Modelling the influence of cell-to-cell variations within lithium-ion battery modules on inhomogeneous module ageing

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When integrating unmatched cells into battery modules, cell-to-cell variations can lead to local temperature peaks which may result in selective accelerated cell aging. Fresh commercial lithium-ion cells show variations in capacity and impedance within a certain range due to manufacturing tolerances [1]. These variations lead to an inhomogeneous current distribution across the module depending on the module topology. As a consequence, the individual cells are subjected to different currents and temperatures during module operation. Over time, these differences will lead to variations in the state of health (SOH) of the connected cells within the module.

The presented work offers a model based framework towards analysing the impact of cell-to-cell variations within lithium-ion battery modules on inhomogeneous module ageing. In order to provide generally valid guidelines for various module topologies, this work focuses on analysing the smallest units of connected cells, namely 2s, 2p and 2s2p battery modules. These topologies result in a different ageing behaviour across the connected cells during module operation. Different operating scenarios are investigated to discuss their effect on module ageing when cell-to-cell variations are present: static CC-discharge-CCCV-charge cycling is compared to a commonly used dynamic EV driving cycle.

Each cell is described electrochemically by a p2D Newman model [2] which is coupled to a 0D thermal model of the cell. The thermal model accounts for heat generation and heat storage within the cell as well as heat dissipation to its surroundings due to conduction, convection and radiation. The ageing model is based on the work of Kindermann et al. [3] and accounts for solid electrolyte interphase (SEI) growth as the dominating capacity fade mechanism. By distinguishing between electronic (σ_{SEI}) and ionic (κ_{SEI}) conductivity of the SEI, the model allows to differentiate between capacity and power fade. The single cell models are coupled electrically based on Kirchhoff's circuit laws to reach electrical consistency according to the respective module topology. The electrical model additionally accounts for potential drops due to electrical resistances of the cell connectors and welding spots. The presented model is solved in COMSOL Multiphysics 5.3a.

The simulation results are discussed regarding the performance of the battery module topology and the development in SOH of the individual connected cells under the aforementioned cycling conditions. For this purpose, the behaviour of a system with a certain cell-to-cell variation is compared to the behaviour of an ideal, i.e. initially homogeneous system over its lifetime. Using this analysis, we can discuss the effect of thermal management with the impact of the degree of cell matching on module ageing. The discussion results serve as a guideline for superior battery module design.

References:

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