Cycle life testing of 18650 Li-ion cells with pulsed charge/discharge profiles

Andrew Burke, Jingyuan Zhao
University of California-Davis, California USA, afburke@ucdavis.edu

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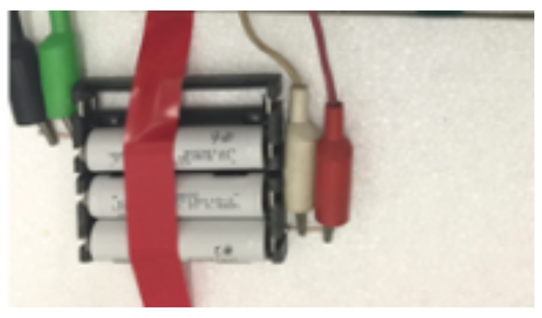
Objectives of the Research

The purpose of this research was to experimentally determine the cycle life variation of the Ah capacity and resistance of LiNiCoAl and $LiFePO_4$ cells under constant current and dynamic pulsing discharge profiles as they would experience in an electric vehicle with and without supercapacitors. Specifically, cycle life testing of 18650 cells of the LiNiCoAl and $LiFePO_4$ chemistries was performed. One module of each of the two cell chemistries was tested using a dynamic pulsed discharge profile and one module at a constant current equal to the average current of the dynamic pulse profile. The Ah capacity and resistance of the modules were monitored every 30 cycles to assess the degradation of the cells.

3-cell modules of 18650 cells cycled



Test conditions for the cycle life testing

- Charging algorithm: full charge with taper
- Initial and final SOC: 100%-20%
- Discharge profiles: constant current, dynamic pulses
- Module cut-off voltage: 9.0V for NiAlCo, 7.5V for LFP
- Temperature: room temp. (25deg C)

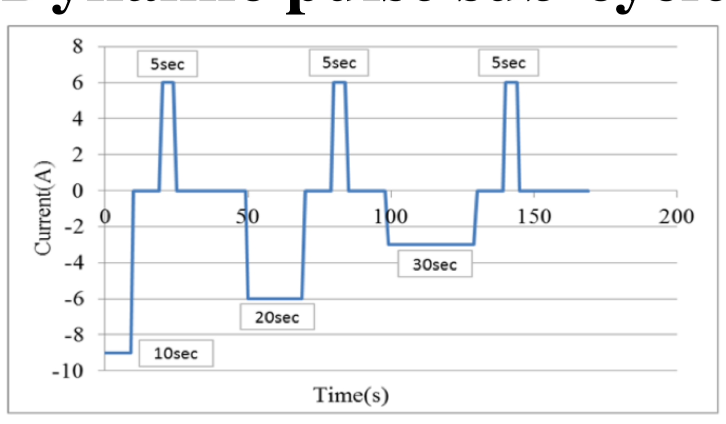
Performance characteristics of the cells

Constant Current (A)	Time (sec)	Ah	Pulse tests Pulse Current (A)	Pulse Time (sec)	Steady-state Resistance (mOhm)	Rebound Resistance (mOhm)
Panasonic - LiNiCoAl / Nominal voltage: 3.6 V / Nominal capacity: 3100 mAh						
1	10476	2.91	-9	10	74	76
2	5130	2.85	-6	10	78	77
3	3271	2.73	-3	10	77	78
			7	5	76	75
Device: K2 – $LiFePO_4$ / Nominal voltage: 3.1 V / Nominal capacity: 1500 mAh						
0.5	10368	1.44	-6	10	101	101
1	4965	1.38	-4	10	107	108
2	2309	1.28	-2	10	115	115
			4	5	106	101

