Impact of grid storage functions on battery degradation

NIST Workshop

PCS Architectures for PEV Fleets as Grid storage

06/13/2011

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Agenda

- **Introduction**
- **Energy storage Grid applications**
- **Duty cycles**
- **Degradation modes**
- **Sample power applications**
- **closing**

Grid Storage Applications- Energy

- **Energy**
  - Hours
  - Peak shifting
  - Wind integration
  - PV integration

Grid Storage Applications - high power applications

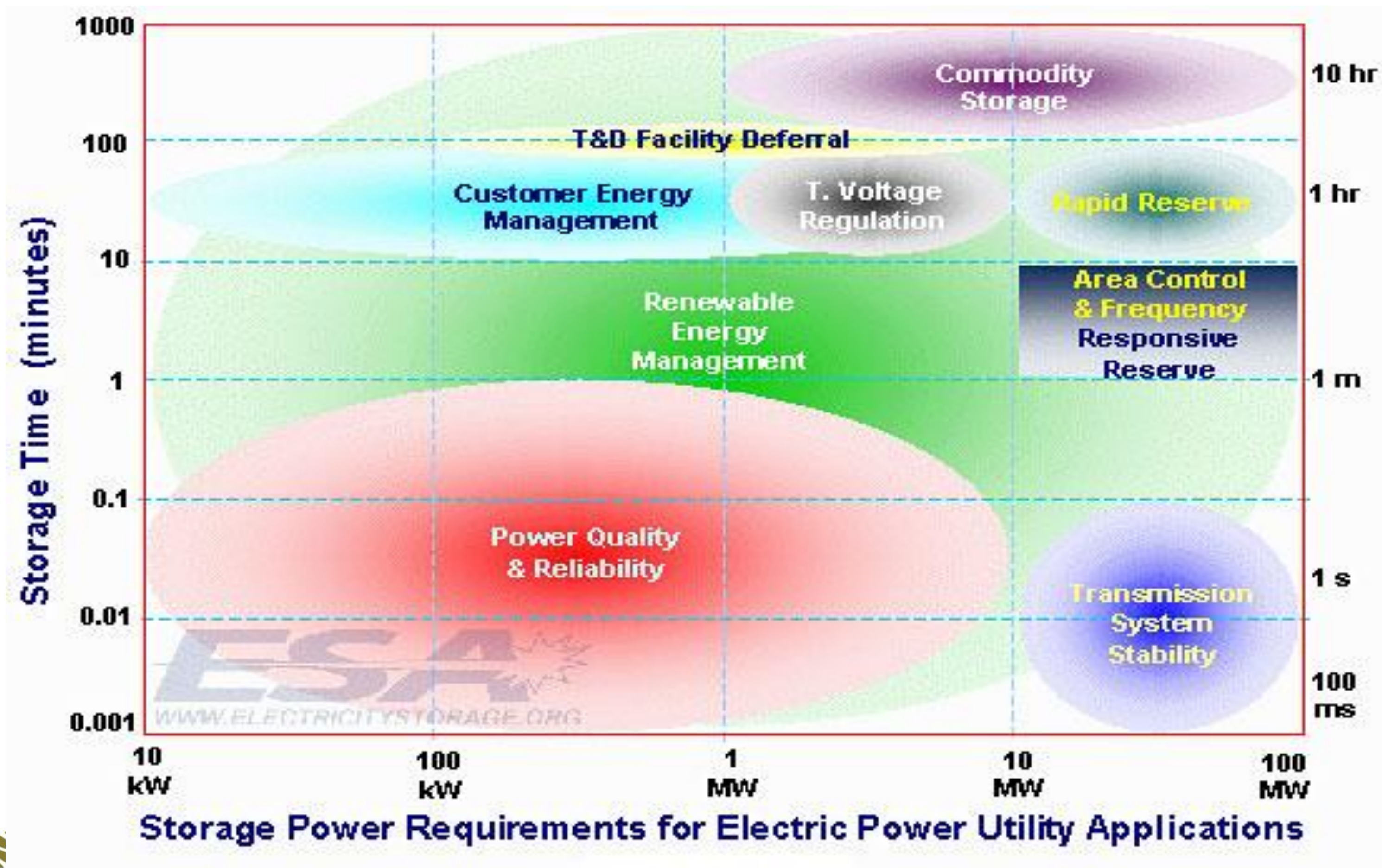
- Seconds to minutes
- Frequency Regulation
- Wind integration
- PV integration
- Microgrid integration
- Power quality solution
- Synthetic system inertia
- Synthetic System primary frequency control
- Black start

Energy Storage Attributes for These Applications

- **Energy rating**
- **Power rating**
  - charge
  - discharge
- **Cycling capability**
  - Useful depth of discharge
- **Energy efficiency**
- **Self-discharge characteristic**
- **Storage**
- **Calendar life**
- **Cycle life**

Energy Storage Applications-Time & Size Range

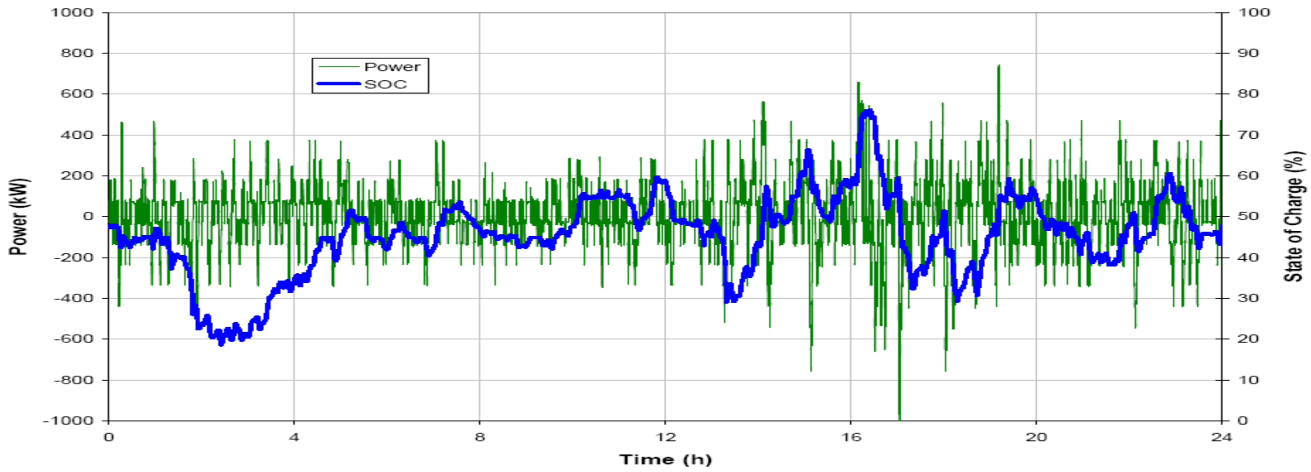
ESA (Electricity Storage Association), provides a map of applications



