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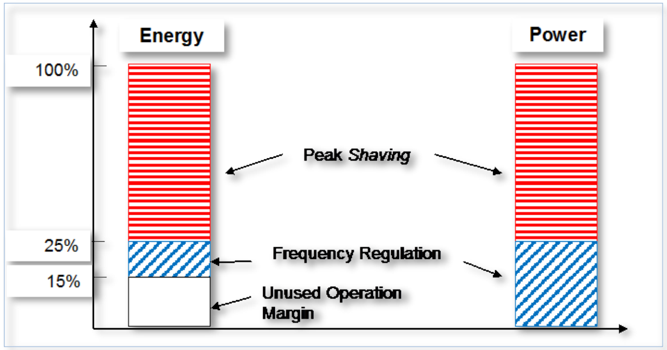

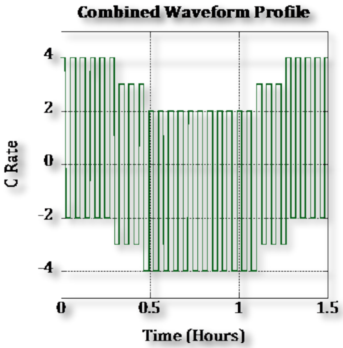

Multiple Uses in Storage:

Results of Lithium-Ion Cells Tested under Stacked Cycling Profiles

Summer Ferreira

Sept 22, 2015

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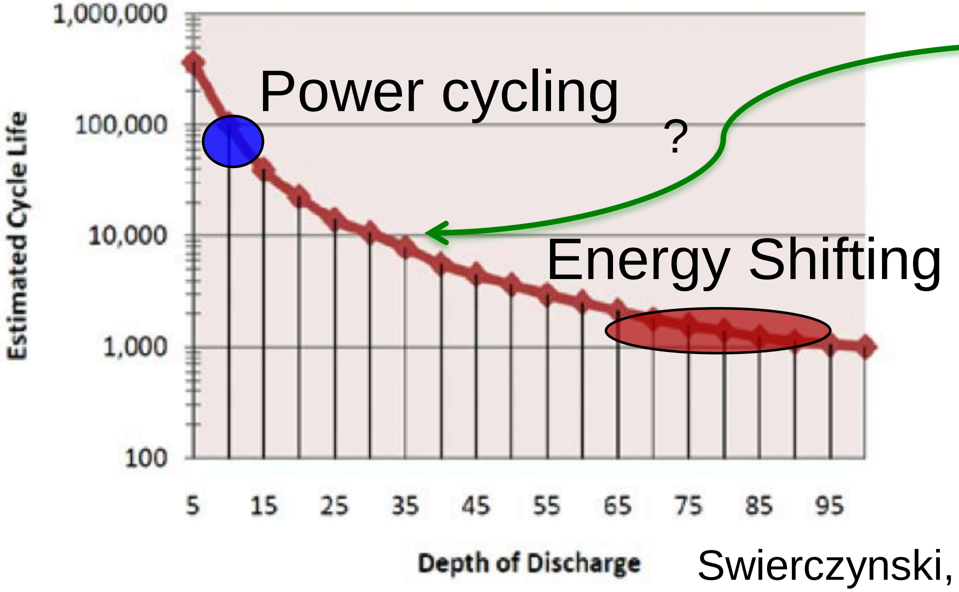
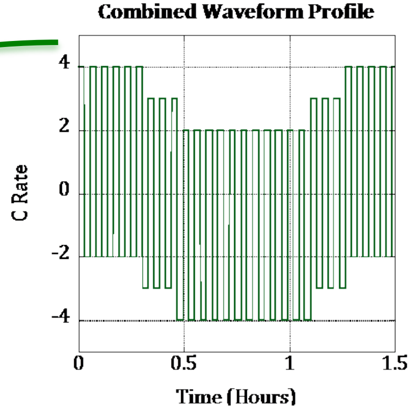
- Dr. Imre Gyuk and the DOE Office of Electricity
- DNV GL
- ARPA-E AMPED program
- Technologist Wes Baca

Outline

- Motivation
- Methodology
- Results
- Conclusions

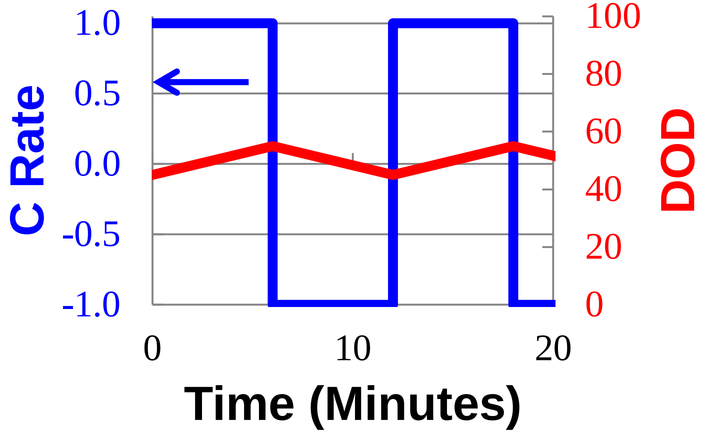
EOL as a Function of SOC in LFP



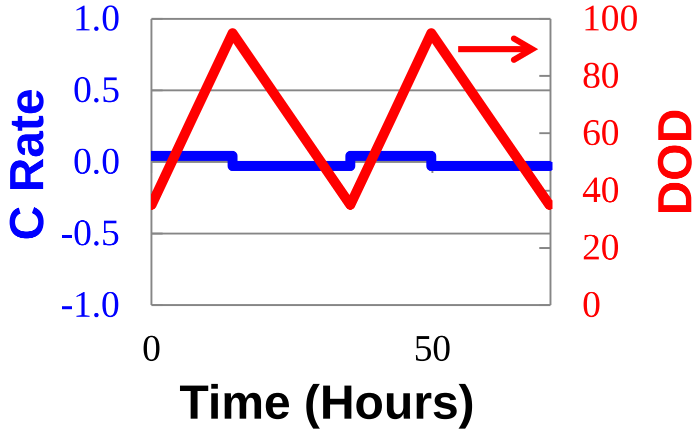


Swierczynski, M., et al. Battcon (2011)