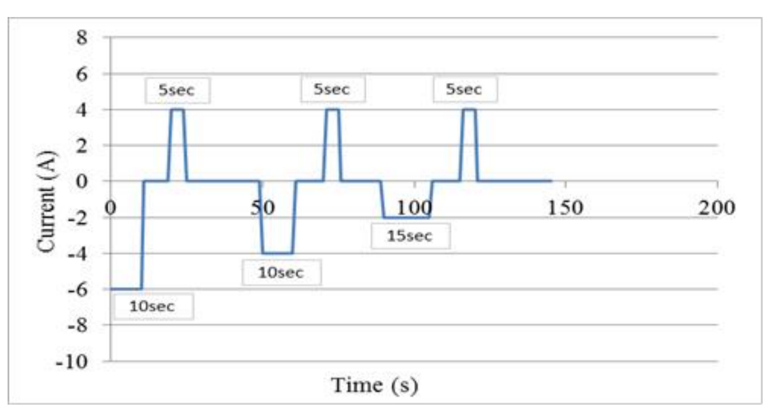
Initial characteristics of the modules

Module Panasonic NiCoAl (V_{cutoff}=3.0V/cell)	Charging current (A)	Initial Ah capacity	Initial Pulse Resistance (Ohm)
Constant current tests	1	2.719	.2436
Dynamic pulsing tests	1	2.72	.2412
Module K2 Energy $FePO_4$ (V_{cutoff}=2.5V/cell)			
Constant current tests	.6	1.389	.2118
Dynamic pulsing tests	.6	1.286	.2436

Dynamic pulse sub-cycles



(W/kg) max = 675,
Average current: 1.15A (C/2.4-rate)
Pulse sub-cycles for Panasonic cells

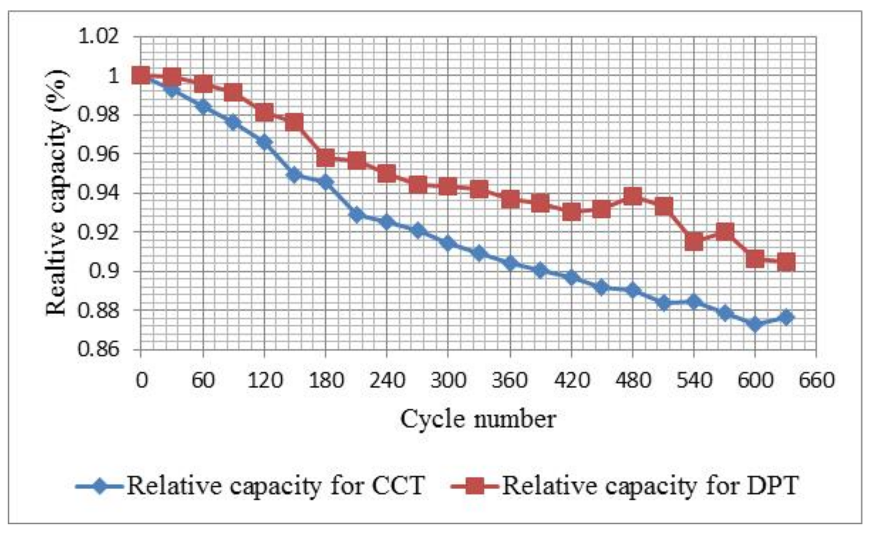


(W/kg)max = 375,
Average current: 0.48A (C/2.7-rate)
Pulse sub-cycles for K2 Energy cells

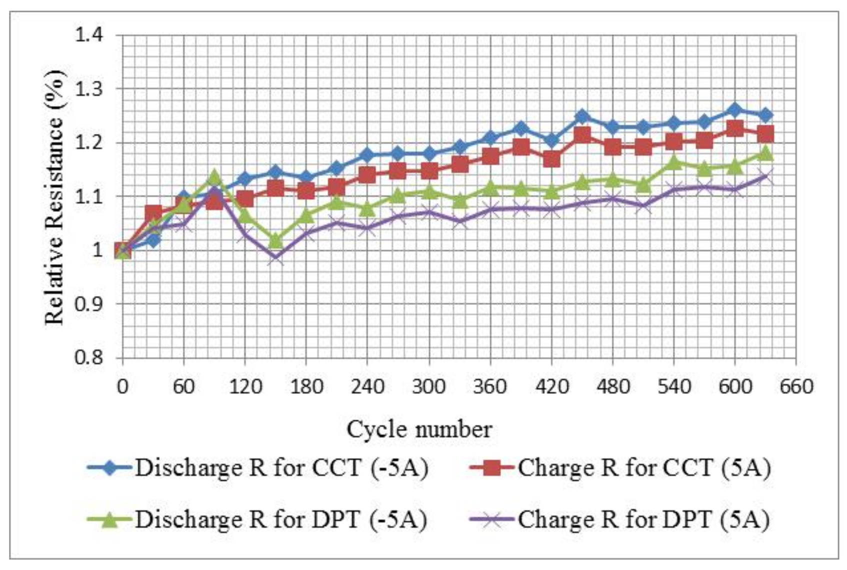
Method of tracking the cell characteristics during cycling