Data from Sandia Report 2002-1314

Example: Frequency Regulation

Typical 24 hour Profile



In two Years of Operation in PJM ISO

- **Performed over 250,000 small cycles and charged or discharged over 3,300 MWhr**
- **Less than two percent energy capacity degradation and no significant power capacity degradation**
- **Expected to maintain rated power and energy capacity for over twenty years without battery replacements or upgrades**

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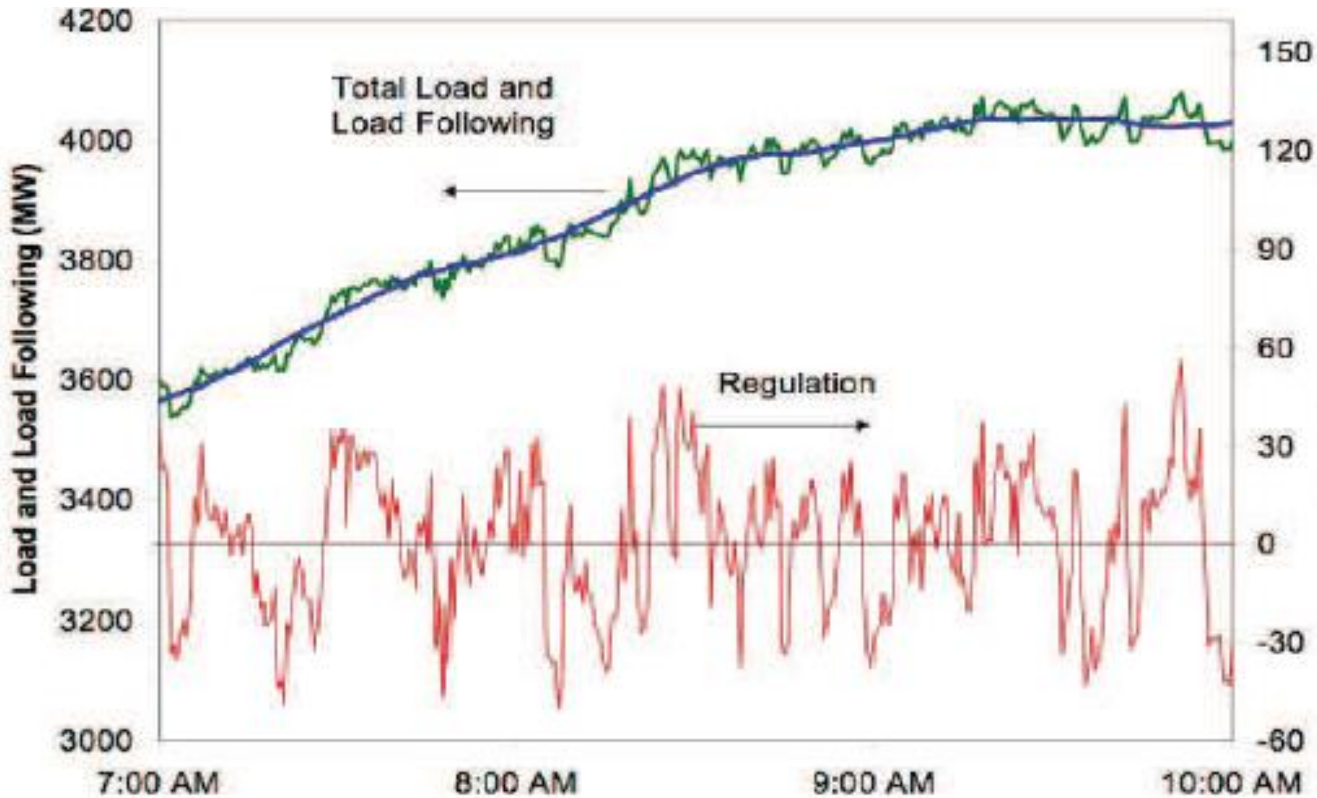
Grid Stability is maintained through the balancing of load and supply

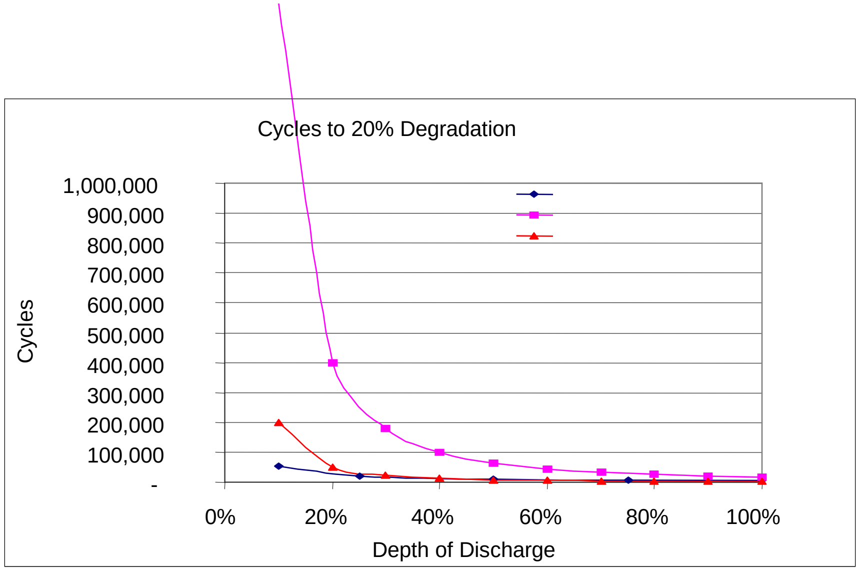


Regulation is near zero-energy service compensation for minute-to-minute fluctuations in total system load and uncontrolled generation

