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Energy Storage & Distributed Generation

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Highlights of this Issue:

- Focus on performance and reliability metrics for energy storage
- Overview of recent Colorado, New Jersey, and Hawaii policies and laws
- Update PJM frequency regulation market and FERC DER Technical Conference and Staff Report
- Insights from ESNA Solar + Storage Summit, IEEE T&D Conference, ESA Annual Conference, and the Battery Show Europe

Energy Storage Performance and Reliability

Although energy storage is advancing quickly, utilities and other stakeholders are finding it difficult to make informed decisions about how well storage will meet their needs. The vast array of energy storage technologies, chemistries, and possible use cases compounds this uncertainty. The field of energy storage—and its current and prospective clients—will benefit from a more thorough understanding of these systems' expected performance and reliability characteristics. This knowledge will support efficient investments, safe and reliable operation, cost-effective maintenance of energy storage systems (ESSs), and bring the industry closer to maturity. This article investigates concepts related to grid-connected ESS performance and reliability. It will explore the importance of understanding and quantifying ESS performance and reliability metrics, what these metrics could be, how they can be measured and modeled, and current industry efforts on this front.

Contents

The Importance of Quantifying ESS Performance and Reliability

Grid-connected energy storage systems are increasingly being contemplated for real-world roles in utility grids. Although vast knowledge about consumer electronics and electric vehicle (EV) batteries is available, grid-connected asset track records are much more limited, with significant uncertainty surrounding performance and reliability in real-world conditions. These ESSs are composed of an assortment of complex sensors, power electronics, energy storage modules, communications devices, and auxiliary hardware (Figure 1). Depending on the equipment and vendor, the storage facility operator may have access to an overwhelming amount of real-time data or, conversely, not have access to enough relevant data. These data can range from high-level facility data, such as AC power measurements and weather information, to cell-level voltage and temperature readings. The time interval between measurements can be on the order of milliseconds to minutes. Effective collection and analysis of standardized (similar across systems) and granular data from a range of deployed technologies and applications may enable rich insights into the mechanisms that influence operational performance and reliability characteristics. These insights could support improved energy storage investment and implementation by allowing high-level performance assessments and comparisons of various possible technologies. Robust analysis will also inform and refine ESS operation and preventive maintenance practices by identifying technology- and component-specific degradation and failure mechanisms.

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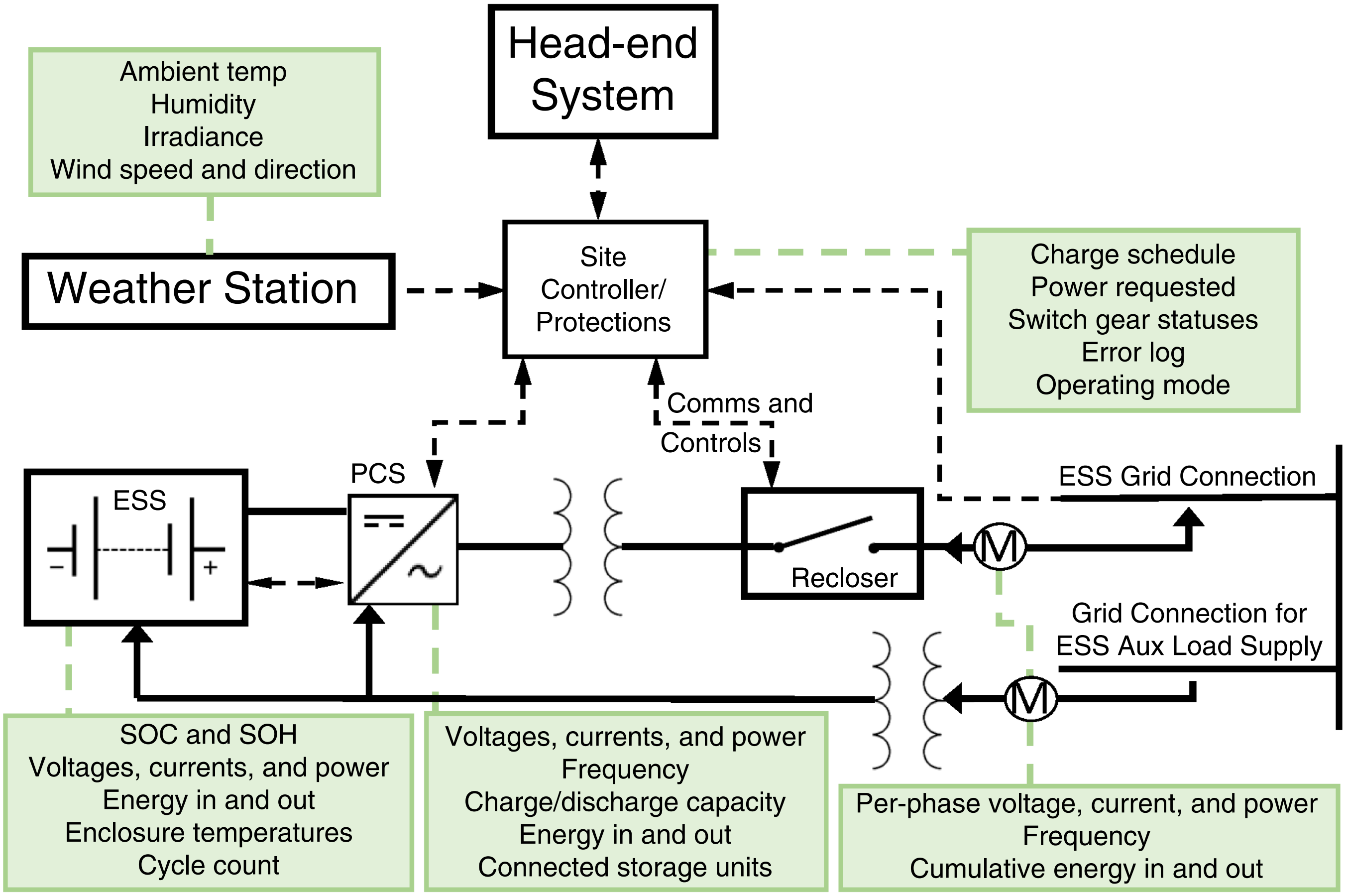

