Comparison between Bernardi's equation and Heat Flux Sensor measurement as Battery Heat Generation Estimation Method

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Introduction

Comparison between the use of a heat flux sensor (HFS) for a measurement of heat losses in Li-Ion cells, and the widely used and simplified version of Bernardi's equation [1, 2].

Validation in temperature response.

Thermal characterization with HFS

- The Thermal Characterization platform of Figure 1 was built to record current, voltage, ambient temperature, surface temperature, and HFS output voltage.
- Thermal characterization to obtain heat capacity and thermal equivalent resistance of lumped thermal model (Figure 2) with Static (Figure 3) and Dynamic tests (Figure 4) [3].
- Internal and external cell temperature are considered equal ($R_{th,conv}$ = 0)

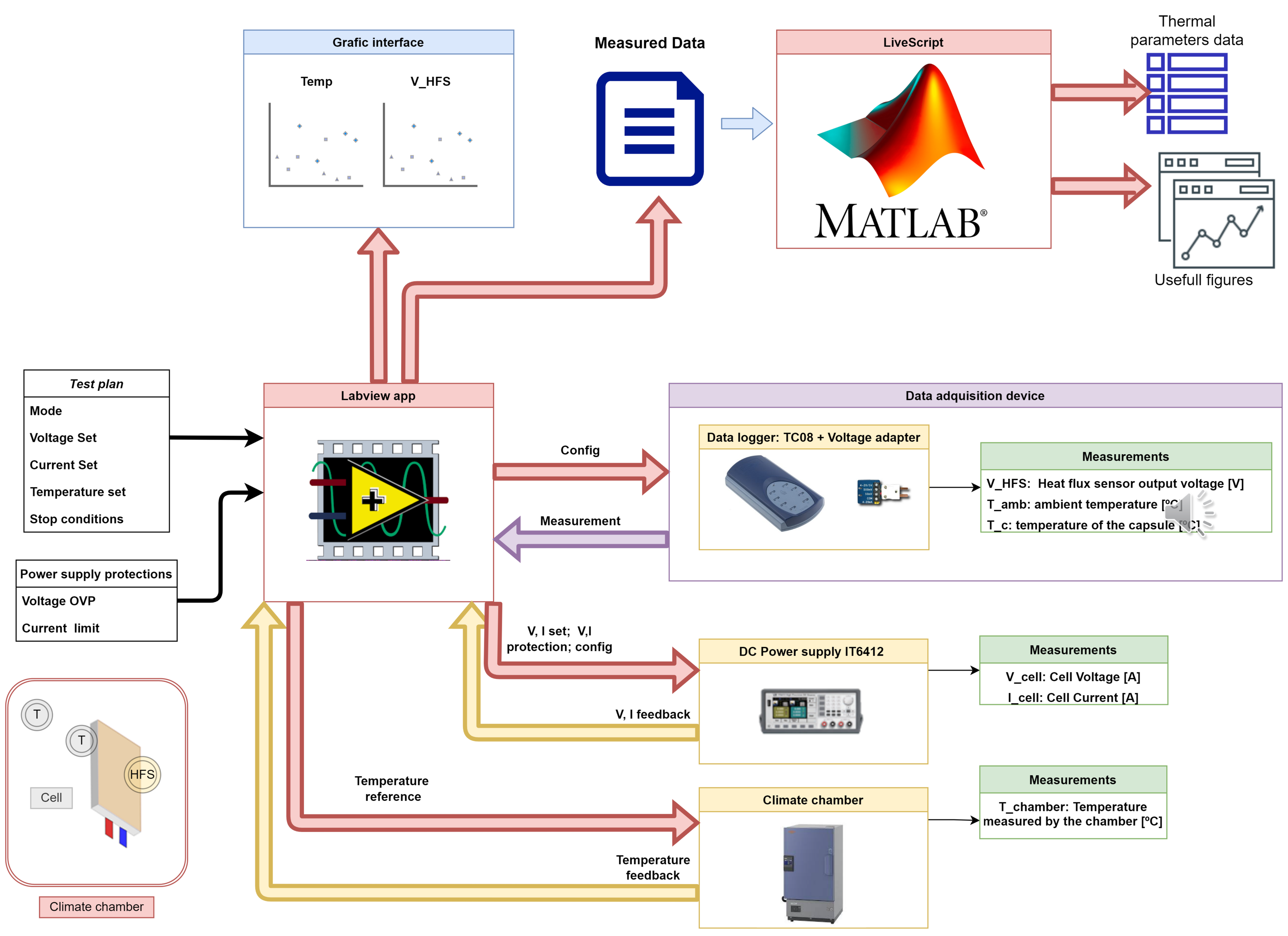

Figure 1. : Thermal characterization platform

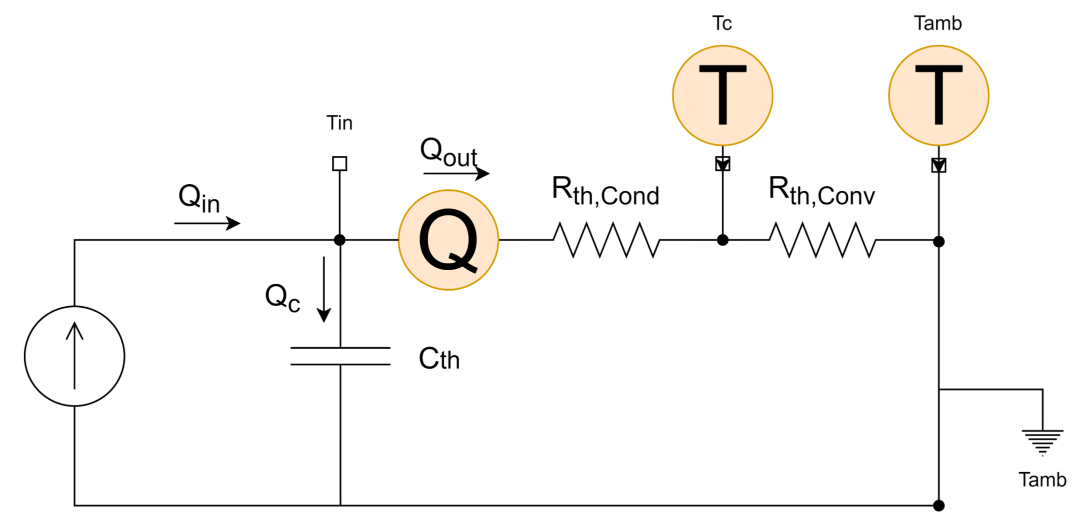

Figure 2. : Lumped thermal model

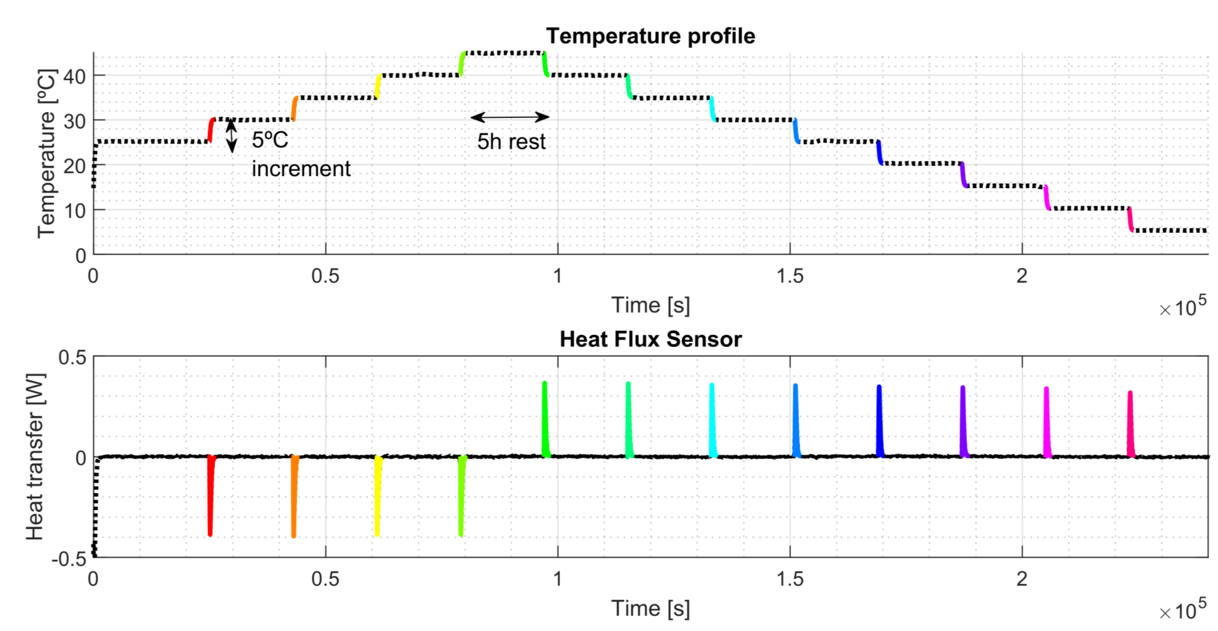

Figure 3. : Static test, temperature profile and HFS output

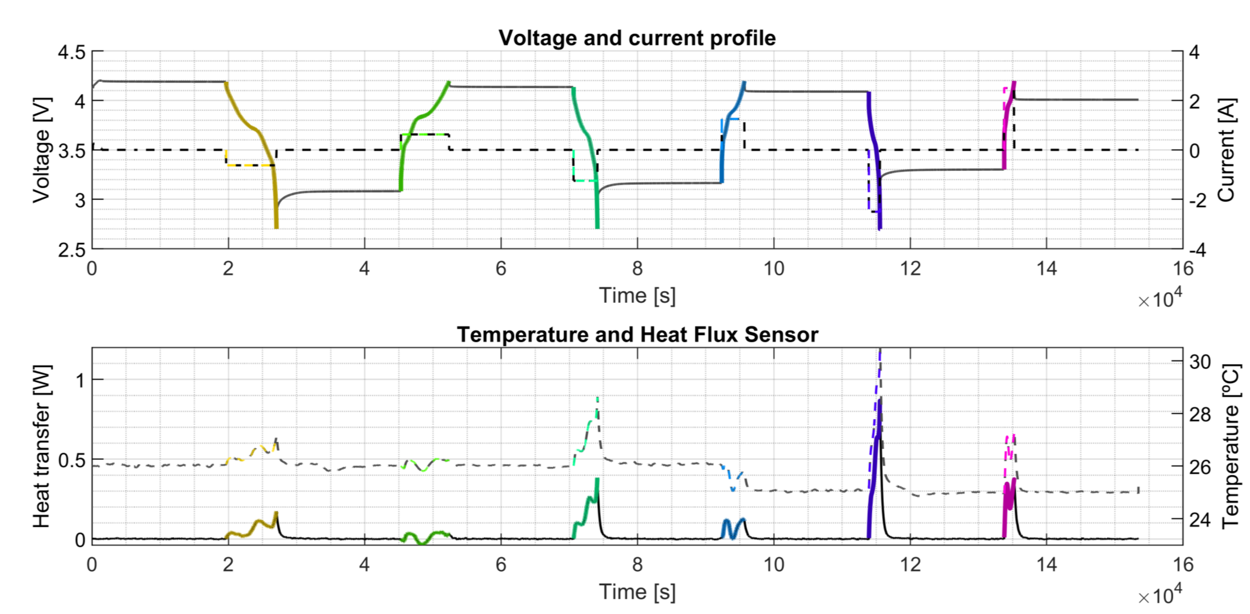

Figure 4. : Dynamic test, Current profile and HFS output

Comparison Bernardi's simplified equation and measurement of heat generation with HFS

