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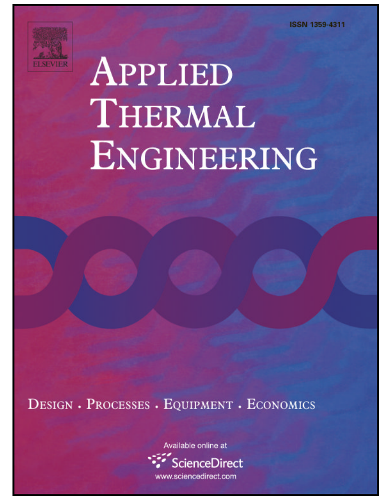

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A Combined Thermo-Electric Resistance Degradation model for Nickel Manganese Cobalt Oxide based Lithium-Ion cells

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Abstract

This paper presents a novel effort in combining an electro-thermal internal resistance model for Nickel Manganese Cobalt Oxide (NMC) cathode and graphite anode based cells, designed for predictive analysis for automotive applications. This unique approach provides insight in the degradation rate of the internal resistance with respect to the Depth of Discharge, Current rate, cycle number, storage State of Charge and storage time. The data used for the model development is courtesy of a huge test-campaign, spanning the course of 2.5 years, and provides a good insight in the behavior of what is considered to be a very promising battery cell technology for automotive applications. Experimental results show that the internal resistance evolution is strongly dependent on Depth of Discharge and temperature, while high storage State of Charges and high storage temperatures increase the degradation rate during calendaring aging. The combined electric and thermal models make it possible to estimate the influence of the current rate on the degradation of the internal resistance. The developed lifetime model is capable of correctly estimating the degradation and temperature behavior of static load profiles, while also providing insight in the evolution of the temperature profile and other cell characteristics.

Keywords: Predictive model, Internal Resistance, Aging, Thermal model, Electrical model

1. Introduction

Lithium-ion batteries (LiBs) are widely used as Rechargeable Energy Storage Systems (RESS) in virtually all industries, from consumer electronics to automotive applications, off-grid storage, the space industry and so on, due to their energy and power capabilities [1]. As all electrochemical devices, LiBs show time and usage-dependent degradation of their performance, which is usually expressed and quantified in either capacity loss or internal resistance (RINT) increase. These measurable phenomena have been a research topic for a long time, with majority of the effort being put into the modeling of the capacity fade. This lack of predictive internal resistance models could be attributed to some reasons: it is generally accepted that capacity fade is more noticeable, and has a larger impact in both consumer electronics ("bad battery life for a smartphone") and Electric Vehicles (EV's), where driving range in directly impacted by the capacity losses. Also, considerable research has been done in estimating/measuring the internal resistance on board of an EV, using so-called online State-of-Health (SOH) estimation techniques and models [2–8]. These techniques rely most often on sampled measurements of the battery pack voltage, and can estimate the capacity loss or internal resistance change, either while parked or during operation. They are not capable however of predicting the internal resistance change.

So far, to the best of the authors knowledge, only a few researchers have published a predictive internal resistance model. In [9] a simplified electrochemical and thermal aging model is proposed for $LiFePo_4$, simulating both capacity and power fade. It includes different possible explanations to the impedance increase of the cell, including SEI film resistance and the electrolyte mass transport resistance. However, their validation data was based on a very limited number of cells, and while some measurements were performed by the researchers, other data was taken from other literature. In [10], they propose a semi-empirical model for NMC/graphite cells based on an exponential time dependent aging rate for calendaring aging, fitted to accelerated aging data. It is important to note that the developed model was only concerned with calendar ag-

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