State of Health Estimation

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Overview

- Define State of Health (SOH)
- Motivation for paper
- Methods and models of the paper
- Thermal analysis
- Battery model
- Modified Battery Model/Tuning of Model
- Reproduction of graphs/results

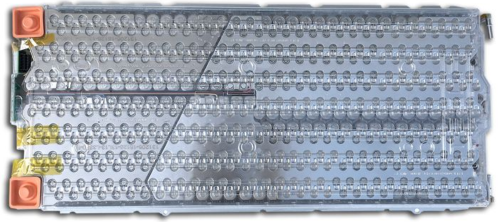
State of Health (SoH)

Estimation of the battery's condition & parameters over time.

As secondary batteries are cycled internal side reactions degrade the battery's performance.

The battery's internal resistance increases over time reducing the capacity and output of the battery

Knowing how a battery's performance and capacity fade over time is valuable in electric vehicle and consumer product applications.



Motivation for the paper

State of health plays an important role in the battery design and application.

Battery health must be monitored and understood in order to prevent malfunctions and ensure the battery operates safely through its life.

Using an available battery model it is possible to estimate the change in battery capacity and output voltage. These models can use internal resistance, charge and discharge efficiency, and other parameters for estimation.

State of Health Estimation for Lithium-Ion Batteries

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Abstract: The state of health (SoH) of lithium-ion batteries and battery packs must be monitored effectively to prevent failure and accidents, and to prolong the useful lifetime of the batteries. Many studies have suggested that temperature and discharge/charge current rate are the primary factors causing battery aging. However, due to the complex and often poorly understood internal dynamics of lithium-ion batteries, no reliable mathematical models to predict the battery SoH are available. In this article, we introduce two SoH prediction models: (1) the decreasing battery V_{0+} model and (2) the increasing CV charge capacity model. Additionally, we derive a simple thermal model for the cell based on variation of temperature data.

Keywords: lithium-ion battery, state of health, temperature profile, state of charge

1. INTRODUCTION

Lithium-ion battery packs are a source for major or supplementary power for mobile applications such as electric vehicles, electric scooters, and also back-up power systems of several scales. A key aspect of the technology is their proprietary Battery Management Systems (BMS) that monitor the battery pack to maintain safe operation during charging and use, and allow some performance optimization. Such systems have a component that estimates the pack State of Charge (SoC), that is the amount of charge still in the pack to deliver application power (Tulsyan *et al*). The simplest SoC indicators rely on an invariant model of the cell's performance to yield their output and do not take into account how a pack is changing over time. However, in reality the performance of batteries decreases over time and with use, described as a change in the battery's State of Health (SoH).

this work. The nominal cell voltage and capacity are 3.6V and 3.2Ah, respectively. The manufacturer recommended charge/discharge voltage boundaries are between 2.5 and 4.2V.

Fig. 1. Panasonics NCR18650B Lithium-ion Batteries

2.1 Galvanostatic cycling of single battery cells

Methods of the Paper

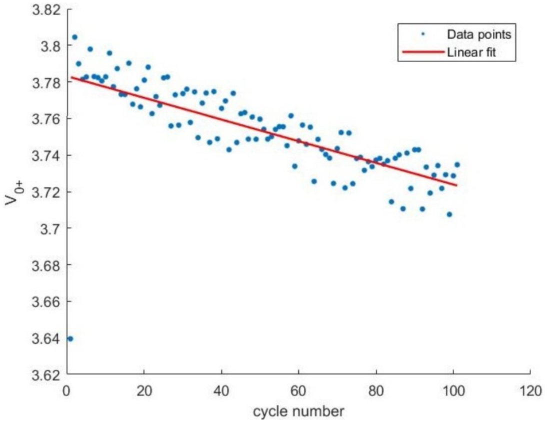
1. Constant current discharge at 1C, or 3.2A, until voltage reaches 2.5V
2. Open circuit voltage (OCV, 30 minutes)
3. Constant current charge at 1C until voltage reaches 4.2V
4. OCV (30 minutes)
5. Constant voltage charge at 4.2V for 4 hours
6. OCV (30 minutes)

