Understanding Li-ion Battery Module Performance under Peak Shaving using Single Cell Data

Daiwon Choi, N. Shamim, E. Thomsen, A.J. Crawford, V.V. Viswanathan, Q. Huang, D.M. Reed, V.L. Sprenkle

Pacific Northwest National Laboratory, Richland, WA 99352

Introduction Lithium-ion (Li-ion) batteries account for over 90% of battery energy storage systems (BESS) currently in use, offering a variety of chemistries, formats, sizes, modules, packs and system integrations. However, assessing their state-of-health during operation remains a challenge due to limited access to comprehensive electrochemical data. In this study, a Li-ion battery module and its identical single cells based on NMC chemistry were tested under peak shaving service for two years, and their performance results were compared and analyzed.

Objectives and Methodology

- ❑ Utilize single cell test results to understand and predict state-of-health of module and eventually BESS system.
- ❑ Tested under peak shaving condition for two years.

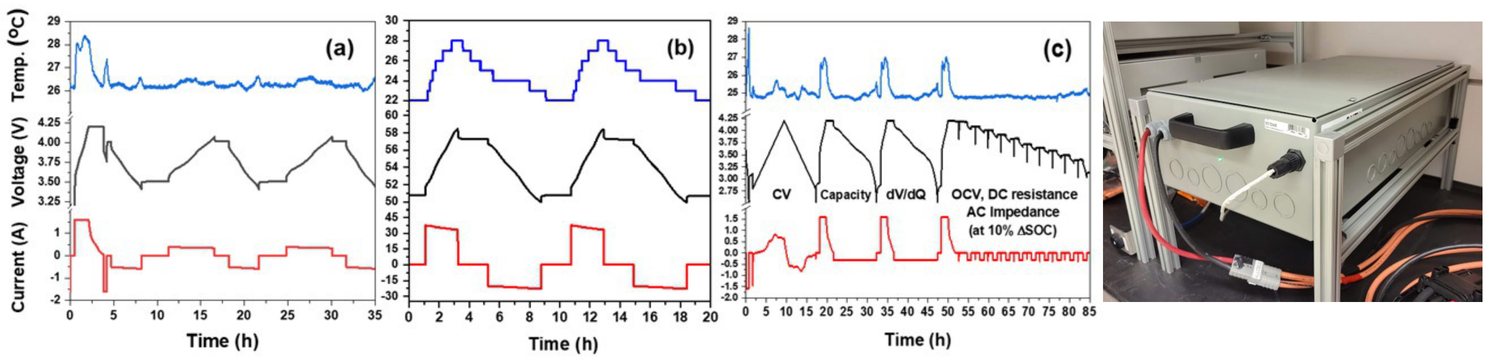

Fig. 1. (a) cell,(b) module over two years of peak shaving cycle and (c) RPT after a month of cycles.

❑ Variables

- **State-of-Charge (SOC) :** 20~80%
- **Depth of Discharge (DOD or ΔSOC) :** 20, 40, 60%
- **Power (C-rate):** within cell specifications
- **Temperature :** 25°C (Module tested inside fume hood with constant air flow)
- **Number of cells:** 4 under same test condition
- **Module** : 7.6kWh a nominal capacity of 150Ah and 51V (14 cells in series and 48 cells in parallel total: 672 cells).

