Development and Investigation of State of Energy Algorithms in a Model-in-the-Loop Toolchain

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Abstract

Users of BEVs expect a long range according to the energy content of the battery as well as reliability and high user-friendliness. Thus, the remaining energy that is dependent on the operating conditions of the battery, such as temperature, State of Charge and current rate, has to be estimated during operation. Two different methods for the State of Energy estimation are developed and assessed in a Model-in-the-Loop Toolchain.

Conclusion

Two energy algorithms are analyzed: One estimates the State of stored Energy based on a 3-RC Thevenin model and an Unscented Kalman Filter. The State of used Energy is an open-loop estimation that is based on the estimation of the dissipated energy and the stored energy. That estimator considers different operating conditions and is validated for different test scenarios.

Model-in-the-Loop Toolchain

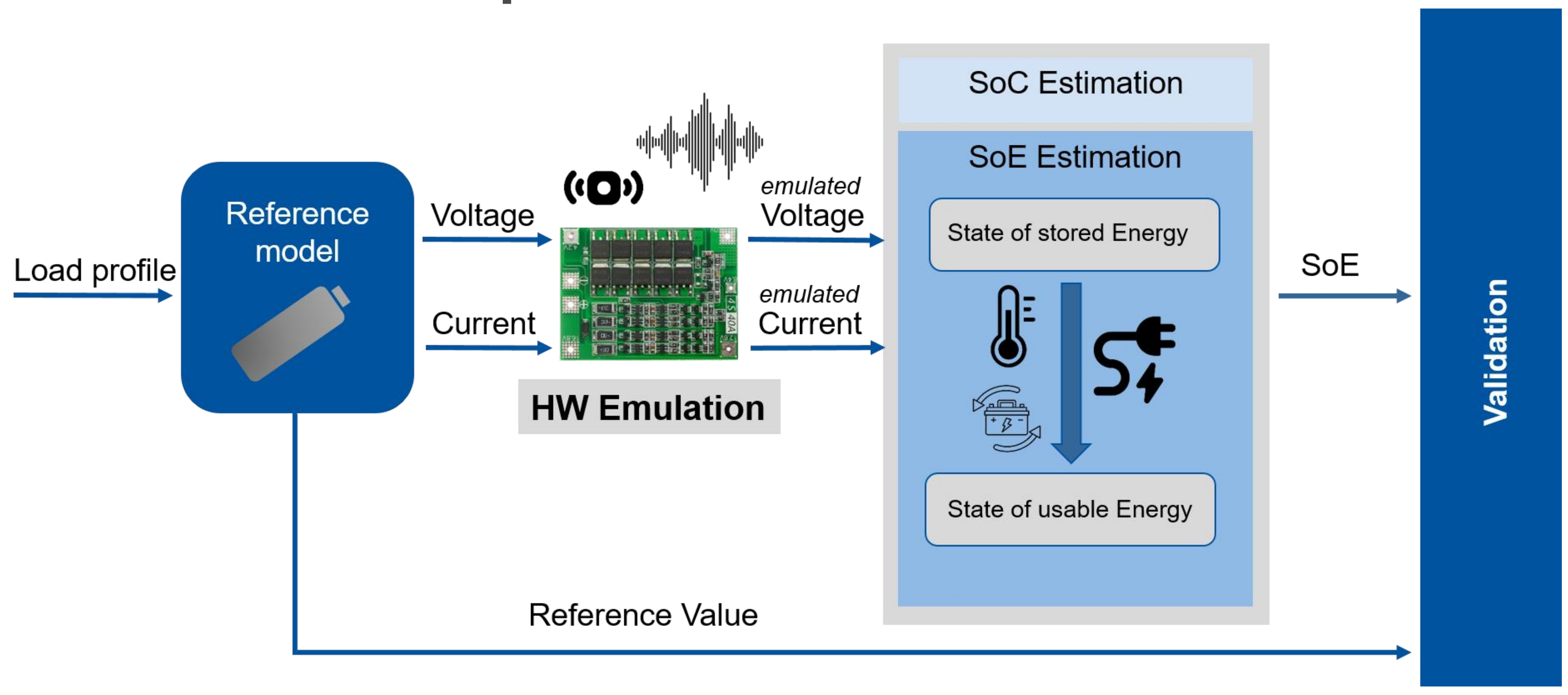


Figure 1: Simulation Toolchain for Estimating the State of Energy

- Model-in-the-Loop Toolchain
  - Simulates the whole signal path of a BMS for different battery types and geometries
  - Allows the evaluation of different algorithms under varying operating conditions (internal and external conditions)
  - Considers the influence of the specific BMS Hardware on the developed algorithms
- A two-step SoE estimation approach in the scope of the toolchain
  - State of stored Energy is estimated that correlates with the SoC and the OCV
  - Usable energy is estimated by considering the dissipated energy that depends on different operating conditions and correlates with the polarization voltage

More information at P3-005

Algorithms for Energy Estimation

State of stored Energy

- Model-based SoE estimation with the help of an Unscented Kalman Filter
- Additional input: maximum storable energy that depends on the OCV