VMP3 Battery Cycler

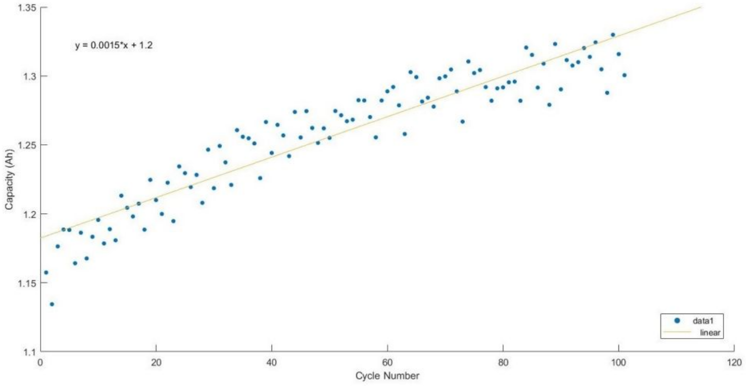
Models of the Paper

Kong et. al. gather voltage, capacity, and cycle data to analyze performance degradation over time. They develop two estimation methods, one based on the OCV voltage at the beginning of discharging as a function of cycles, and another of charging capacity as a function of cycles.

OCV



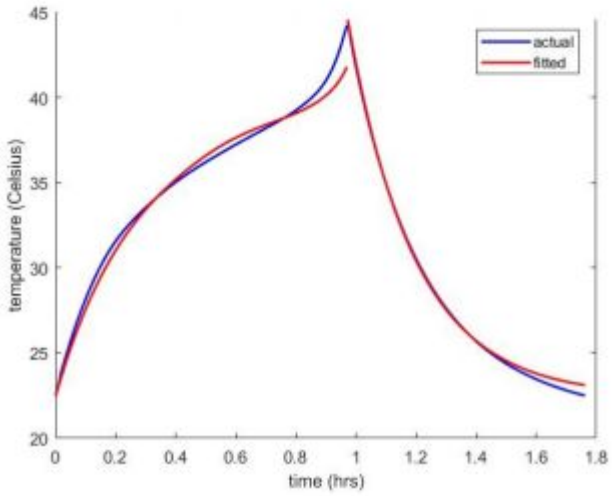
Charge Capacity



Verification using Thermal Analysis

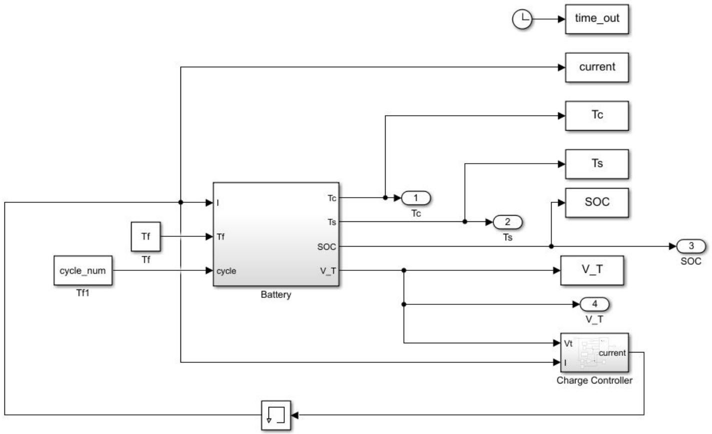
The thermal model is a fitted piecewise nonlinear curve that predicts the temperature of the call throughout charge and discharge.

