A New Multiphysics Modeling Framework to Simulate Large Battery Packs

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**Background and Motivation**

**Microscale, p2D, SPM, etc.**

Electrode length scale:
- <1Ahr
- ~4V

Battery length scale:
- >1Ahr and <100Ahr
- ~4V

Battery pack length scale:
- >100Ahr
- >100V

**Spatially resolved potential and temperature fields**

**MSMD battery model**

**Simplified models or CFD only simulations**

Markus Schindler et al 2020 J. Electrochem. Soc. 167 120542
Battery pack-level modeling framework

Cell and coolant temperature

Pack-level homogenized heat transfer model

Electrode-scale volume-averaged Tank-in-series battery model

0D Electrical model series-parallel connections

Akshay Subramaniam et al 2020 J. Electrochem. Soc. 167 113506
Battery pack-level modeling framework

- Spatially resolved conservation equations
- Full-order CFD simulation
- Closure term calculation and time-series temperature data
- Volume averaging
- Homogenized heat transfer equations
- Mathematical formulation

Fast battery pack heat transfer simulation
>100x reduction

Volume-averaged heat transfer model and simulations

Heat transfer coefficient and validation
Heat Transfer Model Validation

Pack configuration A
- Extended surface Fin
- Prismatic/pouch cell
- Coolant channel

Pack configuration B
- Cylindrical cell
- Coolant channel
Heat Transfer Model Validation

No electrochemical model
Heat generation vs time data from literature
Different discharge and mass flow rates

Pack configuration A

Pack configuration B
Battery pack-level modeling framework

Cell and coolant temperature

Pack-level homogenized heat transfer model

Temperature

Internal states

Electrode-scale volume-averaged battery model

Heat generation

Current

Voltage

Cell terminal voltage

0D Electrical model
series-parallel connections

Pack voltage and module current

100-300 cells*: ~50-150s for one discharge cycle

* 300 cells is not an upper limit in terms of the number of cells simulation tool can handle
Pack level configuration – NsMp

Module 1

Module M

\( I_{pack} = \sum_{i=1}^{M} I_{module,i} \)

Coolant in

Coolant out

Reference potential

\( N \) in series

\( M \) in parallel
Pack level simulation results – Effect of initial temperature – 100s2p

Low heat generation rate
Time to cool/warm up the cells much smaller than discharge time
Effect of initial temperature only visible at early times

C/2 rate
Pack level simulation results – Effect of initial temperature – 100s2p

High heat generation rate
Less time for the cells to cool/warm up relative to discharge time
Effect of initial temperature for a significant portion of the discharge
Pack level simulation results – Effect of initial temperature and C-rate – 100s2p

- Low temperature + High rate = Slower Li+ transport
- = Higher concentration overpotential
Pack level simulation results – Effect of manufacturing variation – 100s3p

Electrode thickness, porosity, and particle radius randomly varied by +/- 2% across the cells in the pack.
Manufacturing variation leads to “noise” in cell-to-cell temperature variation.
Pack level simulation results – Effect of manufacturing variation

The cell voltage variation across the pack dictated by manufacturing variation appears to be negligible at cycle 0.
Summary and future work

- A modeling framework - pack-level heat transfer, voltage and current distribution, and electrode-scale phenomena
- Effect of initial temperature, discharge rate, and manufacturing variation analyzed
- Include charging, cycling, and degradation at the pack level
- Effect of different thermal management approaches
- Study battery pack with different battery chemistry
- Integration with various applications – Space applications, Electric Aircrafts, EVs etc.
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