Field Aging Testbed for Behind-the-Meter PV + Energy Storage

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Need for Dispatchable Storage Testbed

- Storage solutions are being adopted by a wide range of customers to meet grid demand and enable high penetration PV deployments
- Batteries need to be tested in field environments
- Field-aging changes battery performance over time
- We evaluate different field and use conditions by using:
  - Multiple Battery Technologies (Li-Ion and V-flow)
  - Two Environmental Use Cases (Indoor and Outdoor)
  - Real Time Data Logging

Battery Types

TABLE I: BATTERY SYSTEMS CURRENTLY UNDER TEST

Model	Chemistry	Deployment	SOC range	Qty
LG RESU7H	LiIon NMC	Outdoor	15% - 100%	1
LG RESU7H	LiIon NMC	Indoor	15% - 100%	2
Avalon AFB 2.10	Vanadium redox flow	Outdoor	0% - 100%	2

Vanadium Flow Battery – Specs

Avalon Redox Flow

- Power: 10 kW/nominal, 15 kW/peak
- Bus Voltage: 48Vdc, DC boost to 1000V
- Capacity: 25kWh
- Chemistry: Vanadium Flow
- Dimensions: 8m x 2m x 1.4 m
- Weight: 6800 lbs
- Operating temp: -5 – 45 °C
- Lifetime: 20 years, no capacity fade

Lithium Ion Residential Battery – Specs

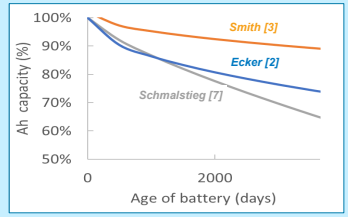
LG CHEM RESU7h

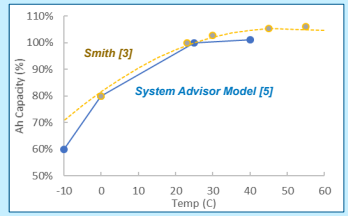
- Power: 7 kW/nominal
- Bus Voltage: 350-450Vdc
- Capacity: 6.6kWh
- Chemistry: LiIon NMC
- Dimensions: 0.7m x 0.69m x 0.2 m,
- Weight: 170 lbs
- Operating temp: -5 – 45 °C
- Lifetime: 10 years warranty (60% of capacity)

Long Term Goals

- Lifetime Battery Evaluation, Lifetime Efficiency and Operational Capability
- Lifetime State of Health
- Comparison Between Technologies
- Evaluate Seasonality in Models
- Field-aged Data to Improve long-term cost modelling
- Identify Gaps in Standards and Measurement Methods for PV +BESS

Model Validation





Calendar Fade *[1],[2],[3]*

$$Q_{Li} = Q_0 - b_1 t^{1/2} - b_2 N$$

$$b_1 = b_{1,ref} \exp\left[-\frac{E_{a3}}{k_B}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right] \exp\left[\alpha\left(\frac{U}{T} - \frac{U_0}{T_0}\right)\right]$$

Q_{Li} – capacity loss, cycles (N)
Q_0 – initial system capacity (Ah)
b_1 – calendar fade rate due to temperature (T), voltage(U)
E_{a3} – SEI growth for temp
α – exponential voltage – dep. factor

Site Loss Capacity vs Cycles and Temperature *[3]*

$$Q_{neg} = [c_0^2 - 2c_2 c_0 N]^{\frac{1}{2}}$$

$$c_2 = c_{2,ref} \exp\left[\frac{-E_{a4}}{k_B}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right] DOD^{\beta}$$

Q_{Neg} – capacity loss negative electrode sites
DOD – depth of discharge
E_{a4} – activation energy ($-0.5eV$)
E_{a3} – SEI growth for temp
c_0 – intal negative site capacity
c_2 – capacity site loss

SAM & BLAST Capacity vs Temperature *[5],[6]*

$$Q_0 = Q_{0,ref} \exp\left[-\frac{E_{a1}}{k_B}\left(\frac{1}{T} - \frac{1}{T_0}\right) - \left(\frac{E_{a2}}{k_B}\right)^2 \left(\frac{1}{T} - \frac{1}{T_0}\right)^2\right]$$

$Q_{0,ref}$ – intial and reference capacity
$E_{a1,a2}$ – activation energies
k_B – Boltzmann sconstant
T – temperature

Data Analysis (Lithium Ion Initial Data)

Discharge Charge Ratio Data

- Daily Charge/Discharge Cycle
- Filter for 80% of SOC
- Plot as Daily and Monthly vs. Time and Battery Temperature

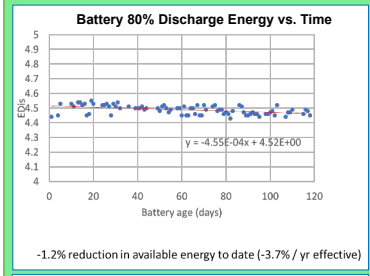
$$\eta_{RTM} = \frac{\sum E_{dis} + E_N(SOC_{start} - SOC_{end})}{\sum E_{ch}} \quad [4]$$

Charge/Discharge Testing

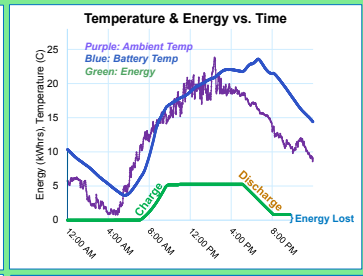
- Charge in morning using PV
- Discharge in evening to grid
- Record bidirectional energy
- Plot efficiency vs time
- Comparison with models

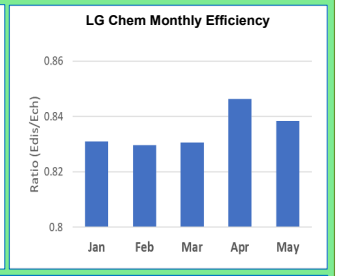
Data to Date

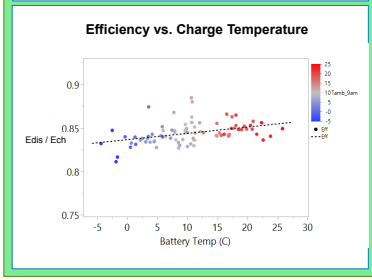
- Lithium Ion -1.2% reduction in energy (-3.7% / yr effective)
- Avalon Battery Packs online June 2019
- Next 2 Lithium Ion Batteries online July 2019



-1.2% reduction in available energy to date (-3.7% / yr effective)







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