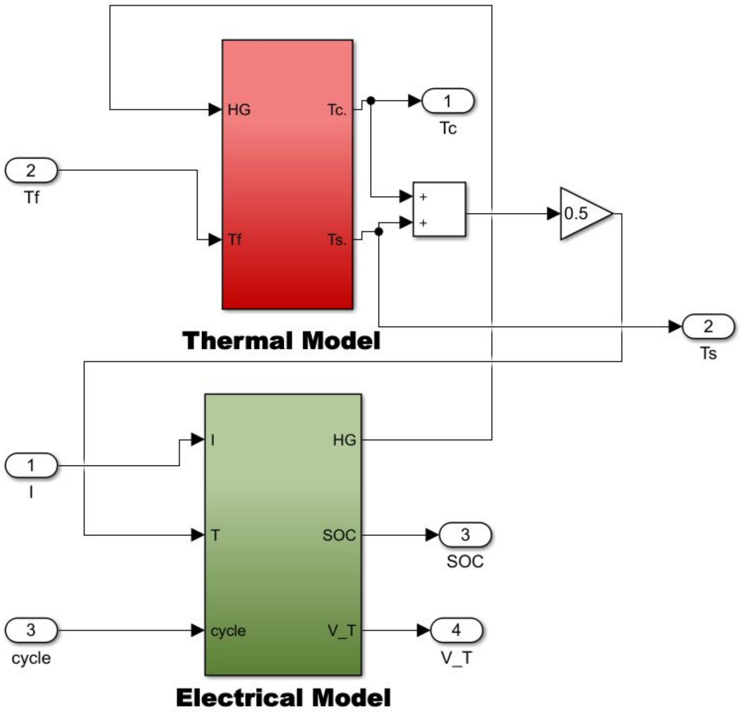
The changes in this profile can be used to analyze changes in internal resistance, a key contributor to changes in SoH.



Battery Model

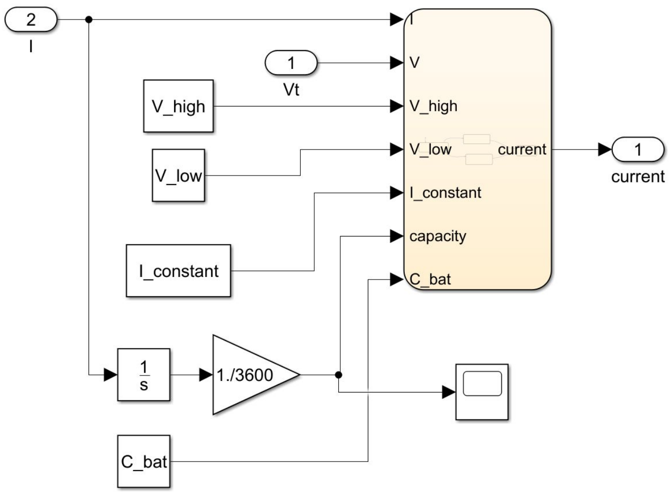
Analysis was done on a battery model created by Lin, Perez, Siegel, and Stefanopoulou. The model was modified to account for changes in cycle number.

