Energy Storage Performance and Reliability Data Initiative

DOE OE Energy Storage Peer Review Online 2020

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EPRI

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Agenda

- Overall EPRI/PNNL Project Status
- Li-ion and Flow batteries operational performance
- EPRI/SNL Electrical Energy Storage Data Submission Guidelines Update
- Drivers for Further Storage Performance and Reliability Assessment Research
- Next Steps

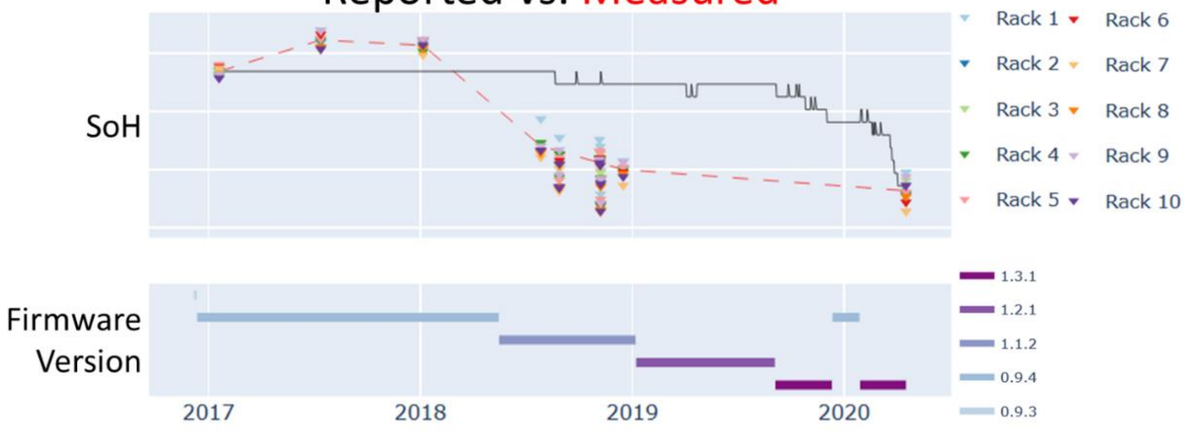
EPRI PNNL Collaborative Agreement Deliverables and Milestones

- ***Task 1: Provide Recorded BESS Performance Data (Months 1-24)*** - Achieved (and surpassed)
  - Secure access enabled and data relayed – delivery is on-going
- ***Task 2: Develop Methods for Analysis of Performance Data (Months 1-6)*** – In Process
  - Collaborated with PNNL Staff on parallel degradation analysis. EPRI based techniques include:
    - Independent SOC estimation
    - Coulombic counting
    - Decay in capacity from curve fit – align with expected capacity decrease on full cycle events
    - Impact of operating temperature and discharge power on RTE
    - Analysis of temperature and voltage distribution
    - dV/dQ analysis to relate degradation with specific loss mechanisms
- ***Task 3: Develop Test Procedures for BESS Reliability Performance (Months 6-12)*** - In Process
  - Focusing on performance standards inputs to data needed to modify or manifest degradation measurement techniques for respective protocols
- ***Task 4: Project Reporting (Months 18-24)*** - In Process
  - Presented initial findings at 2020 PNNL ES Safety & Reliability Forum
  - Started drafting final report for 2021 Joint Publication
  - Posturing for forthcoming IEEE (revision of cancelled April 2020 PES T&D), ESA and similar forums
  - Presented success of collaboration to internal EPRI Member Forums

Performance and Reliability Data Initiative Overview

- Vendor Health Assessments are proprietary and need verification
  - Developed independent degradation analysis based on calculations external from battery vendor computational platforms
  - Developed a relationship with DOE to tackle science-based approaches to understanding degradation
- Other metrics are needed to understand storage performance
  - Many systems do not inherently deliver data required for in depth analysis due to vendor restrictions
- System data lacks uniformity and difficult to use in analysis
  - Developed a Data Guide with DOE to help standardize points lists and data specifics
  - Developed internal tools to ease data ingestion into analytics database
  - Standards are typically a multi-year effort; data uniformity has only recently been identified as a standards issue
- O&M reporting is minimal
  - Developed O&M event reporting tool - currently underway in EPRI Energy Storage Integration Council (ESIC)