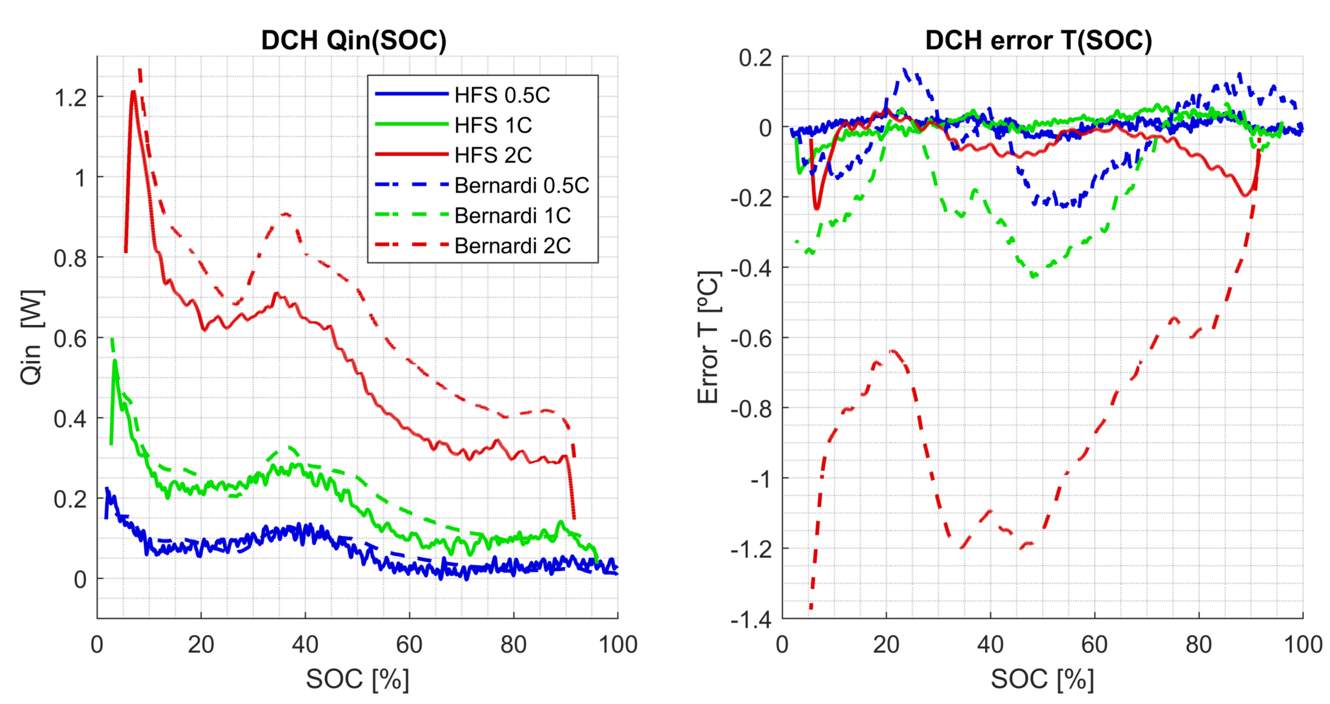

Figure 5. Comparative results during discharge

- Bernardi et al. [1] determined an expression for the calculation of the energy balance of a cell along its whole volume.

$$Q_{in} = Q_{irr} + Q_{rev} = I(OCV_{avg}(SOC) - V) - I\left(T\frac{\partial OCV_{avg}(SOC)}{\partial T}\right)$$

- The HFS are based on the Seebeck effect by sensing tangential gradients of electric potential produced by heat flux across the surface of the sensor.

Assuming uniform distribution of the temperature along the cell, the heat generation can be expressed as:

$$Q_{in} = Q_{out} + Q_c = Q_{out,HFS} + R_{th,conv} \cdot C_{th} \cdot \frac{dQ_{out,HFS}}{dt}$$

Conclusions and outlook

- HFS gives a more precise estimation than Bernardi's simplified equation. The maximum temperature prediction error with HFS is 0.28 ºC, in contrast with 1.38 ºC with Bernardi's simplified equation.
- Bernardi's simplified equation differs from cell temperature measurements during charge and discharge, at high C-rates.

References

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[3] C. Ziebert et al., "How calorimeters and heat flux sensors improve thermal management and safety of cells and packs."

Acknowledgements

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