SAND2018-7920PE

Exceptional service in the national interest

Sandia National Laboratories

Using Electrochemical Impedance Spectroscopy (EIS) and Differential Capacity (DC) Analysis Techniques to Determine the State of Health (SoH) of Active Load Battery Systems

Research conducted by: L. Torres-Castro, J. Lamb, M. Karulkar, J. Stanley, and C. Grosso
Presentation by: Eric J Deichmann

Problem

Modern Battery Management Systems (BMSs) are not capable of detecting early signs of battery degradation, and often are only able to predict battery failure once a thermal runaway is imminent

Objective

To determine the viability of EIS & DC analysis techniques used in active load BMSs by determining their ability to accurately detect early signs of battery degradation, thus preventing thermal runaway incidents

What is EIS

EIS is an in-situ (non-invasive) monitoring technique capable of determining the SoH of electrochemical systems by measuring system impedance over a range of frequencies. Results are generally analyzed through use of either a Nyquist or Bode plot

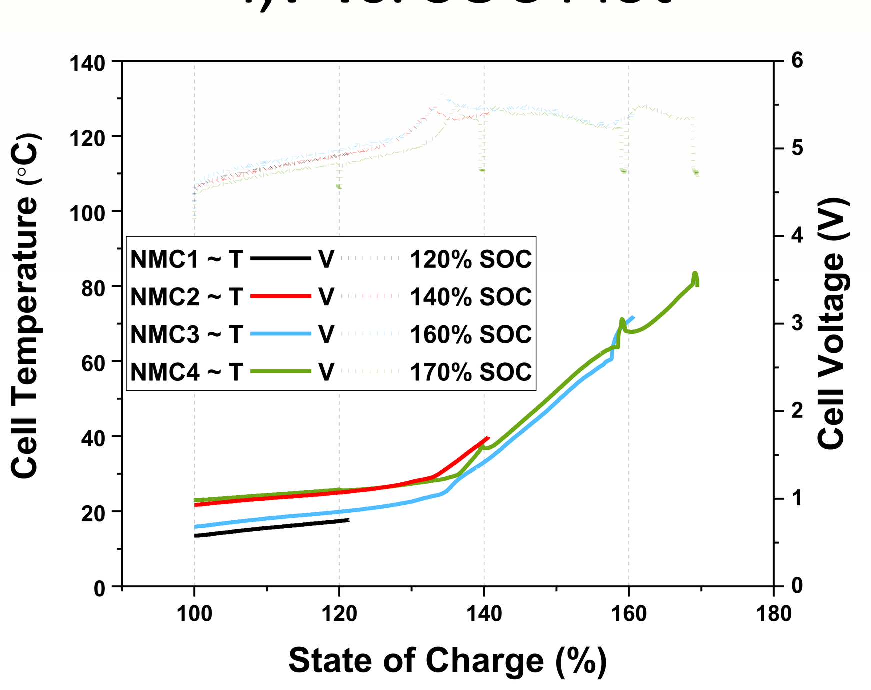
What is DC

DC is equivalent to the first derivative of the galvanostatic curve (dQ/dV), and is commonly used to identify component degradation within batteries through analysis of overlapping peaks. DC is typically plotted against SOC & battery voltage