State of Health:
Reported vs. Measured



Snapshot of ESIC O&M Event Tracking Tool (coming soon)

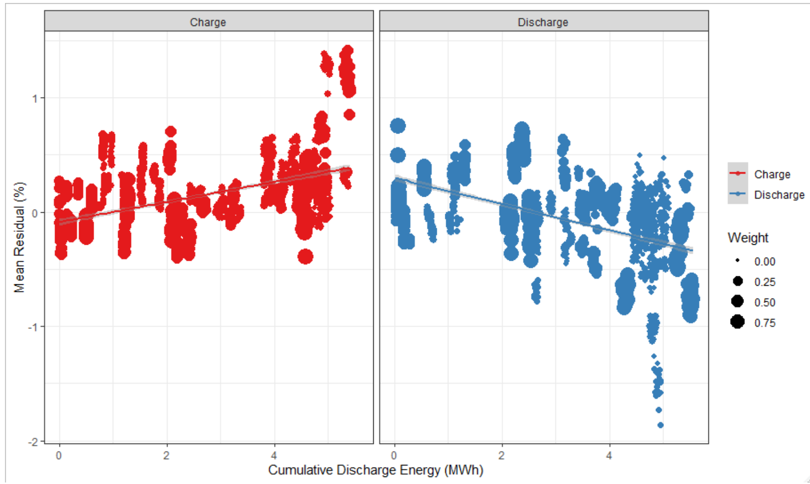
Event #	Planned vs Unplanned	System Limitation Description	Power Outage Percentage As a percentage of plant production power capacity	Energy Outage Percentage As a percentage of plant production energy capacity	Event Category	Event Sub-Category
1	Unplanned	Achieves all intended functions	0%	0%	Hardware	Battery
2	Unplanned	Most functions not available	25%	10%	Firmware / Software	Update
3	Unplanned	Achieves all intended functions	100%	100%	Network	Device Failure
4	Unplanned	Some functions not available	50%	50%	External	Loss of Grid Power

EPRI PNNL Collaborative Approach to Degradation Analysis

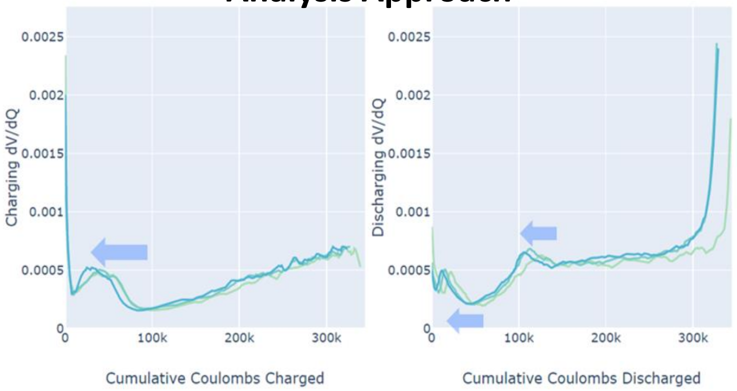
Numerous approaches to degradation assessment exist – key is to develop the most accurate and usable approach

- EPRI Work – Bottom Up
  - Independent SOC estimation
    - Coulombic counting
    - Decay in capacity from curve fit – align with expected capacity decrease on full cycle events
  - Impact of operating temperature and discharge power on RTE
  - Analysis of temperature and voltage distribution across racks, modules and cells for Li-ion battery system
  - dV/dQ analysis to relate degradation with specific loss mechanisms
- PNNL Work - Top down
  - Empirical model to predict SOC change during operation using operating power and calendar aging
  - Use battery operating history to predict degradation
    - Analyzing interaction of operating power P along with SOC, temperature (T), cumulative discharge
    - Targeting in situ without full cycle events