After each set of 30 cycles, a diagnostic test was performed to determine the Ah capacity and resistance of the module. The resistance was determined from an 8 sec, 4-5A pulse at 60% SOC; the Ah capacities were determined using a cut-off voltage of 9.0V/cell for the Panasonic NiCoAl module and 7.5V/ cell for the K2 Energy FePO4 module.

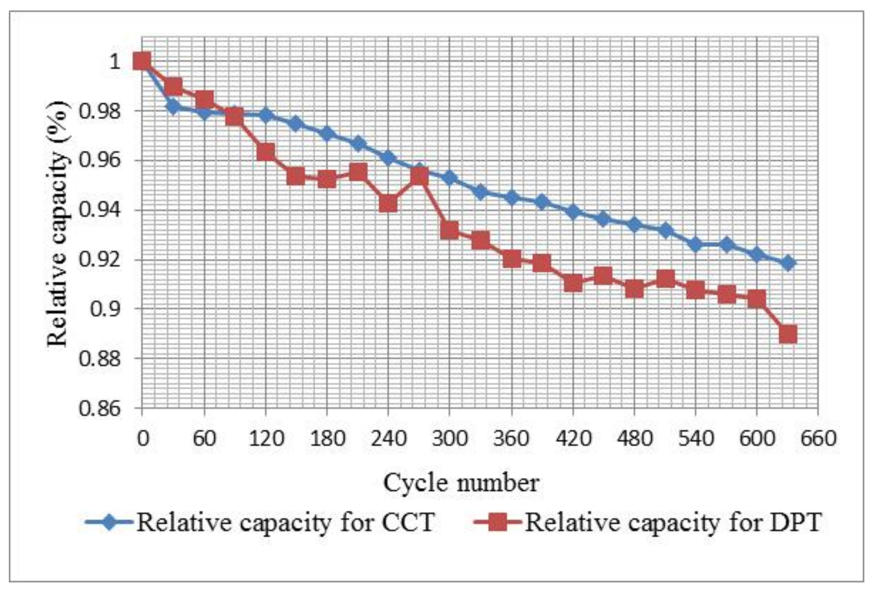
The life cycling results for the NiAlCO and LFP cells



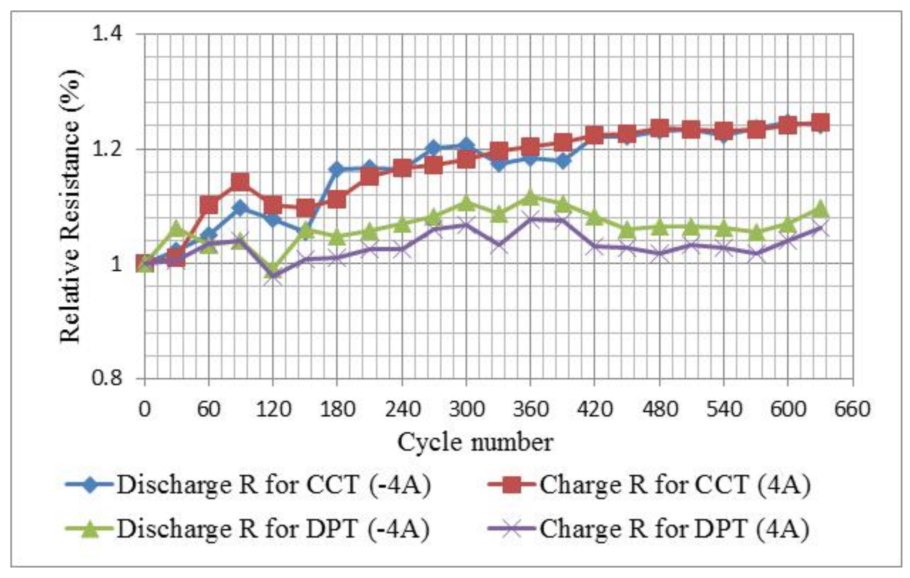
Capacity degradation for LiNiCoAl module