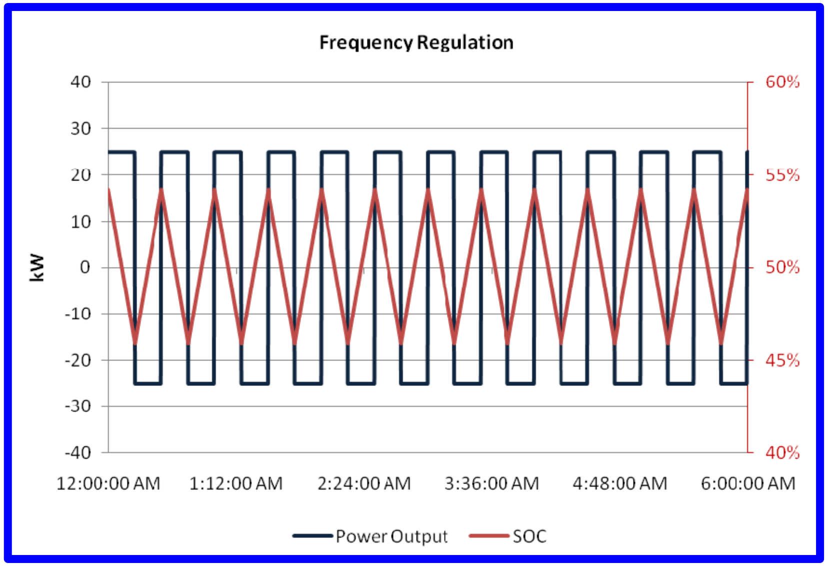
Power Cycling

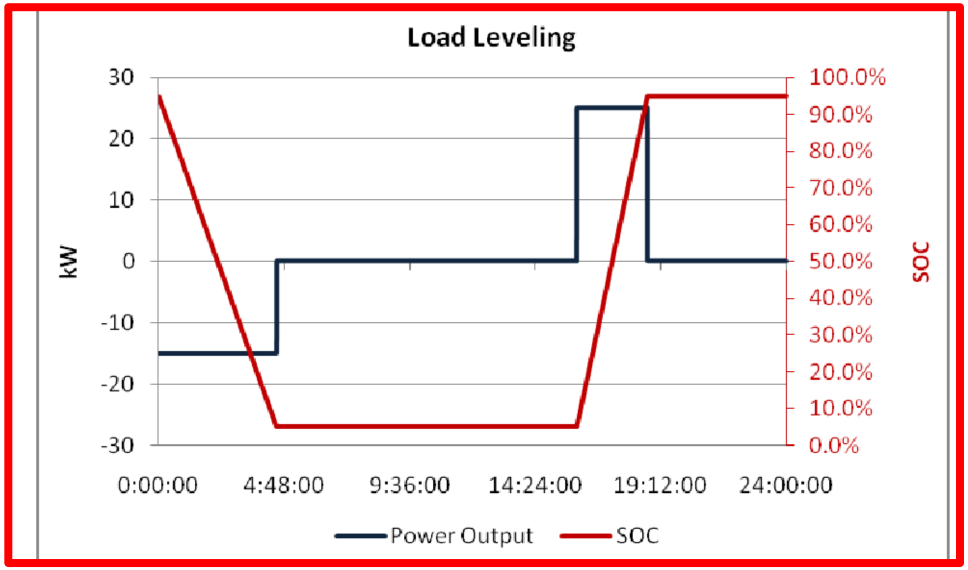


Energy Cycling



Individual Application Test Protocols





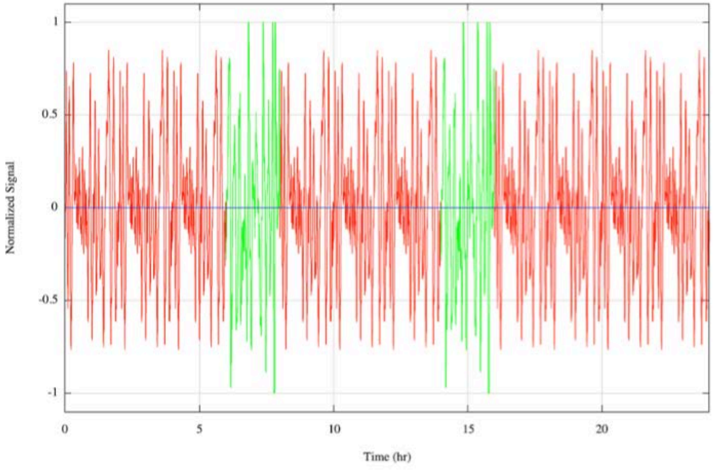


Figure 4. Frequency Regulation Duty Cycle.

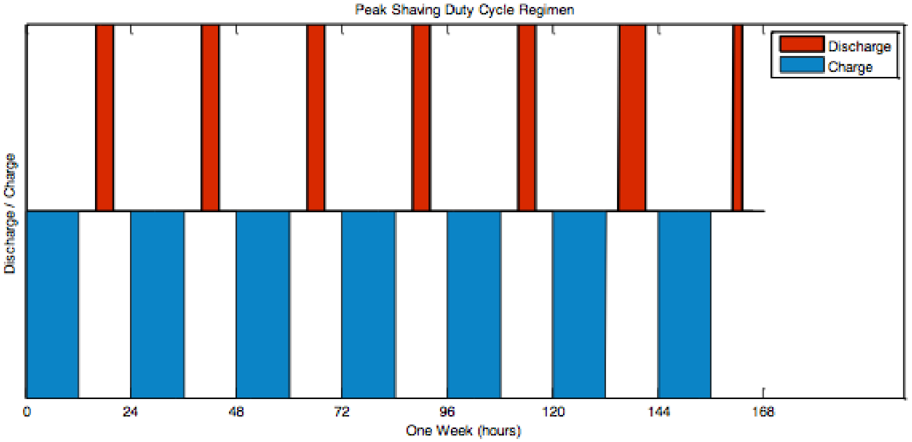
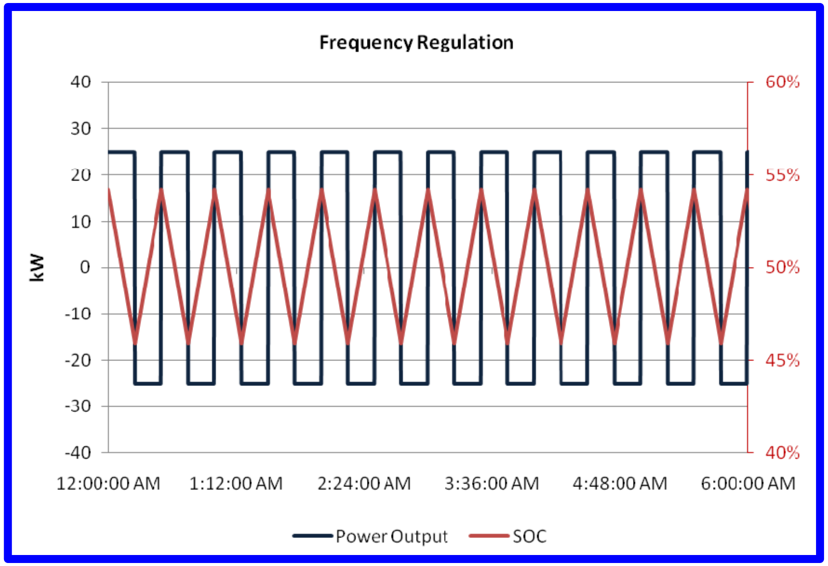
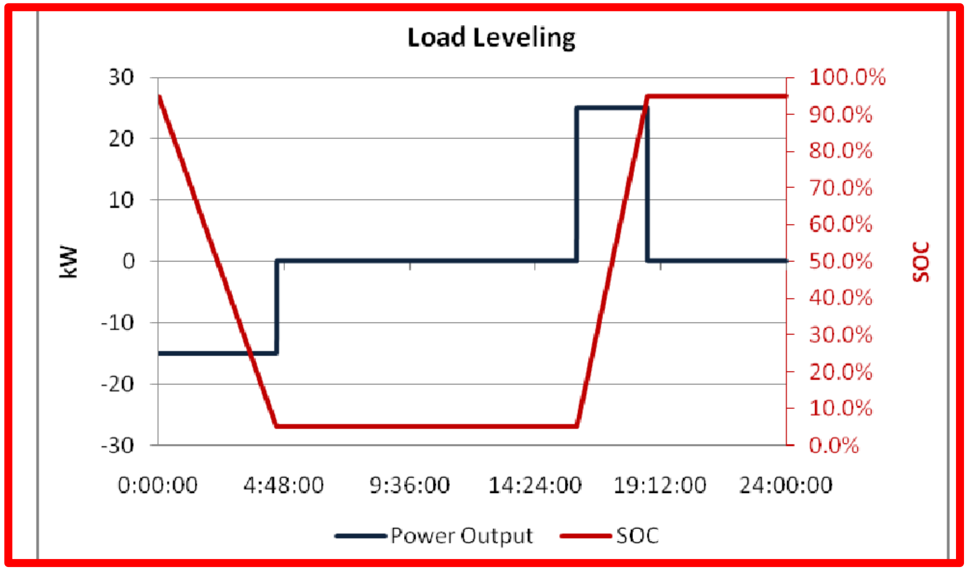


Figure 3. Peak Shaving (Management) Duty-Cycle Regimen.