EPRI Initial Degradation Analysis Approach



PNNL/EPRI Collaborative Degradation Analysis Approach



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Summary of High-Level Performance Assessments

EPRI Energy Storage Performance & Reliability Initiative Host Systems - August 2020			
System Name	**Nameplate Power (MW)**	**Nameplate Energy (hours)**	**Current Status**
Li-Ion 1	1	2	Operational
Li-Ion 2	1	1	Partially Operational
Li-Ion 3	0.25	4	Operational
Li-Ion 4	20	0.5	Shut down
Li-Ion 5	1	2	Non-Operational (computer failures)
Li-Ion 6	0.25	2	Relocating
Flow	0.09	3	Limited Operations
Li-Ion 7	0.006	2	Operational

High level performance is somewhat indicative of performance

- Need very long term data sets
- Standby losses can have an impact on project economics

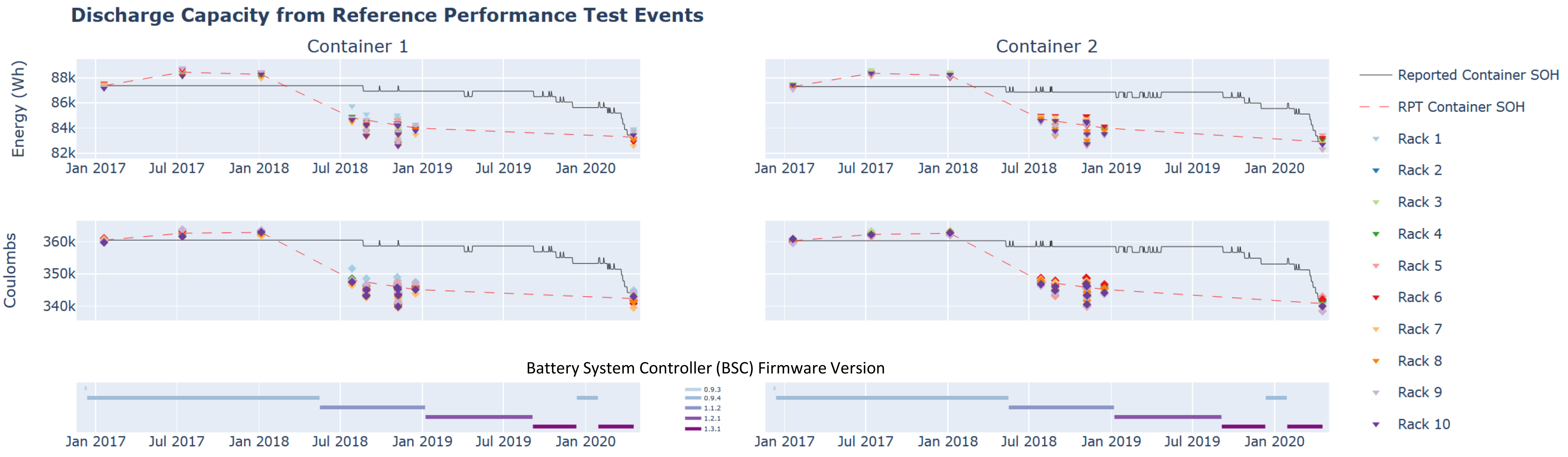
EPRI is monitoring a variety of fielded systems

- Some are well instrumented and present granular data from thousands of points
- Others present sparse data with vendor restricting visibility to pertinent points
- Many data quality issues are introduced by the data transport systems (SCADA)
- Many availability issues stem from ancillary system failures

		Approximate Avg. AC RTE	**Approximate Avg. DC RTE**	**Avg. Self Discharge** (% SOC Loss/day)[1]
Aux Loads (e.g. thermal mgmt.) **NOT** included in RTE calcs	Li Ion (Site A)	No AC data	95.7%	0.7
	Li Ion (Site B)	No AC data	97%	0.45-5.4
Aux Loads (e.g. thermal mgmt. or electrolyte pumps) included in RTE calcs	Vanadium Flow	54%	57.3%	0.49
	Li Ion (Site A)	84%	No DC data	0.14
	Li Ion (Site B)	No test cycles	No DC data	0.32