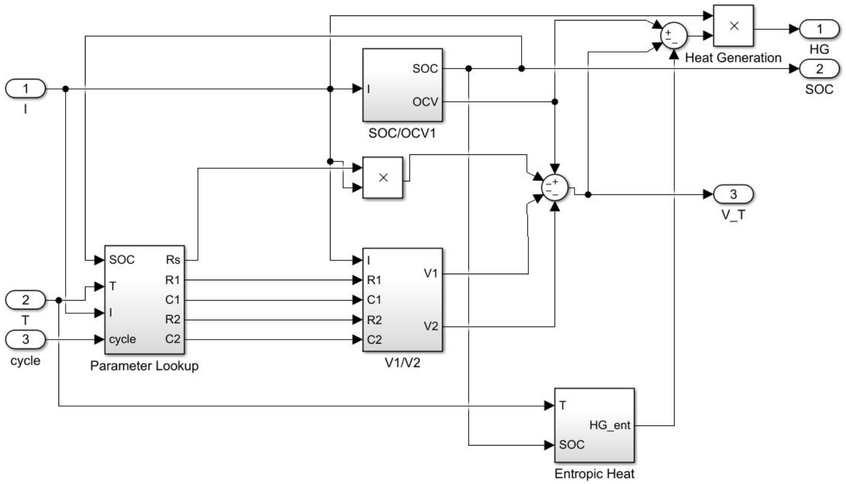




Modified Battery Model

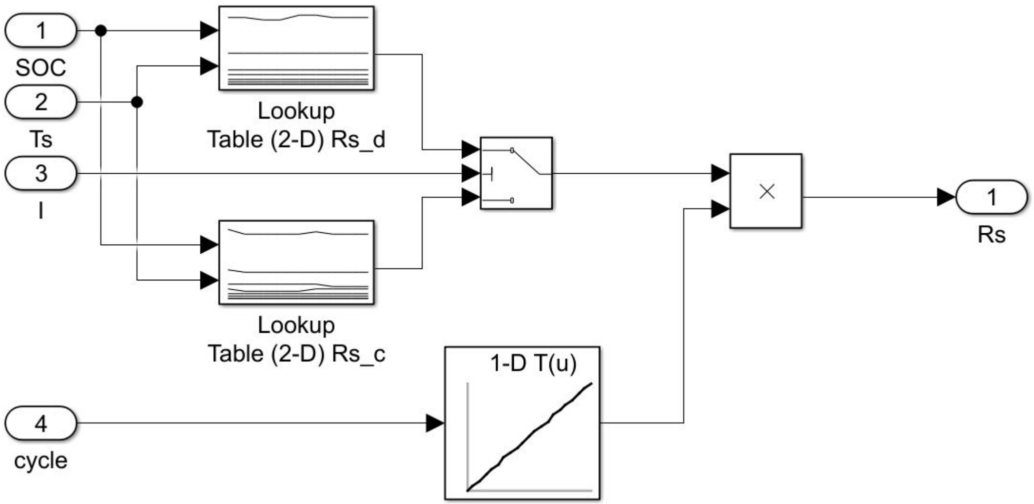
A charge and discharge controller was added to observe the OCV after charge and discharge was completed.





Series Resistance Modification

The series resistance changes as a function of SOC and is dependent on the discharging/charging state. This was built into the model, but a multiplier based on cycle count was added.



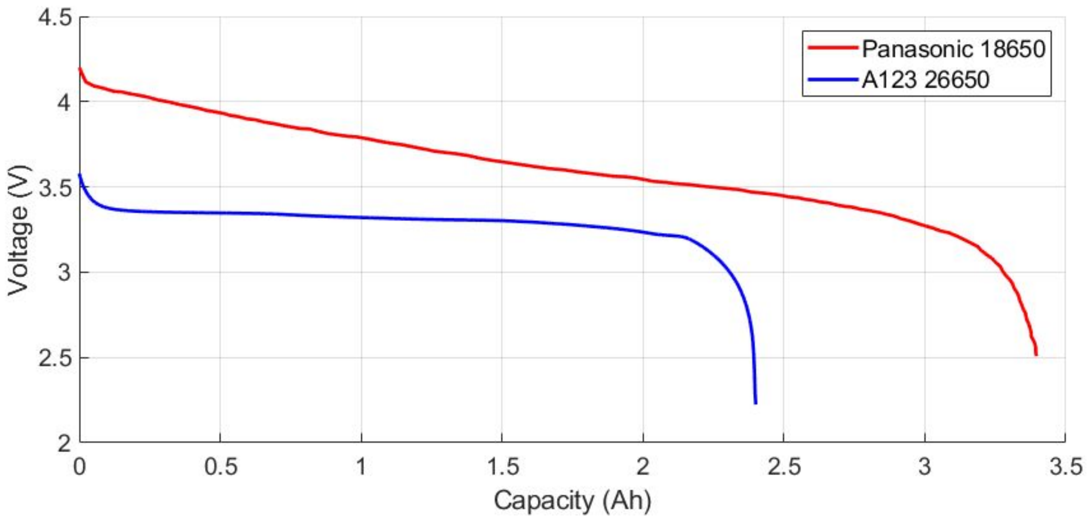
Model Tuning and Battery Parameters

The model supplied uses parameters from a A123 LiFePO4 26650 battery. The paper uses a Panasonic NCR18650 B. The table below compares the two batteries.