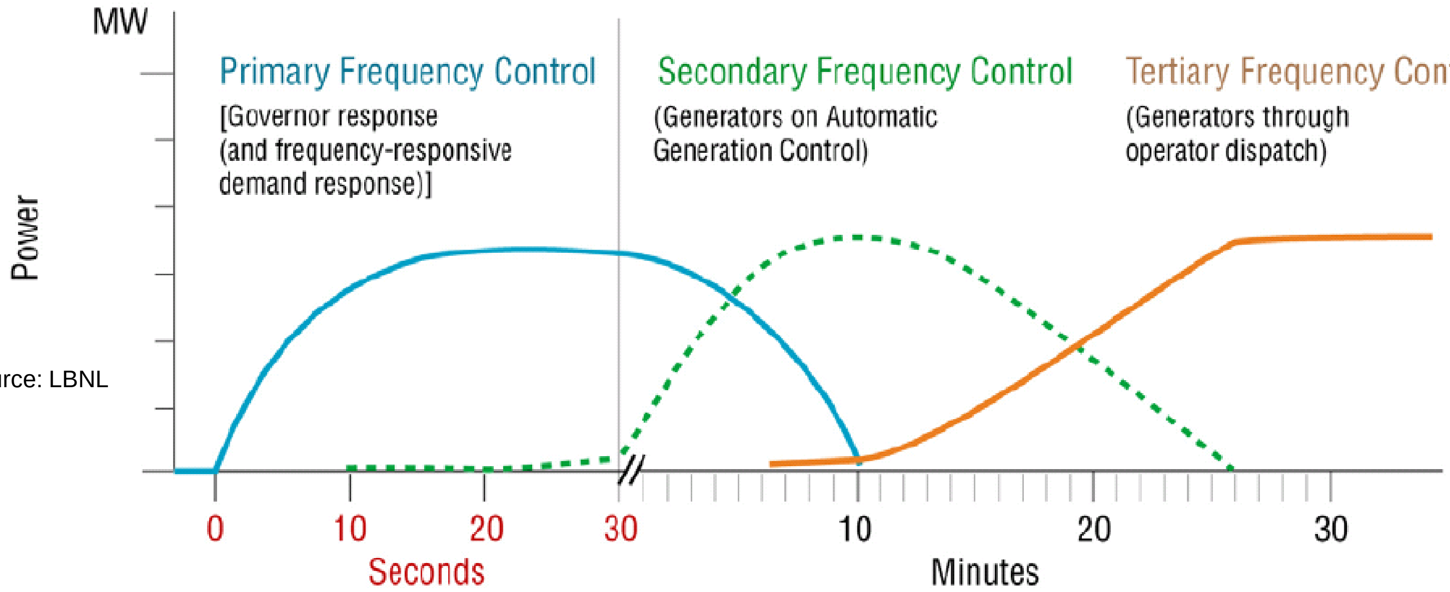
Battery technologies have different life characteristics dependent on DOD and number of cycles

- **At 100% depth-of-discharge, one technology provides 3-6 times more cycle life than others**

- **At low depth-of-discharge cycles, over 1 million cycles and up to 100X more life than others Li-Ion**