Reference Performance Test (RPT) Analysis

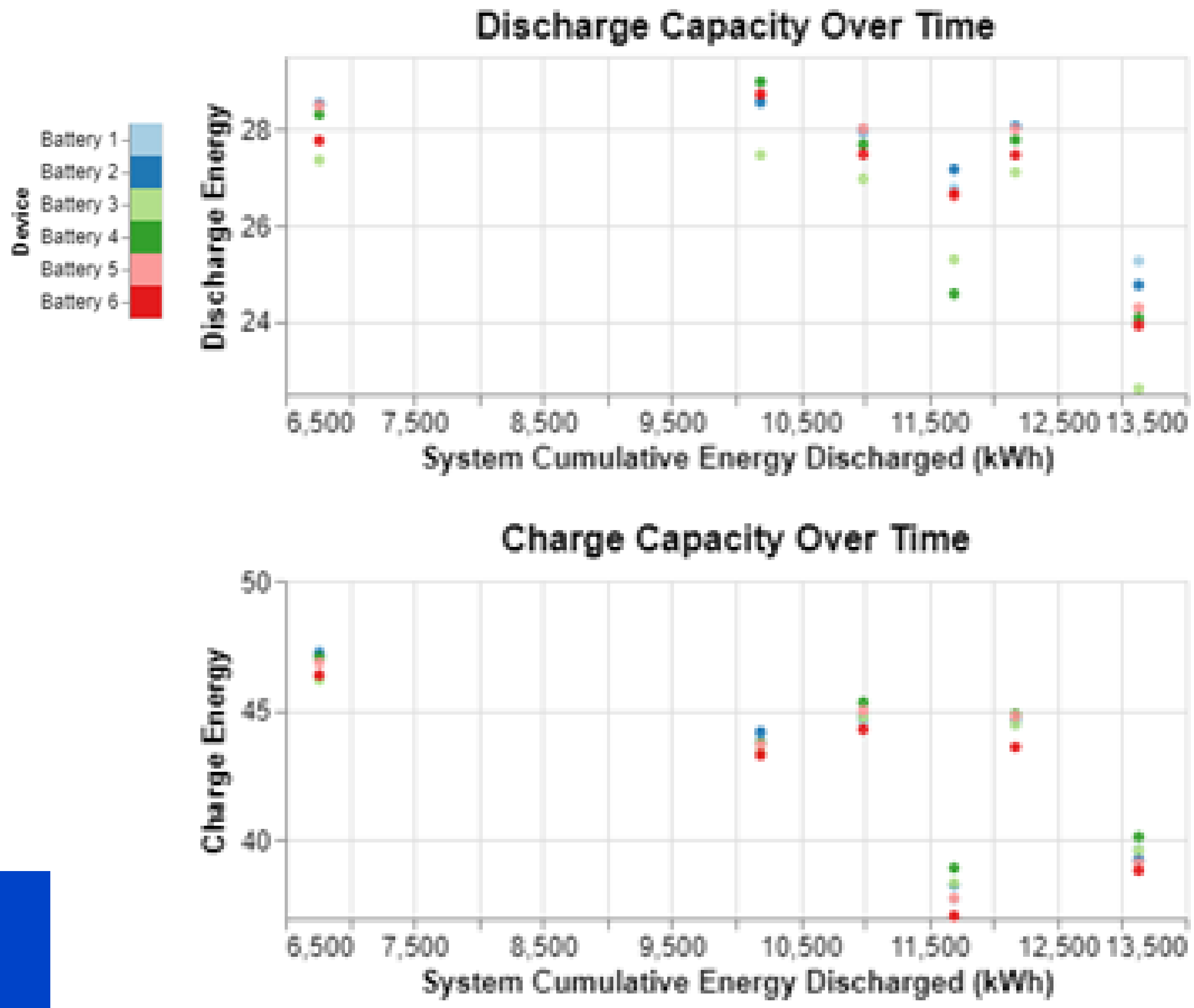
- Analysis of periodic (~every 6 months) RPT events provides insight into the system's discharge capacity over time (i.e. SoH)



- Based on discharge capacity trend, acute degradation seems unlikely
  - In response to SoH drop, Operator adopted more conservative operation limits (allowed SoC & temperature). SoH has stabilized at ~95%.