Traditional In-Situ Battery Analysis

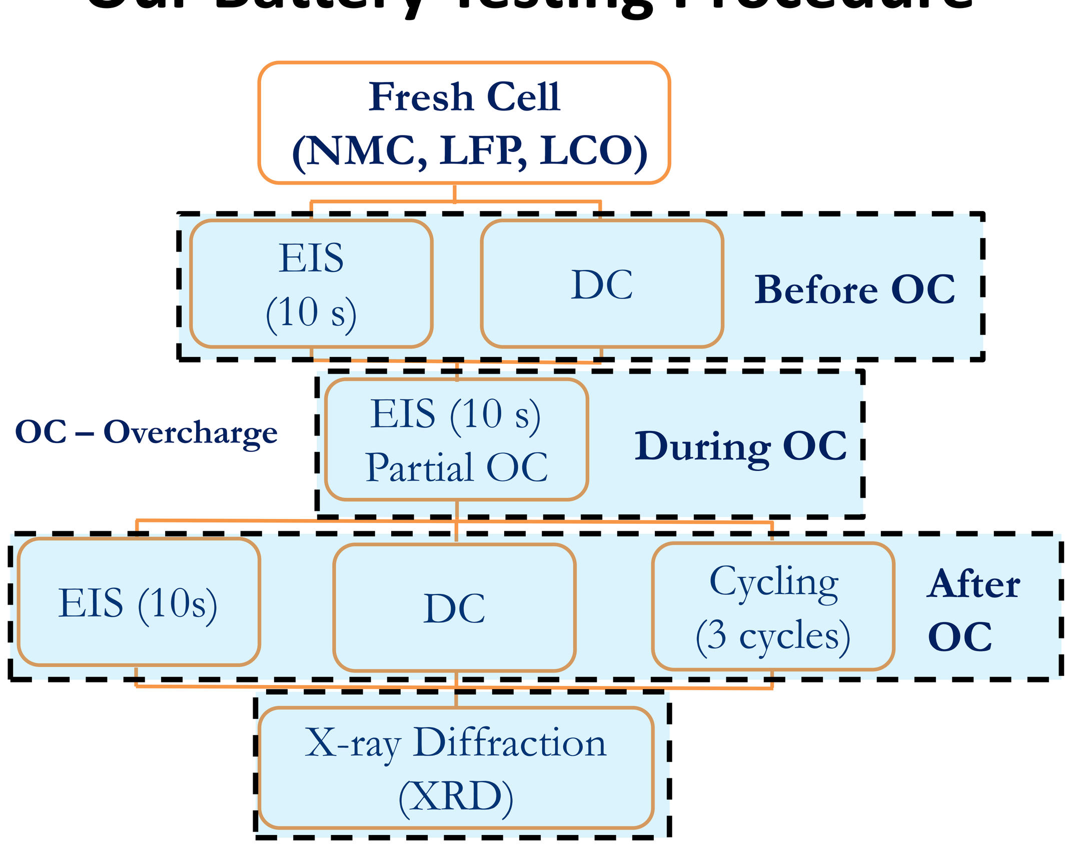
Basic voltage and temperature measurements are lagging indicators of cell SoH, and do not indicate signs of internal component damage until significant battery degradation has already occurred

T,V vs. SOC Plot



A BMS requires more sophisticated analytical measurements capable of detecting early signs of battery failure before a significant increase in V, T occurs. In order to achieve this, the following measurements are taken during each battery pack test

Our Battery Testing Procedure

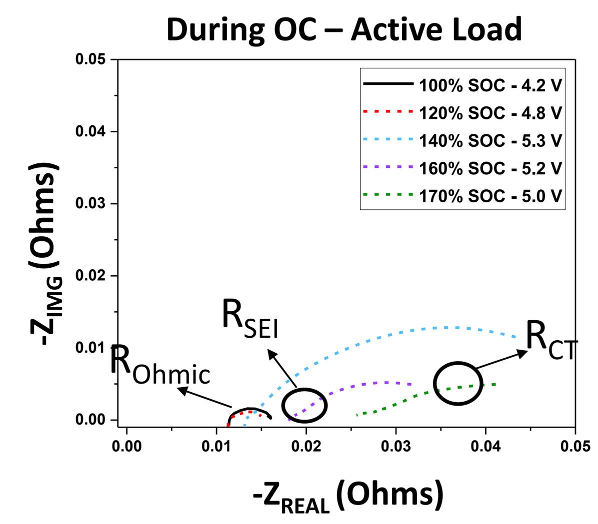


Interpretation of EIS test results requires understanding of the following terms:

