Evaluate the Effectiveness of Pack Thermal Management Strategy for Both Heating and Cooling Operations using AutoLion™

Introduction

Robust thermal management of a Li-ion battery pack is a key enabler to deliver desired performance and maintaining life and safe operation. In a large Li-ion battery pack (such as automotive as well as energy storage units for grid and distributed power), designing an efficient thermal management requires heating and/or cooling of pack with minimal electrical energy loss as well as minimization of cell-to-cell imbalance that may be caused by temperature distribution in a pack during operation.

Problem Statement

An automotive battery pack may face significant cell-to-cell imbalance during transient operation. Evaluate cell-to-cell imbalance in a multi-cell pack with 1C discharge during pack heating from subfreezing temperature (-10°C) and pack cooling in a hot environment (45°C). For pack heating condition, a practical drive cycle (US06 drive cycle) is also applied to evaluate the cell-cell imbalance for real world driving in cold weather.

Technology Used

AutoLion-3DTM with parallel computing

Setup

- Twenty four cell pack consisting of 35Ah cells of NCM/Graphite set up in AutoLion-3DTM.
- Battery pack with 2P-12S configuration (12 groups in series, each group containing 2 cells in parallel) designed with AutoLion-3DTM.
- Thermal mesh with air as coolant/heating agent running parallel to cells as coolant.
- For pack heating simulation, pack initial temperature is set to -10°C with inlet air (heating agent) temperature set as 50°C with air flow rate of 36 g/sec. For pack cooling simulation, the initial pack temperature is set to be 45°C and the air temperature is set as 25°C with the same air flow rate.
- Cells initial SOC is set as 100% for the 1C discharge simulation. For US06 drive cycle, the cell initial SOC is set to be 80%.

Results

Figure 1 2P12S pack configuration schematic with cell group 1 and 12 highlighted.

Figure 2 Spatial temperature distribution throughout the pack after 500 sec during pack heating and 1C discharge
Figure 3 Average cell temperature distribution in the whole pack, cell group #1 (cell #1 and #2) and #12 (cell #23 and #24) as a function of time during pack discharge with heating from -10°C at 1C rate

Figure 4 Discharging current as a function of time for cells #1, #2, #23 and #24 during pack discharge with heating from -10°C at 1C rate

Figure 5 Voltage as a function of time for cells #1, #2, #23 and #24 during pack discharge with heating from -10°C at 1C rate

Figure 6 SOC as a function of time for cells #1, #2, #23 and #24 during pack discharge with heating from -10°C at 1C rate

Figure 7 Average cell temperature distribution in the whole pack, cell group #1 (cell #1 and #2) and #12 (cell #23 and #24) as a function of time during pack discharge with cooling from 45°C at 1C rate

Figure 8 Discharging current as a function of time for cells #1, #2, #23 and #24 during pack discharge with cooling from 45°C at 1C rate
Figure 9 Voltage as a function of time for cells #1, #2, #23 and #24 during pack discharge with cooling from 45°C at 1C rate.

Figure 10 SOC as a function of time for cells #1, #2, #23 and #24 during pack discharge with cooling from 45°C at 1C rate.

Figure 11 Average cell temperature distribution in the whole pack, cell group #1 (cell #1 and #2) and #12 (cell #23 and #24) as a function of time during US06 drive cycle with heating from -10°C.

Figure 12 Currents as a function of time for cell group 1 (#1 and #2) during US06 drive cycle with heating from -10°C.

Figure 13 Currents as a function of time for cell group 12 (#23 and #24) during US06 drive cycle with heating from -10°C.

Figure 14 Voltages as a function of time for cell group 1 (#1 and #2) during US06 drive cycle with heating from -10°C.
Summary and User Benefits

- Heating and cooling of a pack creates a different set of challenges for pack integrators. For instance, for the cooling/heating arrangement for the pack simulated here, heating pack from -10°C creates a very significant cell-to-cell imbalance that will warrant change in thermal management strategy or aggressive cell balancing BMS algorithms. In contrast, during pack cooling thermal imbalance was minimal. Thermal management strategy and its impact on heating and cooling of pack can be very reliably investigated with AutoLion-3D™.

- Thermally-driven SOC imbalance has performance, life, and safety consequences, and can only be simulated with a thermally coupled battery (TCB) model such as AutoLion-3D™.

- During pack 1C discharge with heating, in group #1, cell #1 remains substantially colder than cell #2 due to its location in the pack cooling design; lower temperature in cell #1 renders higher resistance, and hence carries substantially less current than cell #2 at the beginning of discharge. Similarly, in group #12, cell #24 remains substantially colder than cell #23 hence carries substantially less current than cell #23. AutoLion-3D™ is the only software that can simulate voltage and current change under any safety condition in addition to the temperature rise estimation.

- During pack 1C discharge with cooling, the temperature difference between cells is smaller. In group #1, cell #1 remains slightly hotter than cell #2 due to its location in the pack cooling design; lower temperature in cell #2 renders higher resistance, and hence carries less current than cell #1 at the beginning of discharge. Similarly, in group #12, cell #23 remains colder than cell #24 hence carries less current than cell #24.

- For 1C discharge with pack heating, over time, greater current carried by colder cells #1 and #24 leads to substantial cell SOC imbalance, and limits performance of entire pack. The same cell-cell imbalance happens for US06 drive cycle and as the temperature difference between cells increases, the imbalance becomes more and more significant. However, for 1C discharge with pack cooling, the magnitude of imbalance seems much smaller due to less temperature difference between cells.

- AutoLion-3D™ has demonstrated capabilities of simulating large packs with >10 million mesh size. The parallel computing capabilities allow users to simulate large packs in a very time-efficient manner.