Figure 1. General topology for an energy storage facility labeled with some points of interest that are often monitored and reported

Metrics

Objectively comparing a diverse group of technologies' performance and reliability characteristics is a challenging task. It requires the definition of generalized metrics that can be accurately and repeatedly measured from a range of technologies using only data that are common to all systems. Currently, there are no industry standards for which data should be reported by the components of an ESS. Parties interested in analyzing data are limited to the offerings of the hardware vendors and the data they choose to make available or export for analysis. This makes certain metrics difficult to compare for technologies that exist at opposite ends of the data-accessibility spectrum.

Ideally, generalizable performance and reliability metrics would be measured in a noninvasive manner. Some contemporary measurement techniques require the system to follow a precise charge/discharge procedure to calculate the metric of interest. During these procedures, the ESS must be placed in a testing mode, effectively removing the system from normal operation—which may not be economically or technically feasible. A noninvasive solution should be developed to deduce these metrics from data collected during normal operation.

Performance Metrics

Some performance metrics, such as state of charge (SOC), state of health (SOH), and efficiency, are currently provided by some systems, but analysts must take extreme caution when comparing systems. The calculations behind these vendor-supplied values are proprietary and vary between systems. The relationships among the reported metrics and the systems' environmental conditions (for example, ambient temperature), use-case cycling demands (for example, backup power, peaker facility, or frequency regulation), and vendor definitions are also unknown. For example, a vendor might create an algorithm for calculating the SOH of its battery, which changes over its lifetime—this can lead to an underestimation of the system's degradation. If the metrics' definitions are not thoroughly understood, they cannot be used to produce reliable conclusions.

Following are some metrics and issues to consider when comparing ESS performance characteristics:

Roundtrip efficiency (RTE). This is typically defined as AC energy out divided by energy into the facility, including auxiliary load. At first glance, this seems like a good, generalizable metric for comparing ESS technologies; however, one must be cautious when assessing RTE. The following items should be considered before using efficiency to compare ESSs or deduce other metrics, like degradation:

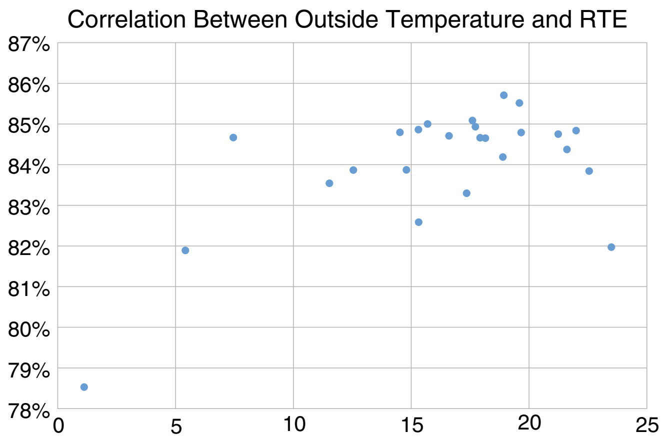

Figure 2. A plot of roundtrip efficiency vs. ambient temperature for an operational storage system

- Are parasitic/auxiliary loads incorporated into efficiency calculations? These include energy used for thermal management (Figure 2), transformation losses (from power electronics), self-discharge within battery cells, and energy lost to keeping the electronics in standby mode.
- Environmental factors affect efficiency. Because they rely on chemical reactions, batteries have an optimal cell temperature range. Deviations from this range result in efficiency sags and lead to higher auxiliary power loss from HVAC unit operation.
- Variations in operational characteristics, such as charge/discharge power rates, will affect the measured RTE. These interdependencies make it difficult to determine the cause of efficiency variations.

State of charge (SOC) and state of health (SOH). SOC (presented as a percentage) describes a battery's current level of stored energy relative to the battery's minimum and maximum allowed energy levels. (Note that this definition corresponds to *usable* SOC as opposed to *actual* SOC; see Figure 3). Theoretically, SOH provides only high-level insight into the degradation that a battery has experienced. These metrics are notoriously opaque and difficult to rely on for comparisons.

- There are numerous techniques for measuring SOC. The appropriate calculation technique is technology- and vendor-dependent.
- Some of the more accurate measurement techniques are highly invasive, requiring a pause in operation for calculation.
- The vendor's calculation method may also change over time, making it difficult to use for meaningful comparisons.

Reliability Metrics

A thorough understanding of ESS reliability will better inform financing, design, operation, and preventive maintenance procedures. Developing methods for cell degradation analysis and performing comprehensive classification of underperformance and failure mechanisms are necessary to acquire this understanding.

Consider the following metrics related to ESS reliability:

Cell degradation. Irreversible performance erosion sustained by a battery cell during operation (Figure 4). Degradation limits the battery's life. The degradation experienced by a cell is a function of cycle count and calendar degradation.