	A123 26650	Panasonic 18650
Chemistry	LFP	NMC
Maximum Voltage (V)	3.4	4.2
Nominal Voltage (V)	3.3	3.6
Minimum voltage (V)	2.0	3
Nominal Capacity (Ah)	2.4	3.2
Mass (g)	76	48.5
Size (mm)	25 OD, 65 L	18 OD, 65 L

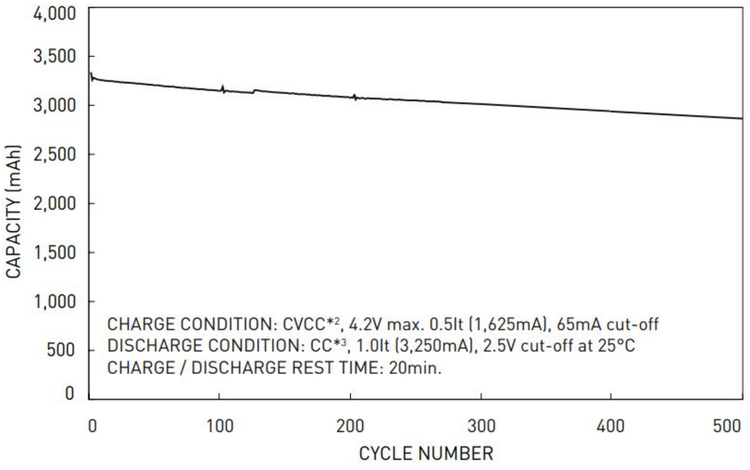
OCV Replacement

The OCV curve used by the model was replaced with the NCR18650B discharge curve. The OCV curve was approximated by the 0.2C discharge curve.



Model Tuning

The series resistance as a function of cycle is approximated as a linear model. The intercept of the initial internal resistance from the datasheet, leaving the only unknown parameter to be the slope.

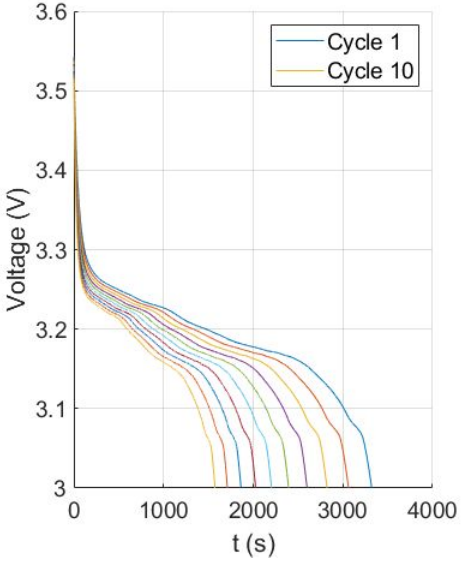


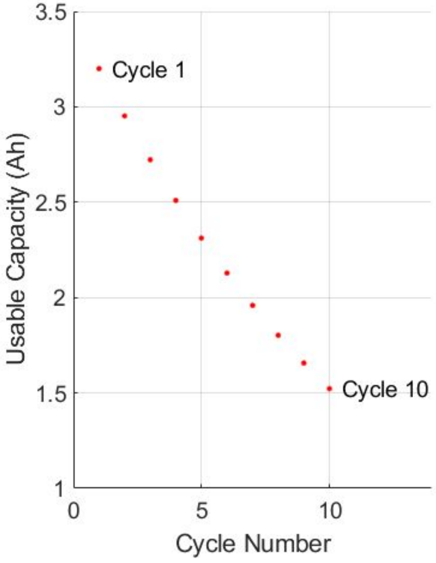
The slope can be approximated using datasheet plots of voltage vs. capacity, and the known test parameters.

Initial Model Verification

The series resistance was increased linearly over 10 cycles to a factor of 10 higher than the first cycle. This is exaggerated but will produce similarly shaped plots.

The voltage drops faster as the internal resistance increases at constant current, decreasing the usable capacity.



