EV cell degradation under electric utility grid operations: Impact of calendar aging & vehicle to grid strategies

Matthieu Dubarry & Arnaud Devie

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

Matthieu.Dubarry@gmail.com

Introduction

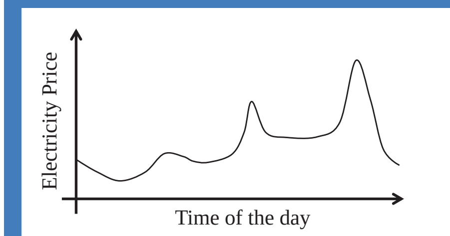
Plug-in electric vehicles (EVs) and renewable energy sources offer the **potential to substantially decrease carbon emissions** from both the transportation and power generation sectors.
Mass adoption of EVs could have a number of impacts, including the ability to **assist in the integration of renewable energy** into existing electric grids by **sourcing/sinking energy to/from the grid** known as vehicle to grid (V2G) and grid to vehicle (G2V) respectively.

The potential benefits of V2G and G2V have been heavily investigated in recent years. **One key parameter to weigh in** regarding the applicability of V2G or **G2V is the degradation of the batteries induced by the additional use**. The success of V2G/G2V strategies will depend on consumer acceptance and desire to participate in the program. On the consumer side, it is essential to **compare** the reward **– the financial gain from "selling" some of their EV battery capacity** to the grid utility – to the risk **– a potential faster degradation of the battery and thus, a reduced lifetime**.

As part of the US Department of Transportation funded Electric Vehicle Transportation Center (ETVC), HNEI has partnered with the Florida Solar Energy Center to perform laboratory testing on commercial Li-ion cells to **evaluate the impact of V2G and G2V strategies on the cells via laboratory testing of different aging conditions, from cycling to calendar aging.**

Why V2G/G2V?

Electricity production marginal cost varies with the time of the day.

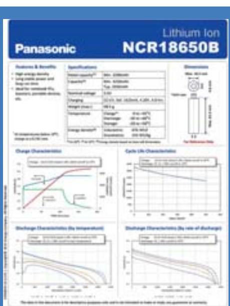


Utility side:
Need to fire additional generators @ peak hours
and to store excess energy from renewables during off-peak hours
⇨ Expensive
⇨ EVs represent an easy access to readily accessible source/sink

Could potentially reduce the need for large single purpose Battery Energy Storage Systems (BESS)

Consumer side:
Electricity is more expensive @ peak hours
Selling it when expensive and buying when cheap could provide income when the battery is sitting (cars are parked 95% of the time).

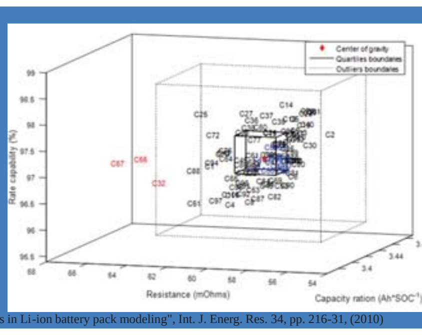
Cell selection



High quality Graphite//NCA cells
Reported to be used in some EVs today

Cell-to-cell variations assessment*:
- 100 cells purchased
- < 0.5% rate capability variations
- < 0.5% capacity ration variations
- < 3% resistance variations
- 3 outliers

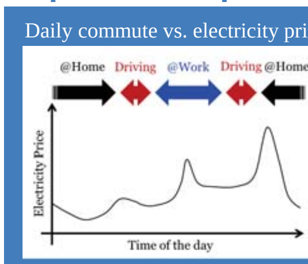
Reproducibility:
- 3 cells per cycle aging conditions
- 2 cells per calendar aging conditions



* Methodology in Dubarry M., Vuillaume N., Liaw B. Y. "Origins and accommodation of cell variations in Li-ion battery pack modeling", Int. J. Energ. Res. 34, pp. 216-31, (2010)

Experimental protocols

Daily commute vs. electricity prices:

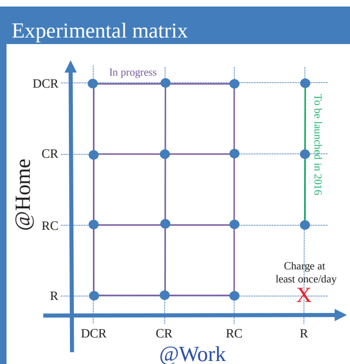


@Home, @Work
Different possible scenarios:

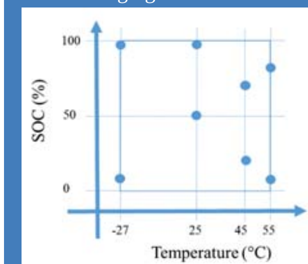
V2G
- Discharge, charge and rest (DCR)
- Charge then rest (CR)
- Rest then charge (RC)
- Resting (R)

G2V

Experimental matrix



Calendar aging matrix



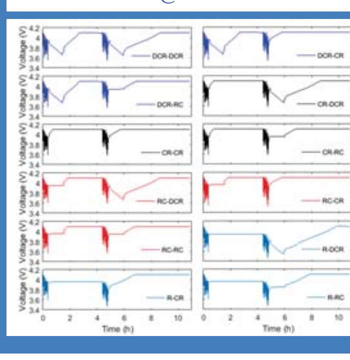
Calendar aging experiment designed for maximum accuracy @ high temperature & high SOC

Schedules compressed to 11 hours
⇨ Test accelerated > x2

⇦ Need for calendar aging experiment to assess impact of the missing 13 hours/day

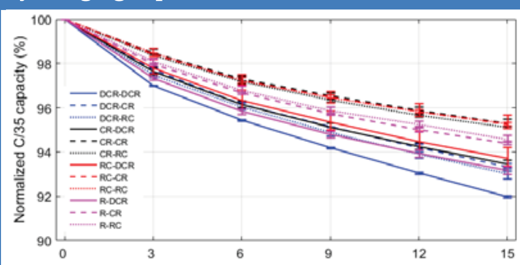
Other details & Hypothesis:
Driving data from HNEI database*
V2G step: 1hour @ 7kW (P/4)
EV battery pack: ~ 25 kW,
@Work battery charger:
- Max power to grid ~ 7kW
- Fast charger (4h/full charge)
@Home battery charger:
- Max power to grid ~ 4kW
- Regular charger (8h/full charge)

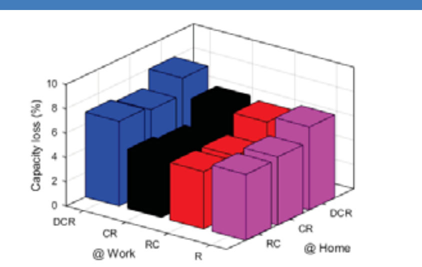
* 30km round trip



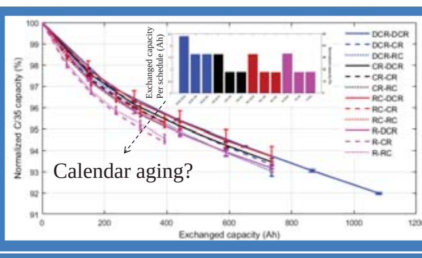
Cycle aging preliminary results

Cycle aging experiment – 10 months in

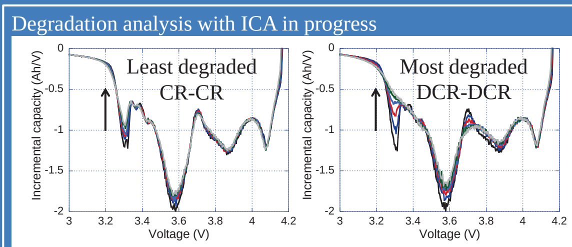




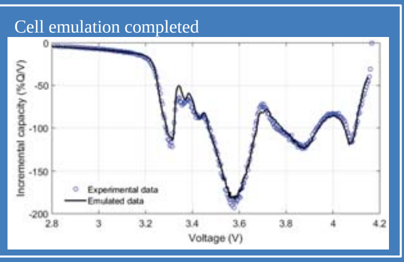
- Cells lost between 4.5 and 8% capacity after an equivalent 15 months of driving.
- V2G strategy induced 2% extra degradation per daily occurrence (@work and/or @home).
- RC / CR strategies have similar capacity loss
  - Calendar aging study shows weak influence of SOC at RT
- 2 charges / day strategy degraded the cell the least.
- After 100 equivalent cycles completed
  - Cells that used more capacity lost less %Q/Ah used



