BTMS Testing Section

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Background

Cell testing is an important part of understanding the performance and life capabilities of state-of-the art energy storage technologies, particularly with respect to the distinct technical and functional requirements posed by the BTMS program. In order to test energy storage components and systems against these requirements, test procedures must be created. System usage scenarios are concurrently being developed with testing of baseline cells intended to illustrate their capabilities relative to a broad set of initial system assumptions. The results from these early performance tests and aging procedures, though only loosely framed by a baseline 1 MWh BTMS system supporting six 350kW DCFC units, will produce both slow and accelerated cycle-life aging information through a mix of empirical observations and modeling.

Results

Testing commenced on three commercially available cell types including NMC/LTO, NMC/Graphite, and LFP/Graphite. Three parameters including temperature, rate, and SOC window, were varied to accelerate cycle-aging and to provide early data to support future test design of experiment to improve modeling capabilities. Calendar aging at 55 degrees C was also added as an accelerated calendar aging condition, compared to the expected system operating conditions closer to room temperature.

The 2-hr discharge capacity of each cell was measured at beginning-of-life, and monthly in a reference performance tests. A set of 20-hr charge and discharge cycles, which can be analyzed to understand differences in aging mechanisms among test conditions, was also performed at each RPT.

It was discovered that the NMC/Graphite cells suffered rapid degradation in the first set of cycle-aging, and the rate of capacity loss generally increased with increasing charge and discharge rates. Only the cells in the slowest 2-hr charge and 2-hr discharge cycling condition retained enough capacity to complete the first, and second reference tests. The NMC/Graphite cells in the other cycling conditions, including up to 1C charge and 1C discharge, lost more than 25% capacity before RPT1. The results from the cells tested in RPTs 1 and 2 are shown below in Figure 1.

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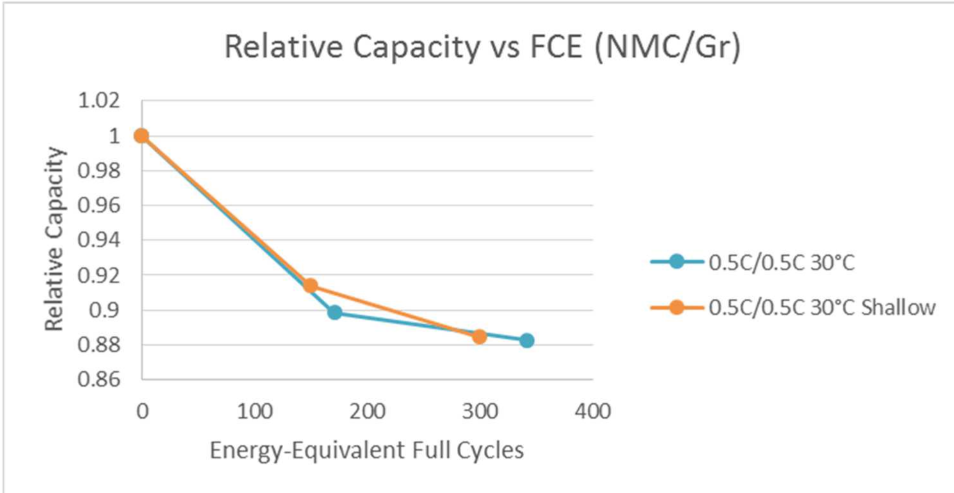

Figure 1. Capacity retention through full charge cycling for NMC/Graphite cells.

The same cycling protocol was applied to NMC/LTO cells. These cells had a maximum continuous discharge rate of 6C, and that condition was applied, along with 1C and C/2 cycling conditions. Only the colder cycling condition showed significant fade at the second RPT. Due to the different rates, and different temperatures, varying amounts of capacity was discharged from each test condition, resulting in disparate numbers of cycles per time period. These data are shown in Figure 2, plotted relative to the full-cycle equivalent of cumulative energy discharged.

