Hawai'i Natural Energy Institute Research Highlights

Electrochemical Power Systems

Path Dependence of Battery Degradation

OBJECTIVE AND SIGNIFICANCE: The objective of this project is to characterize the impact of different stresses on the durability of Li-ion batteries using large experimental campaigns and design of experiments. Studies could address, among others, the impact of fast charging and grid-vehicle interactions on the performance of batteries for electric transportation. The knowledge gained in this project informs best practices to successful battery durability, safety, fast charging, or vehicle-to-X integration.

BACKGROUND: Electrification of transportation and grid-storage are crucial to combat climate change. Understanding and mitigating battery degradation is key to improving durability of electric transportation and the reliability of power grids. Complexity stems from the fact that battery degradation is path dependent. This implies that usage affects not only the degradation pace, but also the type of degradation the batteries experience. Lithium-ion batteries are known to degrade slowly at first before a rapid acceleration of which starting time will depend on the mix of degradation mechanisms and thus on how the battery was used. To maximize the utility of large battery systems, it is essential to understand the impact of all the stress factors associated with an application and their combined effects.

PROJECT STATUS/RESULTS: Our study already showed that a simplistic approach to V2G, namely that an EV is discharged at constant power for 1 hour without consideration of battery degradation, is not economically viable because of the impact additional V2G cycling has on battery life. However, we showed that if the batteries are to be used for frequency regulation, there is a much lesser impact. We also showed that, with good battery prognostic models and further advances in understanding the causes, mechanisms, and impacts of battery degradation, a smart control algorithm could take all these aspects in consideration and make V2G and fast charging a reality. It must be noted that, because of path dependence, different usages might lead to different results and thus that our results should not yet be generalized on cells different than the one tested.

Current work with DSTG (Australia) involves an experimental campaign of more than 700 cells tested under a HNEI defined design of experiments to predict the degradation of MW systems and maximize durability and reliability in the field. Collaborative work is also ongoing with Sandia National Laboratories and Aalborg University (Denmark).

Research conducted for this project is completed in the **PakaLi Battery Laboratory**. This project is ongoing and has led to 11 publications, which are listed on the following page.

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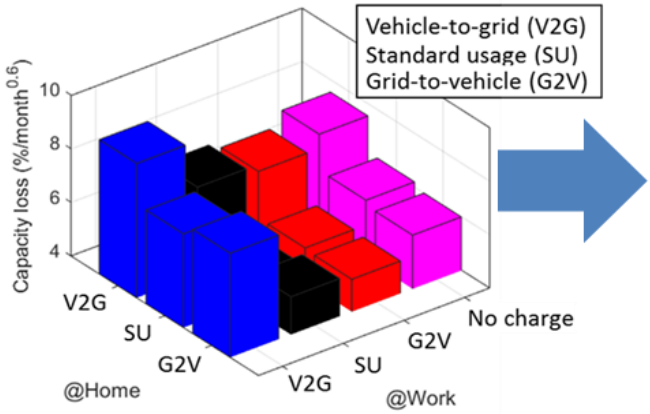

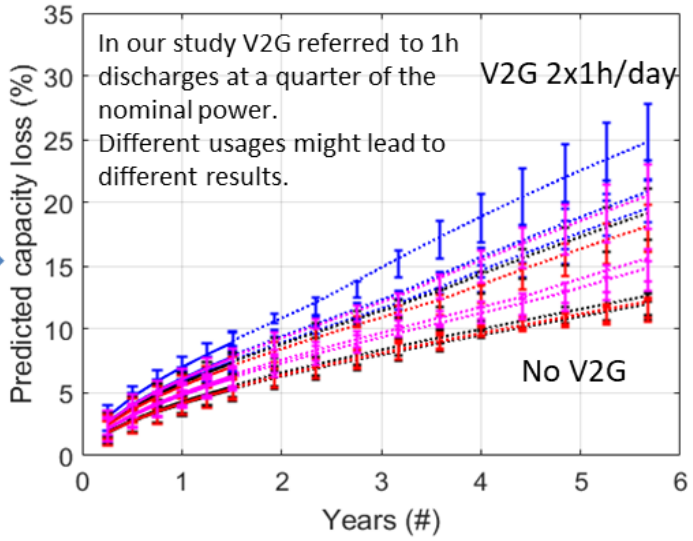

ADDITIONAL PROJECT RELATED LINKS

PAPERS AND PROCEEDINGS:

1. 2022, P.M. Attia, et al., **Review—"Knees" in Lithium-Ion Battery Aging Trajectories**, Journal of The Electrochemical Society, Vol. 169, Issue 6, Paper 060517. (Open Access: **PDF**)
2. 2021, D. Beck, et al., **Inhomogeneities and Cell-to-Cell Variations in Lithium-Ion Batteries, a Review**, Energies, Vol. 14, Issue 11, Paper 3276. (Open Access: **PDF**)
3. 2020, M. Elliott, et al., **Degradation of electric vehicle lithium-ion batteries in electricity grid services**, Journal of Energy Storage, Vol. 32, Paper 101873.
4. 2020, G. Baure, et al., **Durability and Reliability of EV Batteries under Electric Utility Grid Operations: Impact of Frequency Regulation Usage on Cell Degradation**, Energies, Vol. 13, Issue 10, Paper 2494. (Open Access: **PDF**)
5. 2019, G. Baure, et al., **Synthetic vs. Real Driving Cycles: A Comparison of Electric Vehicle Battery Degradation**, Batteries, Vol. 5, Issue 2, Paper 42. (Open Access: **PDF**)
6. 2018, M. Dubarry, et al., **Durability and Reliability of EV Batteries under Electric Utility Grid Operations: Path Dependence of Battery Degradation**, Journal of the Electrochemical Society, Vol. 165, Issue 5, pp. A773-A783. (Open Access: **PDF**)
7. 2018, K. Uddin, et al., **The viability of vehicle-to-grid operations from a battery technology and policy perspective**, Energy Policy, Vol. 113, pp. 342-347. (Open Access: **PDF**)
8. 2017, M. Dubarry, et al., **Durability and Reliability of Electric Vehicle Batteries Under Electric Utility Grid Operations: Bidirectional Charging Impact Analysis**, Journal of Power Sources, Vol. 358, pp. 39-49.
9. 2017, D. Ansean, et al., **Operando lithium plating quantification and early detection of a commercial $LiFePO_4$ cell cycled under dynamic driving schedule**, Journal of Power Sources, Vol. 356, pp. 36-46.
10. 2016, A. Devie, et al., **Durability and reliability of electric vehicle batteries under electric utility grid operations. Part 1: Cell-to-cell variations and preliminary testing**, Batteries, Vol. 2, Issue 3, paper 28.
11. 2016, D. Ansean, et al., **Fast charging technique for high power LiFePO4 batteries: a mechanistic analysis of aging**, Journal of Power Sources, Vol. 321, pp. 201-209.

PRESENTATIONS:

1. 2022, R. Wittman, et al., **Path Dependence of Li-Ion Battery Degradation During Cycling to 80% Capacity**, Presented at the Material Research Society Spring Meeting, May 8-13.
2. 2021, R. Wittman, et al., **Characterizing Materials and Electrochemical Changes in a Range of 18650 Li-Ion Cells Cycled to 80% Initial Capacity**, Presented at the 239th ECS Meeting, Chicago, IL, May 30-June 3.
3. 2019, M. Dubarry, et al., **Synthetic vs. Real Driving Cycles: A Comparison of EV Battery Degradation**, Presented at the 236th ECS Meeting, Atlanta, Georgia, October 13-17.
4. 2019, G. Baure, et al., **A Diagnostic and Prognostic Study of the Impact of Electric Utility Grid Operations on EV Batteries**, Presented at the International Coalition for Energy Storage and Innovation Meeting, Waikoloa, Hawai'i, January 5-10.
5. 2017, A. Devie, et al., **Durability and Reliability of EV Batteries under Electric Utility Grid Operations**, Presented at the 232nd ECS Meeting, National Harbor, Maryland, October 1-5.
6. 2016, M. Dubarry, et al., **Path Dependence in Lithium-Ion Batteries Degradation**, Presented at the ECS PRiME Meeting, Honolulu, Hawai'i, October 2-7.
7. 2016, M. Dubarry, et al., **EV Cell Degradation under Electric Utility Grid Operations**, Presented at the Next-Generation Energy Storage Conference, San Diego, California, April 18-19.
8. 2015, M. Dubarry, et al., **Experimental diagnostic of Li-ion commercial cells, case studies**, Presented at the 225th ECS Meeting, Orlando, Florida, May 11-15.