Results and Discussion

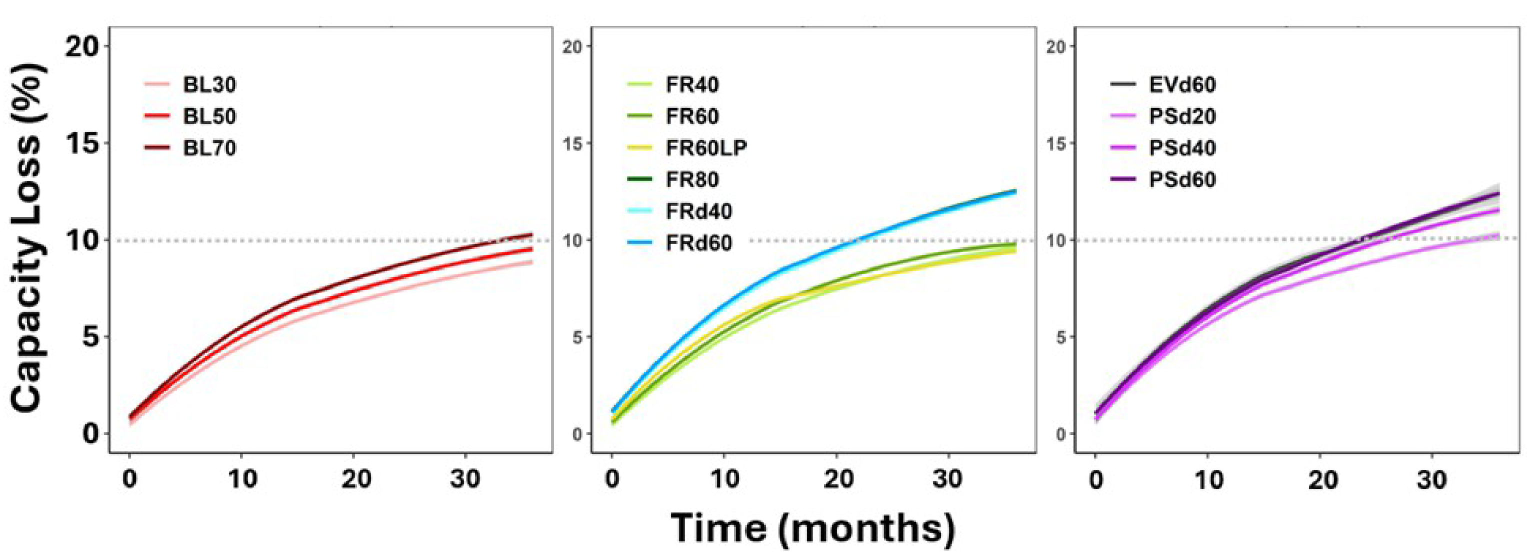

Fig. 2. Capacity loss of NMC cell over two years of aging base line (BL), frequency regulation (FR), peak shaving (PS) and electric vehicle (EV) cycles over 3years. (dXX: SOC change, XX: SOC level, LP: low power)

- ❑ NMC cell degraded ~11% after two years of peak shaving cycles with ΔSOC of 60% (PSd60).
- ❑ Higher SOC levels increased aging (BL) degradation.
- ❑ The most degraded grid service was frequency regulation (FRd60), peak shaving (PSd60) and electric vehicle (EVd60) cycles. This show larger ΔSOC changes effects during increases degradation.

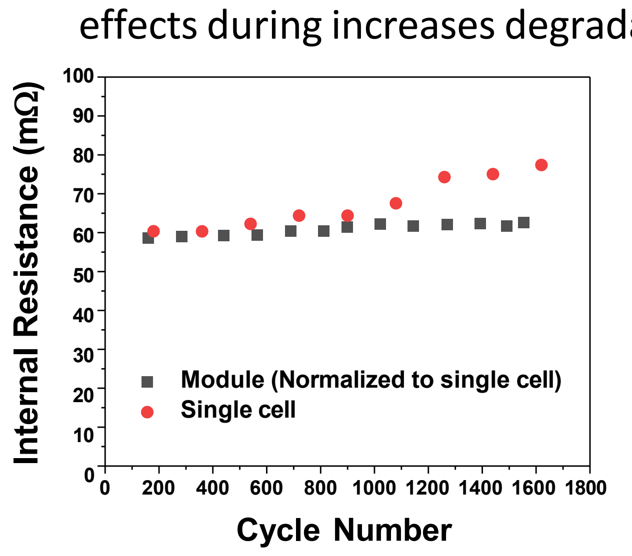

Fig. 3. Internal resistance change comparison between single cell and module.

- ❑ ΔSOC and SOC levels effect degradation behavior, but high/low-rate pulse (LP) have negligible effects on degradation.
- ❑ Most important factor for degradation was time (aging) when compared to service cycles.
- ❑ The internal resistance remained within a close range but deviated with cycles. These differences may be attributed to the measurement and calculation methods used for cell and module levels. Future test setups should clarify this discrepancy.