Resistance increase for LiNiCoAl module



Capacity degradation for LiFePO4 module



Resistance increase for LiFePO4 module

Estimated cycle life for the NiCoAl and $LiFePO_4$ modules for constant current and dynamic pulse cycling

Lithium battery Chemistry	Estimated cycle life for a 20% degradation in Ah capacity	Estimated cycle life for a 50% increase in resistance
Panasonic NiCoAl *		
Constant current cycling	1000	1750
Dynamic pulse cycling	1500	3050
K2 Energy $FePO_4$ *		
Constant current cycling	1620	2000
Dynamic pulse cycling	600**	Resistance increase less than 10% until Ah limit was reached

*all the modules consisted of 18650 cells
** module was discharged to 87% of its original Ah capacity rather than 82% during the cycling

Summary of life cycle test data from various sources

Battery	Test conditions and profiles	Capacity fade (%)	Resistance increase (%)	Reference
$LiFePO_4$ 12 Ah	SOC 80-30%, 45 °C	600 1200 cycles	600 1200 cycles	China [6]
	Without ultracaps	7.7 17	5 10.5	
	Moderate leveling	7.5 14	7 9	
	Load -leveled	7.5 13.7	0 4.5	
LiMnO 5 Ah	SOC 90-30%, 40 °C	250 500 cycles	250 500 cycles	ANL [3]
	Full DST	4.5 12	27 57	
	Modified DST	0 4	5 10	
LiNiCoAl 3.1 Ah	SOC 100-20 %, 25 °C	300 600 cycles	300 600 cycles	Present study
	Dynamic pulsing	6 9.6	8 16	
	Load-leveled	8.4 12.4	18 26	
$LiFePO_4$ 1.5 Ah	SOC 100-12%, 25 °C	300 600 cycles	300 600 cycles	Present study
	Dynamic pulsing	7 10	15 14	
	Load-leveled	4 8	20 24	

Conclusions

- **Present results indicated that load-leveling the cells <u>did not</u> increase cycle life. This was an unexpected result.**
- **Most of the cycling data in the literature indicated that load-leveling <u>did</u> increase cycle life, but the magnitude of the effect varied greatly among the studies.**
- **Most of the studies were done at elevated temperatures (> 40deg C).**
- **It is thought that the difference in temperature between the present tests and most cycling tests in the literature is the major reason for the difference in the test results.**

Module OCV at the end of cycling as an indicator of SOH

Panasonic NiCoAl module (3 cells)

Constant current cycling* Cycle	OCV †	Ah Degradation factor	Dynamic pulse cycling* cycle	OCV †	Ah Degradation factor
150	10.384	.956	120	10.28	.985
210	10.32	.932	240	10.228	.954
390	10.246	.903	330	10.198	.945
510	10.207	.887	540	10.135	.918
600	10.176	.875	630	10.104	.908
690	10.160	.869	720	10.075	.891
750	10.154	.865	780	10.047	.888

* 2.21 Ah discharged on each cycle; † at the end of discharge

K2 Energy (3 cells)

Constant current cycling** cycle	OCV †	Ah Degradation factor	Dynamic pulse cycling** cycle	OCV †	Ah Degradation factor
150	9.617	.975	90	9.608	.99
240	9.617	.961	180	9.600	.949
360	9.602	.943	300	9.532	.933
480	9.595	.934	420	9.414	.910
630	9.564	.918	540	9.305	.905
720	9.548	.912	630	9.00	.889
810	9.521	.903	750	8.546	.879
840	9.515	.900			

** 1.14 Ah discharged each cycle; † at the end of discharge