Individual Application Test Protocols





Power Cycling

- Frequency Regulation
- PV Smoothing

Energy Cycling

- Load Leveling
- Peak Shaving
- PV shifting
- Arbitrage
- UPS Backup

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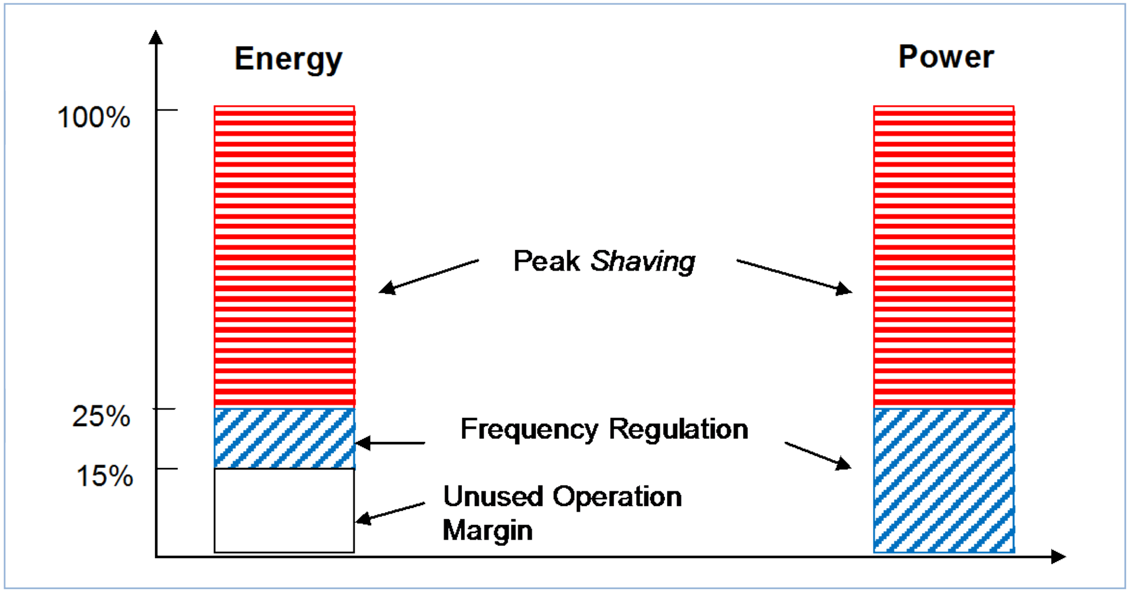
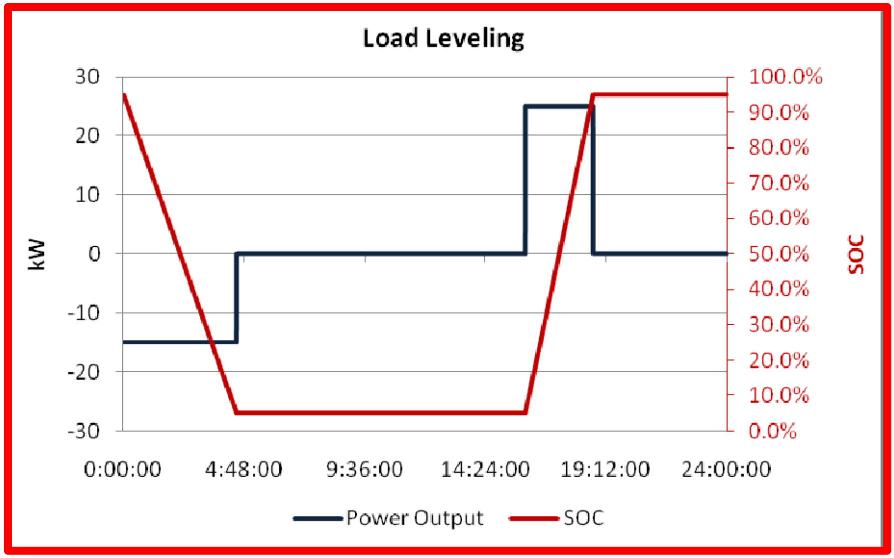
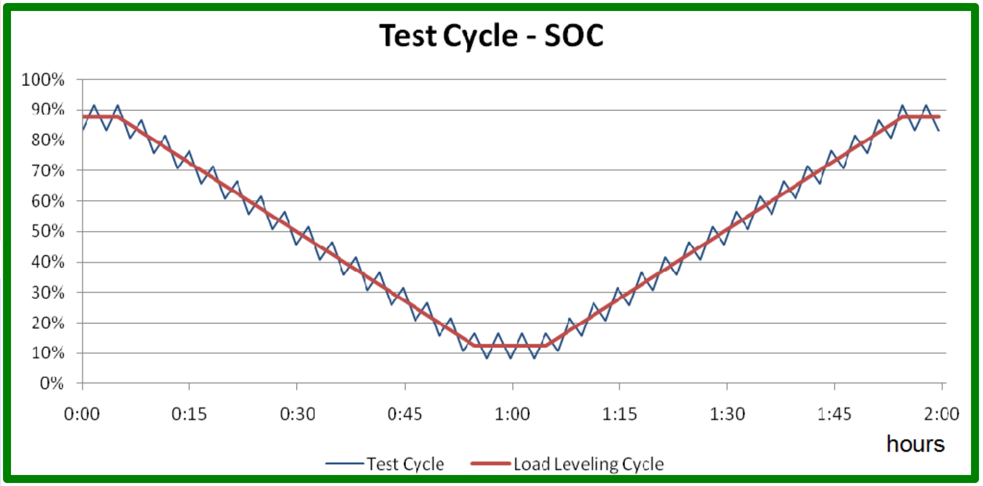
Individual Application Test Protocols

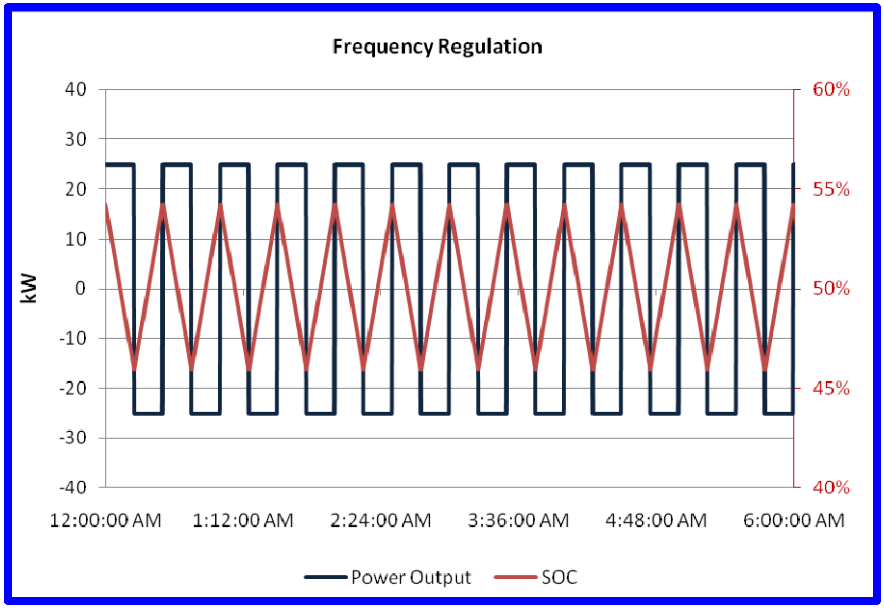


- Growing interest in using a single asset for multiple use-cases
- Choose how to allocate division of energy and power