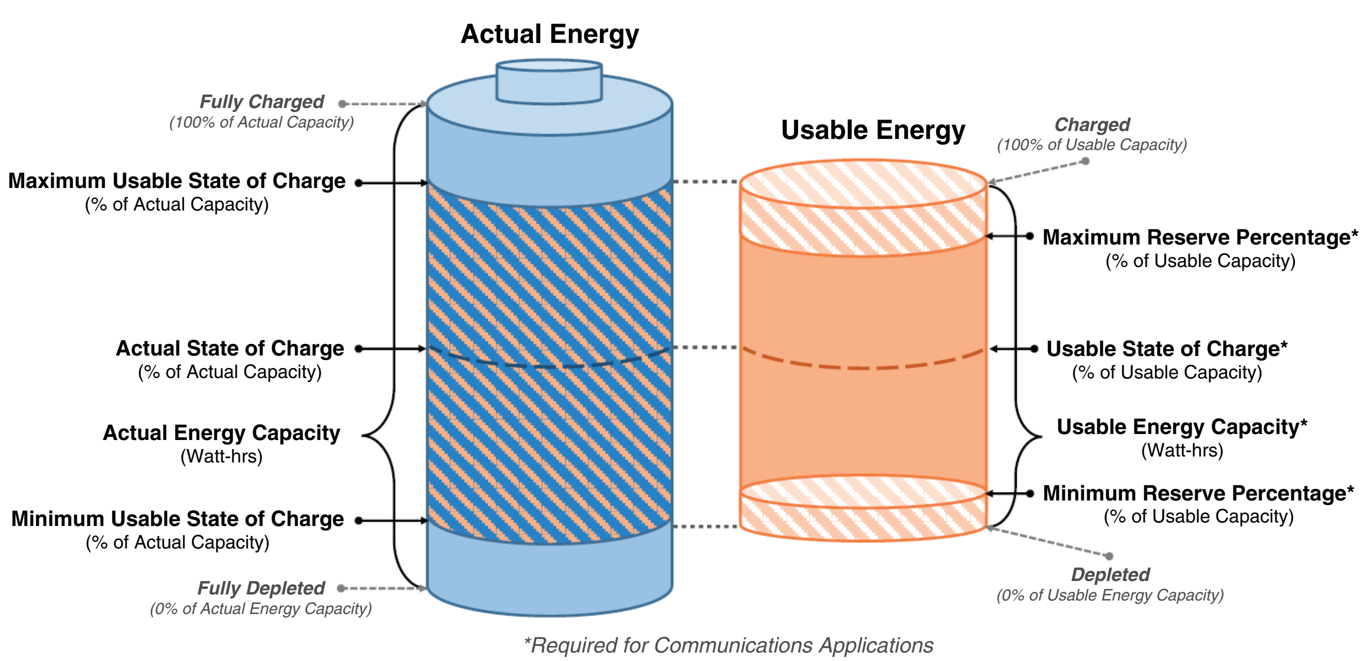

Figure 3. Visualization of the differences between "actual" and "usable" Energy and state of charge measurements. These definitions vary across technologies and vendors and are sometimes proprietary

Source: Seal, B. (2016). Common Functions for Smart Inverters 4th Edition. *Electric Power Research Institute*

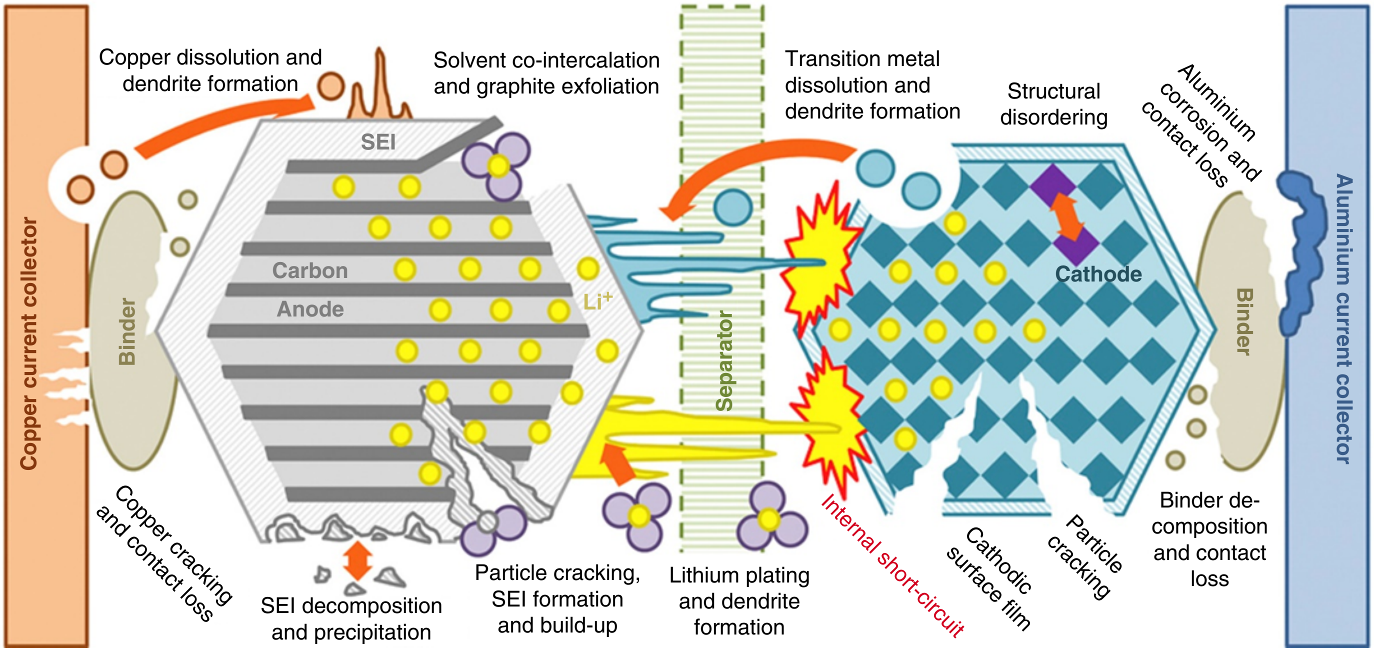

Figure 4. Depiction of the many degradation mechanisms experienced by Lithium Ion battery cells. Cell degradation diminishing performance eventually leads to the end of the battery's life

Source: Birkl, Roberts, McTurk, Bruce, & Howey, 2017. License information: https://creativecommons.org/licenses/by/4.0/

- Degradation mechanisms vary across technologies.
- The most comparable vendor defined metric is SOH.
- Cell degradation affects both performance (lower capacities) and reliability (replacement time).