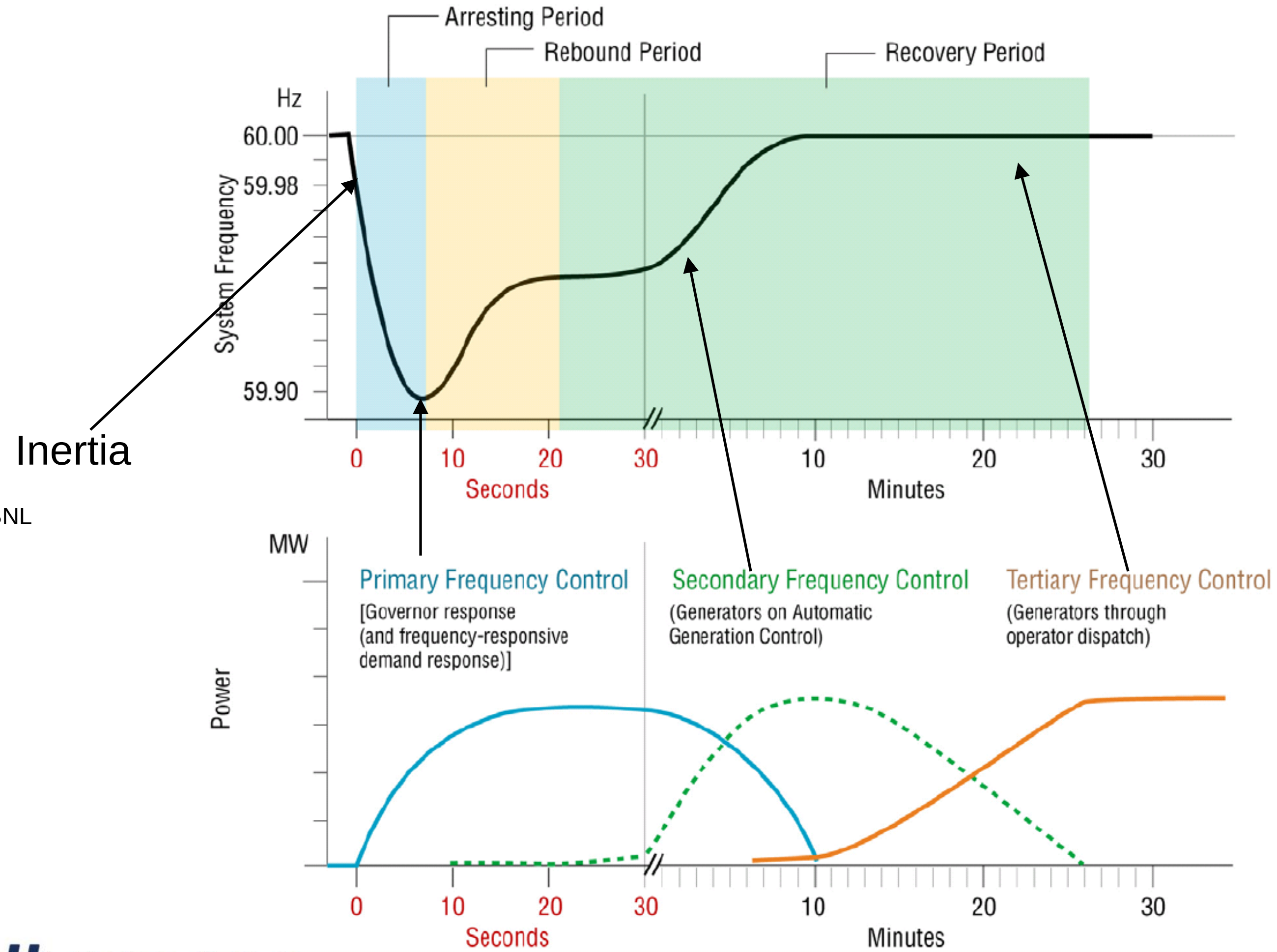


Types of Frequency Control by Timeframe



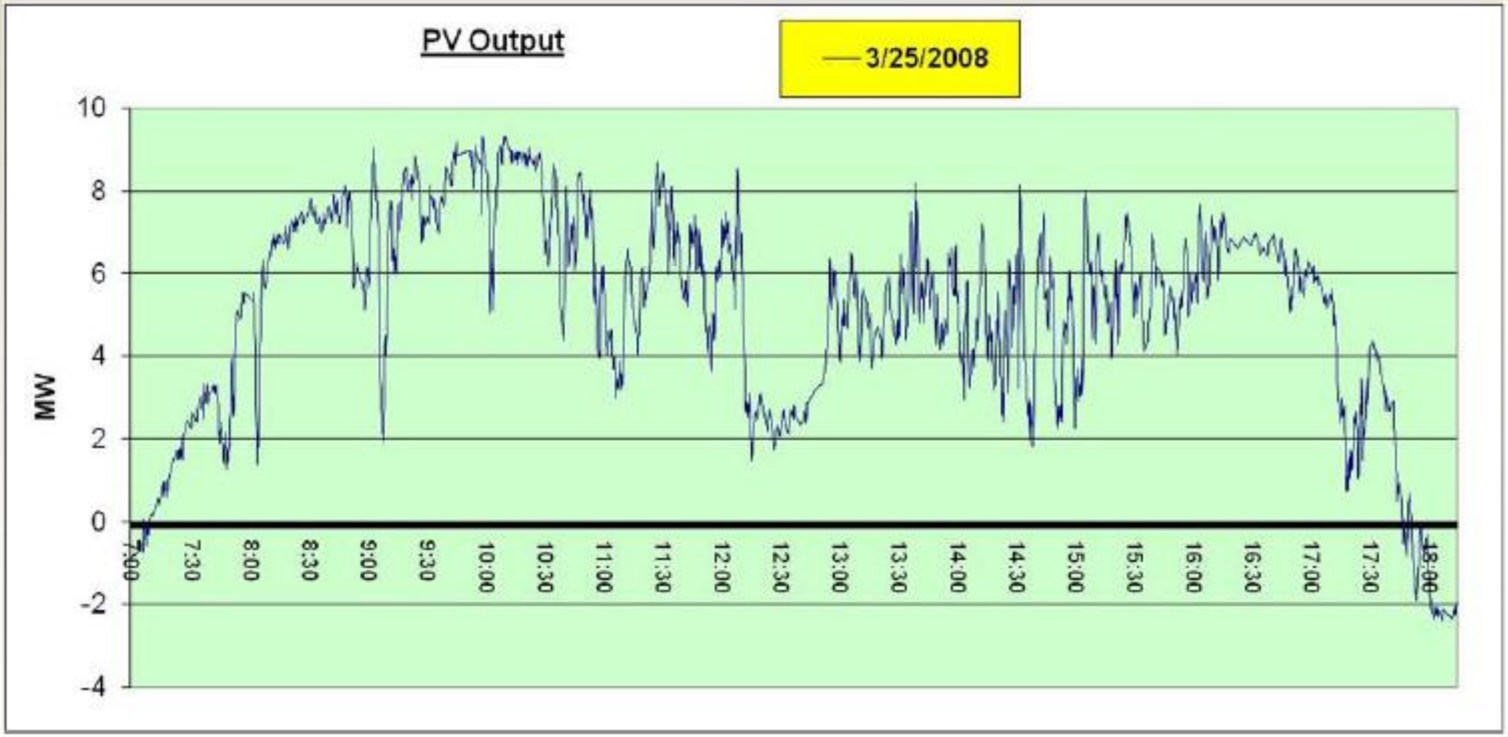
Source: LBNL

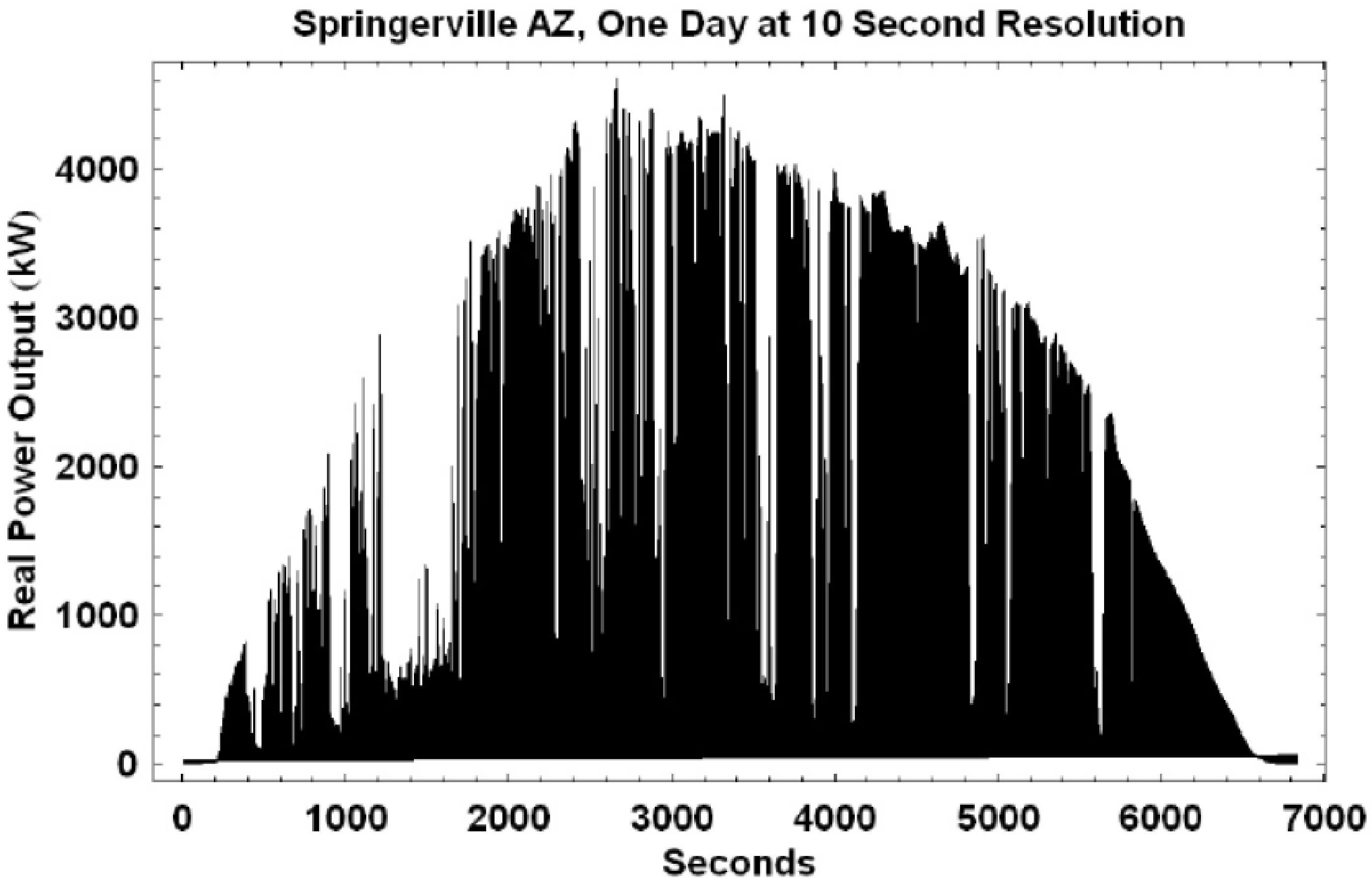
Actions of Frequency Control in a Loss of Generation Incident

