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

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Introduction

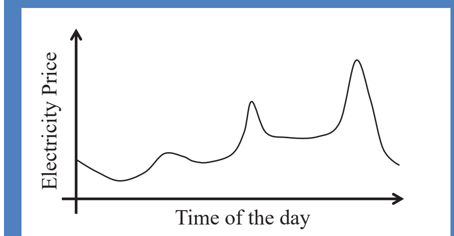
Plug-in electric vehicles (EVs) and renewable energy sources offer the **potential to substantially decrease carbon emissions** from both the transportation and power generation sectors. Mass adoption of EVs could have a number of impacts, including the ability to **assist in the integration of renewable 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.

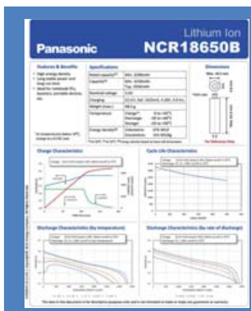


Utility side:
Need to fire additional generators @ peak hours and to store excess energy from renewables during off-peak hours
⇨ Expensive
⇨ EVs represent an easy access to readily accessible source/sink

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).

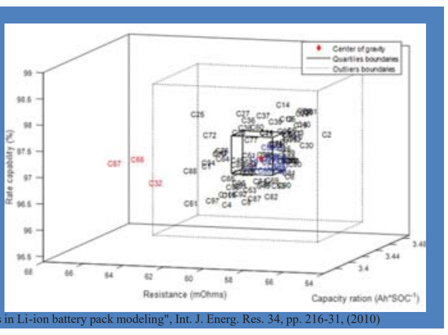
Cell selection



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

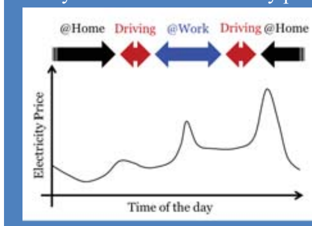
Reproducibility:
- 3 cells per cycle aging conditions
- 2 cells per calendar aging conditions



* 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:

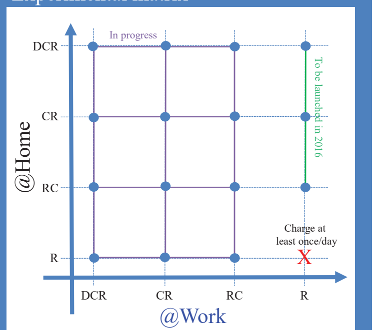


@Home, @Work
Different possible scenarios:

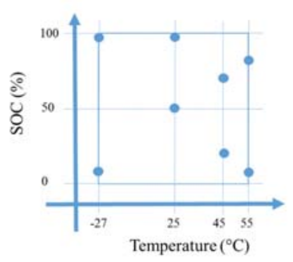
V2G
- Discharge, charge and rest (DCR)
- Charge then rest (CR)
- Rest then charge (RC)
- Resting (R)

G2V

Experimental matrix



Calendar aging matrix

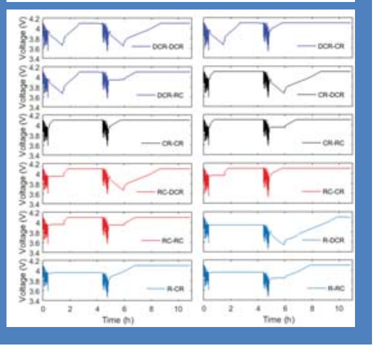


Calendar aging experiment designed for maximum accuracy @ high temperature & high SOC

Schedules compressed to 11 hours
⇨ Test accelerated > x2

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

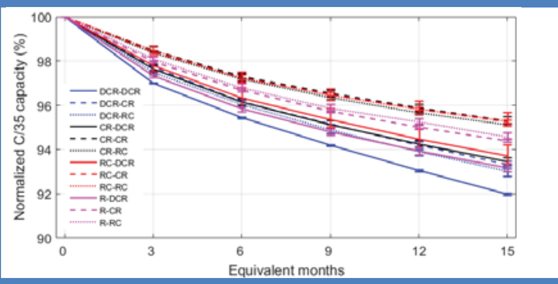
Other details & Hypothesis:
Driving data from HNEI database*
V2G step: 1hour @ 7kW (P/4)
EV battery pack: ~ 25 kW,
@Work battery charger:
- Max power to grid ~ 7kW
- Fast charger (4h/full charge)
@Home battery charger:
- Max power to grid ~ 4kW
- Regular charger (8h/full charge)