Cycle life: the number of times a storage module can charge/discharge to a given depth of discharge before sustaining too much degradation to operate within predetermined performance criteria. Each time a storage system stores and releases energy, it sustains some performance erosion. Different use cases expose ESSs to different charge/discharge profiles (duty cycles); therefore, the rate of degradation is also a function of use case.

- Relies on accurate, verifiable, and reliable SOC measurements to count the depth of discharge.
- Various technologies and chemistries have different duty cycle "sweet spots" where they suffer the lowest rate of degradation. This means that certain technologies may be ideal for specific applications. (Pacific Northwest National Laboratory, 2018)

Calendar degradation: degradation that occurs independent of charge/discharge cycling. This performance erosion occurs even when the battery is in standby/SOC maintenance mode. Higher temperature and average SOC will degrade lithium ion systems more quickly, particularly if both conditions are concurrent. Degradation may not be linear, and degradation rate may accelerate later in life.

System underperformance, interruptions, and failures. Because ESSs are so complex, it is important to understand and recognize the symptoms of an underperforming or failing component, which experiences a ranges of failure rates and mechanisms (Figure 5) metrics applicable to ESSs and their components include the following:

Component-level metrics:
Mean time between failures (MTBF)Time Between Failures
Mean time to repair (MTTR)
Hazard rate
System-level metrics:
Availability

These metrics must be calculated with historical operational data at the system and component levels. Note that the term *reliability* is used in many sectors and is defined as "the probability a device will reach its expected life without failure." This definition is not very applicable to batteries because they suffer more from gradual performance degradation as opposed to instantaneous failures. The degradation of the batteries is better captured by a cycle life curve than a hazard rate.

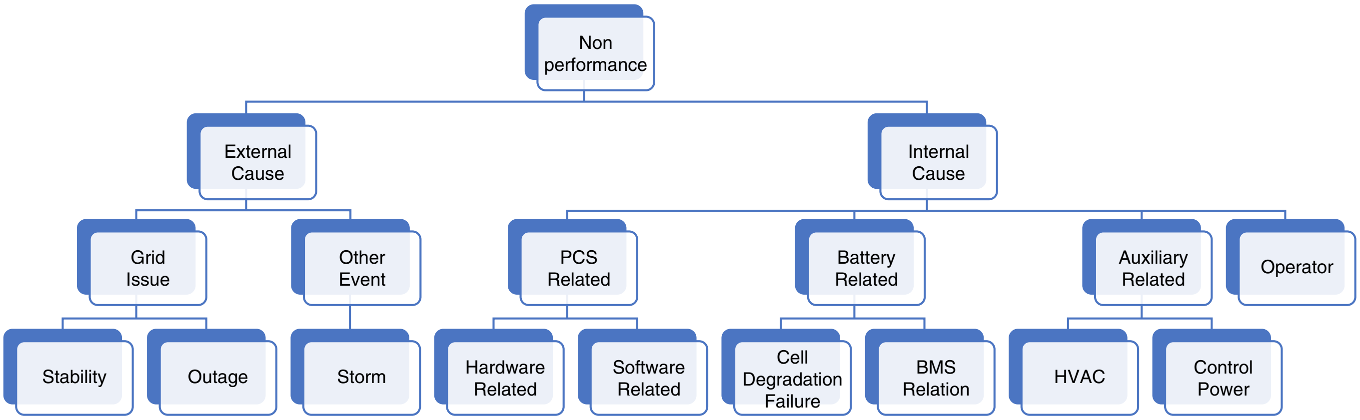

Figure 5. Prototype of a generalized outage classification tree to assess reasons for system "non-performance"

Modeling Performance and Reliability

Proprietary and public tools exist for modeling the variables associated with ESS investments.[1] These tools are used to evaluate the economic costs and benefits, grid impacts, and/or optimal operation of an ESS for a specific use case. The accuracy and overall usefulness of a modeling tool depend on the quality of the data used to develop the model. Not all models are the same, so it is important to understand the strengths and weaknesses of each modeling approach to select the right tool for the job.

The methods and algorithms used by a tool to model performance and reliability characteristics will impact how closely the analysis results represent reality. For instance, consider a set of competing modeling tools performing an identical task: optimizing (sizing, operation, and so on). and evaluating the economics of an ESS for frequency regulation. The results generated by a tool that uses simple, fixed values for metrics—such as efficiency, power limitations, and battery life cycle—are expected to differ from those of its competitor, which uses complex, dependent performance and reliability variables during simulation. Which model is most relevant should be decided through a model validation effort in which each tool's results are compared with information from similar systems in the field to assess the tool's accuracy.

Although efforts to model ESS performance and reliability characteristics exist, the lack of access to diverse sets of operational data has limited the robustness of these models. A more thorough understanding of the complicated interdependences between performance and reliability metrics—and the factors that affect them—will better inform the modeling process. This will lead to more effective ESS modeling tools and reliability assessment.

Modeling Performance and Reliability with StorageVET®

This section will demonstrate the modeling challenges that today's ESS analysis tool developers face by examining the performance and reliability modeling scheme used by EPRI's current version of the Storage Value Estimation Tool (StorageVET®). The following discusses the way in which StorageVET models performance and reliability and envisioned steps to improve the model.