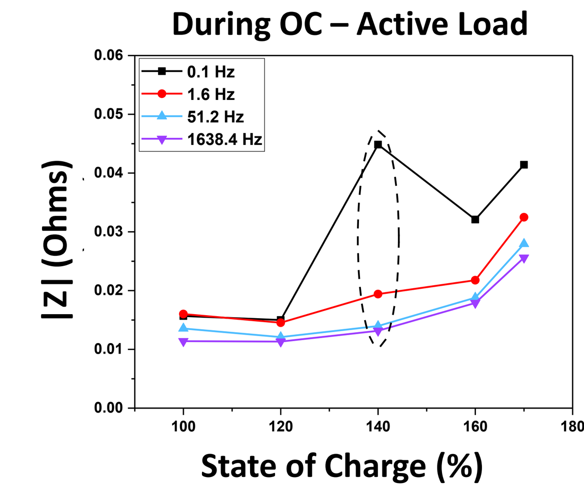
Resistance / Impedance Present	Significant Effects	Frequency Range
Ohmic Resistance (R_{Ohmic})	Models resistance in current collectors, connectors (tabs), and electrolyte	High
Solid Electrolyte Interphase Resistance (R_{SEI})	Models resistance resulting from formation of SEI layer on anode	Middle-High
Effective Charge Transfer Resistance (R_{CT})	Models resistance against electron transfer in and out of current collectors	Middle-Low
Warburg Impedance (Z_W)	Models diffusion occurring at electrode interphase	Low

Nyquist Plot

100 – 170% SOC



As SOC increases, we see increase in R_{ohmic}, indicating an increase in conductivity loss



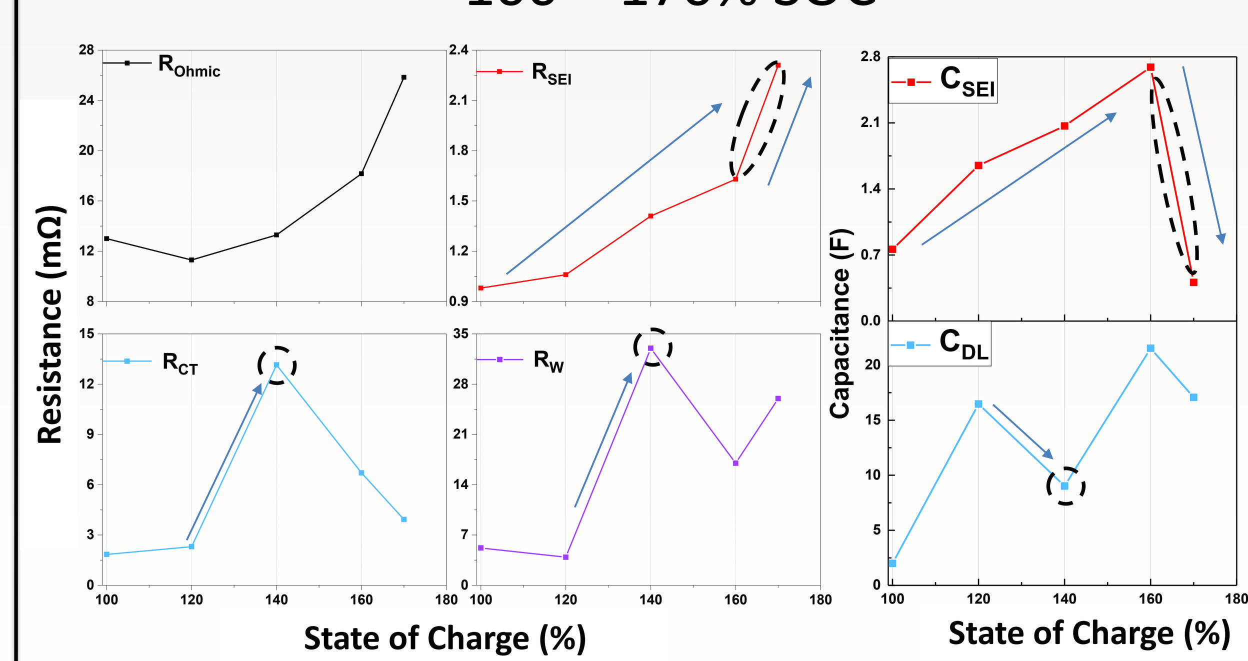
$$|Z| = \sqrt{Z_{REAL}^2 + Z_{IMG}^2}$$

A significant increase in R_{CT} was observed at 140% SOC, which is consistent with battery's chemistry. This same marker was observed in a magnitude vs. SOC plot