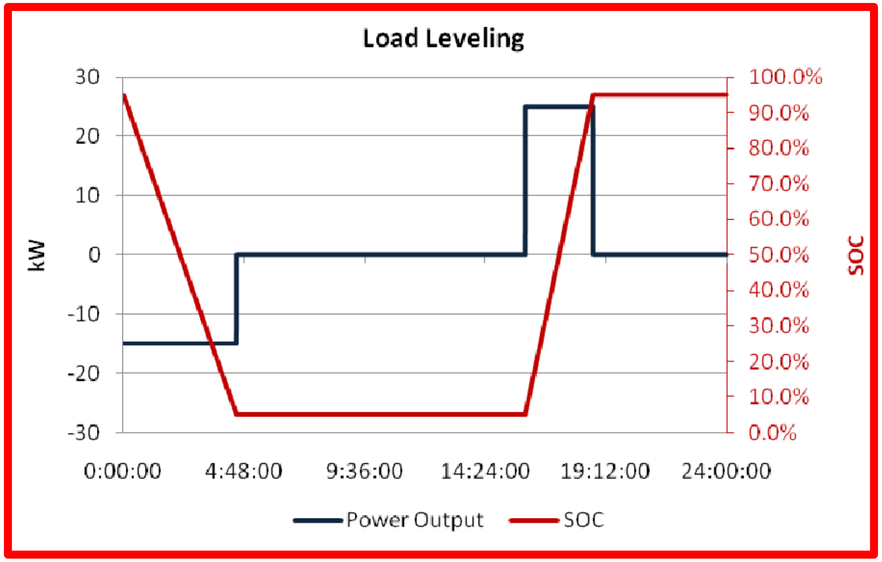
Stacked Waveform Testing:

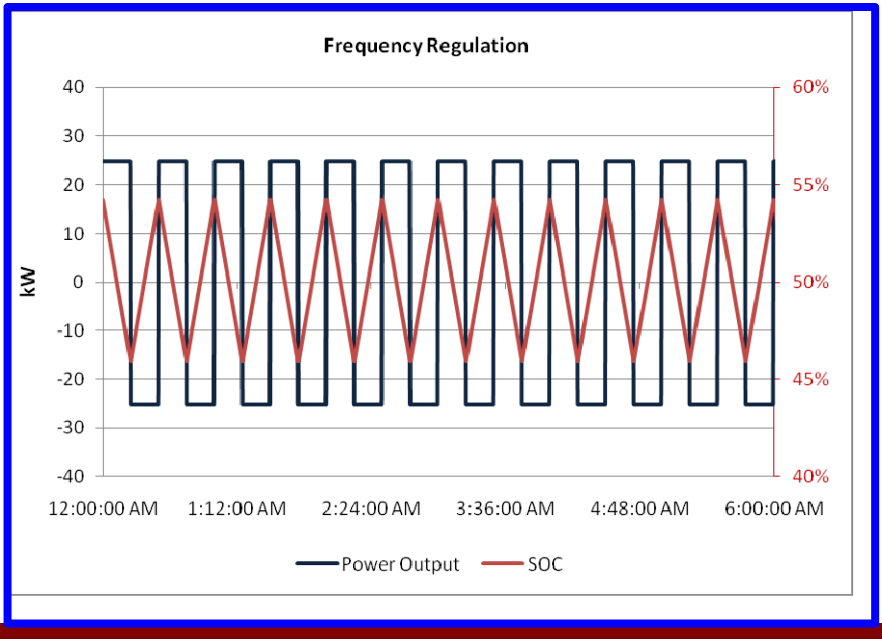


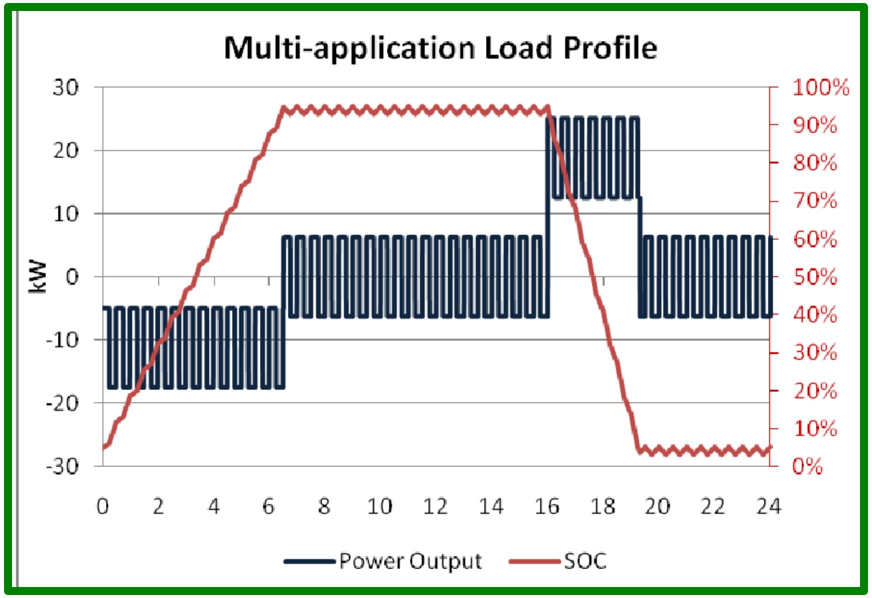




Stacked Waveform Testing:







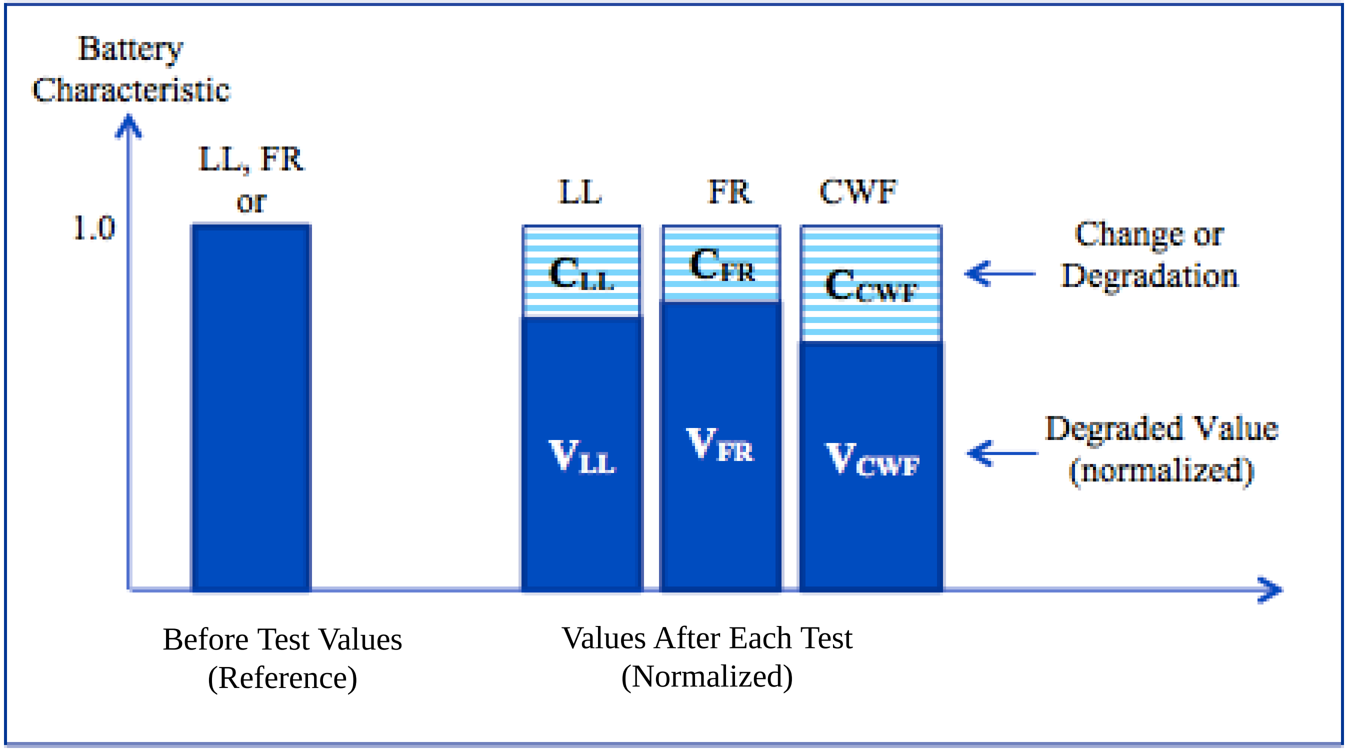
Metrics

- More exhaustive set of metrics to include:
  - C rate capacity testing at 0.1C, 0.2C, 1C, 2C and 4C
  - Round trip efficiency
  - Power density at 1C, 2C, and 4C

- Set to run metrics at roughly monthly intervals

- Chose a commercial Li-ion cell
  - A123 nano-phosphate cell

Evaluation to Compare Cells



- **Correlating <u>degraded values</u> of parameters**
- Suggested equation: $\mathbf{V_{CWF} = K_1 (V_{LL} \times V_{FR})}$
  - V = degraded values
  - K_1 is the acceleration factor for degradation.
  - A factor K < 1 = degradation under combined waveforms is happening faster

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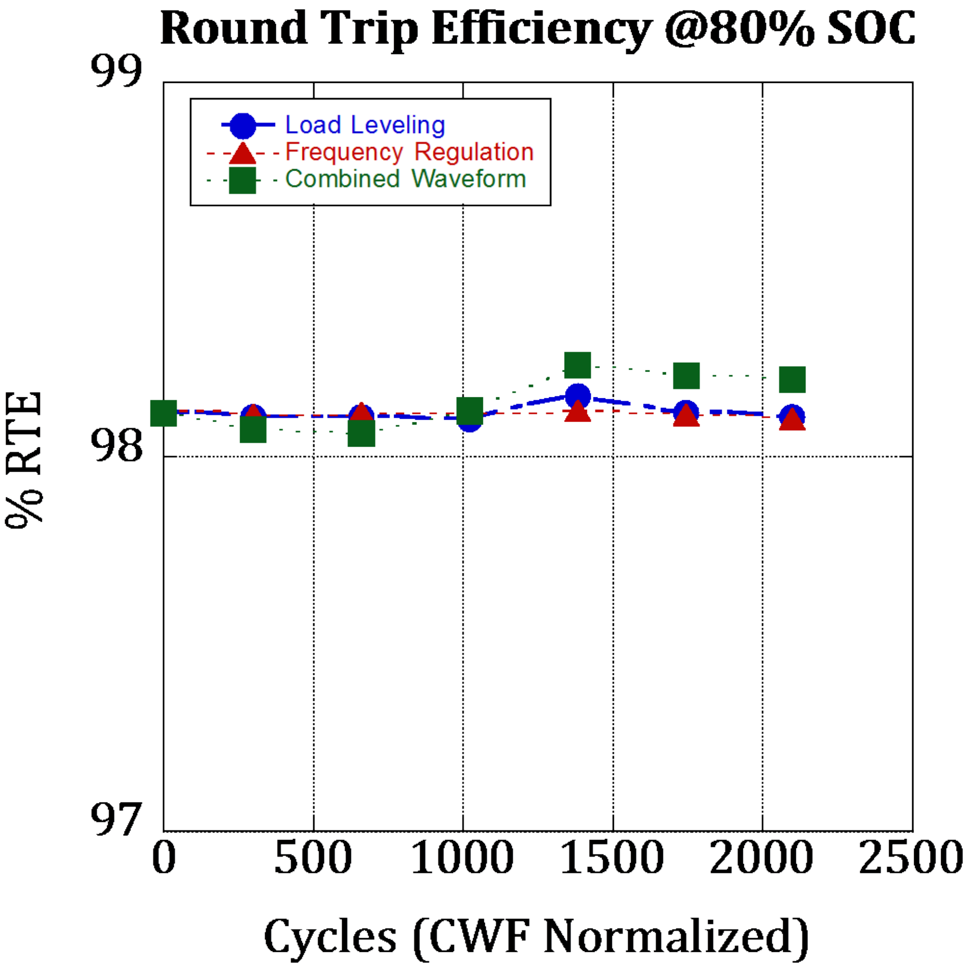
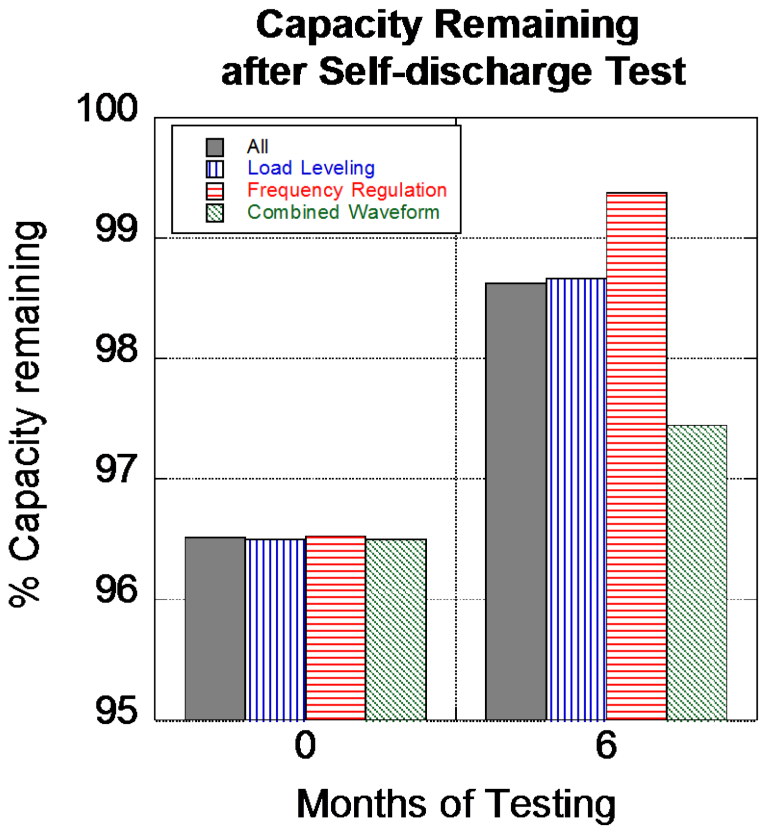
Metric: Round Trip Efficiency