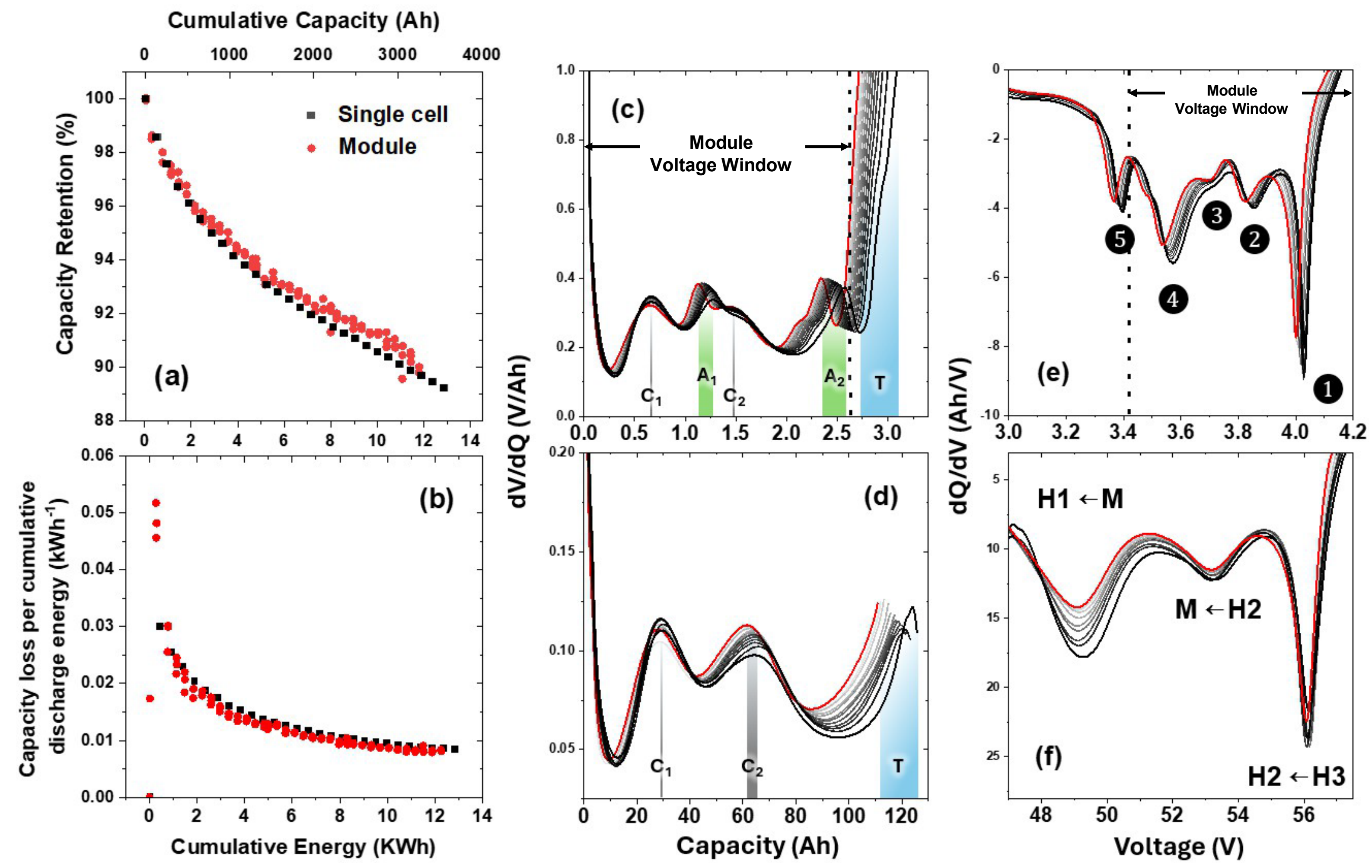

Fig. 4. (a) capacity retention, (b) capacity loss per cumulative energy, dV/dQ of (c) cell and (d) module, dQ/dV of (e) cell and (f) modules. (C: cathode peak, A: anode peak, T: total capacity)

Table 1. Capacity loss components from dV/dQ analyses.

	Cell	Module
Total capacity loss	11.65 %	10.58 %
loss of active material of positive electrode (LAMPE)	≈ 0 %	≈ 0 %
loss of active material of negative electrode (LAMNE)	2.86%	No peaks

- ❑ Single cell and module over two years of peak shaving cycle show very close degradation behavior.
- ❑ Differential capacity (dQ/dV) profiles show phase transition from hexagonal (H1,H2,H3) to mononclinc (M) phase transitions.
- ❑ Peaks shifts indicated resistance increase.
- ❑ Differential voltage (dV/dQ) profile of single cell show both cathode (C1&C2) and anode (A1 &A2) peaks, but module does not show anode peaks possibly due to limited electrochemical data resolution .
- ❑ Most of the capacity loss is due to lithium loss (T) and some anode active materials loss from SEI growth but cathode material loss was negligible.

Summary and Perspective

- ❑ NMC cells test results can predict module performance when tested at same temperature.
- ❑ Degradation mechanism is mostly due to SEI growth with Li consumption (loss of lithium).
- ❑ Module performance data resolution limits accurate state-of-health diagnostics.

Future Work

- ❑ Data accumulated here will be applied to modeling battery degradation and state-of health analyses for larger energy storage modules and systems.
- ❑ Additional chemistries including Na-ion cells will be tested.
- ❑ In-operando/post-mortem cell characterization using advanced techniques.

Acknowledgements

This material is based upon work supported by the U.S. Department of Energy, Office of Electricity (OE), Energy Storage Division. PNNL is operated by Battelle Memorial Institute for the DOE under contract DE-AC05-76RL01830.

References

1. D. Choi *et al.*, "Reliability Testing of Commercial Li-Ion Battery Cells for Electrochemical Energy Storages (EES)," 2025 IEEE Electrical Energy Storage Applications and Technologies Conference (EESAT), Charlotte, NC, USA, pp. 1-5, 2025.
2. D. Choi, N. Shamim, A.J. Crawford, Q. Huang, C.K. Vartanian, V.V. Viswanathan, and M.D. Paiss, *et al*. 2021. "Li-ion Battery Technology for Grid Application" *J. Power Sources,* 511.(2021)
3. A.J. Crawford, D. Choi, P.J. Balducci, V.R. Subramanian, V.V. Viswanathan, "Lithium-ion battery physics and statistics-based state of health model" *J. Power Sources*, 501, p.185-193 (2021).

This project is testing new energy storage technologies under grid duty cycles, which is crucial to meeting the Administration's goal of providing affordable, secure, and resilient energy.

7/31/2025 | PNNL-SA-213143

For additional information, contact:

Daiwon Choi, Ph.D.

Tel: (509) 375-4341

Email: daiwon.choi@pnnl.gov