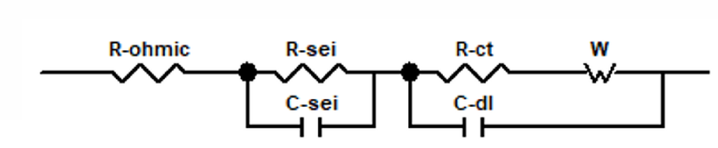
Degradation Modes

Conductivity Loss (CL)	Loss of Active Material (LAM)	Loss of Lithium Inventory (LLI)
Degradation of electronic components within battery - Current collector corrosion - Binder decomposition	- Structural transformations in active material - Electrolyte decomposition	- Variation in number of lithium ions available for intercalation & de-intercalation

100 – 170% SOC

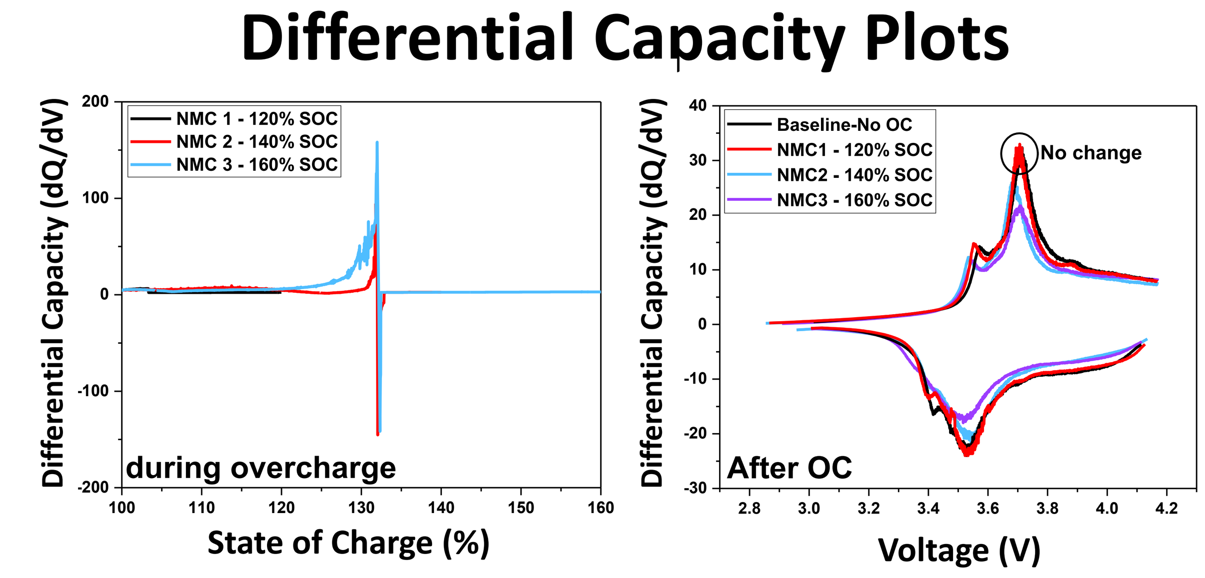


Randles Circuit



We see consistent increase in R_{SEI} and C_{SEI} until 160% SOC, where a sharp increase in R_{SEI} and significant decrease in R_{CT} occurs. This is likely due to steady growth of SEI layer, followed by subsequent decomposition of SEI layer

Differential Capacity Plots



- Differential capacity was calculated during OC, identified redox reaction between 130-135% SOC
- DC vs V plot and subsequent calculations show little effect to redox process up to 120% SOC

Key Takeaways

- Both EIS & DC analyses provide substantial insight into battery SoH prior to thermal runaway
- Important to conduct EIS & DC analyses concurrently, as each analysis capable of providing unique information for BMS
- EIS is more practical for on-board applications considering low current requirement for DC method

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.