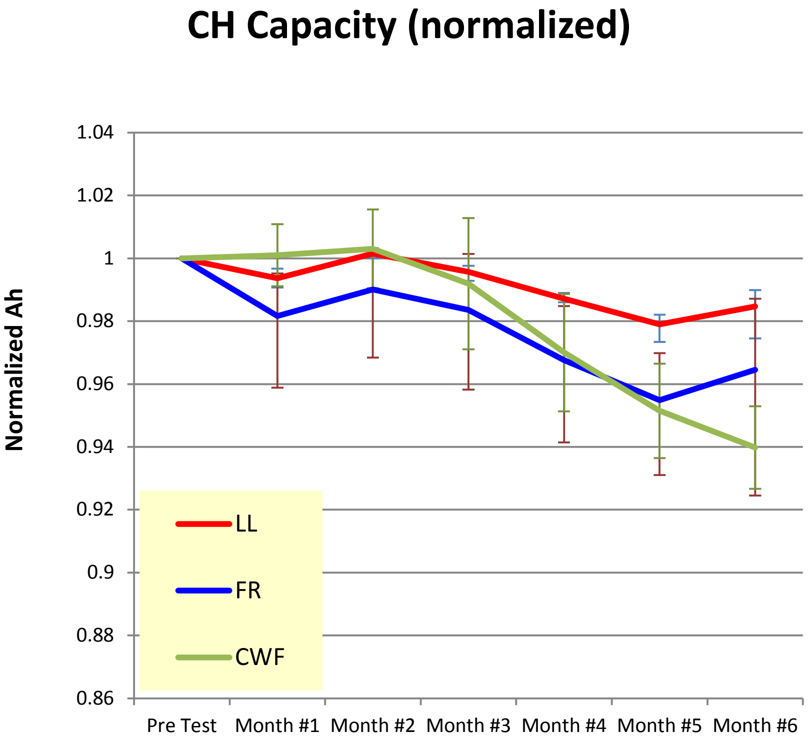
- RTE went up or stayed the same
- No significant correlation found
- Combined Waveform (CWF) improved most significantly
- RTE appears to improve with time as side reactions are extinguished

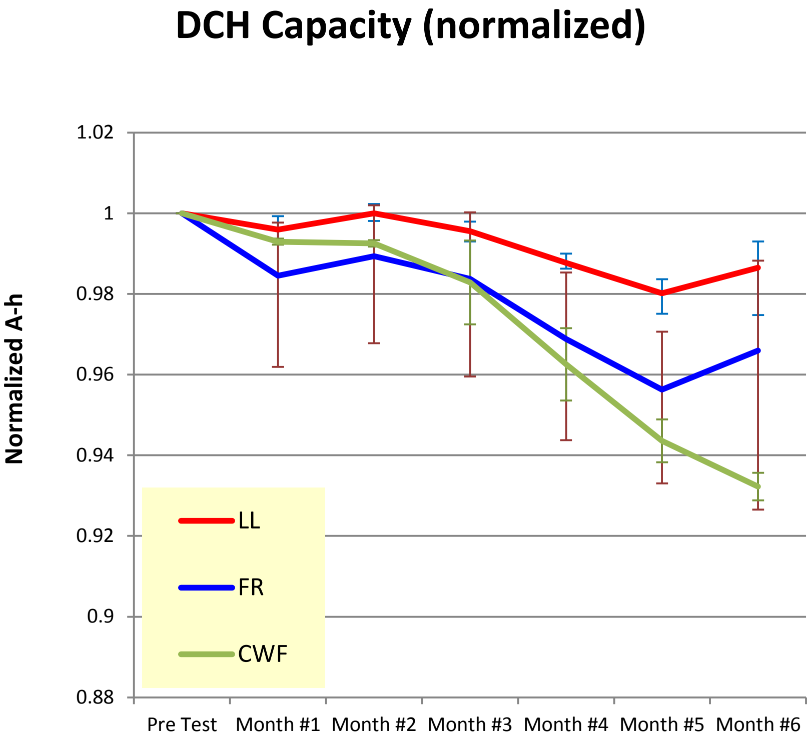
Metric: Self Discharge



- Self Discharge improved
- No significant correlation found
- Frequency Regulation (FR) improved most significantly
- Self Discharge improves with time; as side reactions are likely extinguished

