Laboratory testing of Lithium Titanate based cells for BESS applications

Matthieu.Dubarry@gmail.com

Matthieu Dubarry & Arnaud Devie

Introduction

HNEI is leading a team engaged in the research, development, deployment, and **analysis of grid-scale battery energy storage systems (BESS).** The program seeks to identify high value BESS applications at various system levels and develop control algorithms that maximize the benefit to the grid/customer and the lifetime of the BESS.

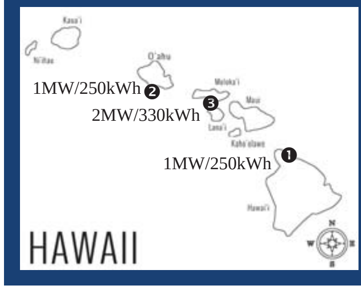
One of the task of this endeavor is to **understand the degradation of the individual batteries to anticipate failures**.
Laboratory testing of advanced Li-ion battery cells is performed to support life-time analysis of technologies targeted for large-scale grid energy storage applications.

Accelerated testing of **lithium ion titanate battery technology** identical to the one used in deployed BESS was performed and those results will be used to develop predictive performance models.

As real world data is collected from the grid batteries, the predictive models will be compared and assessed for accuracy and ability to predict performance.
This work presents preliminary results on the definition of the testing protocols and on the testing of the cells.

HNEI monitored LTO based BESS

3 LTO based BESS installed in Hawai'i



❶ COASTAL1, Big Island, HI (grid: 190MW)
1MW/250kWh, Commissioned in December 2012
Altairnano GEN1 50Ah cells, 384S(1S7P)
Frequency regulation, Wind Smoothing

❷ COASTAL2, O'ahu, HI (grid: 1.1TW)
1MW/250kWh, Commissioned in February 2016
Altairnano GEN2 60Ah cells, 384S(1S6P)
Volt-VAR, Power quality

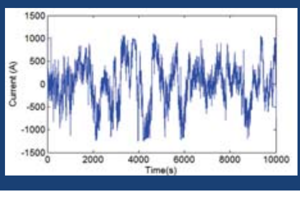
❸ COASTAL3, Moloka'i, HI (grid: 5.5MW)
2MW/330kWh, Commissioned in February 2016
Altairnano GEN2 60Ah cells, 416S(1S7P)
Reserve, Fault response

Approach

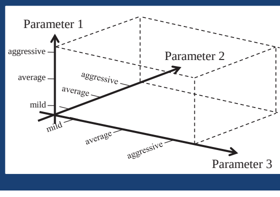
Field data → **Usage analysis** → **Laboratory testing** → **HNEI custom analysis**

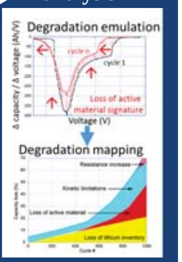
COASTAL 1 BESS

Usage analysis: Understand how the cells were utilized in the field



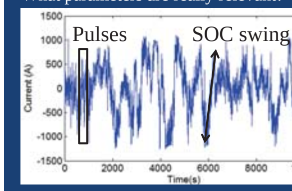
Laboratory testing: Custom design of experiment: Cover representative and aggressive usage





Usage analysis and Experiment design

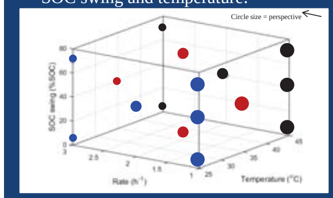
Battery usage is sporadic
Before testing average usage must be known
What parameters are really relevant?



Varying parameters:
- Pulses duration
- Pulses intensity
- SOC swing
- SOC ramp rate
- Temperature

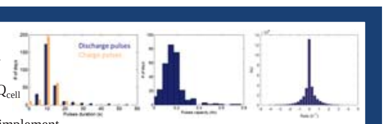
We assumed that pulses duration and SOC ramp rate variations do not impact battery aging. They will be constant in this study.