Flow Performance Analysis: Capacity Over Time

- 22 full charge / discharge cycles have been run since March 2020
- Charge and Discharge capacities appear to be decreasing over time
  - Unclear whether this is permanent degradation (e.g. membrane damage) or something that is reversible with maintenance (electrolyte crossover)
- Additional testing is needed. At this time the leaking stacks have been replaced and the system is able to operate at full discharge power but charge power and power factor range are restricted
  - Tests to compare used and replaced batteries are ongoing

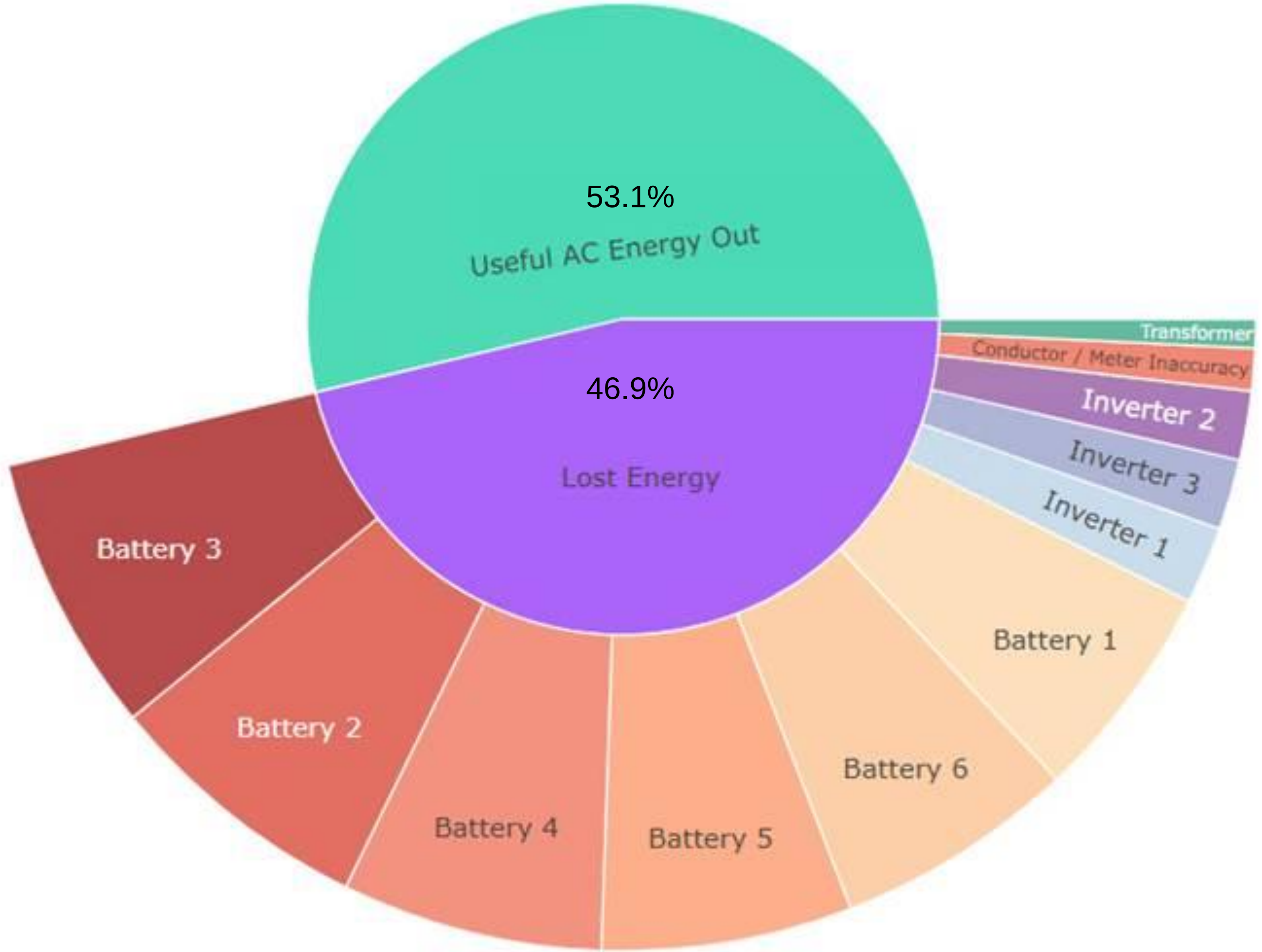


A downward trend in energy capacity has been observed though sample size is insufficient for conclusion

Flow Performance Analysis: Energy Loss Attribution

Components of energy loss in a charge discharge cycle

- Only operational time is included
- Inclusion of idle time may alter these results