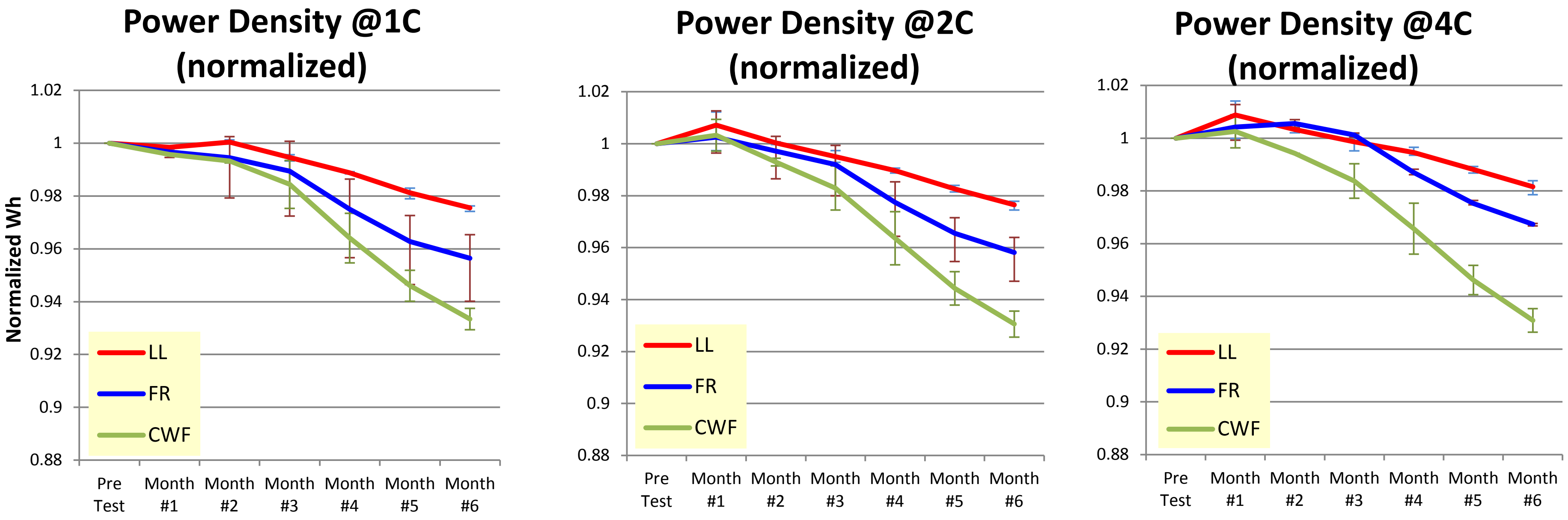
Metric: Capacity





Decreases small for LL, and greater for FR and CWF

Metric: Power Density



Decreases small for LL, and greater for FR and CWF

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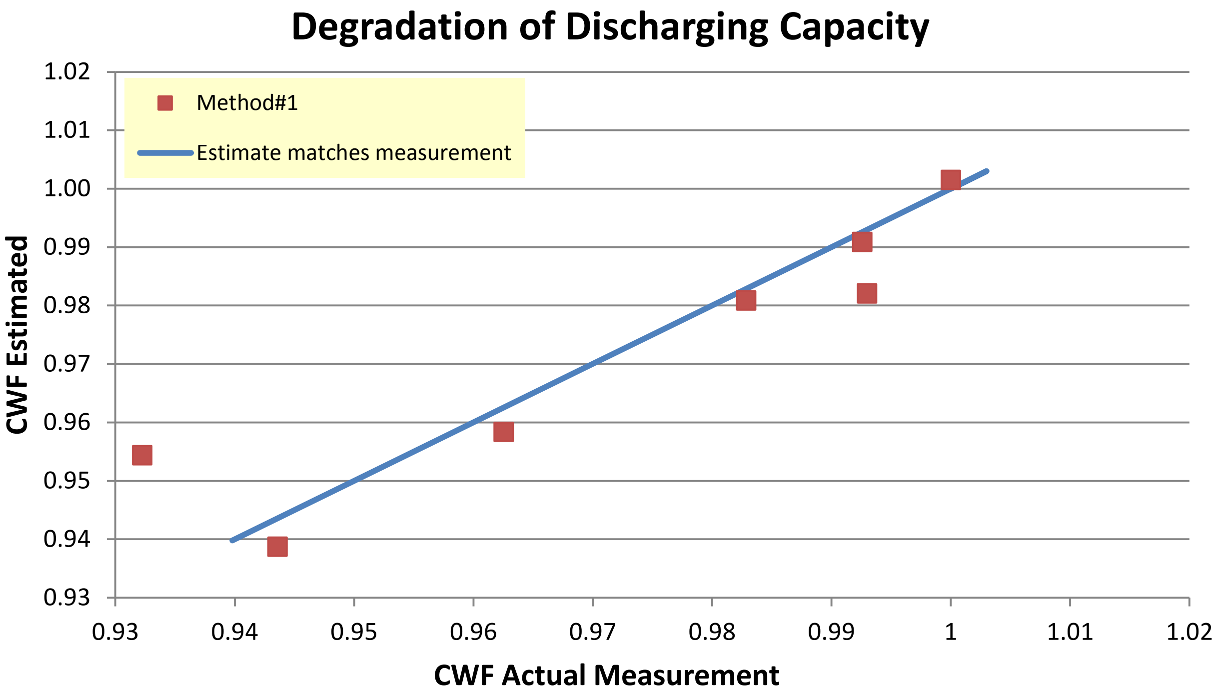
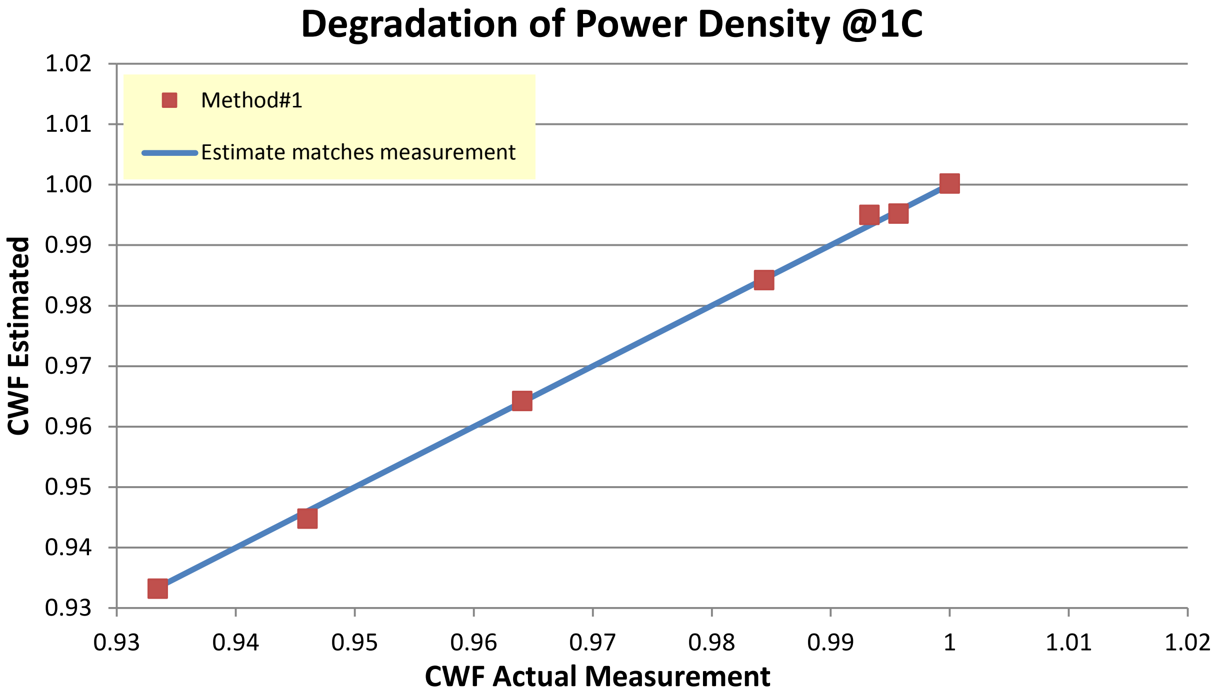
Correlation of Capacity Degradation