⇨ Experimental design with pulses intensity, SOC swing and temperature:

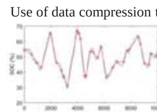


⇨ Calendar aging matrix (cf. other poster)

Pulses
Charge and discharge pulses symmetrical
Average pulses: 12s, 90% < 30s
Ave. capacity: 0.25% Q_{cell}. 25% > 0.7% Q_{cell}
Absolute rate mostly < C/4. Up to 4C.
Low currents ~ calendar aging: easier to implement

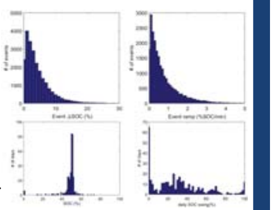


SOC events
Use of data compression technique for determination

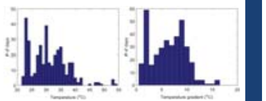


Swinging door algorithm: Scan data point by data point and test whether or not they are still contained in a parallelogram of a set size. If points cannot be contained anymore, a new reference point is created and the scan is resumed. Details on the algorithm principles: E.H. Bristol, ISA #90-493, 1009. http://ebristoliclrga.com/PDF/SwDr.pdf

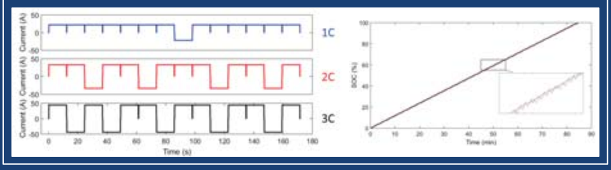
Average ΔSOC = 5%, <12% 95% of the time
Average ramp rate < 1%SOC/min. <2.5% 95% of the time
Average SOC = 50%. Daily SOC range utilization: 0-100%.
Average usage: 6 full cycles/day. Max at 15 cycles/day.



Temperature
Temperature varied between 25°C and 55°C
Average temperature: 28°C, rare excursions > 40°C
Temperature gradient in average ~ 7°C, 18°C at most



Testing implementation:
Constant pulses duration and SOC ramp rate with varying current
Not straight forward: need to define microcycles.



Cell selection

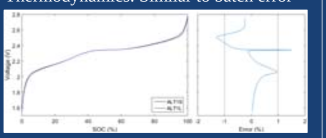
Altairnano provided 2 sizes of cells

50Ah and 11Ah cells. Are they comparable?
Large ones in BESS but small ones easier to test

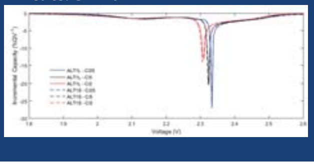
⇨ Compare thermodynamics and kinetics

⇨ Small cells are representative

Thermodynamics: Similar to batch error

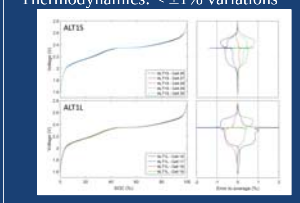


Kinetics: Similar



Cells were manufactured in 2007
⇨ Calendar aging conditions?
⇨ Compare cells from same batch first

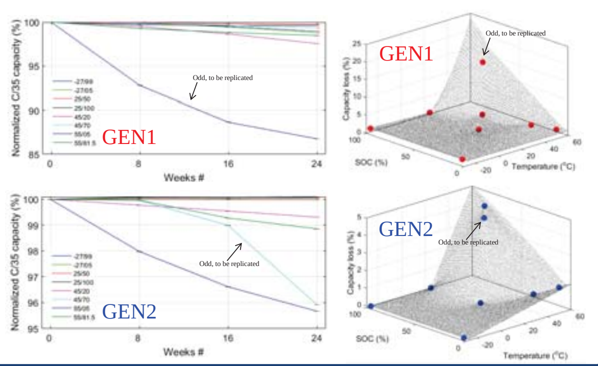
Thermodynamics: < ±1% variations



Kinetics: < ± 0.3% variations
Resistance < ± 3% variations

Calendar aging

Calendar aging experiment
Test degradation under different storage conditions for GEN1 and GEN2 cells – In progress, 8 months in
Test designed to be more accurate at high temperatures and high SOCs



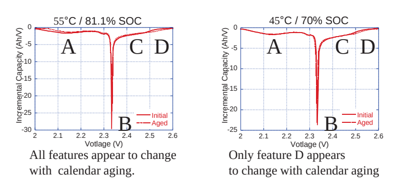
GEN1:
- ~1% loss after 8 months for T ≤ RT,
- Above RT, capacity loss and SOC becomes aggravating factor
- 20% loss at HT/HSOC: needs to be replicated.