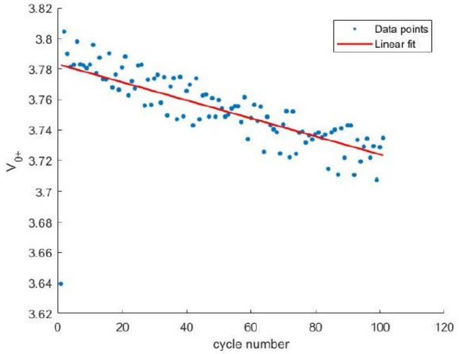


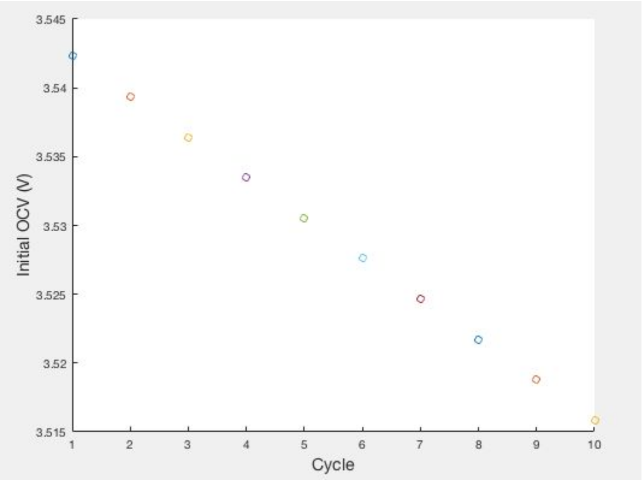
Charge Capacity vs Cycle

A charge capacity vs. cycle plot was generated to match the paper.

Actual battery data was not as linear

A simple linear fit to this model could be useful to a battery’s BMS to predict SoH

