

## Electrothermal Analysis of Lithium Ion Batteries

Ahmad Pesaran<sup>1</sup>, Andreas Vlahinos, and Desikan Bharathan  
National Renewable Energy Laboratory\*  
1617 Cole Blvd, Golden, CO 80401, USA

Tien Duong  
U.S. Department of Energy  
Washington, D.C., USA

<sup>1</sup>Corresponding Author  
Ahmad Pesaran, Principal Engineer, [ahmad\\_pesaran@nrel.gov](mailto:ahmad_pesaran@nrel.gov)  
Tel: 303 275-4441, Fax: 303 275-4415

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#### Extended Abstract

Temperature greatly affects performance, safety, and life of large lithium ion batteries in hybrid vehicles under real driving conditions. Therefore, automakers and battery suppliers are paying increased attention to thermal management for these batteries. Good thermal management starts with proper thermal design of each cell and then a module. For hybrid vehicle applications, particularly for high-power 42V systems, the current through the battery could exceed more than 200 A, so the resistive elements of a battery may generate more heat than the electrochemical components. For this reason, we recently developed an **electrothermal** finite element analysis approach for predicting thermal performance of various components of cells/batteries. In this approach, we can capture realistic geometries, loads, and boundary conditions of a cell/battery with particular attention to resistive components such as winding-terminal, terminal-case, and terminal-post connections. We applied the electrothermal analysis to two design iterations of Saft lithium ion cylindrical cells developed for the U.S. Department of Energy's FreedomCAR program for the period of 2003-2005. Our goal was to identify any areas of thermal concern on each design and propose recommendations for improving cell performance.

**Electrothermal Model.** It is particularly challenging to capture and model all the physical elements and details of a cell, and drive the design parametrically for simultaneous electrical and thermal (electrothermal or E-T) modeling, plus structure performance limits and specifications for optimum efficiency and cost considerations. The process of engineering optimization by using highly connected computer-aided engineering (CAE) approaches is not standard industry practice, although it may be considered to be the ideal method. During the course of this project, the National Renewable Energy Laboratory (NREL) and Saft worked closely to develop such a

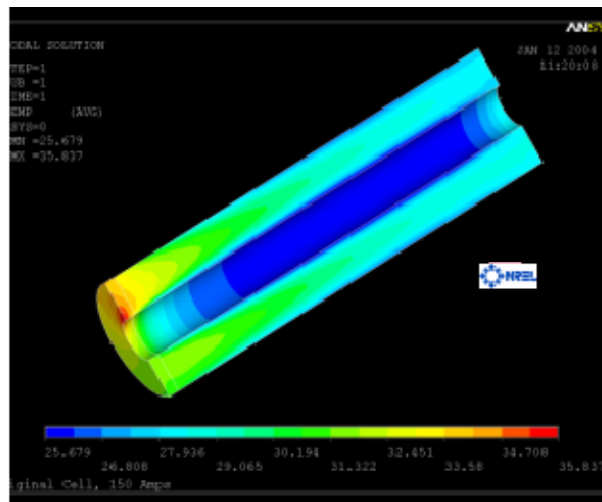
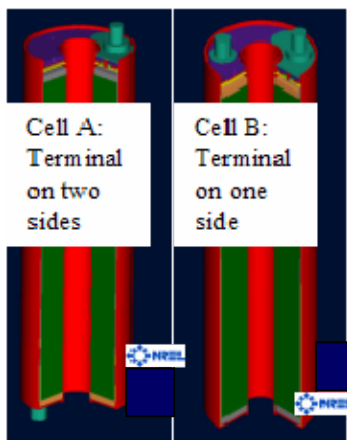
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tool. We used ProEngineer (Pro-E) software to build a CAE model of each cell. Then we transferred the Pro-E models to a finite element analysis software (ANSYS) to create a finite element model capable of both electrical and thermal analysis. Once the geometry and material properties were entered, ANSYS could calculate the electrical resistance of each component. By applying a voltage drop across the two terminals, a current flowed through the cell, causing resistive heat generation that increased the temperature of all components proportional to the internal DC resistance. ANSYS used the heat generated in each element to estimate the temperature distribution in the cell. Using this approach the designer can improve thermal design by reducing resistances, improve power capability of batteries, and avoid extreme hot spots in cells that lead to premature aging of cells.

**Analysis of Saft Li-Ion Cells.** We applied E-T analysis to two Saft lithium ion cylindrical cells using the same current flow and convection boundary conditions. Two different designs were used: in Cell Design A, the terminals were on opposite sides; in Cell Design B, the terminals were on the same side. We used both steady-state and transient loads. The steady-state heat generation data were based on measuring heat generated from cells under US06 standard drive profile using the NREL calorimeter. For transient load we used the P-HEV Heat Load test recommended in the 42V FreedomCAR Battery Manual. The E-T analysis showed that in the Cell Design A, a hot spot occurs on the negative side next to a weld junction. The Cell Design B runs cooler because of lower electrical resistance in the areas of concern.

In this paper, we have described the electrothermal model and presented the results and findings from the electrothermal analysis of the two cylindrical Li-Ion cell designs.



Temperature distribution in the winding Cell A