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Li-ion battery and parallel capacitor bank exposed to an AC signal

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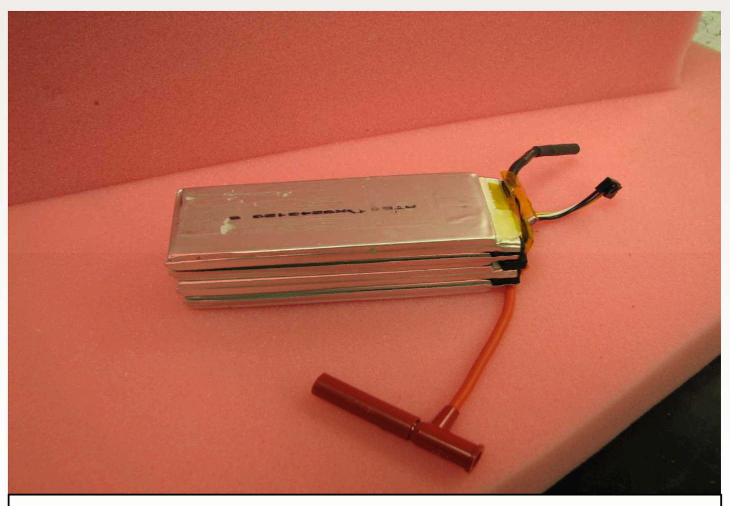
Abstract: To lower the impedance caused by inductance in a lithium ion battery, the addition of a capacitive element seemed to be a logical hypothesis. To test this hypothesis, a model was to be created. Electrochemical impedance spectroscopy(EIS) was used to gather data to characterize the battery properties and build an equivalent circuit to use in the simulation of the Li-ion battery with a parallel capacitor bank.

Introduction: Achieving maximum power output from a battery is ideal as well as necessary especially in high demand applications. To do this, voltage drop across the battery should be minimized by lowering the magnitude of the combined real and complex impedance(|Z|). However, the capacitor bank cannot lower the real impedance which is equivalent to the DC resistance, but it can lower the complex impedance. The complex impedance is the impedance associated with the phase shift caused by capacitance and inductance of the battery. Along with lowering the voltage drop, the capacitor bank may allow some of the AC signal to be stored in the capacitor preventing the energy from being dissipated as heat inside the battery which would otherwise contribute to battery degradation and potentially hazardous failure; in fact, the capacitor bank may assist in partially recharging of the battery.

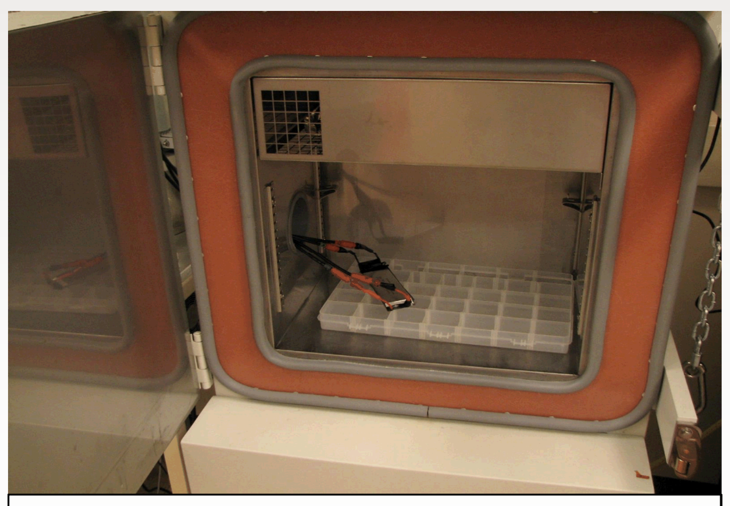
Methods: The greatest hurdle to developing a realistic simulation is reproducing the battery properties. To create the simulation:

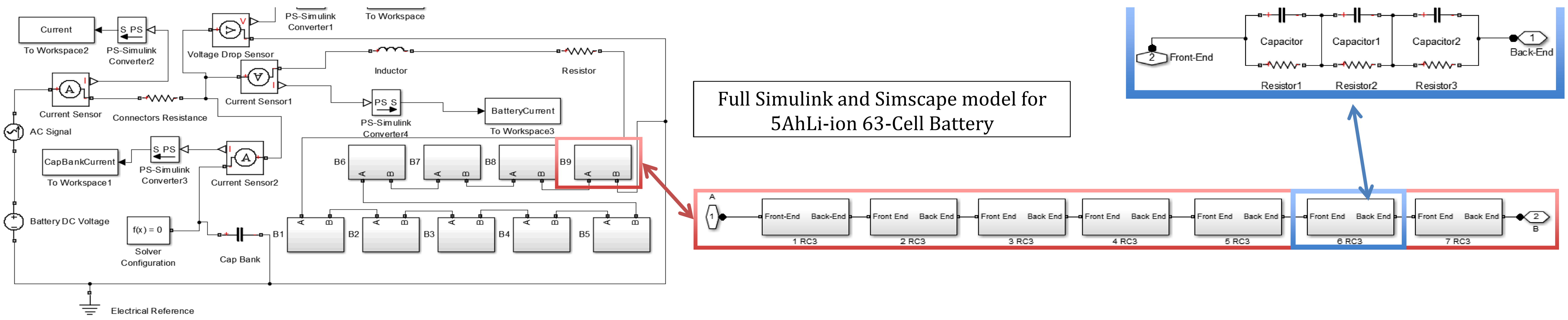
- Electrochemical Impedance Spectroscopy(EIS) was run on Kokam and Thunder Power 5Ah single cells of the 63 cell battery measuring real and complex impedance using a Solartron frequency response analyzer.
- Impedance data was fed into ZPlot to generate an equivalent circuit of a single Kokam cell
- An EIS simulation was run in Simulink to compare the simulation model and the experimental data.
- The single cell was expanded and simplified to 63 cells.
- A capacitor bank in parallel to the battery was added to the model.
- EIS was run on the entire model with capacitor banks of 10μF, 100μF, and 1000μF.
- The data was collected and analyzed.