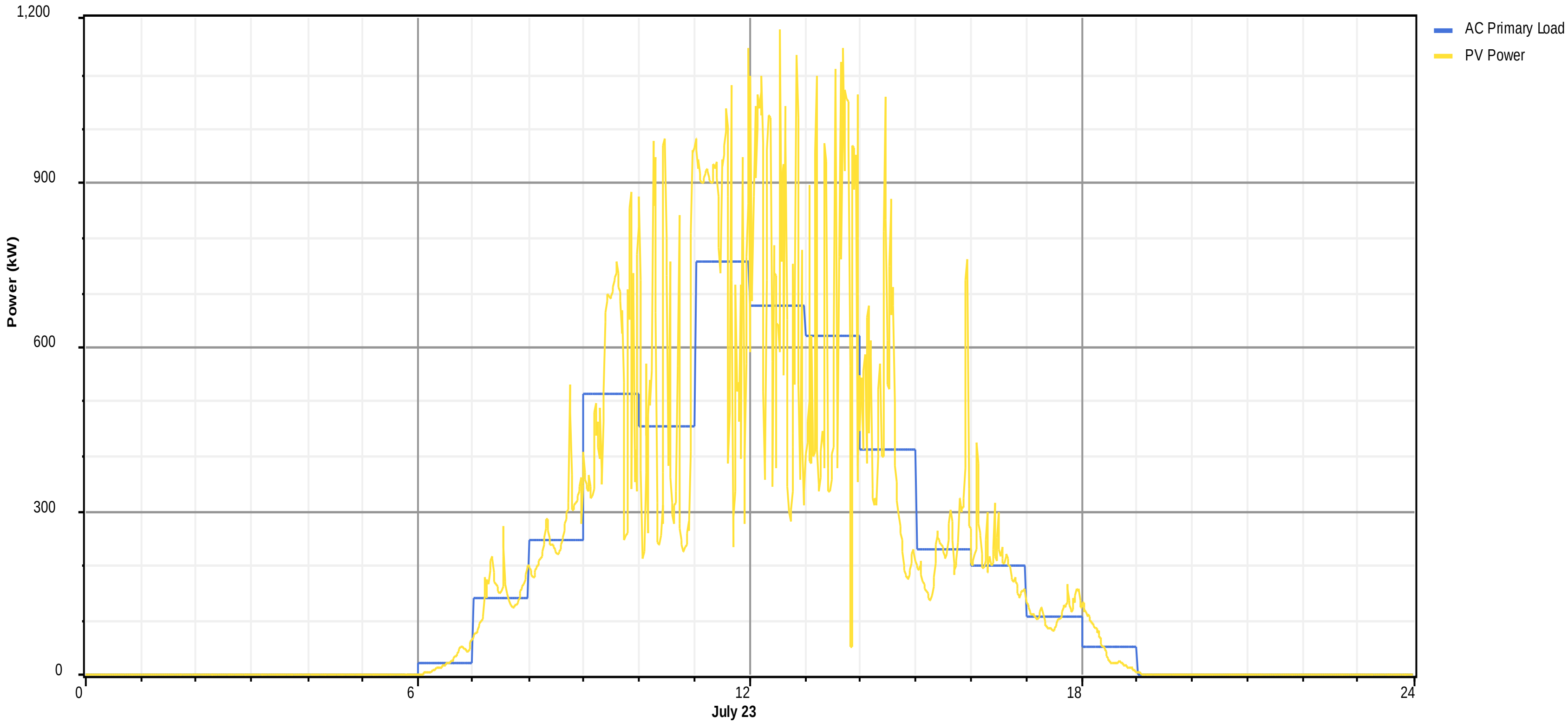


Source: LBNL

PV plant output on a partly-cloudy day (10-second sample)




Springerville AZ, One Day at 10 Second Resolution
Real Power Output (kW)
4000
3000
2000
1000
0
0
1000
2000
3000
4000
5000
6000
7000
Seconds

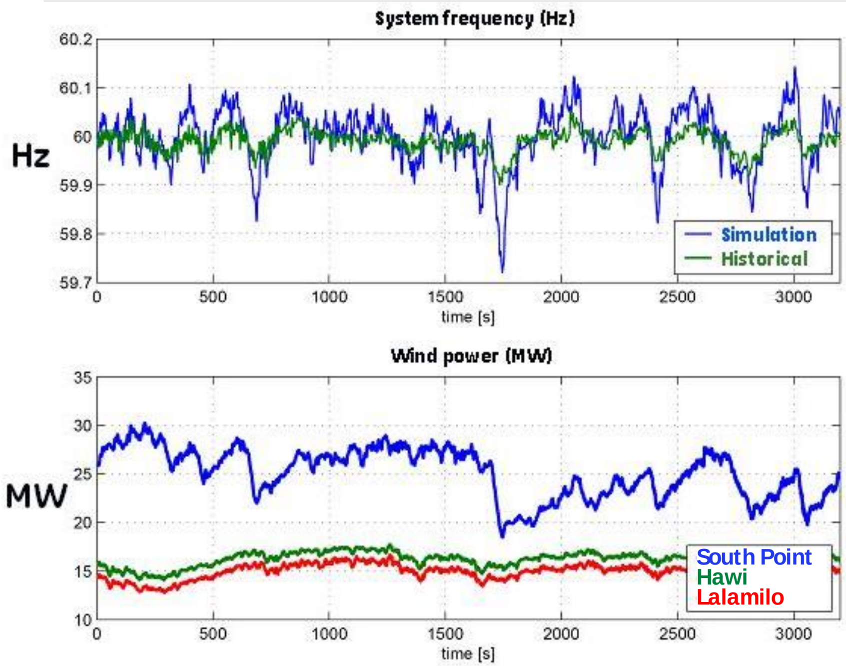


"If PV penetration levels increase much more, the work conducted here suggests that the problems most likely to be encountered are voltage rise, cloud-induced voltage regulation issues, and transient problems caused by mass tripping of PV during low voltage or frequency events. "

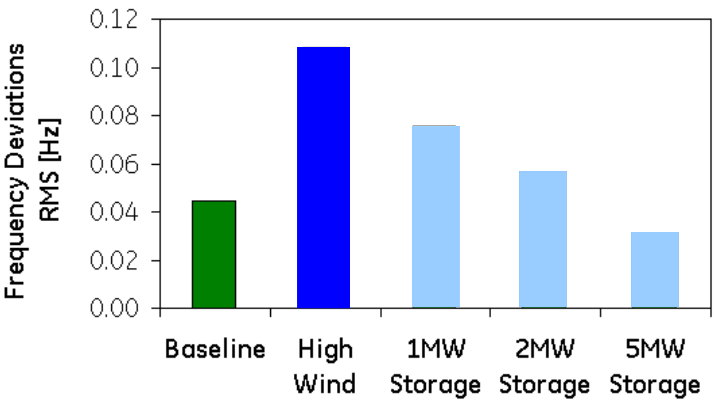
SAND2008-0946 P , Printed February 2008

Big Island Energy Roadmap Study

At 40% wind penetration, system frequency is severely affected



Incremental additions of "fast" energy storage increasingly stabilizes system frequency