Degradation. During ESS valuation, StorageVET produces a lifetime SOC profile, which simulates how the SOC fluctuates as the ESS performs its use case. A rainflow-counting algorithm[2] is applied to the SOC profile to monitor the cycles of the ESS over its lifetime. A simple degradation calculation is derived from this cycle count:

- Only used for financial calculations (for example, the system will be replaced after x discharge cycles to y depth of discharge).
- The degradation calculation does not derate the system's performance. Performance characteristics remain constant throughout the lifetime of the simulated ESS.

Efficiency. The charge and discharge efficiency inputs are fixed throughout the simulation:

- Efficiency changes due to ambient temperature, degradation, and charge/discharge power are not incorporated.
- Auxiliary loads may be input by the user. These loads remain constant throughout simulation.

Equipment failures and outages. All ESS equipment is assumed to operate properly for the component's specified lifetime. Replacement or augmentation costs are considered when a component reaches its end-of-life criterion prior to the system's end of life:

- Does not capture possible premature failures for various technologies and system components.

Efforts to address StorageVET's performance and reliability modeling limitations are underway, but without access to operational ESS data, this is a difficult task. Access to these data would allow the examination of the relationships between factors that affect a system's performance and reliability. The following is a short list

1 Navigant Consulting. (May 2014). *Survey of Modeling Capabilities and Needs for the Stationary Energy Storage Industry*. Energy Storage Association.

2 For more information about rainflow-counting algorithms, visit the algorithm's Wikipedia page: https://en.wikipedia.org/wiki/Rainflow-counting_algorithm.

of StorageVET performance and reliability modeling improvements envisioned once these data are available for analysis:

- Degradation tracking to derate performance over the system's lifetime by including parameters that affect degradation, such as temperature, average SOC level, and cycle count.
- Efficiency calculations that account for charge/discharge power levels, cycle and calendar degradation, auxiliary loads, and so on.
- Availability simulations based on observed component MTBF and MTTR for improve reliability and maintenance cost predictions.

Industry Efforts

Numerous efforts exist to understand and quantify performance and reliability metrics in the power sector. Although some of these are not directly applicable to ESSs, they can provide valuable insight and direction for similar ESS efforts. This section highlights EPRI's efforts to better understand ESS performance and reliability, similar database initiatives for other grid technologies, ESS communication standards developments, and recent lab-based battery performance and reliability studies.

EPRI Energy Storage Performance and Reliability Data Initiative

In late 2017, EPRI's Energy Storage and Distributed Generation program announced the Energy Storage Performance and Reliability Data Initiative supplemental project. This new project aims to develop a pilot database and mature database specification along with an analysis platform to answer key questions about the performance and reliability of operational ESSs. This project will also leverage and advance common definitions and evaluation methods, developed through the Energy Storage Integration Council, to engage with suppliers to push for increasingly useful and standardized system data through incorporation in relevant industry standards.

Project's Desired Outcomes

This project is expected to result in improved characterization of risk, reliability, and performance factors associated with energy storage deployments. Desired outcomes include:

- The development of a standard platform for real-world ESS performance and reliability data analysis.
- Analysis of performance, degradation, and reliability over time followed by a range of projects to inform project and operations and maintenance (O&M) planning for future deployments.
- An understanding of failure modes and sources of downtime of energy storage.

Project Approach and Summary

This project will support data specification, collection, and analysis of energy storage performance for systems in the lab and the field. The planned project approach is to:

- Collect data from a range of EPRI and project host systems as well as from publicly available sources. Coordinate with hosts to schedule field tests, where possible, to generate data for structured characterization.
- Build a pilot database from existing data sets. Define standard data fields that are common across ESS projects.
- Perform data analysis to assess failure modes and performance and reliability characteristics, including investigation of downtime and null data causes and key drivers of operational characteristics.
- Perform gap analyses on data sets to determine research needed.
- Work through the Energy Storage Integration Council to engage the vendor community to communicate gaps and provide guidelines for improved data availability and consistency.
- Develop specifications for an advanced, second-generation database along with uniform and robust data capture and transport criteria.

Progress to Date

Since the project's announcement in 2017, the initiative has been progressing according to schedule. The initiative is collecting data from several mostly lithium systems. Analyses of these host systems has produced preliminary results showing the magnitude of standby-mode losses and the effect of ambient temperature on roundtrip system efficiency. Research of literature related to the systems' various component reliabilities is underway. A platform for on-the-fly degradation calculation is being developed, and the initiative is proposing new field terminology standards. The specifications for a pilot database are being constructed in tandem with a "standard points list" to allow for smooth, universal integration of a variety of host ESS technologies and topographies.

In terms of database specification, above and beyond the following efforts, focus has been placed on integration and alignment with the existing Trouble Management Systems (TMS) to ease integration of field data and avoid duplication of systems.

EPRI/Sandia National Labs PV Reliability Operations Maintenance (PVROM) Database Initiative

This 2013–2015 collaboration documented data from multiple photovoltaic (PV) systems with various system components, configurations, and operating environments to analyze real-world PV system reliability. PVROM's findings and analyses were intended to inform industry best practices around the optimal O&M of solar assets. Figure 6 shows some PVROM results depicting a histogram of the maintenance actions for a PV system broken down by component. The data collected for the PVROM database provided valuable insights that were not previously possible.

PVROM's database development approach and lessons learned are being incorporated into efforts related to an energy storage performance and reliability database.

