Enhanced Physics-Based Models for State Estimation of Li-Ion Batteries

Degree programme: Master of Science in Engineering | Specialisation: Energy and Environment
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The current increase in energy and power density of Li-ion batteries combined with a continuous cost reduction for cell and battery system have led to the successful introduction of electric vehicles to the mass market. Besides the Li-ion cell, the Battery Management System (BMS) has become a core component of the complete battery system, providing safety and availability. This Thesis examines the crucial battery models for an accurate state of charge and health estimation.

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Introduction and Research Objectives

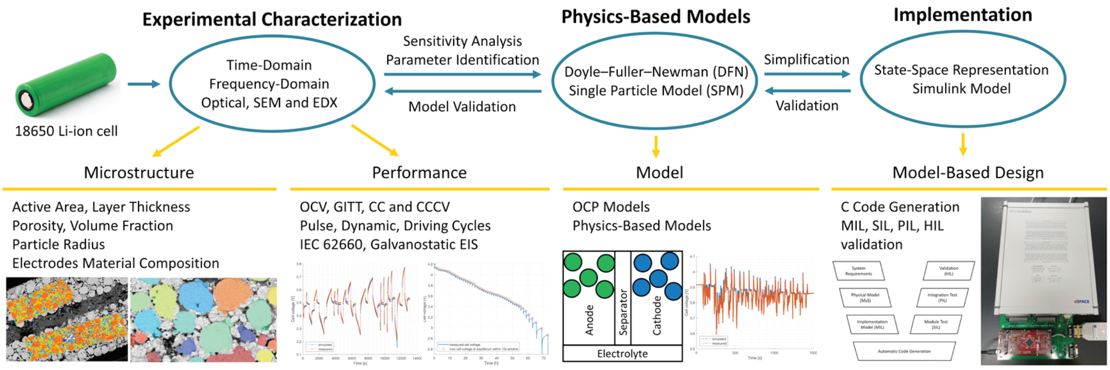
Today, the states of batteries are mostly estimated using Kalman filters and battery models based on equivalent circuits. Unfortunately, these models are not capable to represent electrochemical states that are necessary for degradation minimization strategies to prolong battery life. The Doyle-Fuller-Newman (DFN) model is a pseudo-2D physics-based battery model (PBM) that accurately describes the electrochemical process of Li-ion cells. The model relies on theories of multiphase porous electrodes and concentrated solutions and is governed by a set of coupled nonlinear Partial Differential Equations (PDEs). The main objectives of this Thesis are the implementation of a PBM for state estimation on a BMS using parameters experimentally identified on a Li-ion cell.

Investigation and Implementation Methodology

To identify the DFN model parameters, they are first grouped into geometric, thermodynamic and kinetic parameters. Microstructure analysis determines the geometric parameters by optical and scanning electron microscopy including energy dispersive X-ray spectroscopy and subsequent image processing. The thermodynamic parameters are optimized with the Levenberg-Marquardt algorithm using Open Circuit Voltage (OCV) and Galvanostatic Intermittent Titration Technique (GITT) tests. The most sensitive kinetic parameters are classified by QR decomposition with column pivoting and identified with nonlinear least-square regression techniques based on trust region and multiple data sets with shared parameters. To implement the PBM on an embedded system, the DFN model is simplified to the Single Particle Model (SPM) that approximates the solid phase of each electrode with a single spherical particle. The PDEs of the SPM are reduced to Ordinary Differential Equations (ODE) assuming polynomial lithium concentration in the particle and applying volume-averaged methods to the solid and liquid phase to preserve the electrolyte dynamics. Finally, the model is implemented as a state-space representation in Simulink combined with an Extended Kalman Filter (EKF) for optimal state estimation. The Simulink model is converted into C code and validated on the embedded system according to Model-Based Design (MBD).

Results and Expected Impact

The parameters for a physics-based Li-ion battery model were successfully identified using state-of-the-art testing and optimization methods, resulting in excellent model performance for realistic driving cycles. PBMs are therefore expected to become the key technology in advanced BMSs due to their ability to estimate electrochemical states and thus control degradation processes to maximize battery life.



Research methodology illustration encompassing experimental characterization, physics-based models and implementation into an embedded system.