5MW of "fast" energy storage resulted in similar frequency performance as the baseline scenario; near-term potential project

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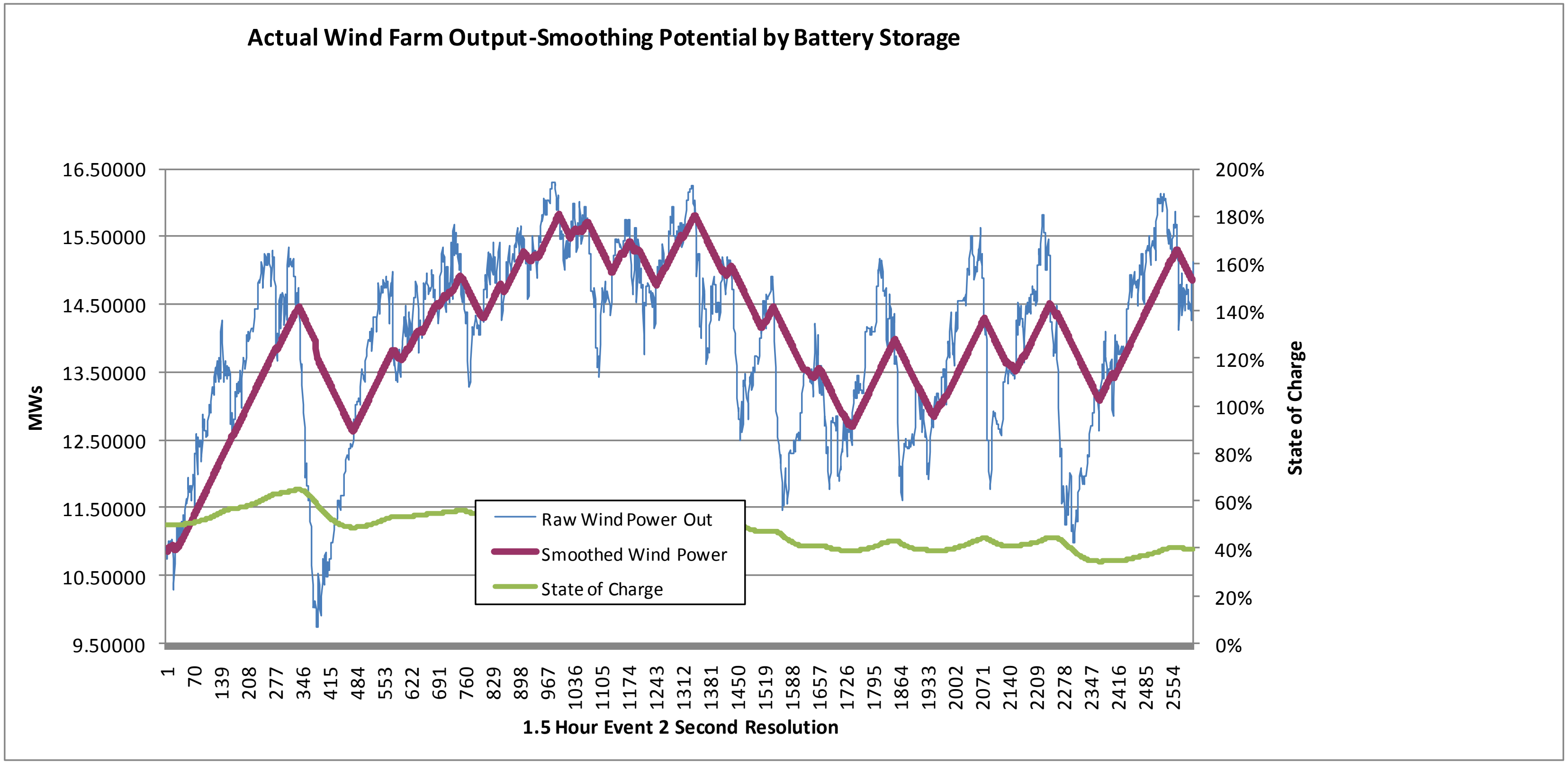
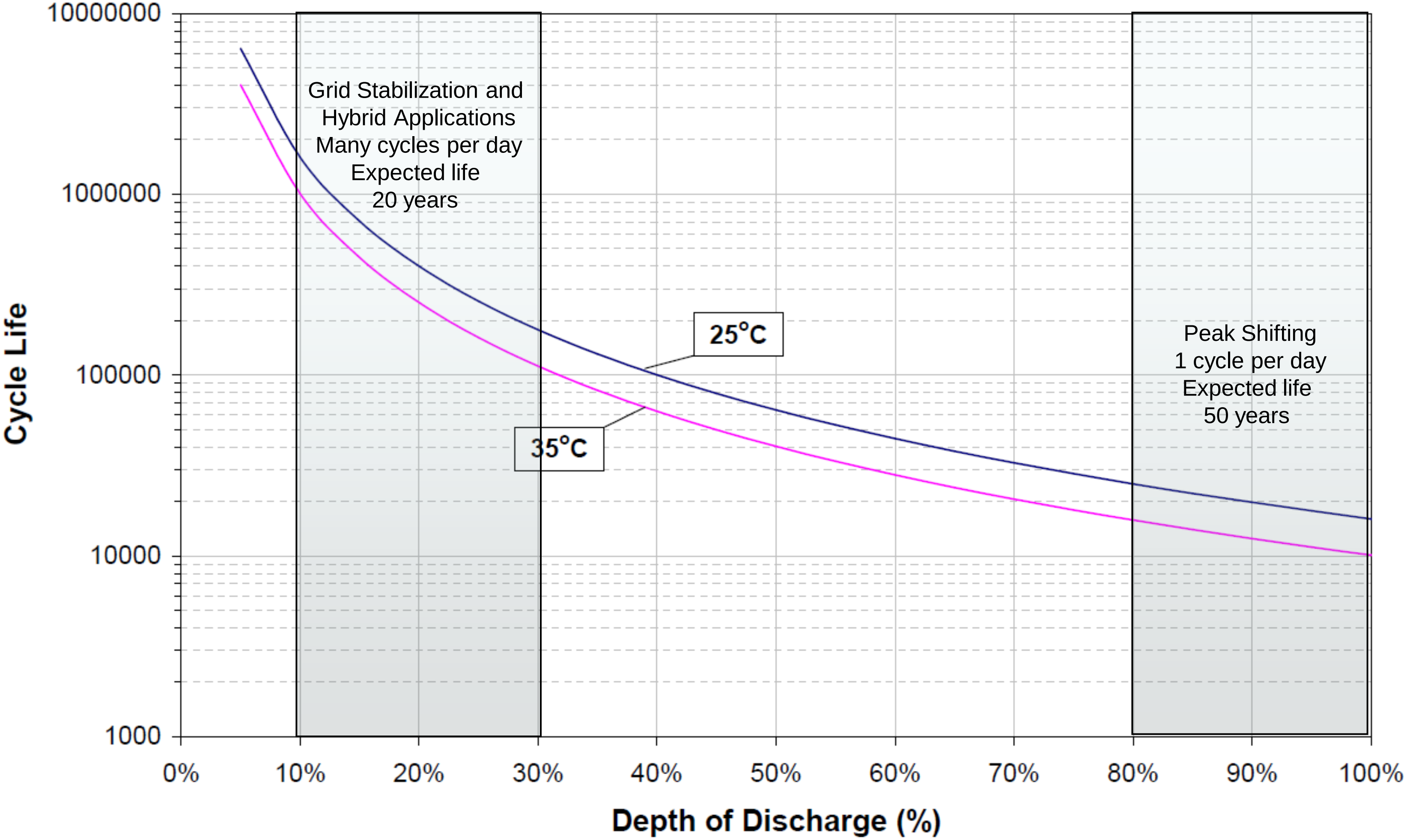
Storage System Size Customized to Utility Ramp Rate