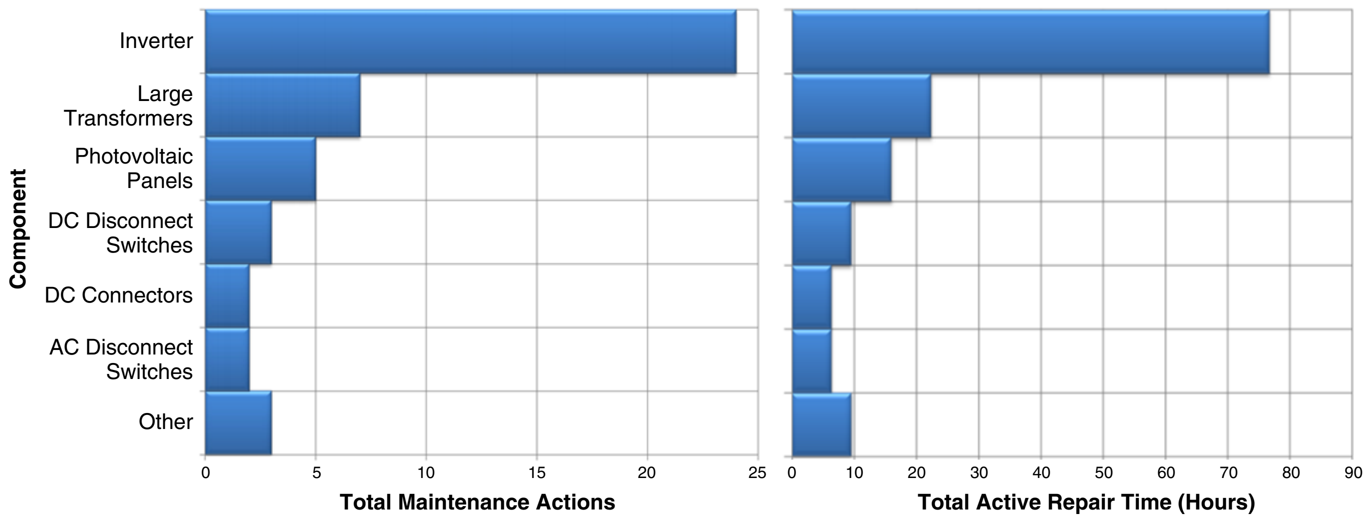

Figure 6. Second year findings from the PVROM database Initiative. This chart illustrates the number of maintenance actions and repair times observed for a system that experienced the most maintenance actions
Source: EPRI and SNL, 2013

Industry-Wide Database (IDB) for Power Transformers[3]

EPRI's 2006–present IDB initiative is a repository of detailed transformer performance data sourced from supporting utilities. The data—from multiple sources—are captured in a common format that enables data mining and statistical analysis to better understand transformer reliability characteristics. The IDB provides a rational, quantitative basis for asset management decisions to improve service reliability and return on investment.

The IDB is a mature and productive database that stands as an industry leading example of the effectiveness of a thoughtful, well-executed database and reliability analysis. Since its inception in 2006, the IDB has provided continuous insight to participants. Similar energy storage database efforts will lean heavily on the IDB for guidance.

Military Generator Reliability Analysis

Recent Department of Defense policies to ensure "available, reliable, and quality power to continuously accomplish Department of Defense missions" are forcing military bases to assess the reliability and effectiveness of their backup power systems. A base's backup power system typically consists of independent diesel generators assigned to serve a single building's load. The number of units, lack of assured fuel supply, and sub-par maintenance practices are raising concerns about many bases' ability to supply reliable power to critical loads during long-term outages. Microgrids featuring centralized diesel and renewable sources of generation coupled with ESSs are being examined as tools to ensure that energy is available when and where it's needed.

Quantifying the expected reliability of ESSs by analyzing the field data of various components individually would allow more accurate comparison of traditional backup systems with modern microgrid alternatives. These efforts could remove some of the guesswork associated with the cost-benefit and reliability analyses associated with critical load power supplies.

Pacific Northwest National Laboratory (PNNL)

PNNL recently presented preliminary results of a study comparing lithium ion chemistries (LFP and NCA) under different baseline and service cycles (frequency response and peak shaving) to deduce which technology exhibits the best performance under each duty cycle.[4] Degradation metrics were obtained through nondestructive mechanisms, including differential voltage analysis, roundtrip efficiency, and internal resistance.

The results and procedures from this research are relevant to efforts to analyze ESS field data. Although research organizations have demonstrated lab-based degradation measurements, the challenge of developing an accurate and noninvasive method for acquiring degradation metrics from operational data still exists.

Sandia National Laboratories (SNL)

At a March DOE storage conference, SNL presented concepts related to optimization of an ESS's limited resources and how they can be used to improve a system's overall reliability.[5] This method uses statistical models (based on fault trees) to represent an ESS's individual component reliabilities. These models are fed into an optimization algorithm, which attempts to improve reliability using any combination of available actions (for example, system redesign, replacement of components with higher reliability counterparts, or increasing the number of spare components) while considering budget, time, and size constraints.

3 Electric Power Research Institute. (2017). *Industry-Wide Transformer Database: Definitions, Contents, and Applications*.

4 Pacific Northwest National Laboratory. (2018). Li-ion Battery Performance under Grid Services. *Department of Energy Energy Storage Forum*. Seattle, WA.

5 Sandia National Labs. (2018). System Availability and Sustainment. *Department of Energy Energy Storage Forum*. Seattle, WA.

Accurate ESS reliability modeling is important for the future of ESS design, valuation, and integration. Access to real-life component and system-level failure and under-performance data is vital for efforts to accurately model ESS reliability characteristics.

IEEE and IEC Standards

To create uniform and efficient approaches to storage reliability assessment, it is necessary to not only conduct the research and identify approaches, but also engender these findings in industry standards to allow for uniform future approaches. IEEE and IEC standards organizations are currently refining existing standards to better address field performance and reliability assessments. EPRI, through its Energy Storage Performance and Reliability Data Initiative, has proposed modifications to both organizations based on initial learnings. Successful efforts to standardize communications—and the way in which components acquire and report measurements—will streamline the energy storage data acquisition and analysis process in several ways:

- Provide a detailed list of relevant data points visible from the many ESS components. A subset of this list of points would define the foundational structure for a database so that it is able to record accurate data from a diverse range of ESSs.
- Simplify the communication of data sent from the ESS to the database, and ensure transparency related to the definitions of measurements.