- $V_{CWF} = K_1 (V_{LL} \times V_{FR})$

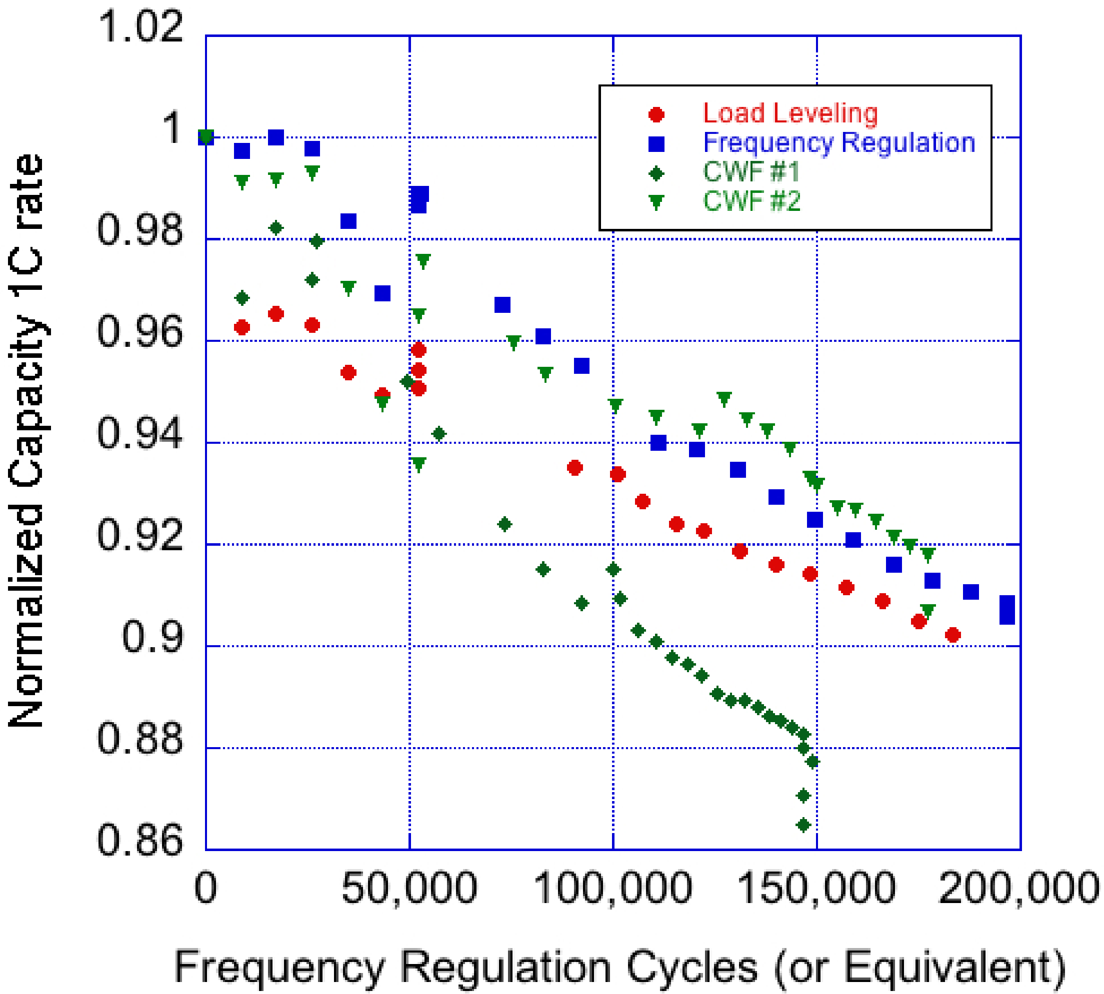


Correlation of Power Degradation

- $V_{CWF} = K_1 (V_{LL} \times V_{FR})$



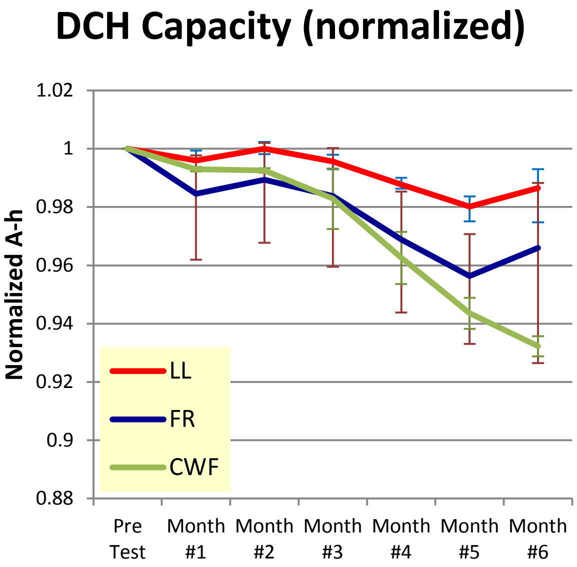
Follow-on testing – 1 additional year



- Limited test (x2)
- CWF : 1 cell failing
  1 cell excelling
- K = 1.06 (averaged)
- Tests ongoing

Incorporating high precision cycling periodically to help elucidate SOH and performance

Conclusions



Suggested equation:

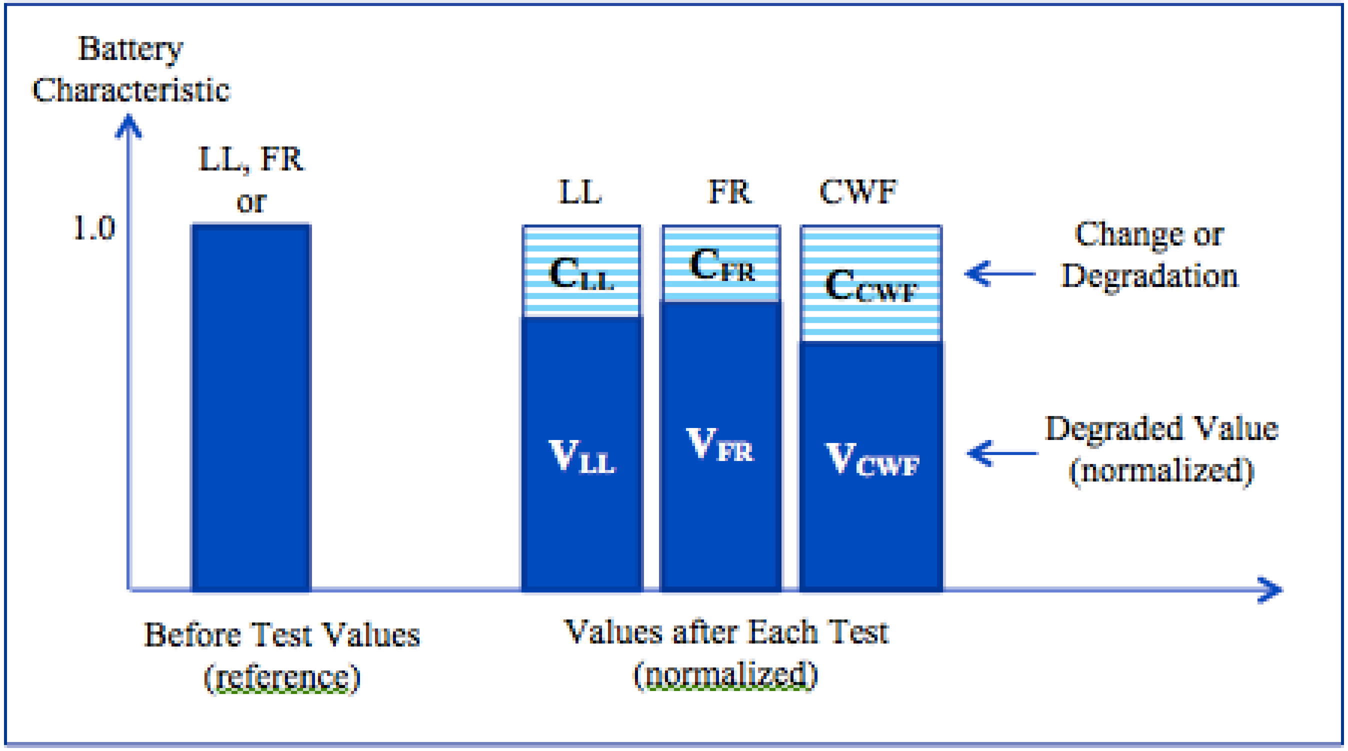
$$V_{CWF} = K_1 (V_{LL} \times V_{FR})$$

- V = degraded values
- K_1 is the acceleration factor for degradation.
- A factor K < 1 = degradation under combined waveforms is happening faster

- **After 6 months** of testing **K_1= 1.02**
- Indicates that CWF not significant effect on degradation
- Cycled another +12 months to reevaluate
- **K_1 = 1.06 after 18 month testing;** 149,000 FR cycles

Conclusions

- Correlation between degradation on performance metrics between waveforms using equation $\mathbf{V_{CWF} = K_1 (V_{LL} \times V_{FR})}$



Conclusions

- Correlation between degradation on performance metrics between waveforms using equation $\mathbf{V_{CWF} = K_1 (V_{LL} \times V_{FR})}$
- K_1= 1.02 after 6 months of testing (~50,000 10% cycles)
- K_1= 1.06 after 18 months of testing (~150,000 10% cycles)
- Combined waveform shows increased degradation over singular profiles above the additive losses
- Value of combined uses must be weighted against this increased degradation