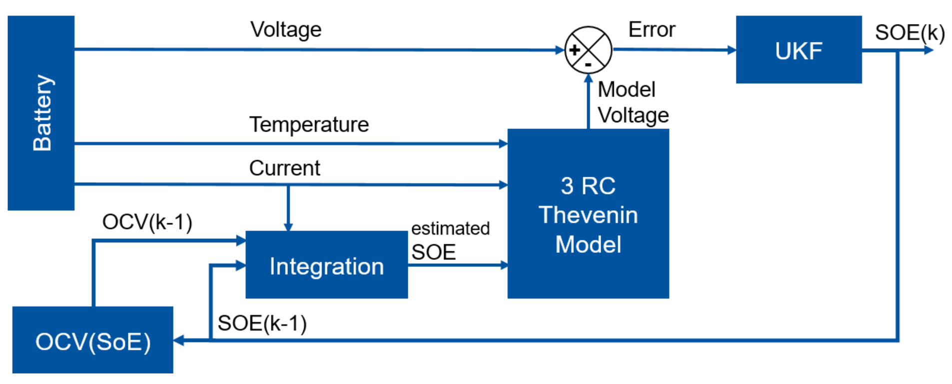


Figure 2: Model-based State of stored Energy estimation

- Update of the model parameters for the 3 RC Thevenin model
- Unscented Kalman Filter corrects the SoE based on the comparison of model voltage and measured voltage

Usable Energy Estimation

- Energy estimation based on the estimation of dissipated and stored energy
- Dissipated energy depends on different influencing factors; estimation of the resistance is important

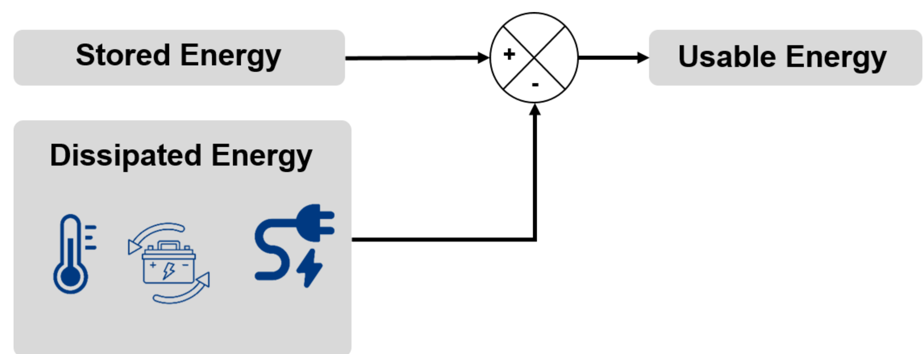
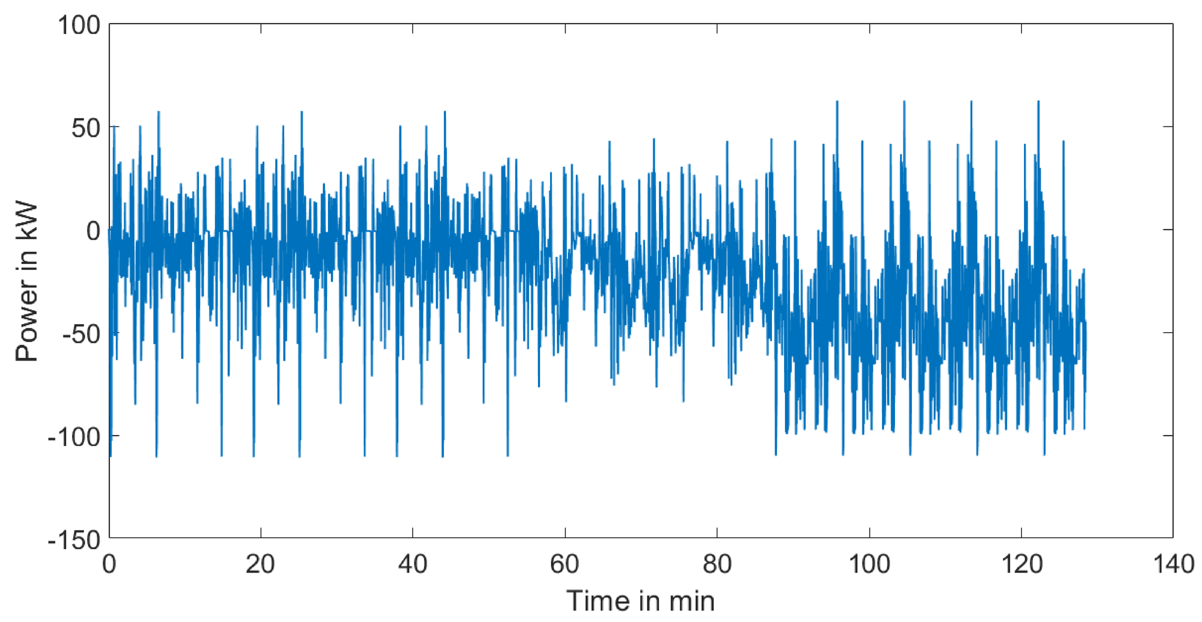


