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Hardware-in-the-Loop Test Rig for Rapid Prototyping of Battery Management System Algorithms

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Motivation

- Testing is an integral and inseparable part of Battery Management System (BMS) software development process:
  - Model-in-the-Loop (MiL)
  - Software-in-the-Loop (SiL)
  - Hardware-in-the-Loop (HiL)
- Limitations of battery emulators and MiL/SiL [1]:
  - Battery model accuracy
  - Resolution and iteration rate of emulation hardware
- Handicaps of testing model based algorithms with model based emulators

➢ Reliable validation of state algorithms requires HiL testing with real battery cells [2].

Objectives

- Main Objective of the study is the development of a hardware-in-the-loop test bench for **rapid prototyping, testing** and **evaluation** of **BMS algorithms** in **real-time** with **real cell packs**.
  - **Cost** and **time efficient** HiL testing
  - **Validating** algorithms with real cell packs
  - **Fine tuning** of algorithms under realistic conditions

System Structure

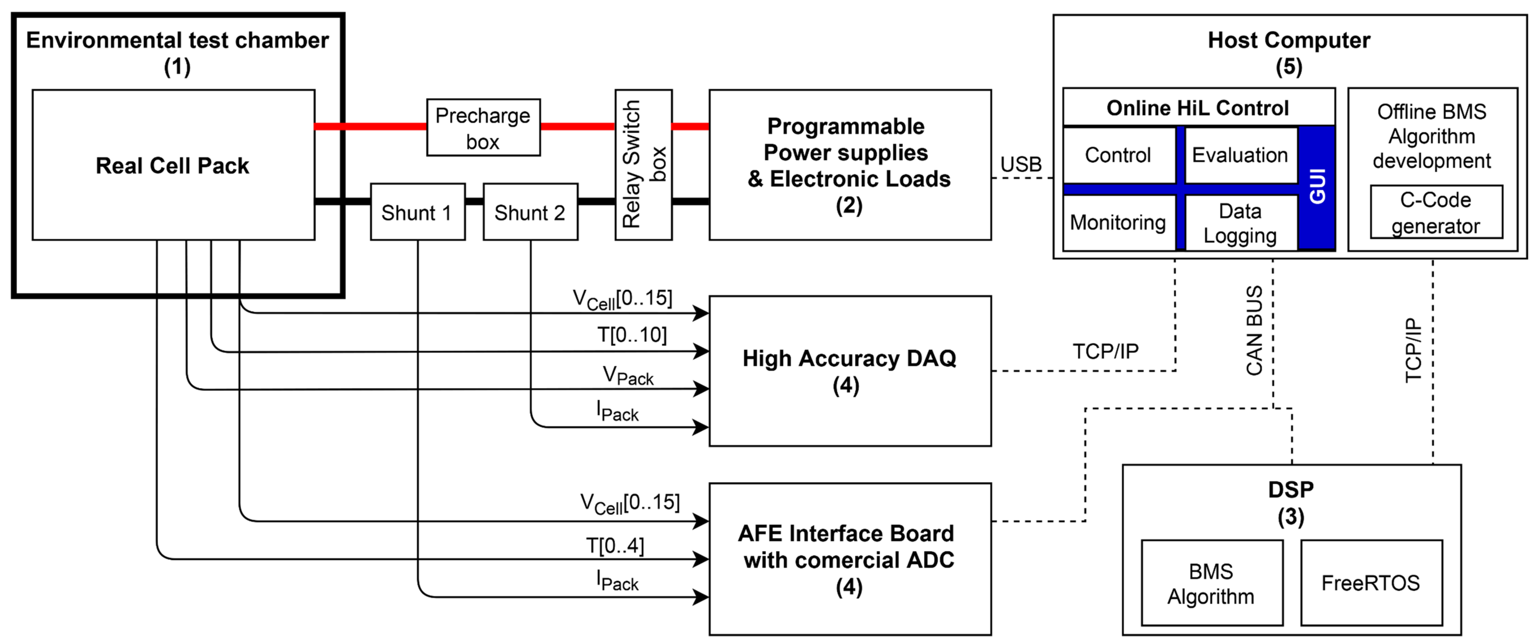

Fig. 1 Structure of HiL-System

System Structure

- Testing up to **100V** and **80A**
- **Modular** structure supports upscaling
- **Safety** test chamber with temperature conditioning
