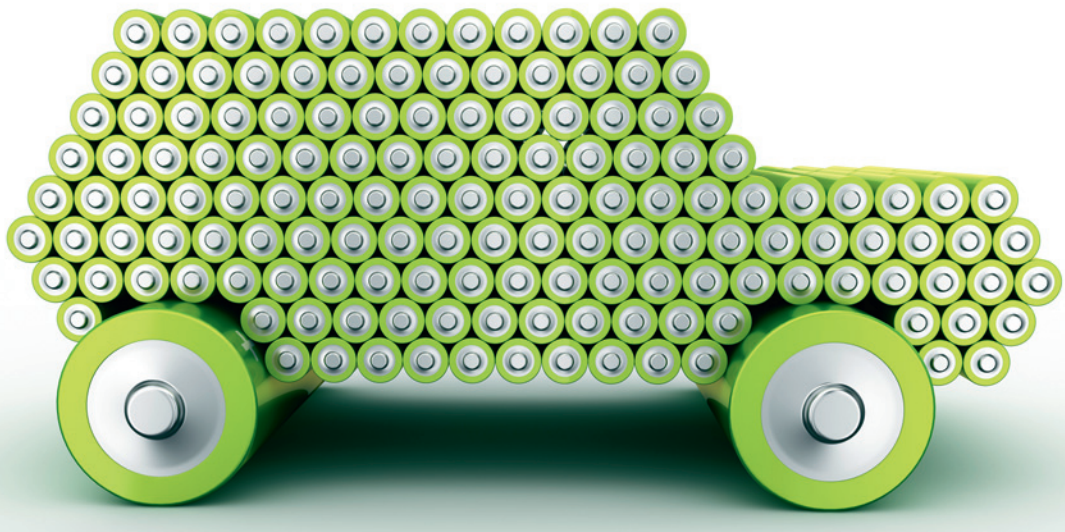
Gefördert durch das
Bundesministerium
für Bildung
und Forschung
KF2588601WD0



Electrothermal Simulation
of a Battery Pack

Efficient Thermal Management

High power energy storage systems are crucial for the new age of electric vehicles. Lithium-ion batteries have the advantage of high energy density, good aging characteristics and high efficiency, but at the same time the thermal range of operation is limited. At temperatures below 0 °C, the power capacity of the lithium battery is reduced up to 70 % and temperatures of more than 40 °C could generate an irreversible damage (over 70 °C also thermal runaway may occur). Hence an efficient and accurate thermal management is necessary.

The process to set up an electrothermal simulation is shown in Fig. 1 and it will be explained in detail below. First we need a temperature dependent electrical battery model which is also capable to describe heat losses. Heat losses from a battery enter into the thermal subsystem where temperature distribution is evaluated. Temperature influences electrical properties of the battery as well as its power dissipation. The joint simulation of an electrical and a thermal subsystem can therefore be referred to as electrothermal simulation.

A practical problem is related to the fact that finite elements are usually employed to develop a thermal model of the battery pack. Such models are high dimensional and incompatible with system simulation as its transient simulation takes too much time. The development of a compact thermal model based on a finite element

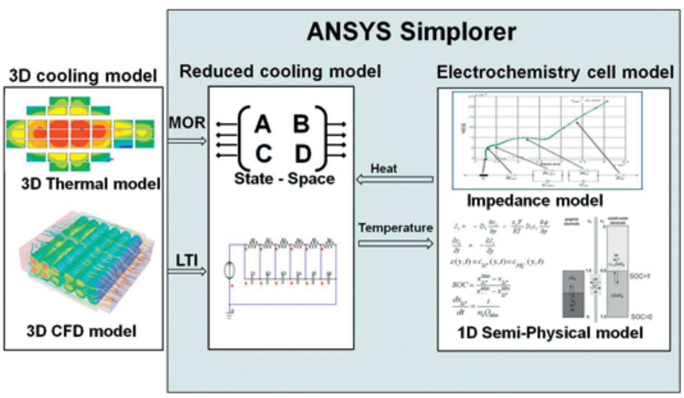


Fig. 1: The overview of electrothermal simulation of a battery pack

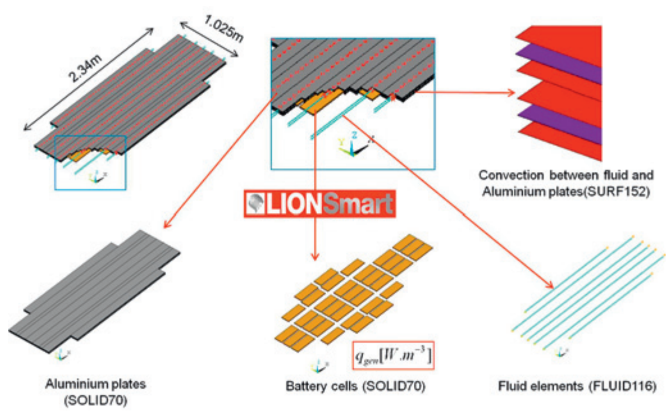


Fig. 2: The battery pack model (http://www.lionsmart.de/).

model is therefore necessary as an intermediate step (Fig. 1).

Electrochemical Model of Li-ion Battery in Simplorer

Physically based electrochemical battery models are complex since different physics are coupled to enable the transformation of electrical energy into chemical and vice-versa. Electrical current is the driving force of electrochemical reactions at battery electrodes. Thermodynamics determine the electrodes' operation limits, like maximum and minimum potential and the chemical reactions' direction. Ion transport exists between electrodes in the electrolyte to match the electron transport in the circuit.