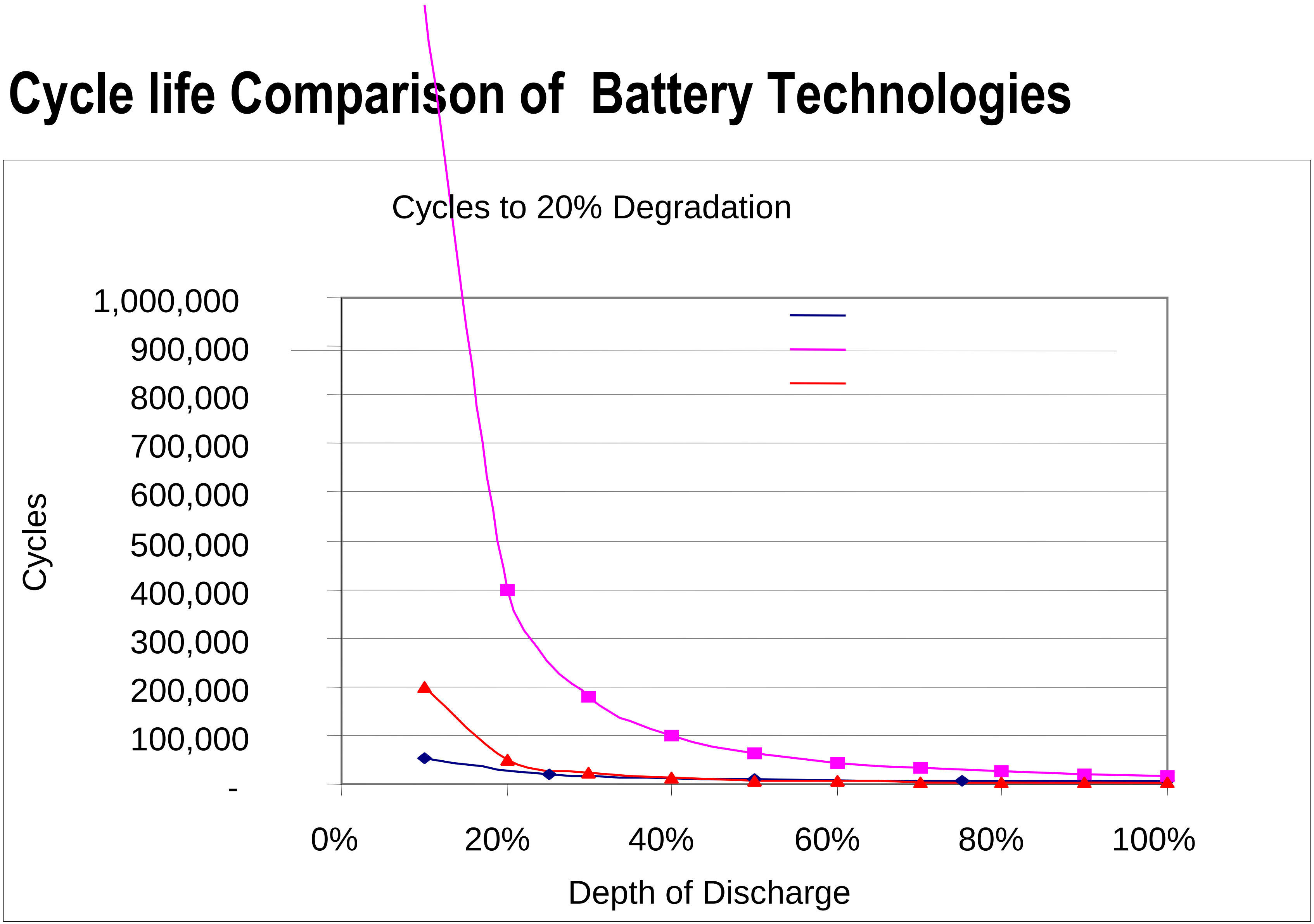
- 4 MW Battery smoothes ramp rate of 18 MW wind farm to .5 MW/min