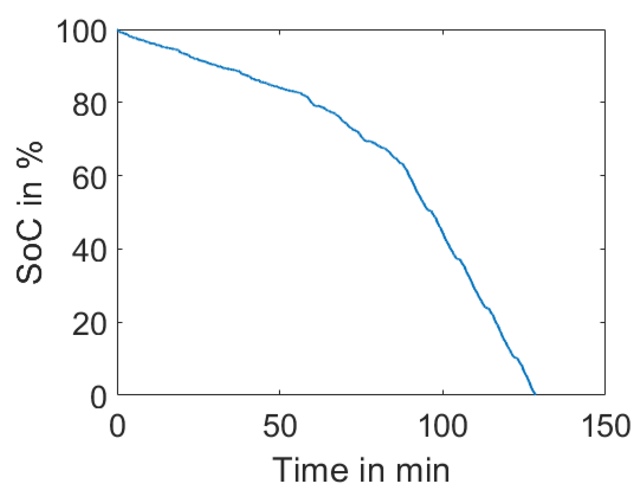
Figure 3: Open-loop energy estimation

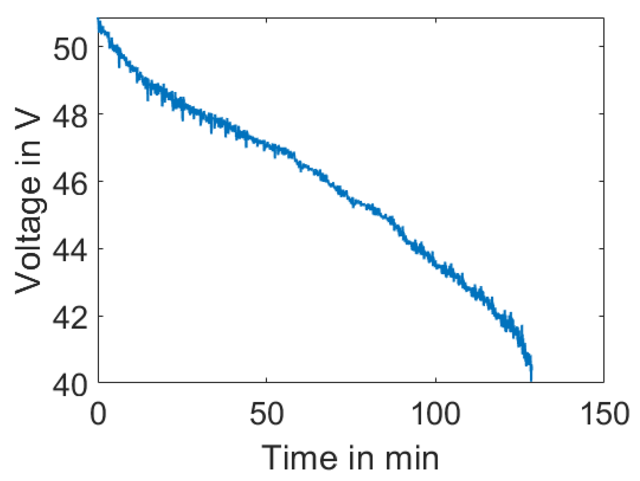
- Some presumptions are necessary such as average temperature and average expected current
- Different filter methods can be used for minimizing the error of usable energy estimation

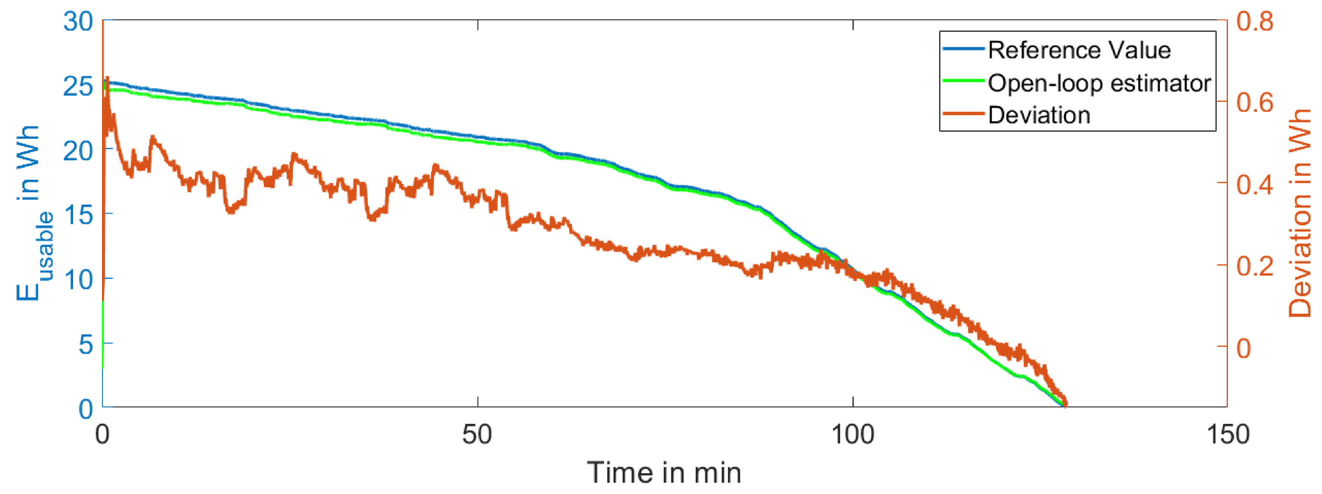
Exemplary Validation

- Scalable real load profile with city, freeway and highway parts
- Modeled lithium-ion battery is a 20s1p NMC/LTO system









- Estimation for one cell with total usable energy of approximately 25 Wh
- Max. error for this profile: ~ 0.7 Wh → < 3%
- Temperature effect interesting, but in this work neglected

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