The best known physically based model of Li-ion battery is the Newman model that is now available in Simplorer. However, its simulation takes longer and we have developed its simplified version that is shown in Fig. 1 as a semiphysical model. On the other hand, the physico-chemical properties of a Li-ion cell necessary to run the Newman model are usually unknown in practice. The only practical way to develop an electrical model is to characterize the battery by means of charge-discharge measurements and electrochemical impedance spectroscopy. Such models are usually referred to as impedance models and they could be easily implemented in Simplorer using look-up tables.

Thermal Model of a Battery Pack in ANSYS Mechanical

Let us consider the finite element model of a battery pack developed by the company Lion Smart in ANSYS Mechanical (see Fig. 2). The model consists of 33 individual batteries that have been cooled by means of channels between battery layers. The cells have been modeled as solid bodies with orthotropic material properties to deal with different heat conductivity of electrodes and electrolyte. The channels have been modeled using one dimensional CFD (FLUID116 elements in ANSYS). The one dimensional elements allow us to model the bulk temperature in the channel and they are connected with the cells through surface elements that model convection boundary conditions. The film coefficient was evaluated by a CFD-analysis of the detailed fluid flow geometry in ANSYS CFD.

The presented model has been already simplified using one dimensional CFD and orthotropic material properties, yet it is still too high dimensional in order to employ it directly at system level simulation.

Compact Thermal Model through Model Reduction

MOR for ANSYS is an add-on to ANSYS Mechanical and implements the newest algorithm developed by mathematicians to accurately and automatically approximate a high dimensional dynamical system. The process is shown in Fig. 3. A command object in Mechanical allows us to write information about system matrices of the finite element system in binary FULL files. The software MOR for ANSYS reads the system matrices, runs the model reduction algorithm and writes a reduced model out. It is possible to obtain the reduced model either in the state space format as input-output representation or as a thermal port when one pin possesses two values (temperature and heat generation). In both cases the reduced models can be directly imported into Simplorer. If one dimensional CFD is not an option to develop an accurate thermal model and the full scale CFD is necessary, then ANSYS offers an alternative technology (see Fig. 1) to develop a compact thermal model that is implemented as a link between Fluent and Simplorer.

Electrothermal Simulation in Simplorer

A typical electrothermal simulation is shown in Fig. 4. In this case an electrical model of a Li-ion battery could be either an impedance model, or a physically based model. Each cell is modeled separately and has two electrical terminals and one thermal. The thermal terminal transmits the heat dissipation from the battery into the thermal subsystem and returns back the battery temperature. For simplicity reasons only four cells are shown in Fig. 4 but the technology presented in the paper is scalable up to 100 Li-ion cells in the battery pack.

InfoAuthor | CADFEM
Dr. Evgeny Rudnyi, CADFEM GmbH, Grafing

InfoContact | CADFEM
Udo Killat, CADFEM GmbH
Tel. +49 (0)8092-7005-23
ukillat@cadfem.de

InfoSoftware applied
ANSYS Workbench; Simplorer, ANSYS Mechanical, MOR for ANSYS

RelatedInfo | emobility
www.cadfem.de/emobilitaet
http://ModelReduction.com

InfoSeminar
Simulation von Batteriepacks für Hybrid- & Elektrofahrzeuge (HEV/EV)
www.esocaet.com/seminare/vertiefung

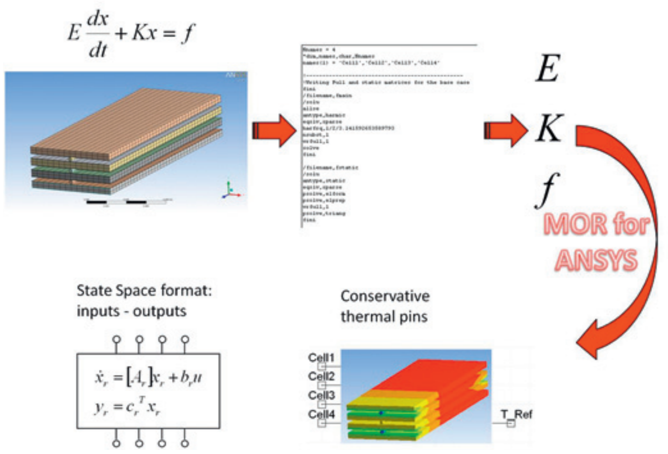


Fig. 3: Model reduction process.

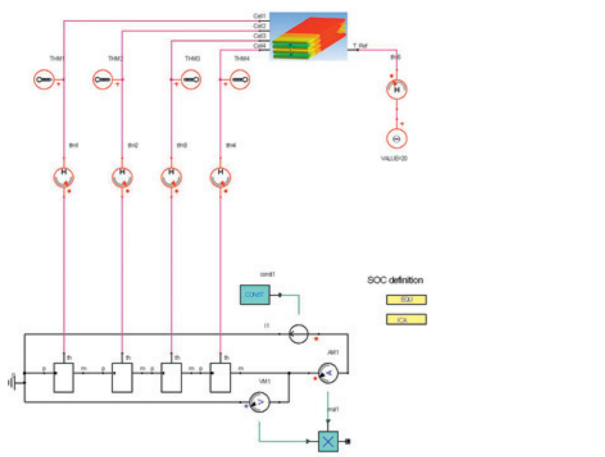


Fig. 4: Electrothermal simulation of the battery pack at system level.