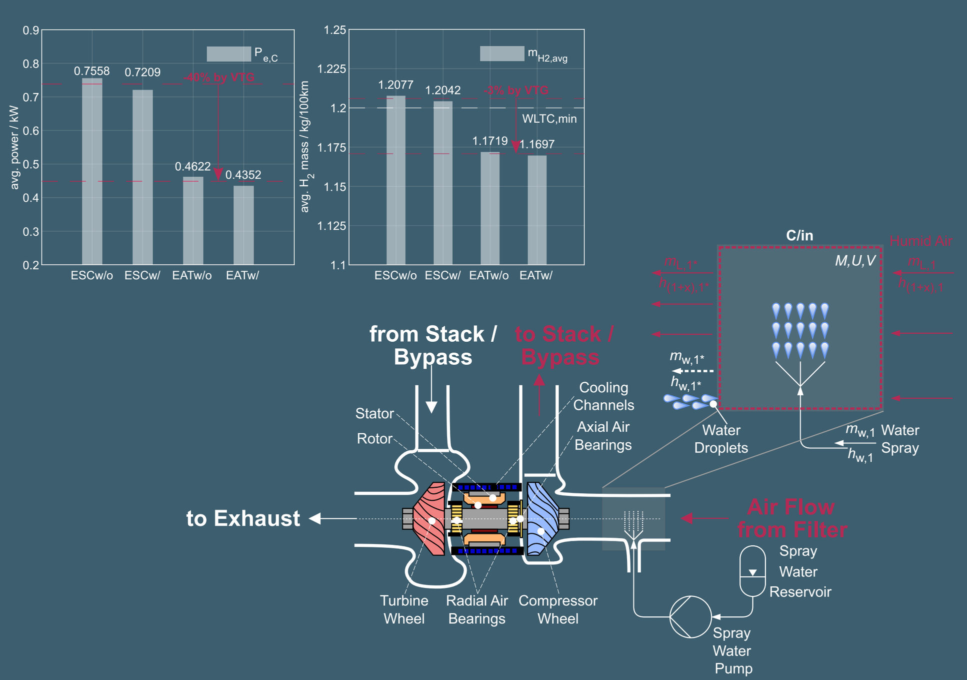
A **thermal management co-simulation** framework was developed for an **FCEV** at the overall vehicle level. In this co-simulation, **advanced simulation methodologies** were implemented at the subsystem level of fuel cell, battery, electric motor and HVAC. By **combining the 1D thermal management software KULI with MATLAB/Simulink,** advanced modeling and simulation capabilities were achieved.

2D Thermal Stack Modeling



A **high-resolution 2D thermal stack model** that precisely **resolves temperature inhomogeneities** within the PEM fuel cell stack was developed. By segmenting the stack macroscopically and modeling microscale thermal networks, it accurately captures local heat transfer between cells and fluids, allowing detailed analysis of flow-dependent **effects on heat transfer and temperature gradients.**

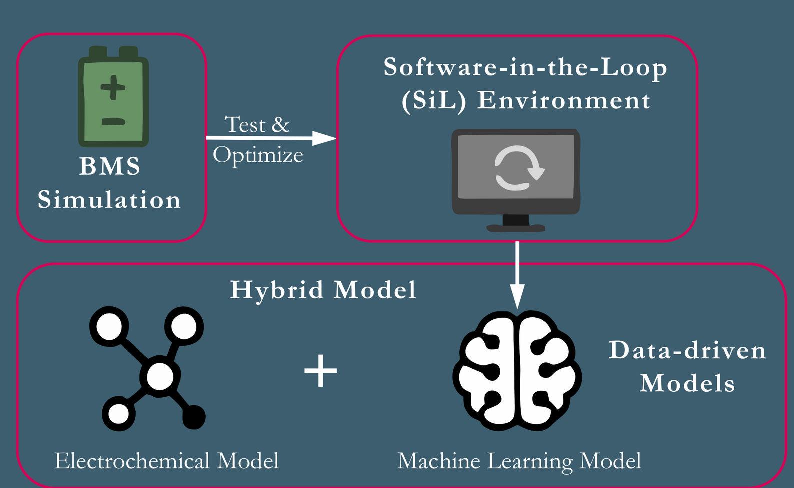
Fuel Cell Air Compressor Concepts



Electric Supercharger (ESC) and **Electrically Assisted Turbocharger (EAT)** were analyzed to enhance the efficiency of the air supply system and the overall vehicle. **EAT highly reduces compressor power (−40 %) and H_2 consumption (−3 %)** under high-temperature, low-humidity conditions. **Water spray injection (WSI) at compressor inlet** further decreases compressor power, especially at elevated ambient temperatures.