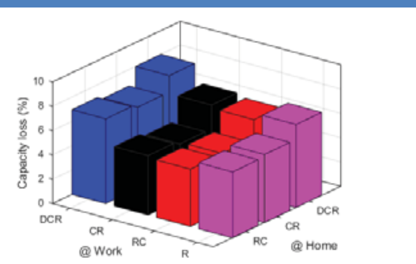


* 30km round trip

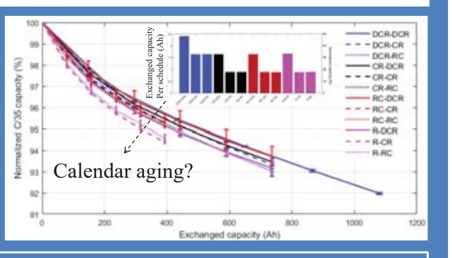
Cycle aging preliminary results

Cycle aging experiment – 10 months in

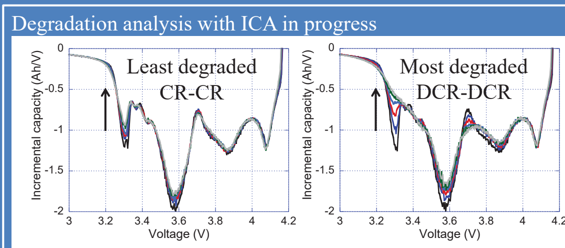




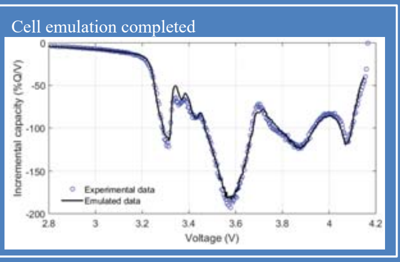
- Cells lost between 4.5 and 8% capacity after an equivalent 15 months of driving.
- V2G strategy induced 2% extra degradation per daily occurrence (@work and/or @home).
- RC / CR strategies have similar capacity loss
  - Calendar aging study shows weak influence of SOC at RT
- 2 charges / day strategy 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

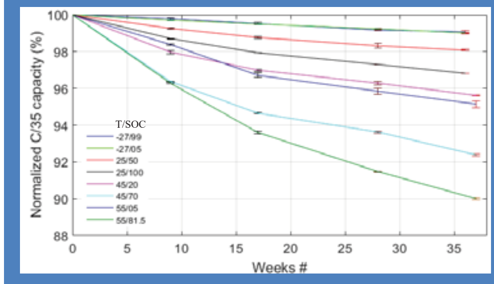


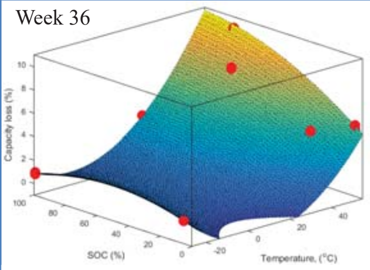
Cell emulation completed



Calendar aging preliminary results

Calendar aging experiment – 37 weeks in

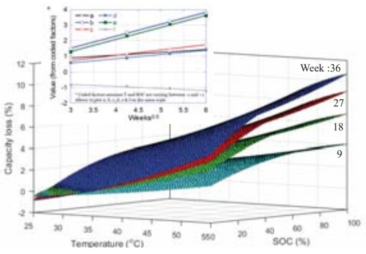


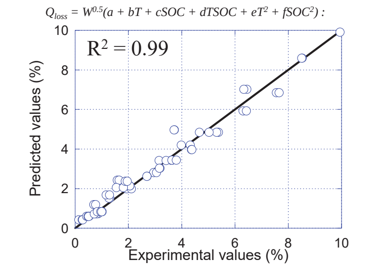


Capacity loss influenced by both temperature and SOC.
For all weeks, data can be fitted with a quadratic model:
$Q_{loss} = a + b\,T + c\,SOC + d\,T\,SOC + e\,T^2 + f\,SOC^2$ ($R^2 = 0.99$)
Works well for T > RT, not below RT. OK since Q_{loss} > RT

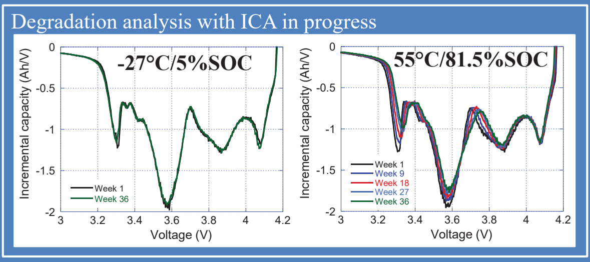
a, b, c, d, e and f seems to mostly vary linearly with $Weeks^{0.5}$:
$Q_{loss} = W^{0.5}(a + b\,T + c\,SOC + d\,T\,SOC + e\,T^2 + f\,SOC^2)$

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

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