CHALMERS

ELKRAFT 2017

Electro-thermal modeling of high-performance li-ion batteries

Background and Aim

The currently available lithium-ion battery technologies offer unprecedented energy storage capabilities, and are yet in its disruptive phase of development. In order to understand how they behave electrically and thermally during high load, a reasonably complex model must be found to capture the essential properties.

Electrical pulse testing to parametrize equivalent circuit models

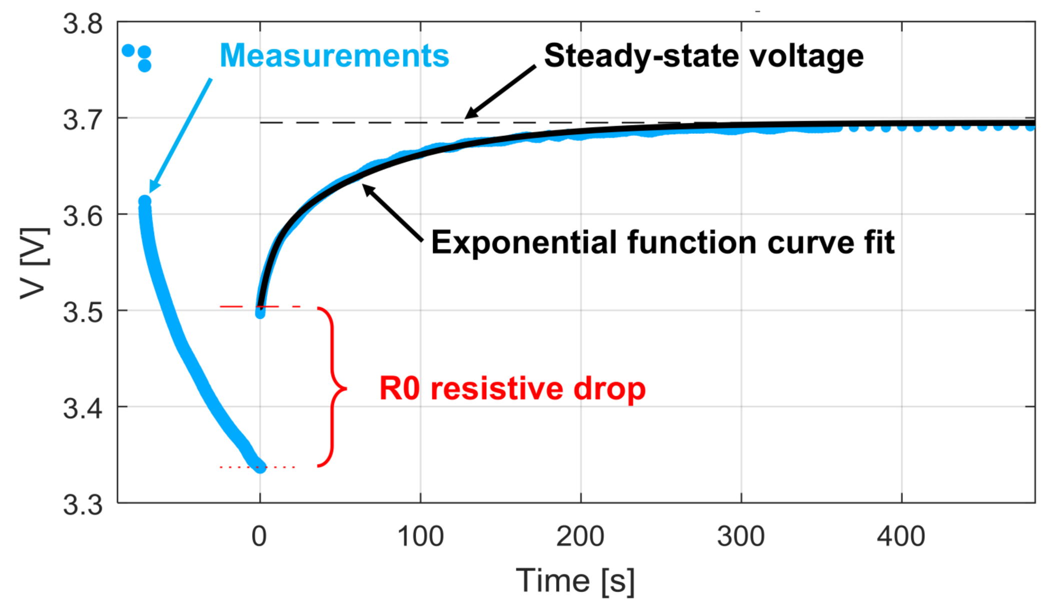

Fig. 1 High-current pulse testing is an effective method of capturing the voltage dynamics of li-ion cells. Current amplitudes should be close to the intended application usage

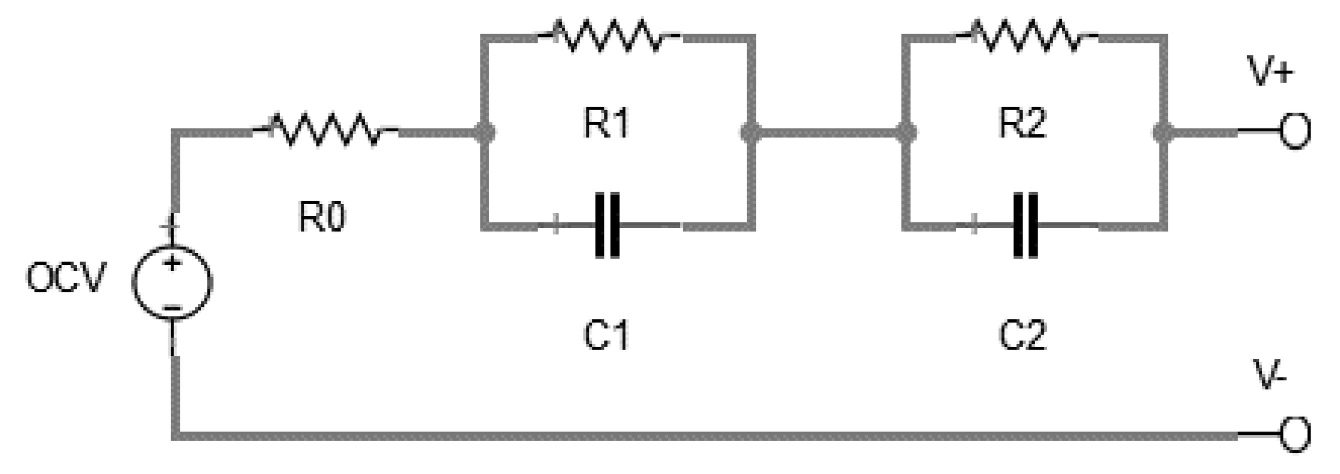

Fig. 2 A two-time-constant dynamical model represents the voltage behavior accurately in the time range of 1 second to 1 hour. All parameters are preferrably a function of SOC and temperature.

