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Comparison between Bernardi's Equation and Heat Flux Sensor Measurement as Battery Heat Generation Estimation Method

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Abstract : The heat generation of an energy storage system is an essential topic when designing a battery pack and its cooling system. Heat generation estimation is used together with thermal models to predict battery temperature in operation and adapt the design of the battery pack and the cooling system to these thermal needs guaranteeing its safety and correct operation. In the present work, a comparison between the use of a heat flux sensor (HFS) for indirect measurement of heat losses in a cell and the widely used and simplified version of Bernardi's equation for estimation is presented. First, a Li-ion cell is thermally characterized with an HFS to measure the thermal parameters that are used in a first-order lumped thermal model. These parameters are the equivalent thermal capacity and the thermal equivalent resistance of a single Li-ion cell. Static (when no current is flowing through the cell) and dynamic (making current flow through the cell) tests are conducted in which HFS is used to measure heat between the cell and the ambient, so thermal capacity and resistances respectively can be calculated. An experimental platform records current, voltage, ambient temperature, surface temperature, and HFS output voltage. Second, an equivalent circuit model is built in a Matlab-Simulink environment. This allows the comparison between the generated heat predicted by Bernardi's equation and the HFS measurements. Data post-processing is required to extrapolate the heat generation from the HFS measurements, as the sensor records the heat released to the ambient and not the one generated within the cell. Finally, the cell temperature evolution is estimated with the lumped thermal model (using both HFS and Bernardi's equation total heat generation) and compared towards experimental temperature data (measured with a T-type thermocouple). At the end of this work, a critical review of the results obtained and the possible mismatch reasons are reported. The results show that indirectly measuring the heat generation with HFS gives a more precise estimation than Bernardi's simplified equation. On the one hand, when using Bernardi's simplified equation, estimated heat generation differs from cell temperature measurements during charges at high current rates. Additionally, for low capacity cells where a small change in capacity has a great influence on the terminal voltage, the estimated heat generation shows high dependency on the State of Charge (SoC) estimation, and therefore open circuit voltage calculation (as it is SoC dependent). On the other hand, with indirect measuring the heat generation with HFS, the resulting error is a maximum of 0.28ºC in the temperature prediction, in contrast with 1.38ºC with Bernardi's simplified equation. This illustrates the limitations of Bernardi's simplified equation for applications where precise heat monitoring is required. For higher current rates, Bernardi's equation estimates more heat generation and consequently, a higher predicted temperature. Bernardi´s equation accounts for no losses after cutting the charging or discharging current. However, HFS measurement shows that after cutting the current the cell continues generating heat for some time, increasing the error of Bernardi´s equation.

Keywords : lithium-ion battery, heat flux sensor, heat generation, thermal characterization
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