- Available measurement points do not allow separation of DC converter loss and auxiliary loads such as pumps and fans



EPRI/DOE Data Requirements Guideline - Targeting Storage Performance Standards

- First version published February 2020
- Current working on next version via ESIC WG3 Task Force
  - *Opt in to join Task Force via chat*
  - Refining and aligning points lists to prioritized Use Cases and MESA Architecture
- Significant follow on opportunities to leverage this new guidance
  - Input and reference for creation of IEEE P2868 BMS Standard, IEEE 1815 updates and Input & Reference for Draft 1547.9 Interop clause
  - Input for MESA plans for expanding testing and certification guidance
  - Reference guidance for the ES Protocol testing (now an IEC Std)
  - Inform Standard Specifications (ESIC)

Electrical Energy Storage Data Submission Guidelines

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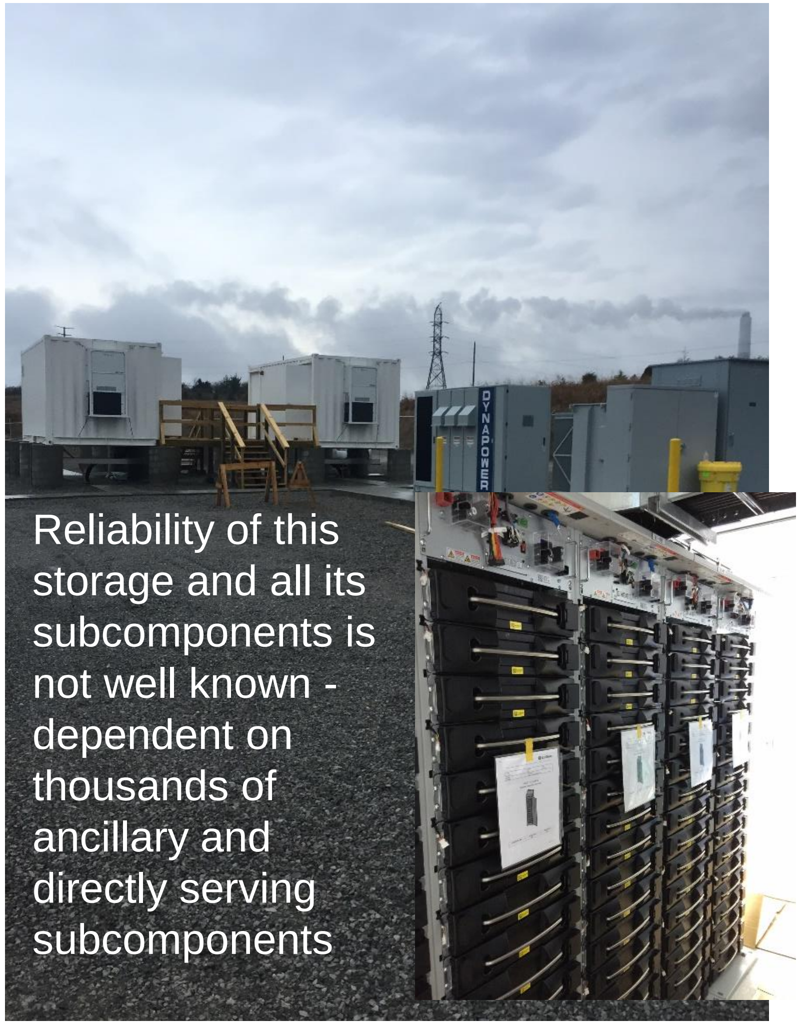
EPRI/SNL Data Guide Revision - Alignment to Standard Architecture