Thermal model for li-ion cells including reversible entropy heat

$$\dot{q} = \dot{q_J} + \dot{q_E} = i^2 R_{tot} + iT\frac{\partial U}{\partial T}$$

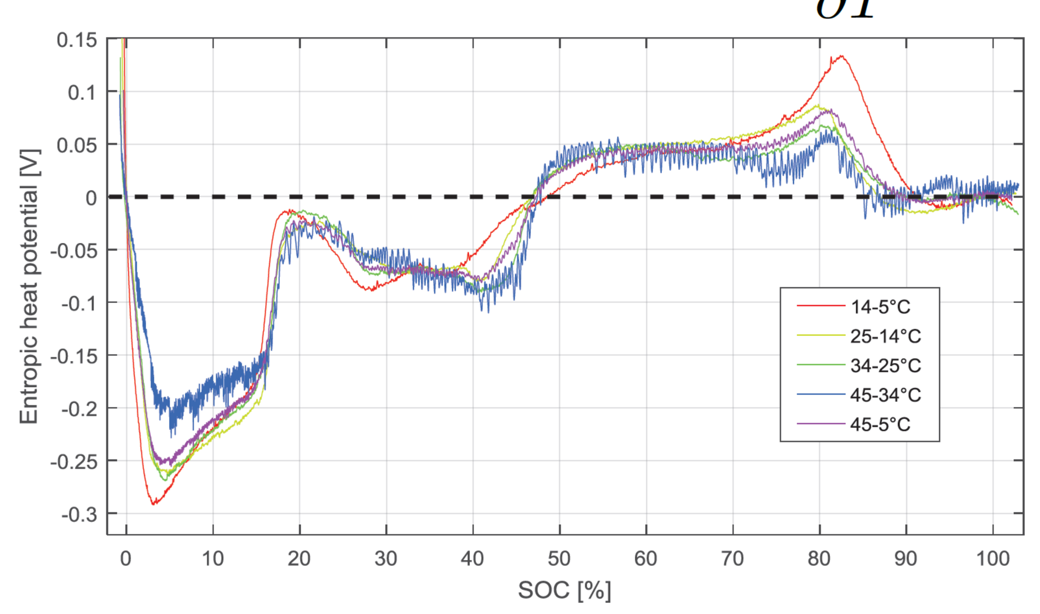

Fig. 3 Including entropic heat in the thermal model increases the accuracy significantly

A lithium-ion cell can cool down itself, even under high current loads. This is due to endothermic reactions taking form during certain charge levels. Unfortunately, the heat is just stored in the chemical bonds and released later in the charge or discharge cycle. Neglecting this strong phenomena will result in large offsets in temperature modeling, making it hard to reach below 1K in long-term accuracy.

Application benefits

When using li-ion cells in high-performance applications, such as electrified vehicles, it is beneficial to be able to accurately predict the voltage and thermal behavior of the cell. Efficient modeling leads opens of for lower safety margins without sacrificing safety, and hence increasing performance per weight or volume unit.

The models suggested here are relatively simple and the dynamics are anchored in the underlying physics, despite originating from empirical modeling. The models are highly suitable to be executed in real-time, e.g. in battery management software in large battery packs. Parametrisation of the models can be done through automated processes with one or a few physical examples of the lithium ion cell of interest.

Conclusions

- A second order electrical model captures slow-acting diffusion dynamics effectively, time ranges 1 second to 1 hour
- An accurate thermal model for li-ion cells should include both irreversible joule heat and reversible entropy heat

Financed by VINNOVA in coorporation with Volvo Cars

Presented at IEEE EPE2016 and IEEE APEC2017

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