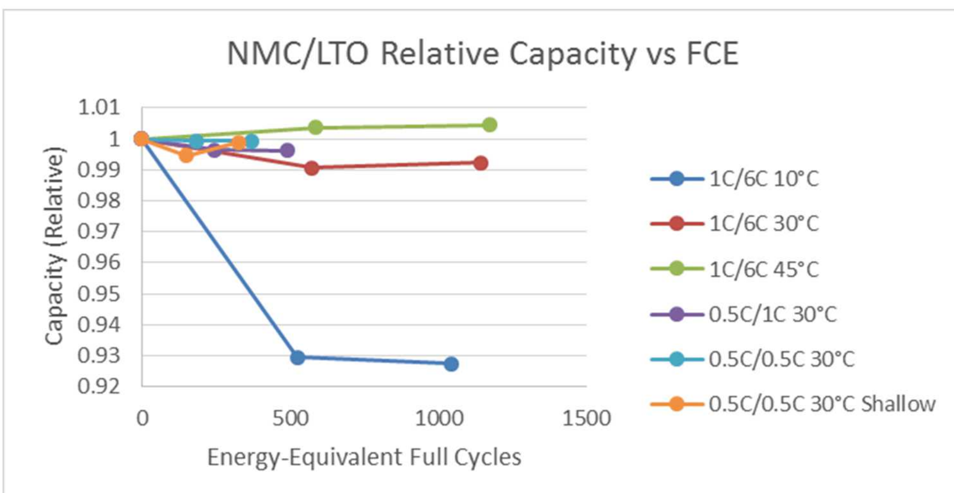

Figure 2. Capacity retention through full charge cycling for NMC/LTO cells.

The cells that are fully cycled from maximum to minimum voltage allow capacity to be shown for each cycle. An example of this data is shown in Figure 3. The constant high-rate charge and discharge cycling of the cell, without rest, likely polarizes the cell, and the rests and slow charge/discharge cycle provided during the reference test, seems to allow for some recovery of capacity, which can be seen in the cycling data following RPT1. It should be noted that the overall capacity fade for the cell shown in Figure 3 is still very small after nearly 1500 cycles –

less than one percent. These cells have a low specific energy, and generally a higher cost than other lithium-ion systems, though the cycle life capability may prove to be quite long.

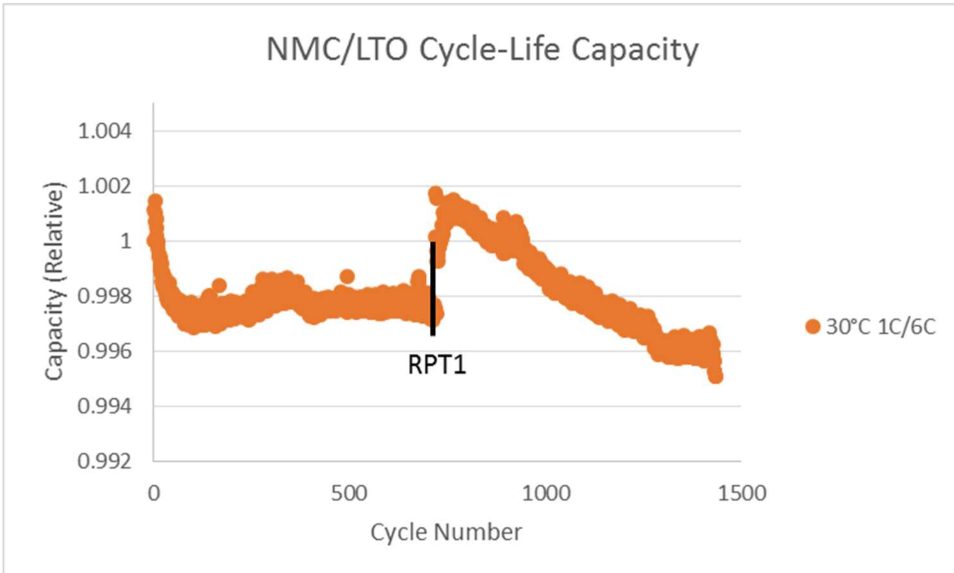

Figure 3. Cycle-by-cycle discharge capacity for an NMC/LTO cell.

Two different cell constructions are currently being investigated for the LFP/Graphite system. These cells have undergone close to 96 consecutive days of continuous cycling. The effects of this cycling on the capacity fade of the cells can be observed in Figure 4.