- Assign relavent points in MESA Architecture to new class designation
  - Alarms and Conditional Points
  - AC Performance - Meters
  - DC Performance - BMS and under
  - Modes of operation
  - Protection
  - Flow Specific
- Allows for clarity on
  - Alarm Management
    - Highlights need for prioritization rules
  - DC Power Quality
  - Alignment to specific Use Cases
    - Peak Shaving focus at first
- Register mapping can then become uniform along with attendant specifications

Data Guide Class	MESA Reference	Point Name
1	BI0	System Communication Error
1	BI2	System Has Priority 1 Alarms
1	BI3	System Has Priority 2Alarms
1	BI4	System Has Priority 3 Alarms
1	BI9	Storage Internal Temperature is Too High
1	BI10	Storage External (Ambient) Temperature is Too High
1	BI101	System Meter Phase A Voltage is Too High
1	BI102	System Meter Phase A Voltage is Too Low
1	BI103	System Meter Phase B Voltage is Too High
1	BI104	System Meter Phase B Voltage is Too Low
1	BI105	System Meter Phase C Voltage is Too High
1	BI106	System Meter Phase C Voltage is Too Low
1	BI107	System Meter Communication Error
1	HM + 7	Phase A Voltage at Meter #1 is Too High
1	HM + 8	Phase A Voltage at Meter #1 is Too Low
1	HM + 9	Phase B Voltage at Meter #1 is Too High
1	HM + 10	Phase B Voltage at Meter #1 is Too Low
1	HM + 11	Phase C Voltage at Meter #1 is Too High
1	HM + 12	Phase C Voltage at Meter #1 is Too Low
1	HM + 13	Meter #1 Communication Error
1	HDU +1	DER Unit #1 Has P1 Alarms
1	HDU +3	DER Unit #1 Has P2 Alarms
1	HDU +4	DER Unit #1 Has P3 Alarms
1	HI + 14	Inverter #1 Communication Error
1	HI + 17	Inverter #1 Ground Fault Alarm
1	HI + 18	Inverter #1 DC Over Voltage Alarm