- Two independent parallel working **Data Acquisition Systems (DAQ)**
  - Reference system: High accuracy DAQ-System
  - Industry standard: DAQ-IC based analog front end (AFE)
- **16 cell voltage** and **11 temperature measurements**
- **DSP-System** to run BMS-algorithms in real-time
- **Automated code generation** from MATLAB/Simulink to C-Code
- Software to control and monitor test process, record data, evaluate results
- Testing procedures:
  - Predefined tests: CCCV, CC, Capacity test, WLTP, NEDC, DST
  - Custom tests: Time or SOC dependent user defined profiles

Fig. 2 Implemented HiL-System

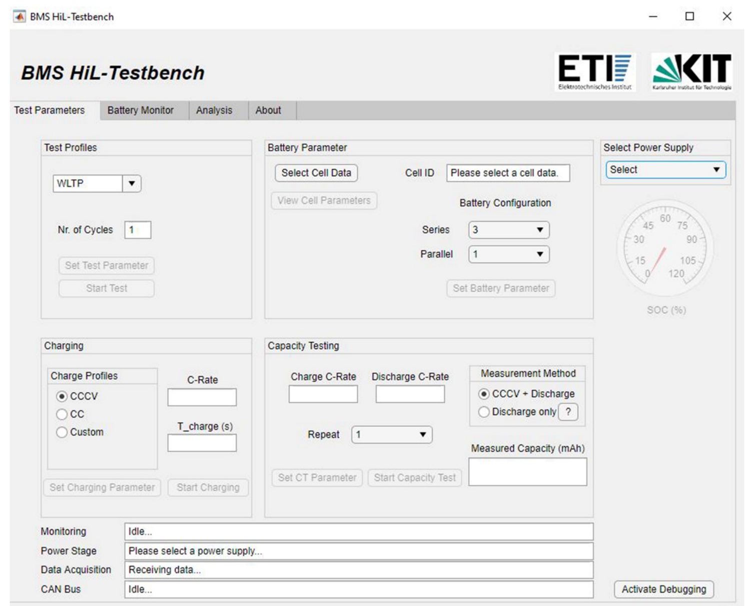

Fig. 3 Main screen of the developed GUI

Experimental setup

- Battery model: Thevenin equivalent circuit model with 1 RC branch
- Parameter identification with HPPC-Test
- State-of-Charge (SOC) estimator: extended Kalman Filter (EKF)
- SiL testing in Matlab/Simulink with battery model
- HiL testing with real cells
- 36V, 10S cell pack of 18650 type cylindrical Li-NMC cells
- Test with Worldwide harmonized light vehicles test procedure (WLTP)

Experimental Results

- SOC estimator tested with real cells successfully in real-time **without** any additional **electronics** and **casing**.
- SiL overestimates performance of estimation algorithm.
- SOC estimator **optimized** significantly with HiL **results**.

