Battery Durability and Reliability under Electric Utility Grid Operations: Representative Usage Aging

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Objective/Significance
Evaluate degradation & lifetime of BESS in support of grid scale deployment
Improve economic understanding of future commercial & base deployments

Approach
Assess battery performance in BESS and under controlled conditions
Analyze degradation using non-destructive methods
Link controlled and deployed degradation to forecast remaining useful life

Field data ➔ Usage analysis ➔ Laboratory testing ➔ HNEI custom analysis

Understanding how the cells were utilized in the field
Custom design of experiment: Cover representative and aggressive usage
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Usage analysis

In three years:
In use 90% of the time
Stored 1.5 GWh of energy
>5000 battery cycles

Usage of the cells can be described by 5 parameters:
9 second pulses, C/2 current, 5% SOC swings, 0.75% SOC/min ramp rate, and 35°C

Big Island, HI (grid: 190MW)
Altairnano GEN1 50Ah cells, 1MW/250kWh, 384(7P)S1P
Commissioned in December 2012
Frequency regulation, Wind Smoothing
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Laboratory testing – Cycle aging

After 880 full SOC swings / 4000 cycles, the cells lost up to 7% of their capacity. Impact of T, C and ΔSOC

3 C rates,
3 temperatures,
3 SOC swings,
1 pulse duration,
1 SOC ramp rate
Design of experiment methodology
→ decompose impact of each effects

Temperature increase responsible for most degradation, followed by current increase and SOC swing decrease.
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Laboratory testing – Calendar aging

~ 1% loss after 16 months for $T \leq RT$

Above RT, lower SOCs becomes aggravating factor

>10% loss at HT and LSoC replicated.
Composite PE: LCO+NCA
No access to individual components
Fit with reference materials

Good fit except for intensity 3.9V peak

Mechanistic modeling
Mechanistic modeling: Use fit to predict voltage response under different degradations

Assessed the impact of each active component of the cell
Degradation is much more important than that shown by capacity loss

Use mechanistic understanding to predict capacity fade

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Incremental capacity analysis – Cycle aging

Use IC curves to quantify $LAM_{NE}$, $LAM_{PEs}$ and LLI
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Incremental capacity analysis – Calendar aging

Use IC curves to quantify $LAM_{NE}$, $LAM_{PE}$, and $LLI$

Degradation is much more important than that shown by capacity loss

Use mechanistic understanding to predict capacity fade
Conclusions

Found major impact for temperature, and SOC swing

Temperature impact could explain the spread observed in the field

Big degradation despite small capacity losses

Significant $\text{LAM}_{\text{PE}}$ (both components) and LLI. Not yet associated with capacity loss

Path dependent degradation: different signature cycle / calendar and $T$ / SOC.

Perspective

Model performance based on laboratory testing

Compare lifetime performance model to field data to determine BESS SOH

Optimize BESS control strategies to limit degradation
Acknowledgments

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Thank you for your attention! Questions?

Interested in energy storage? Join us in January:

ICESI-PPSS 2019 Joint Meeting
January 5-10, 2019
Hilton Waikoloa Village, HI, USA
http://www.soest.hawaii.edu/PPSS-2019/

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Aging path dependence

**Calendar aging** induces different degradations
Significant degradation despite small capacity loss

Different that cycle aging degradation
Highlight importance to test a particular battery for a given application

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Field data

1. O‘ahu, HI (grid: 1.1TW)
   1MW/250kWh, Commissioned in February 2016
   Altairnano GEN2 60Ah cells, 384(7P)S1P
   Volt-VAR, Power quality

2. Moloka‘i, HI (grid: 5.5MW)
   2MW/330kWh, Commissioned in February 2016
   Altairnano GEN2 60Ah cells, 416(7P)S1P
   Reserve, Fault response

3. Big Island, HI (grid: 190MW)
   1MW/250kWh, Commissioned in December 2012
   Altairnano GEN1 50Ah cells, 384(7P)S1P
   Frequency regulation, Wind Smoothing

Demonstrated over 8000 full cycles equivalent operation