Three 5Ah Thunder Power Cells


One 5Ah Kokam Cell

Solartron frequency analyzer

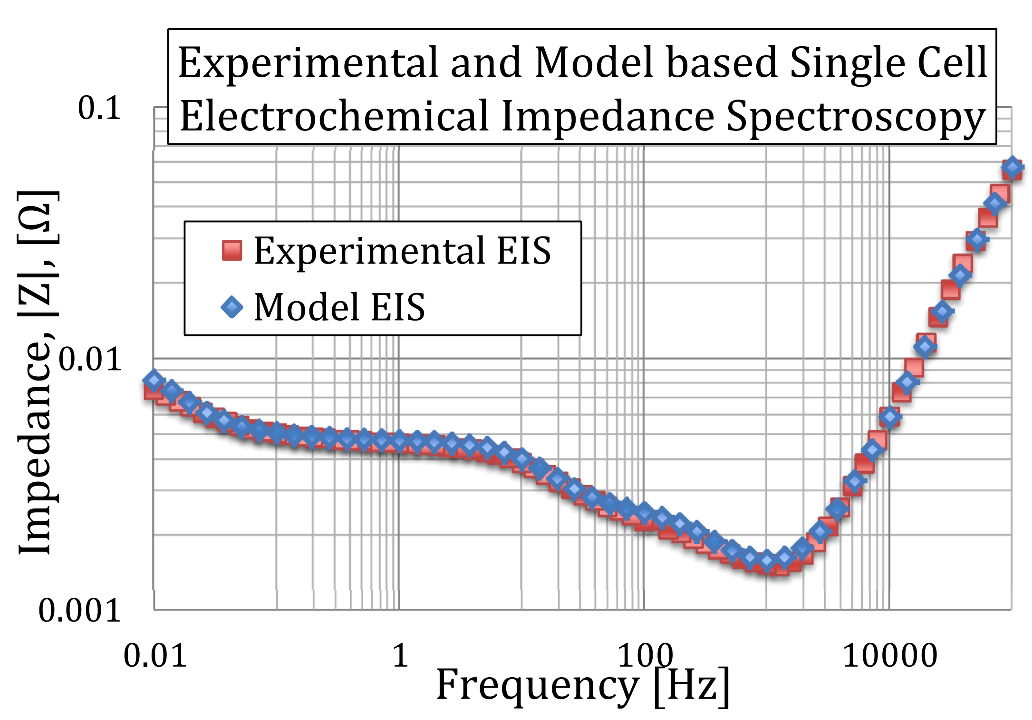

Temperature chamber for EIS

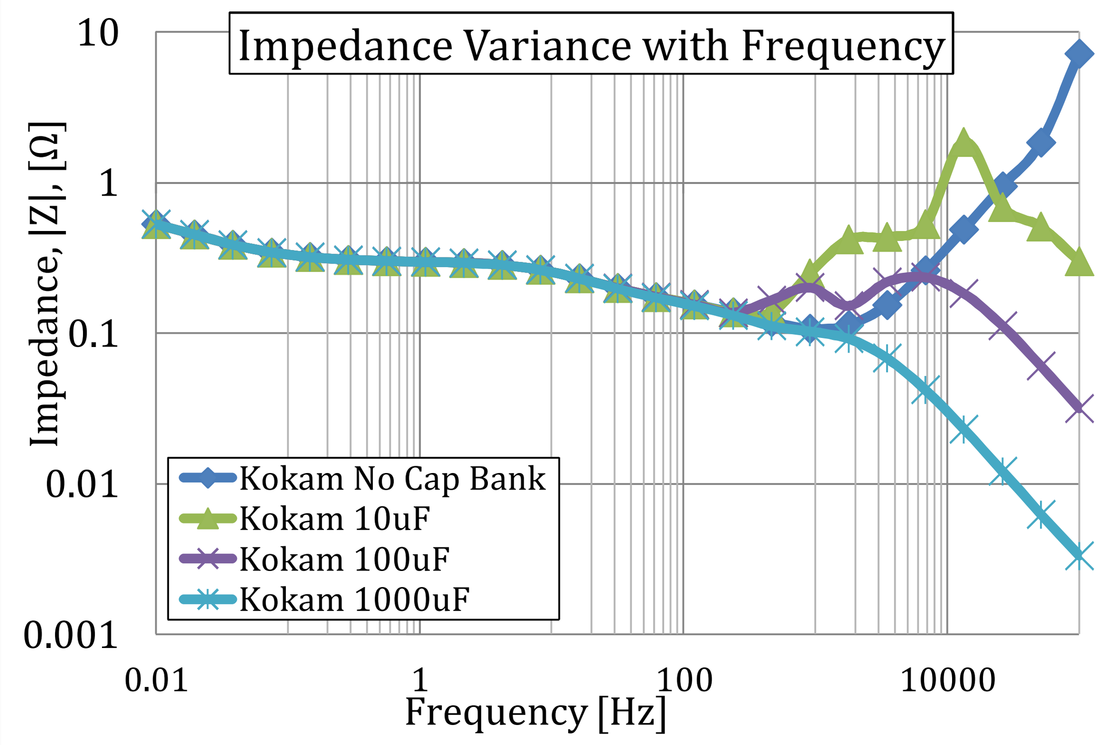


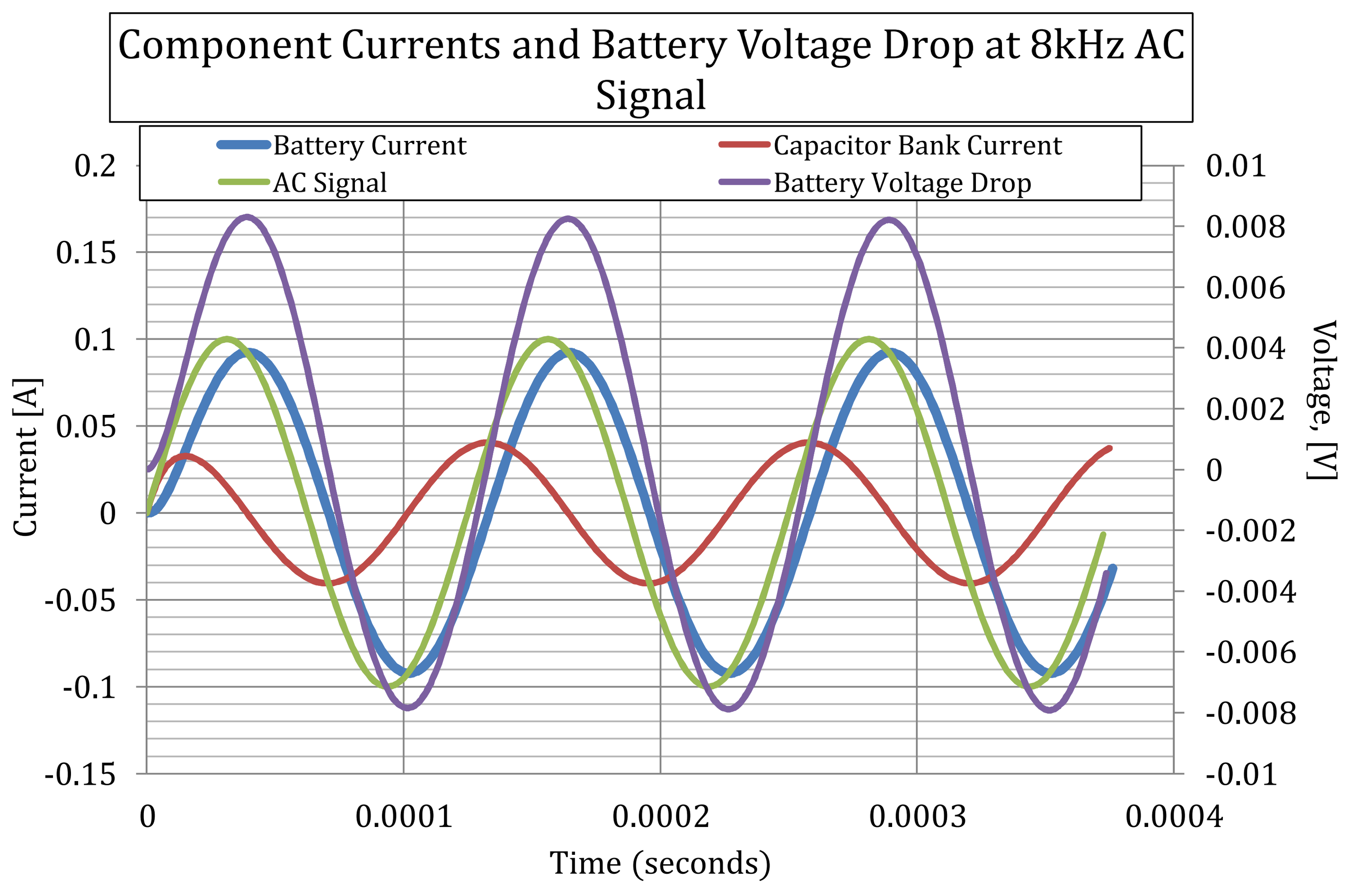
Full Simulink and Simscape model for 5AhLi-ion 63-Cell Battery

Results: The Kokam single cell model when placed under simulated EIS had a coefficient of determination of 0.99986. This assuring that the model accurately predicts the battery variation within the frequency range of 10^{-2} and 10^{5} Hertz. However, EIS of the Thunder Power cell showed a lack of inductance though the Kokam cell and Thunder Power cell have similar characteristics i.e. Li-ion and electrode Z-folding techniques. This may be explained by the electrode placement on the Kokam and Thunder Power cells where the Kokam cells have one electrode on each end and the Thunder Power cell has both electrodes on one end thus canceling out much of its inductive characteristics. Upon further inspection of various EIS data sets for the Kokam cells, the orientation of the signal leads led to fairly significant changes in inductance.

Discussion: Although the varying inductance may present a problem in parameterizing the inductance of the full 63-cell battery in simulation, it is quite possible that, because of the final orientation of the 63-cell battery, there may be much less inductance than what the original 63-cell model suggests with its compounding impedance due to inductance. However, a low inductance estimated model and a high inductance estimated model both show lowered impedance with a capacitor bank of around 100μF at the frequencies of primary interest which are around ~8kHz.







Battery electrical modeling is essential for understanding the performance of complex electrical systems. EIS can be used to provide sufficient data to model battery performance in common electrical modeling circuits, such as Simulink/Simscape or PSPICE.

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ADM1 The greatest hurdle to creating a valid simulation model was modeling the battery properties. Electrochemical impedance spectroscopy(EIS) tests were performed on three cells of what would be a sixty-three cell battery. EIS involves application of a controlled AC current to a single cell. The frequency of the AC current is varied through the range of frequency interest 0.01Hz to 100kHz. Voltage drop and phase shift are used to determine the real and complex impedance of the battery. An equivalent circuit is then matched to the impedance and phase shift data using ZPlot. The equivalent circuit is modeled in Simulink using the Simscape toolbox. EIS is ran in the simulation on the cell model to confirm that the model has similar properties to the original cell. The cells are duplicated and simplified to model the sixty-three cell battery. Parallel capacitors of 10uF, 100uF, and 1000uF were added and EIS was performed once again on the entire model to determine the effect of the parallel capacitors on the battery.

Melad, Aaron David, 7/17/2014