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Scale-up of lithium-ion battery model parameters from cell level to module level – identification of current issues

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Abstract

An automotive Battery Management System (BMS) provides the on-board estimation of remaining energy, which in-turn employs an equivalent circuit model (ECM). ECM provides vital information like state of charge and state of health of the battery. The ECM is commonly developed and parameterised using cell level test data. The lithium-ion battery pack has tens to thousands of cells, connected in series-parallel configuration within the modules, and multiple modules are connected in series/parallel to form the battery pack. The ECM is usually scaled-up from a cell to a battery module and pack; which introduces inaccuracy, reflected as poor prediction of remaining energy. As a first step to the long-term goal to enhance the BMS performance, this research is focused on identifying the sources which contribute toward discrepancies of battery capacity and resistance, two key model parameters measured from cell level and module level test data. To achieve this, capacity and resistance of the battery cells has been measured. The same cells were used to construct four different battery modules and module capacity and resistance were measured. From the capacity test it was found that depending on how the cells are arranged within the module the capacity will vary by 5.3%. The resistance was found to be increasing as well, by 2.1-5.3%. The resistance variation mainly originates from interconnections of the cells within the modules. Electrochemical impedance spectroscopy tests were performed on the cells and modules to measure the impedance, which suggest similar results as internal resistance measured from pulse power test. This research will enable development of a methodology for robust model parameter extraction and thus ECM development for battery packs.

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Keywords: Lithium-ion battery, internal resistance, battery modelling, module testing, ECM

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1. Introduction

Lithium ion batteries have become the energy storage technology of choice due to their high energy density, high efficiency and long life. Carbon emissions legislation, in tandem with rising demand for electric and hybrid vehicles, is driving significant demand for high-power, high-energy lithium ion battery packs in the automotive industry. The demand for lithium ion batteries grew from circa 49 GWh in 2013 to circa 70 GWh in 2016 and is expected to rise to more than 96 GWh by 2020 [1], which is largely governed by the demand from automotive industry.

Typical automotive battery packs are made up of tens to thousands of cells, connected in series parallel configuration within the modules, and multiple modules are connected in series to form the battery pack. The number of cells connected in series parallel configuration varies depending on the battery pack voltage, power and capacity requirement [2]. Series connections are used to achieve higher pack voltage and parallel connections are used to achieve higher current and power capability; also, for higher pack capacity.

The remaining electric range (state of energy), instantaneous power capability, temperature and state of health of a battery pack, have become an increasingly important area of research in energy storage. A Battery Management System (BMS) provide the on-board estimation, which in-turn employs an equivalent circuit model (ECM). The ECM is commonly developed and parameterised using cell level test data. The ECM is usually theoretically scaled-up for lithium-ion battery module and pack; which introduce inaccuracy, reflected as poor prediction of remaining energy, increasing the range anxiety of the driver as reported in [3, 4], and poor estimation of battery degradation in real world operating conditions [5].

There is an inconsistency in cell manufacturing parameters, which manifests itself as a cell-to-cell variation in a lithium-ion battery pack. In addition, another inconsistency in cell connections is also apparent within the battery pack. This may lead to uneven resistance distribution within the battery pack, leading to reduced power capability, higher temperature gradient and thus reduced safety of the battery pack [6]. Furthermore, due to the resistance distribution some of the cells may reach the lowest allowed operating voltage earlier than others, decreasing battery capacity, as an active balancing circuit is not commonly used in mass produced commercial battery packs. These inconsistencies within the battery pack manifest themselves as a deviation of battery performance estimated by the BMS. The lack of knowledge of this process can restrict the advancement of the remaining energy prediction, restricting mass commercialization of electric vehicles.

As a first step to the long-term goal to enhance the BMS performance, this manuscript is focused on identification of the sources which contribute toward discrepancies between cell and module performance and in the longer term pack level performance. To achieve this, performance of battery cells are measured prior to making battery modules of different series parallel configurations; this is later compared to performance of the complete modules.

In this manuscript, outlines the experimental procedure in Section 2; results and relevant discussion with the results are presented in Section 3. Finally, Section 4 summaries the key findings.

2. Experimental procedure

Twenty eight commercially available lithium-ion cylindrical cells (18650) were used for this study. The batteries have Lithium nickel cobalt aluminum oxide ($LiNi_{0.8}Co_{0.15}Al_{0.05}O_2$) cathode and graphite ($LiC_6$) anode. The battery capacity is rated as 3.0 Ah (10.6 Wh), maximum discharge current as 10 Amp, 1kHz resistance of less than 35 mΩ and operating voltage window of 2.5-4.2 V.

As a measure of battery performance, battery cell capacity and internal resistance at 50 % SoC were measured, prior to construction of the battery modules. To measure cell capacity, the cells were discharged at a 1C rate to the manufacturer's recommended cut-off voltage (in this case 2.5 V). The cells were then allowed to rest for 3 hours before being fully recharged via the constant current – constant voltage (CC-CV) protocol using a 1C current for the CC part until cell voltage reached to 4.2 V and a C/20 cut-off rate for the CV part. At the end of charging, the cells were allowed to rest for 3 hours. Afterwards, cells were discharged to 2.5 V using 1C current. The 3 hours rest period was used to allow the cell to reach electrochemical equilibrium [7].