GEN2:
- Virtually no loss after 8 months for T ≤ RT,
- No change of rate capability/resistance either
- Above RT, temperature and SOC become aggravating factors.
- Cell at 45°C/70%SOC seems to degrade differently than others: need to be replicated

Degradation analysis using incremental capacity analysis and the 'alawa toolbox*

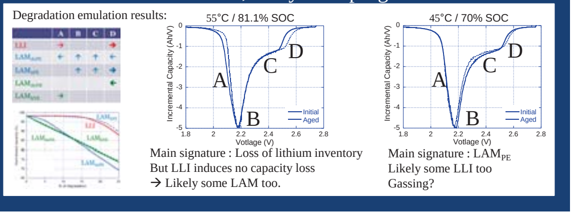
* https://www.soest.hawaii.edu/HNEI/alawa/
** A. Devie, M. Dubarry, and B.Y. Liaw, J. Electrochem. Soc., 162 (6) A1033-A1040 (2015)

GEN1 – Emulation & analysis in progress



All features appear to change with calendar aging.
Only feature D appears to change with calendar aging

GEN2 - Emulation done**, analysis in progress



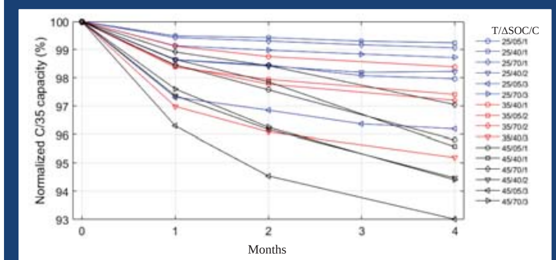
Main signature : Loss of lithium inventory
But LLI induces no capacity loss
➔ Likely some LAM too.

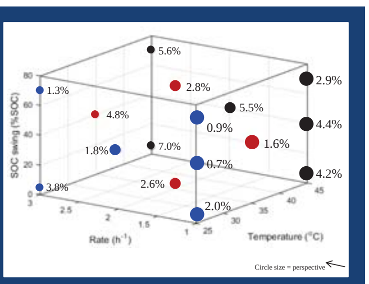
Main signature : LAM_{PE}
Likely some LLI too
Gassing?

Cycle aging

Cycling experiment:

16 GEN1 cells cycling – In progress, 5 months in.

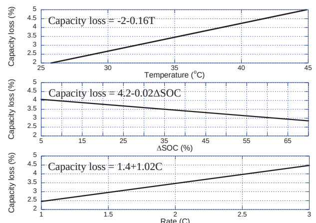




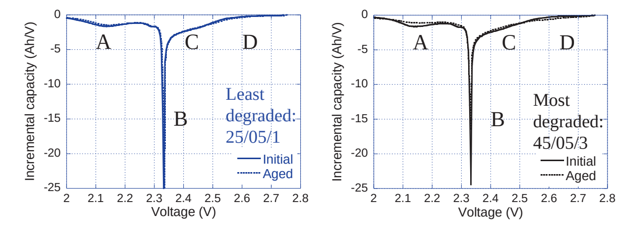
After 4 months of cycling, cells lost up to 7% of their capacity.
Temperature increase is responsible for the larger degradation, followed by current increase and SOC swing decrease.
The fact that ±2.5% SOC swings around 50% SOC are causing more degradation than ±35% is surprising

Capacity loss variations can be expressed in function of the temperature, the current and the ΔSOC via a fit:
Linear model, $R^2 = 0.86$, p-value < 0.0001
$Q_{loss} = -3.54 + 0.16T + 1.02C - 0.02\Delta SOC$

Average perturbation after 5 months:
T > C > ΔSOC



Incremental capacity analysis and cell emulation in progress: should yield diagnosis



More details on HNEI BESS grid integration projects: http://www.hnei.hawaii.edu/sites/www.hnei.hawaii.edu/files/Batteries_for_Grid_Management.pdf
http://www.hnei.hawaii.edu/sites/www.hnei.hawaii.edu/files/Molokai_Microgrid.pdf

Conclusions & Perspectives

The preliminary results of the accelerated testing of BESS deployed LTO cells showcases that battery **degradation is influenced by increases of temperature and current**. More surprisingly, **smaller SOC swings around 50% SOC seems to degrade the cell faster** than of large ones.

Looking at calendar aging, storing the cells at room temperature or below does not seem to degrade them much. This is not the case at higher temperature and state of charge.

Acknowledgements

ONR for funding
Karl Stein, Moe Tun, Marc Matsuura, Keith Bethune, Jack Huizingh, Richard Rocheleau (HNEI), Jerry Haverstick, Mike Coleman (Altairnano)

The authors are also grateful to the Hawaiian Electric Company (HECO) for their partnership on the project and for the ongoing support to the operations of the Hawaii Sustainable Energy Research Facility (HiSERF).

University of Hawai'i Mānoa
School of Ocean and Earth Science and Technology
HNEI Hawai'i Natural Energy Institute, School of Ocean and Earth Science and Technology, University of Hawai'i at Mānoa
HiSERF