In return, an energy storage database could assist standards development organizations by providing analysis-driven insights that are necessary for more effective protocol development.

Conclusion

Collection and analysis of operational ESS data from a variety of deployed and fielded technologies and use cases will open the door to previously unattainable knowledge about the underlying mechanisms that govern ESS performance and reliability. These insights will further the maturation of the grid-connected ESS industry by improving ESS modeling and analysis tools, enabling more effective analysis-based standards development, and guiding more informed and robust ESS investments.

EPRI's Energy Storage Performance and Reliability Data Initiative is leading the charge to develop this understanding by identifying the next logical steps and tools to bridge these gaps. These steps include the refinement and acceptance of transparent ESS standards, creation of an all-inclusive and extensible database to house information from a robust set of ESSs, and development of techniques to extract maximal useful insights from a pool of raw operational data. This initiative, with the help of other stakeholders, will usher in the next era of effective energy storage analysis, deployment, integration, and operation.

State Regulatory and Utility News

Update on State Storage Mandates

In recent months, New Jersey and Colorado became the fifth and sixth U.S. states to establish policies that mandate procurement of energy storage. Table 1 summarizes these state policies to date and provides some comparative details. A storage procurement mandate requires that a certain quantity of storage, denominated as power capacity (MW) or energy capacity (MWh), is procured by utilities or other eligible entities.

New Jersey Assembly Bill A-3723, enacted on May 23, 2018, requires the New Jersey Board of Public Utilities (BPU) to conduct an analysis on mechanisms for procurement of storage within six months. The analysis should identify energy storage "needs and opportunities" and calculate the costs and benefits to ratepayers, local governments, and utilities of potential applications—including emergency backup power, serving peak loads, distribution system stability, facilitating use of EVs, and renewable integration. The analysis must also "determine the optimal amount of energy storage to be added in the State over the next five years in order to provide the maximum benefit to ratepayers" and make recommendations on any needed financial incentives.

After the analysis is completed, "the board shall initiate a proceeding to establish a process and mechanism for achieving the goal of 600 megawatts of energy storage by 2021 and 2,000 megawatts of energy storage by 2030." The bill also expands the state's Renewable Energy Standard to target 50% of annual energy by 2030 and creates a community solar program. New Jersey already has other programs that directly support storage, including the Renewable Electric Storage Program, which provides financial incentives for storage integrated with eligible nonresidential behind-the-meter renewables.

Colorado's Senate Bill 18-09, the Energy Storage Procurement Act, was enacted in June 2018. This policy requires the Colorado Public Utilities Commission (PUC) to establish new rules for utility procurement of storage by February 1, 2019. The objectives of the storage procurement include integration of energy, improved reliability, serving peak demand, and "avoidance, reduction or deferral" of utility investment. These rules include a cost-benefit analysis and improved integration of storage into utility planning methods. Shortly after the rules are finalized, there is a May 1, 2019, deadline for electric utilities to file applications for rate-based storage projects not to exceed 15 MW.

Table 1. U.S. state storage procurement requirements as of June 2018

State	Legislation	Implementing Agency	Year Initiated	Procurement Obligation	Procurement Targets	Procurement Mechanisms
CA	AB 2514 (2011)	California Public Utilities Commission (CPUC)	2013	Jurisdictional load-serving entities (LSEs)	1,325 MW procured by 2020	Utility RFOs, bilateral contracts, utility-owned
		California Energy Commission (CEC)	2013	Publicly-owned utilities	Self-defined with board approval	Utility RFOs, bilateral contracts, utility-owned
CO	SB 18-09 (2018)	Colorado Public Utilities Commission (PUC)	2019	Electric utilities	Up to 15 MW per utility	TBD but utility ownership or contract
MA	H 4568 (2016)	Dept. of Energy and Resources (DOER)	2017	Electric distribution companies	200 MWh by 2020	Grants for 85 MWh of small projects awarded in Dec. 2017
NJ	A-3723 (2018)	Board of Public Utilities (BPU)	2019	TBD	600 MW by 2021; 2 GW by 2030	TBD
NY	A 5671 (2017)	New York Public Service Commission (NYPSC)	2018	TBD	1.5 GW by 2025	TBD
OR	HB 2193 (2015)	Oregon PUC (OPUC)	2017	Major utilities	At least 5 MWh and up to 1% of 2014 peak load by 2020	Utility procurement

Source: Modified from EPRI, 2017

When comparing these and the other state policies to date, they fall into a few categories. Some states—notably California, New York, and now New Jersey—have started with ambitious targets and rapid procurements. Others, notably Massachusetts, Oregon, and now Colorado, have begun with more modest requirements as utilities and other entities demonstrate storage applications and economic value. Other differences include whether procurement is done through relatively standardized RFOs to meet state targets (for example, most but not all California IOU procurements), through utility planning (for example, Oregon), or through state government awards (for example, Massachusetts). In all cases, the mandates are a floor on procurement, so additional capacity could be procured if demonstrated to be cost-effective. In California, subsequent legislation has already authorized additional such procurements.

References

New Jersey Senate Bill 2314, https://legiscan.com/NJ/bill/S2314/2018.

New Jersey Renewable Electric Storage Program, http://www.nj-cleanenergy.com/storage.

Colorado House Bill 18-1270, Energy Storage Procurement Act, https://leg.colorado.gov/sites/default/files/documents/2018A/bills/2018a_1270_signed.pdf.

Section 4, *Energy Storage and Distributed Energy Resources in the United States: 2017 Annual Review of Policies, Markets, and Key Trends*. EPRI, Palo Alto, CA: 2017. 3002010961.