Degradation analysis with ICA in progress

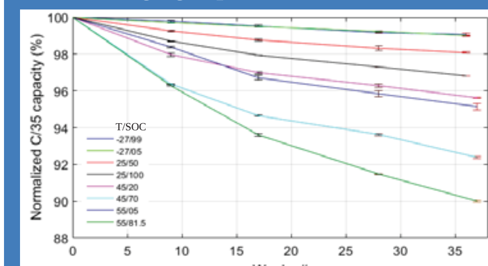


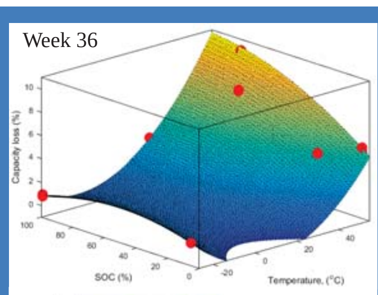
Cell emulation completed



Calendar aging preliminary results

Calendar aging experiment – 37 weeks in

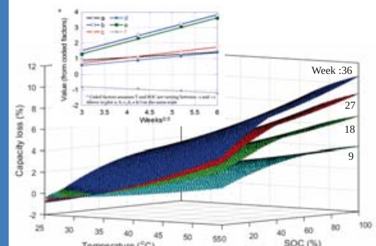




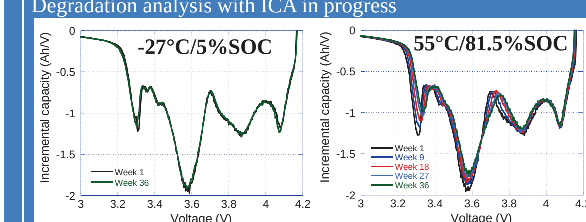
Capacity loss influenced by both temperature and SOC.
For all weeks, data can be fitted with a quadratic model:
$Q_{loss} = a + b\,T + c\,SOC + d\,T\,SOC + e\,T^2 + f\,SOC^2$ (R^2 = 0.99)
Works well for T > RT, not below RT. OK since Q_{loss} > RT

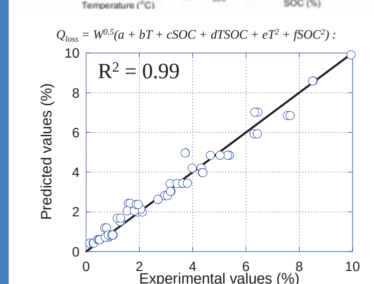
a, b, c, d, e and f seems to mostly vary linearly with $Weeks^{0.5}$:
$Q_{loss} = W^{0.5}(a + b\,T + c\,SOC + d\,T\,SOC + e\,T^2 + f\,SOC^2)$

Model fits well all data (R^2 > 0.99)



Degradation analysis with ICA in progress





Conclusions & Perspective

HNEI is testing commercial Li-ion cells to assess the impact of V2G or G2V scenarios on battery degradation.

Sustained V2G usage (1h @ 7 kW, 1/4th of the car nominal power) seems to induce some additional capacity loss, 0.13%/month. Interestingly, it also appears that charging twice a day is beneficial to the cells.

Regarding calendar aging, the high temperature and high SOC are aggravating factors with losses up to 10% after 36 weeks under harsh conditions. Cells stored at 25°C experienced a 0.05 to 0.1% loss per week depending on SOC.

A quadratic model accounting for time, temperature and SOC was proposed.

More details @ http://evtc.fsec.ucf.edu/research/project9.html

Authors Bibliography

Acknowledgments

This work was supported in part by U.S Dept. of Transportation through the University of Central Florida as part of grant number DTRT13-G-UTC51 and by the Office of Naval Research (ONR) Hawaii Energy and Environmental Technologies (HEET) Initiative, award number N00014-11-1-0391.

Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect those of the sponsor.

The authors are grateful to the Hawaiian Electric Company for their ongoing support to the operations of the Hawaii Sustainable Energy Research Facility

The authors are also thankful to Katherine McKenzie, Keith Bethune, Jack Huizingh and Richard Rocheleau (HNEI) as well as David Block and Paul Brooker (FSEC).