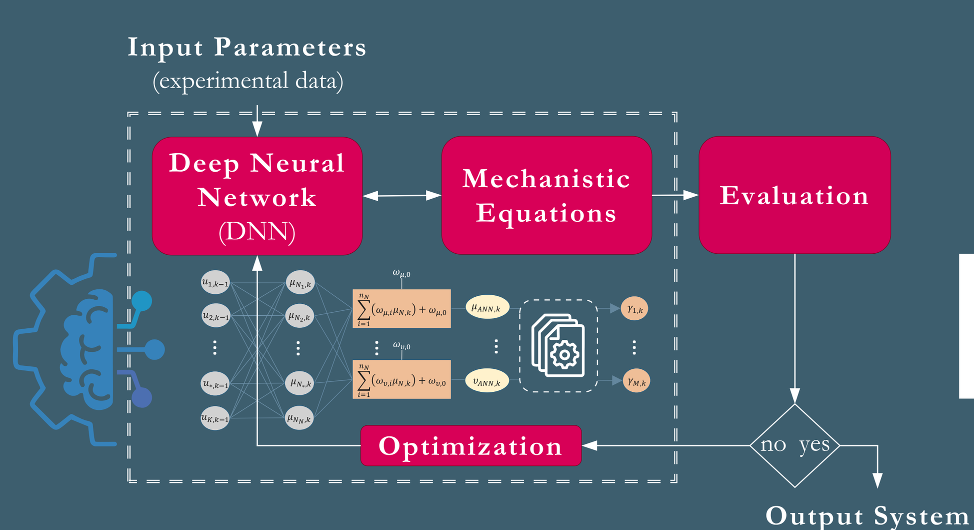
AI-BASED SIMULATION METHODOLOGY

AI-supported Simulation



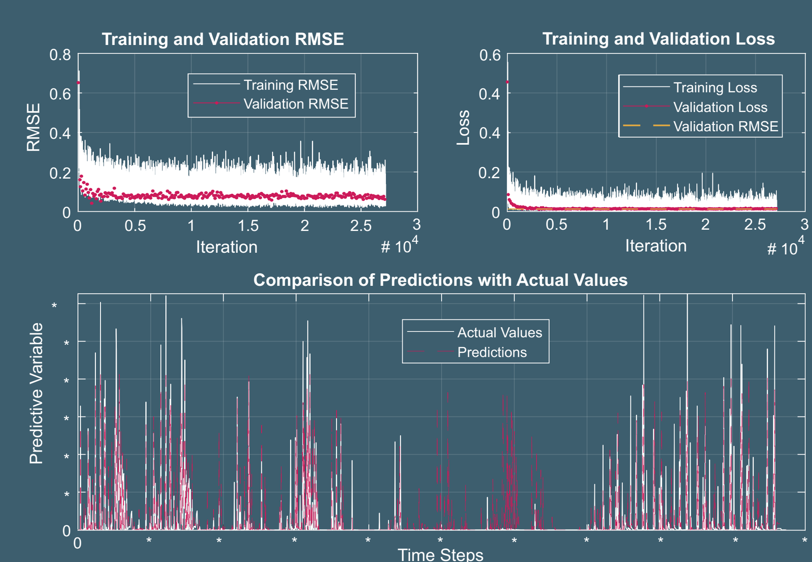
Extends simulation to the **BMS level** for in-depth analysis of **pack dynamics.** A **Software-in-the-Loop (SiL)** setup enables virtual testing, optimization, and integration of **data-driven** models into physical battery simulations.

AI-modeling Methodology



Combines **mechanistic (electrochemical)** and **data-driven** modeling - merging **physical accuracy** with adaptive learning. Enables robust, scalable modeling and clear representation of **nonlinear system behavior** across real operating conditions.

Prediction and Evaluation



Predicts **temperature, state of charge (SOC),** and **state of health (SOH)** using hybrid AI models. Self-learning capabilities enhance adaptability, allowing early **degradation detection** and **real-time optimization** of battery health.

Contributing Authors

DI Frühwirth Christian
fruehwirth@ivt.tugraz.at

DI Lorbeck Roland
lorbeck@ivt.tugraz.at

DI Wilfling Kevin
wilfling@ivt.tugraz.at