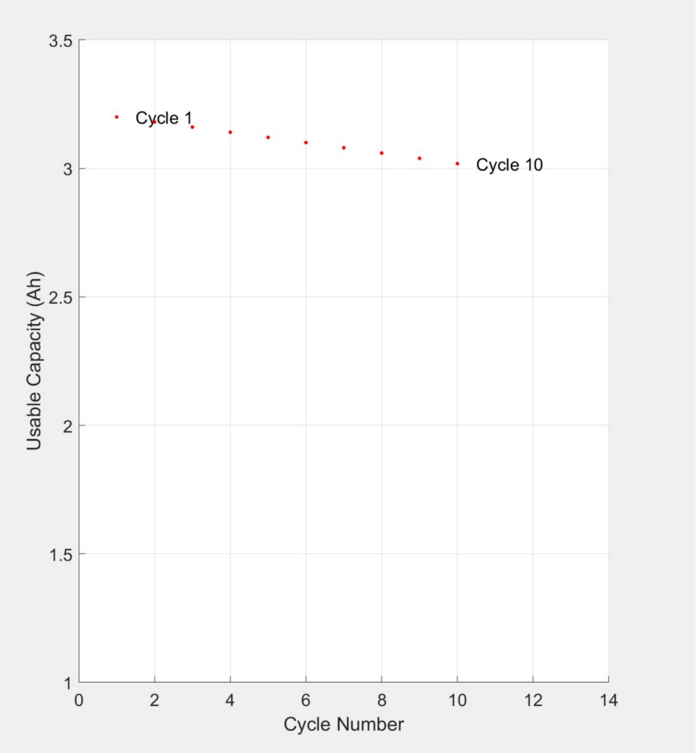




Modeled Discharge Capacity vs. Cycle

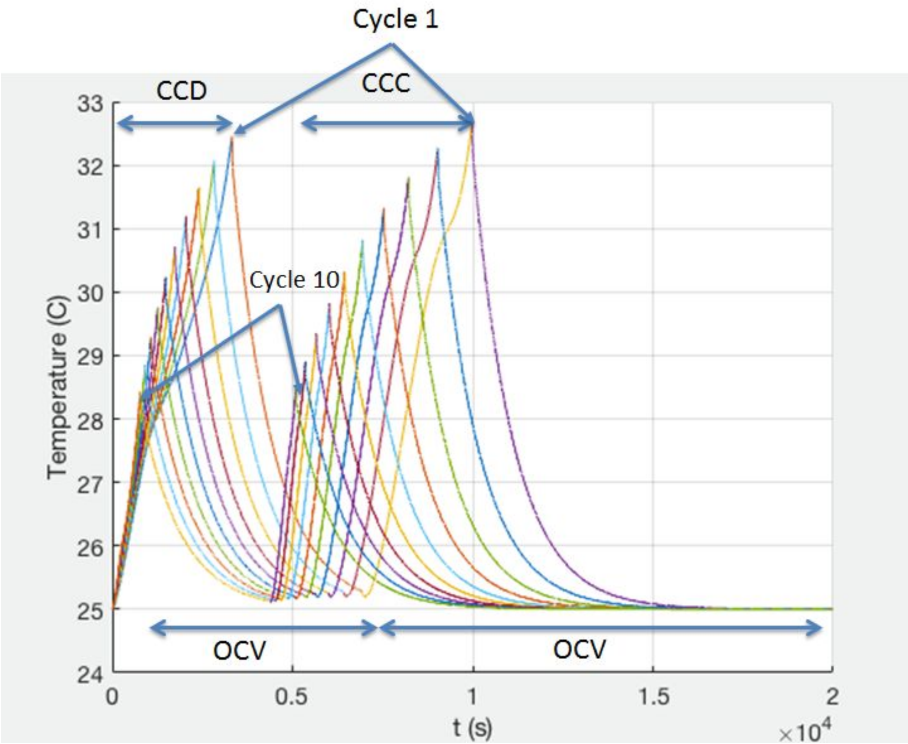
The discharge capacity was also modeled.

Another important correlation to degrading SoH is this downward trend in capacity over cycles (very important predicting range available in an EV)



Thermal Analysis over cycle

Using the modeled change in internal resistance, the heat generation in the battery decreases significantly and the temperature profile on charge and discharges changes significantly. This is due to the significant change in capacity that the battery experiences. Thus, allowing for less output voltage over a shorter period of time. A plot of discharging temperature profiles over time was generated.

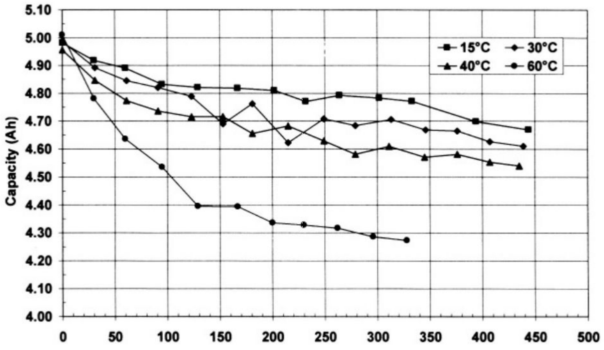


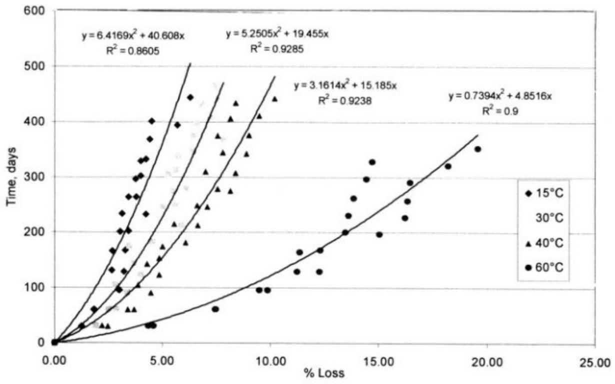
Cycle and Calendar Life

The paper modeled SOH dependence on cycle life but did not develop any models relating to calendar life.

Capacity fade occurs during rest over extended storage intervals, dependent on temperature, SOC, and storage time.

Capacity fade due to storage can be modeled as dependent on √time, as fade levels out after extended storage.





(Michel Broussely, SAFT)

Conclusions

- Internal resistance and usable capacity are largely linearly dependent on cycle.
- Simple linear models can be used to predict SOH based on cycle, and additional models can be factored in to account for calendar life.
- Battery temperature decreases as internal resistance decreases at constant current discharge. This is because the time to discharge is shorter, and this may not be the case in a constant power application.

Future Work

- Factor in charge discharge efficiency due to loss of available electrode material.
- Identify effects of low vs. high discharge and charge rates.
- Develop a complete model of SOH, factoring cycle and calendar life effects.

Questions?