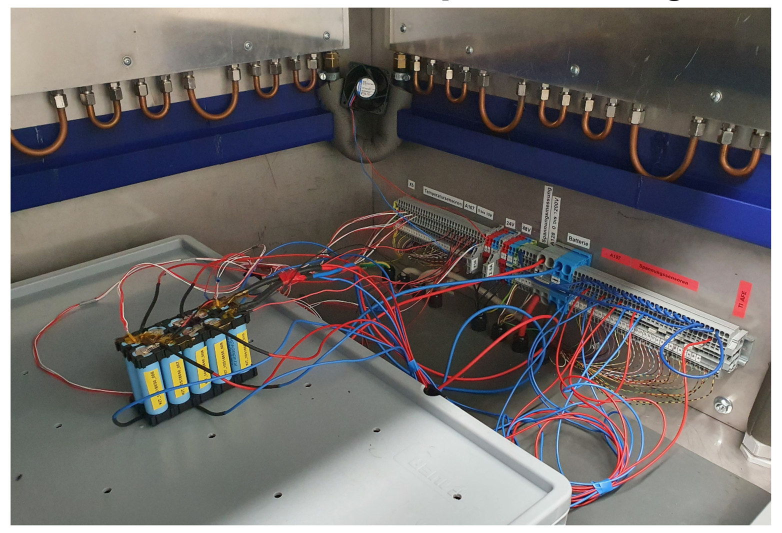

Fig. 4 36V cell pack at HiL test rig

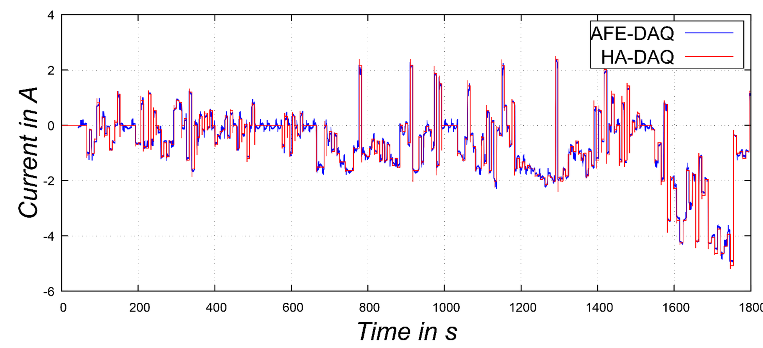

Fig. 5 WLTP Current Profile measurements by HA-DAQ- and AFE-DAQ-System

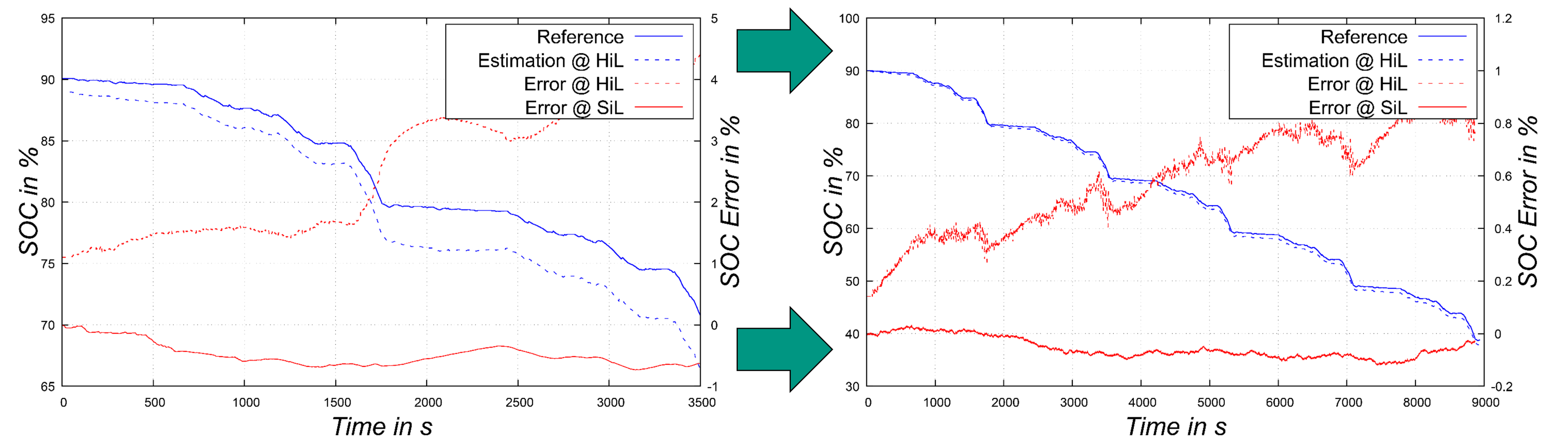

Fig. 6 SiL- and HiL-Test results of an EKF based SOC estimator by testing at 25 °C

Conclusion

- Innovative HiL concept for **rapid prototyping** of BMS software
- **Agile** BMS software development process
- **Realistic** and **efficient** testing
- With exemplary case **verified concept**

References & Acknowledgements

- This work was supported by the Helmholtz Association under the program “Energy System Design”.

- References:

[1] C. Fleischer , et al., “Development of software and strategies for Battery Management System testing on HIL simulator,” in 2016 Eleventh International Conference on Ecological Vehicles and Renewable Energies (EVER),
[2] A. Stadler, “EVERLASTING D2.5: Development of reliability test procedures for EV BMS,” Tech. Rep., 2018. [Online]. Available: http://www.everlasting-project.eu