Battery Cycle Life to 80% Capacity

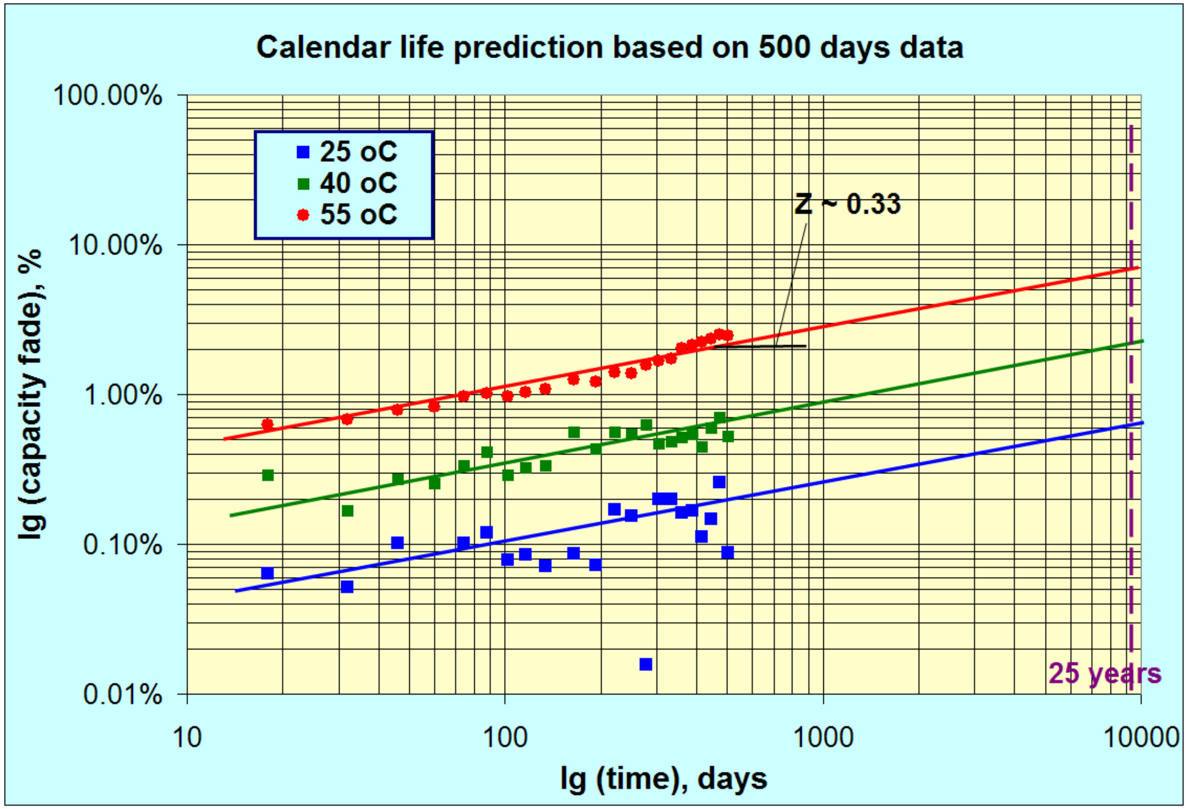


Cycle life Comparison of Battery Technologies



Calendar Life Capacity Degradation

- Arrhenius approach for calendar life prediction



Capacity Loss (Fade) is calculated from:

- **Predicted capacity loss:**
  - Calendar life calculation

    $\text{Capacity Fade}_{\text{Calendar Life}}$
  - Usage calculation

    $\text{Capacity Fade}_{\text{Usage}}$
  - Combine results for total capacity degradation vs. time

    $\text{Capacity Fade}_{\text{Total}} =$

Need Standardized Tests

- **Applications**
  - Vehicle Usage
  - Grid Energy
  - Grid Power
- **Assess**
  - Power
  - Energy
  - Impedance

Sandia National Lab Test Program

1) **Capacity Test** – Establishes a capacity on each cell.
2) **DC Ohmic Resistance** – Establishes a resistance of the cell.
3) **AC Spectral Impedance -** Establishes the AC impedance of the cell.
4) **Cell Power Density and Specific Energy Density** – Measures the cell power and energy density.
5) **Cell Capacity and Recharge As A Function Of Temperature** – Capacity measurements at the 1C rate were conducted at 35, 22, 0, and -20°C.
6) **Cell Utility PSOC Pulsed Cycle Test** – Measures the ability of the cell to PSOC cycle at high power for utility voltage support, frequency stabilization, and wind farm energy smoothing applications.
7) **Hybrid Pulse Power Test** – Measures the 10 second pulse power performance from 90% to 10% state of charge (SOC).
8) **Over Voltage/Charge Abuse Test** – Measures the effects of an uncontrolled continuous 1C (10 A) charge.

Other Test Programs

- **Vehicle Use**
  - PHEV Charge-depleting cycling test
  - The mean charge/discharge rate of 1.42 C of this profile is very close to mean discharge rate of the worst case PJM duty profile of 1.38 C
- **Carnegie Mellon University**
  - The effects of combined driving and vehicle-to-grid (V2G) usage on the lifetime performance of relevant commercial Li-ion cells were studied

Closing comments

- **Questions**
- **Discussion**
- **Next steps**

Main Findings of Berkley Report

1. **Increased variable renewable generation will have four impacts on the efficacy of primary frequency control actions:**
   - a. Lower system inertia. (not expected to be significant)
   - b. Displacement of primary frequency control reserves.
   - c. Affect the location of primary frequency control reserves.
   - d. Place increased requirements on the adequacy of secondary frequency control reserves.

2. **For the Texas and Western Interconnections, our simulation studies confirm that the interconnections can be reliably operated with the amount of wind generation and supporting transmission expected by 2012.**

No Problem?

Half Cycle Capacity Degradation Method

- **Measure change in DoD for a single half cycle**
- **Record temperature for that half cycle**
- **Calculate degradation due to that half cycle**
- **Repeat for each half cycle**
- **Sum the degradation from all half cycles**

2.7 Hybrid Pulse Power Test

The Hybrid Pulse Power Test is extracted from the FreedomCAR Battery Test Manual For Power-Assist Hybrid Electric Vehicles. This test procedure uses a 10 second $5C_1$ discharge pulse and a $3.75C_1$ charge pulse 40 seconds apart (see Fig. 4). The test sequence is listed below:

1) Measure capacity at the 1C rate.
2) Fully recharge cell.
3) Allow cell to rest open-circuit for 1 h.
4) Discharge cell 10% at the 1C rate,
5) Allow the cell to rest for 1 h rest open-circuit (measure Voc).
6) Discharge cell at the $5C_1$ rate for 10 seconds (measure end of discharge V).
7) Allow the cell to rest open-circuit for 40 seconds (measure Voc).
8) Charge at the 3.75 C_1 rate for 10 seconds (measure end of charge V).
9) Discharge at the 1C rate 10% of the cell capacity.
10) Repeat steps 4 through 8 until battery is at 10% SOC.
11) Record open-circuit voltage after the 1 h rest before the discharge pulse, record voltage at 10 second point in charge and discharge pulse and record open-circuit voltage at end of 40 second rest for each SOC.

12) Calculate discharge resistance using the 1 h open-circuit voltage and charge resistance using the 40 second open-circuit voltage for each SOC.

$$R_{Dch} = \frac{\Delta V_{Dch}}{\Delta I_{Dch}}$$

$$R_{Chr} = \frac{\Delta V_{Chr}}{\Delta I_{Chr}}$$

13) Calculate the Discharge Pulse Power Capability for each SOC using the minimum operational voltage.

$$Watts = V_{Min} \bullet (OCV_{Dch} - V_{Min}) \div R_{Dch}$$

14) Calculate the Charge Pulse Power Capability for each SOC using the maximum operational voltage.

$$Watts = V_{Max} \bullet (V_{Max} - OCV_{Chr}) \div R_{Chr}$$

15) Plot the discharge and charge power as a function of % SOC and discharged energy (Wh) at the 1 h rate.

PSOC - Partial State of Charge Test

from Sandia National Laboratory

The utility PSOC pulsed cycle test is designed to evaluate battery performance under short high power charge and discharge environments. In many utility applications the battery is required to both sink and source power for voltage support, frequency stabilization, and wind farm energy smoothing. In Figure 2 are actual utility data obtained from Charles Koontz of WPS Energy Services, Inc. showing the magnitude and duration of the power pulses required to support a utility application. In general, the pulse durations are minutes in length. The utility PSOC charge and discharge pulses chosen for this test were between 1.5 and 3 minutes in length at discharge rates between $2C_1$ (20 A) and $4C_1$ (40 A). The goal of this testing is to evaluate PSOC pulsed cycling, cell stability, efficiency, power performance, thermal management, and charge management strategies.