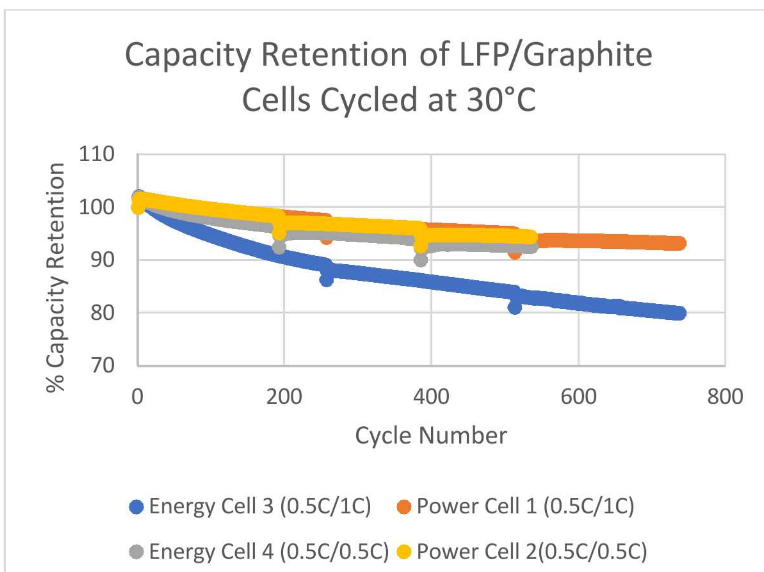

Figure 4. LFP/Graphite Cycling results

Results show that on average the power cells have lost ~5% while the energy cells have lost close to 20% in the worst case. It is difficult to say of the 20% loss in the energy cell is representative without additional cells to provide statistics. Differences in the state of health testing of these cells can also be observed as demonstrated in Figure 5.

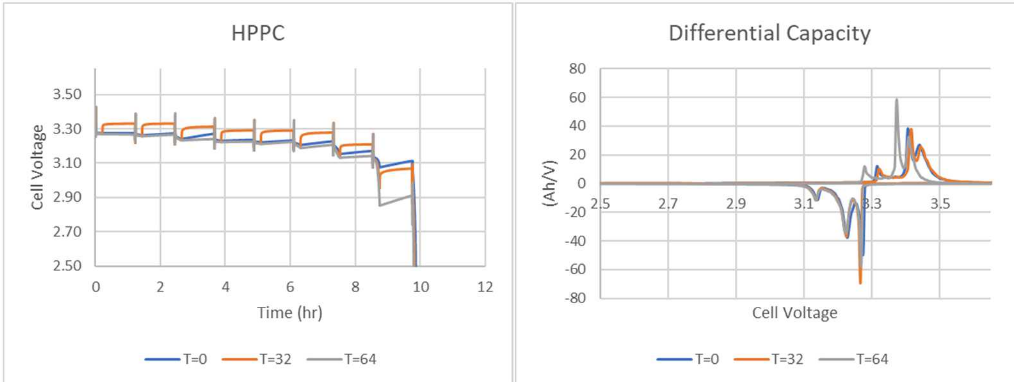

Figure 5: Power Cell 1State of Health Testing of LFP/Graphite Cells

The results in Figure 5 show a drastic difference in performance from the 32 day test and the 64 day test. It is currently unclear what the ramifications of these differences will be as the cells are reproducibly cycling. The outcome of next state of health measurement in a few weeks will interesting as it may display another drastic change.

Though the application case definitions are still under development, the testing team assembled a draft target table, envisioned to further guide testing procedures. The characteristics defined below in Figure 6 are still being refined, while the targets for these characteristics are only placeholders at this point.

End-of-Life Characteristic	Units	System Level Target	System Level Target	Definition
Discharge Pulse Power Capability	kW	400	400	Discharge pulse power available over a fixed duration
Available Energy	kWh	400	1600	The window, over which the discharge pulse target can be met
Minimum Round Trip Energy Efficiency	%	0.9	0.93	Energy discharged by battery / Energy Charged to battery
Lifetime Discharge Energy Throughput/Cycles	MWh/Cycles	1000/10000		Lifetime under certain discharge/charge cycle
Calendar Lifetime	Years	20	20	
Price	$/kWh	295	235	Price
Battery (cells, modules, racks, BMS)	$/kWh	220	200	
Enclosure (Structure, FSS, DC collection, Aux power)	$/kWh	50	30	
HVAC	$/kWh	25	5	
Maximum System Volume	m^3/kWh			Maximum volume of cells (or module or packaged pack?)
Maximum Operating Voltage	V	1000	1000	Maximum DC voltage of battery pack
Minimum Operating Voltage	V	0.55*Vmax	0.55*Vmax	Minimum DC voltage of battery pack
Maximum Charge Time	Hours	<8	<8	Time to charge from SOC corresponding to AE target removed
Maximum Self Discharge	%/month	<1	<1	Energy lost to self discharge per month
Operating Temperature	Deg. C	20-45	20-45	Temperature range that cells should be able to operate
Maximum allowable current	A			Current limit to meet discharge pulse power target
Battery Safety System		No propagation between rack	No propagation between rack	Prevent fire propagation

Figure 6. Early draft of battery system targets.

Summary

Results from the testing discussed above will help to refine methods used for forthcoming testing of articles that are more closely aligned with BTMS goals, particularly the critical materials free mandate. As system modeling progresses the goals will be refined and test procedures will be further developed to emulate the operation of such a system. These procedures, alongside tests designed to yield accelerated aging, will provide data allowing improved prediction of technologies' abilities to meet the long cycle and calendar life goals of the program.

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