Optimize Cell/Pack Design to Meet Safety Requirements Even Before Building a Cell with AutoLion-3D™

Introduction

The growing demand of long-range electric vehicles and stationary energy storage means OEMs are working to make packs and systems with high capacity cells. From cost and system volume perspective, it is beneficial to fabricate thick cells with high capacity (30 Ah to 70 Ah) but is it safe to have thick cells with a lot of energy within one cell? Both from system integrator and cell manufacturer perspective, it is important to find out what is the “thickest cell” or maximum energy within one cell they can have to lower cost but still meet all the safety requirements. Currently, fabricating cells with different energy content and doing safety testing is the only way. But what if a software can reliably help answer the aforementioned questions reliably even before cells are built? AutoLion-3D™ is the software which can enable users to address such practical questions about safety and cell/pack design.

Problem Statement

We are simulating nail penetration for two cases: One for 30Ah thick cell and in the other case a 6P1S (6 cells in parallel and 1 in series) pack with each cell of 5Ah. The energy content in both the cases is same. Obviously, from cost perspective having one 30Ah cell is better than 6 cells with each cell of 5Ah capacity. This case study is aimed at evaluating safety under nail penetration for the aforementioned cases.

Setup

- A 30Ah NCM/Graphite prismatic cell and a battery pack with 6P1S configuration (6 in parallel, 1 in series) pack with each cell being 5Ah capacity with NCM/Graphite chemistry are set up in AutoLion 3D™. Both “thick” 30 Ah cell and 6P1S pack with “thin” 5Ah cells have the same energy content. Both cells have the exactly same internal structure too (foil size, electrodes thickness and porosity, etc.).
- The 30Ah cell is 18 mm thick with foot print area of 80mm X 130mm. The 5Ah cell is 3 mm thick with the same foot print area as 30 Ah cell.

Results

- Nail penetration simulation with nail diameter of 20 mm and stainless steel material is carried out.

Figure 1 shows the temperature distribution for the 6P1S pack at t=220s (the time when the temperature peak of the whole pack is reached) and for the 30 Ah cell at t=400s (the time when the temperature peak is reached). As compared with the 6P1S pack, the max temperature of the 30 Ah cell is about 165 degrees higher (360°C for the 30Ah cell and 195°C for the 6P1S pack), although both have the same energy content. Figure 2 shows the maximum temperature rise with time for 30Ah cell and 6P1S pack. In Figure 2, temperature below 150°C is considered to be safe.
Temperature between 150°C and 225°C (the grey zone) can be considered a danger zone where there is a possibility for thermal runaway. Any temperature above the grey zone will most likely lead to thermal runaway. Based on the simulation result (Figure 2), 6P1S pack is substantially safer than the single 30Ah cell during a nail penetration process; however, even the 5Ah based 6P1S configuration reaches the “danger zone” temperature in this case.

Figure 3 shows simulated voltage and current (in terms of C-rate) response with time during nail penetration for 30Ah cell and 6P1S pack with each cell of 5Ah capacity, respectively. The results from these two designs are almost identical to each other, which can be explained by the same electrochemical structure of the two designs; namely the same internal structure and the same single sheet foil size.

On the other hand, the reason that 30Ah single cell has significantly higher temperature than the 6P1S pack is largely thermal condition and not electrochemical design. The 6P1S has larger total surface area and therefore, even though the heat generations are the same for the two cases, the 6S1P pack is significantly cooler during nail penetration due to better heat dissipation capability. To demonstrate this further, we have created a hypothetical scenario where thermal boundary condition of 30 Ah cell is made the same as 6S1P pack (i.e. h (convective heat transfer coefficient)×A (surface area) of 6S1P pack is inputted for 30Ah cell). As shown in Figure 4, temperature rise for 30Ah cell with this “artificial” thermal boundary condition becomes identical to the 6S1P pack.

Benefits

- **AutoLion-3DTM** is the software that can enable users to optimize cost-safety equation especially for high energy Li-ion battery applications. Users can easily determine the maximum energy (or cell thickness) they can safely put in a cell to minimize cell and pack cost for any chemistry before even fabricating a cell.
- Cell and pack safety simulation for on-field relevant conditions such as internal short, external short can be easily done with AutoLion-3DTM.
- AutoLion-3DTM can readily be used for rapid evaluation of safety designs to prevent thermal runaway of large format Li-ion cell packs during nail penetration.
- AutoLion-3DTM is the only software that can simulate voltage and current change under any
safety condition in addition to the temperature rise estimation.

- Simulation performed in approximately two hours with standard computing resources.
- Different sizes and types of cell chemistries, cell sizes, nail penetration locations, and nail sizes can readily be simulated using AutoLion-3D™.