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Generating high-fidelity reduced-order physics-based lithium-ion cell models

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Due to their computational simplicity and robustness, equivalent-circuit-type cell models are widely used to inform control algorithms in battery-management systems. However, such models lack the predictive capability of physics-based cell models. For example, while equivalent-circuit models can predict a cell's current–voltage behaviors well, they cannot predict internal cell electrochemical variables such as lithium concentration or electric potential at different locations internal to the cell. Consequently, control algorithms based on equivalent-circuit models must be designed conservatively to ensure safe operation of a battery pack. This ultimately results in underutilization of true battery-pack capabilities.

Physics-based models can provide battery control algorithms information on cell internal electrochemical variables that are the instigators of premature aging or early indicators of unsafe operating conditions. However, because these models are generally based on partial-differential equations (PDEs), they require substantially more computation to evaluate than do equivalent-circuit models. Ideally, we would like to find reduced-order physics-based models that accurately represent the internal electrochemical variables, while being computationally simple and robust.

We describe two different methodologies to accomplish this objective. Both are based on linearizing the physics-based model's PDEs and creating transfer functions based on the locally linear model. Then, the discrete-time realization algorithm (DRA) and the continuous-time realization algorithm (CRA) take somewhat different steps to arrive at optimized high-fidelity reduced-order models. Both of these methods are based on subspace-based system-identification methodologies, and both can result in very good reduced-order models. Additionally, correction factors added to model output are able to approximate the nonlinearities that were removed by the linearization process.

We present results comparing and contrasting the DRA and CRA in terms of their tuning parameters and the fidelity of the predictions made by the models resulting from the methods. RMS voltage prediction accuracy of both models falls within a 5 mV range of truth, and internal electrochemical variables are correspondingly well predicted in an open-loop simulation. Online feedback state estimation using the final reduced-order model along with an extended Kalman filter yields accurate state-of-charge and internal variables prediction as well.

Keywords: reduced-order model; physics-based model; battery model order reduction; lithium-ion model