Multi-scale degradation modelling of lithium-ion batteries.

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Empirical stress-factor models are widely used to estimate lithium-ion battery aging in mobility and stationary applications, expressing capacity fade as a function of temperature, state of charge, depth of discharge, mean state of charge, and charge/discharge currents. Such models are parametrized at the cell level and extrapolated to module and pack scales under the implicit assumption of uniform stress across all cells. This assumption neglects thermal gradients, cell-to-cell parameter dispersion, and current redistribution effects that emerge at module and pack scales. The accuracy of this extrapolation has not been systematically quantified for Nordic mobility duty cycles. This work compares three structurally different aging models for a large-format NMC pouch cell a physics-based pseudo-two-dimensional model with SEI growth, lithium plating, and loss-of-active-material submodels implemented in PyBaMM; an equivalent circuit model parametrized from impedance and pulse-current measurements; and a published empirical stress-factor model under identical operational profiles at cell, module, and pack scales. Module and pack simulations are conducted in LIIONPACK with realistic cell-to-cell parameter dispersion and lumped thermal coupling. The cross-model comparison quantifies the extrapolation error of cell-level empirical aging models when applied at pack scale and identifies operating regions where physics-based multi-scale modelling is required for reliable lifetime prediction.