Storage is becoming an essential grid component…

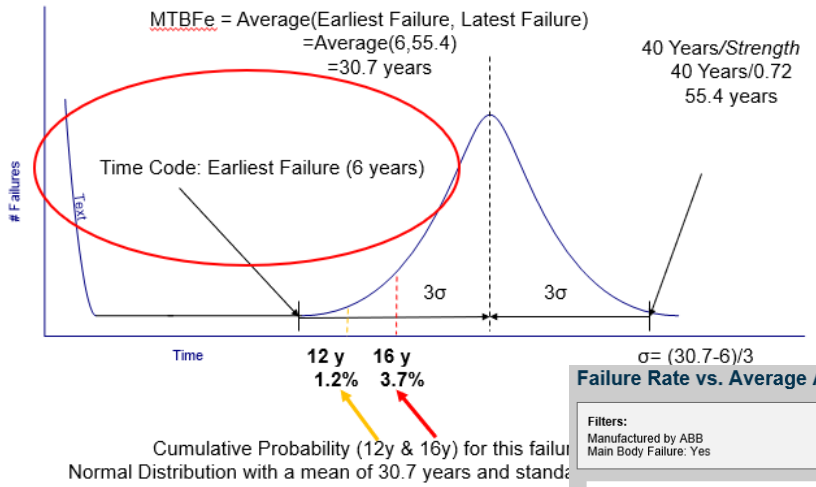


…but is not well understood from a performance and reliability perspective

…and the need is to understand storage performance is growing

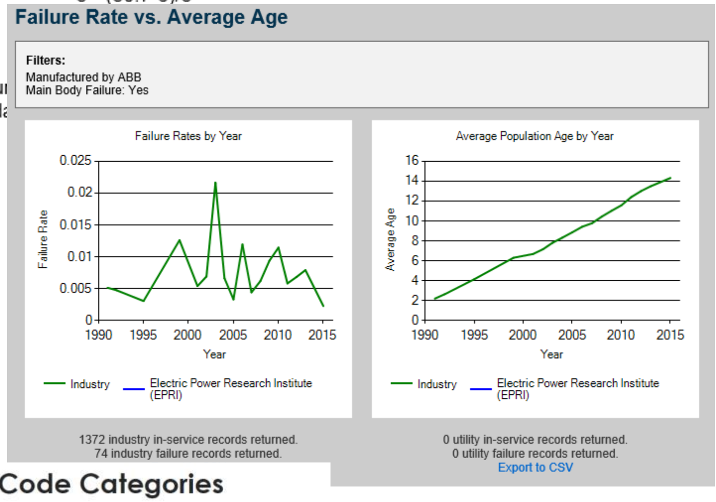
- Energy Storage Performance and Reliability Assessment is nascent compared to other Utility Assets
  - Storage is assuming a more prominent role in all vestiges of the grid - residential based fleets to large network resources
  - Few storage systems of substance have a little more that a few years of operational experience
  - Storage systems subcomponents are all critical to reliable operation, but weak links are apparent
  - Independent assessments are needed to verify vendor reported health assessments
  - Rigorous and independent analysis needs to also inform evolving performance standards and downstream reporting
  - e.g. NERC GADS
  - IEEE/IEC Standards

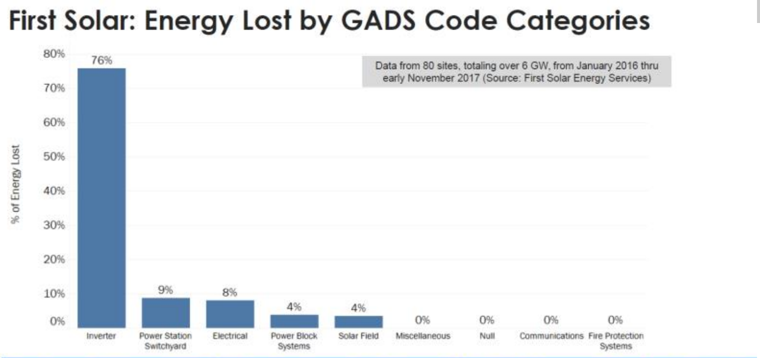
Sources: EPRI TR 3002015543, 3002013671, 3002007394



Generation

Transformers





Inverter events triggered 39% of total work orders and labor hours but 76% of total energy lost, while switchyard and other electrical failures accounted for another 17% of losses. PV modules themselves caused only 4% of energy losses associated with specific maintenance interventions, with breakage the leading failure mode.

Renewables

Next Steps

- Continue PNNL and EPRI degradation analytics collaboration
  - Mining current data sets, acquiring more field, lab and vendor data
  - Create comparative analysis or degradation techniques and field system to peers
- Integrate to parallel activities
  - O&M Tracking Tool dissemination and data acquisition
  - Data Guide New Version
  - Associated Test Protocols
- Present high-level findings in virtual and other settings
  - ESA
  - IEEE
  - Joint PNNL/EPRI Project Review Publication
- Use advanced data science to expand collaborative efforts in
  - Data ingestion and checking
  - Refining degradation estimation and forecasting methods
  - Analysis of overall reliability statistics

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Together…Shaping the Future of Electricity

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