Hawaii Performance-Based Ratemaking

Among the major policy and regulatory challenges facing continued penetration of distributed energy resources (DER) is the divergence that can emerge between the interests or incentives of utilities, which may be experiencing load reductions and cost shifts to remaining retail customers, and those of the customers and nonutility companies installing DER. One approach to this challenge is to establish variants of performance-based ratemaking, which link the regulated rate of return to the utility with how well they perform in meeting certain criteria or metrics that facilitate DER entry.

Types of performance-based ratemaking to facilitate DER entry and integration are being implemented around the country, in most cases initially on a limited or pilot basis (for example, linked to particular projects). However, more ambitious initiatives are now being attempted. In July 2018, Hawaii passed the Hawaii Ratepayer Protection Act to guide performance-based ratemaking to facilitate the adoption of DER. Hawaii is already well on a path to very high DER penetration: as of March 31, 2018, the Hawaiian Electric Companies (HEC) had 702 MW of distribut-

Table 2. Hawaiian Electric Companies, Distributed Generation (DG)/PV Forecasts to 2045 (MW)

Milestone Date	Market DG/PV Forecast	High DG/PV Forecast
December 31, 2020	856 MW	858 MW
December 31, 2030	1,169 MW	1,671 MW
December 31, 2040	1,517 MW	2,562 MW
December 31, 2045	1,697 MW	3,008 MW
Growth (2015–2045)	1,226 MW	2,537 MW
Growth Percent	360%	639%

Source: Hawaiian Electric Companies, PSIP 2016 Update Report, pp. 1–6

ed PV installed, with 75,385 residential and commercial installations. Recent HEC planning forecasts assume that in the "high" forecast shown in Table 2, every house on the islands will have solar panels by 2040 (if not sooner).

The Hawaii PUC first envisioned new regulatory approaches to support new utility business models in a white paper released in 2014. Subsequently, major new policies have been enacted which are driving DER of different types, including a 100% renewable energy target by 2045, reform of net energy metering, creation of several new tariff structures for behind-the-meter resources, and changes to distribution system planning and resource planning.

The Act requires the PUC to establish performance incentives and penalties by January 1, 2020. The specific performance metrics are required to include the following categories, cited directly from Section 3(b) of the Act:

1. The [approved] economic incentives and cost-recovery mechanisms;
2. Volatility and affordability of electric rates and customer electric bills;
3. Electric service reliability;
4. Customer engagement and satisfaction, including customer options for managing electricity costs;
5. Access to utility system information, including but not limited to public access to electric system planning data and aggregated customer energy use data and individual access to granular information about an individual customer's own energy use data;
6. Rapid integration of renewable energy sources, including quality interconnection of customer-sited resources; and
7. Timely execution of competitive procurement, third-party interconnection, and other business processes.

While some of these criteria have been used in performance-based ratemaking elsewhere,[6] many are novel applications and will be of interest to state regulators around the country.

References

Hawaiian Electric Companies, Quarterly PV Summary: https://www.hawaiianelectric.com/Documents/clean_energy_hawaii/going_solar/pv_summary_1Q_2018.pdf.

Hawaii Ratepayer Protection Act: https://www.capitol.hawaii.gov/measure_indiv.aspx?billtype=SB&billnumber=2939&year=2018.

Hawaiian Electric Companies, Power Supply Improvement Plans (PSIP), Update Report: December 2016, December 2016, http://www.hei.com/CustomPage/Index?KeyGenPage=1073751924.

Sections 3 and 13, *Energy Storage and Distributed Energy Resources in the United States: 2017 Annual Review of Policies, Markets, and Key Trends*. EPRI, Palo Alto, CA: 2017. 3002010961.

6 For example, the New York Public Service Commission has granted performance based incentives to Con Edison in its Brooklyn-Queens Demand Management (BQDM) project, including linked to the impact of the following targets: peak demand reductions from customer-side DER, diversity of customer-side DER providers; and reduction in dollar/MW costs; see 2017 *Annual Review*, Section 10.

Wholesale Market and Resource Integration News

Next Steps for Storage in the PJM Regulation Market

Since late 2012, following some market design changes, the PJM Regulation market has provided the primary **market-based** opportunity for new energy storage technologies in the United States (all other storage development has taken place with some degree of federal or state financial subsidy or through long-term contracts under mandated utility procurements). As a result of a high market price and a favorable operating method, almost 300 MW of short-duration lithium ion batteries entered this market from 2012 to 2017, providing almost 50% of PJM's Regulation requirement by the end of 2017 (see Table 3). This stands as the most dramatic demonstration of the capabilities of new battery storage in the United States to date but has become contentious in the past two to three years as market design flaws emerged and rules were changed, leaving some storage projects uneconomic. The Federal Energy Regulatory Commission (FERC) recently sent PJM, the Energy Storage Association (ESA), and some storage developers to a settlement to develop more permanent solutions. This article provides some brief background and then gives a status report on the most recent developments.

Background on the PJM Regulation Market

The market rules for the PJM Regulation market are fairly complicated because PJM attempted to facilitate participation in one market product simultaneously by two classes of resources: those providing RegA—the "traditional" automatic generation control (AGC) signal—and those providing RegD—a "faster" AGC signal that could provide more effective control of area control error (ACE) under most operating conditions. Because the hourly procurement of regulation remains a fixed quantity (MW) in PJM, the market rules established a substitution method between RegD and RegA offers in which RegD supply was initially credited with a higher "effectiveness" than RegA supply, but this credit would decline using a "benefits function" as more RegD supply was selected in the market. In addition, PJM provided RegD resources with a 15-minute energy-neutral control signal. This signal is available to any RegD supplier, but it was intended to facilitate participation by lithium ion batteries and flywheels by allowing for optimal use of those resources if they had only 15–20 minutes of energy duration. Importantly, as originally designed, the 15-minute energy-neutral signal would charge or discharge RegD resources regardless of whether that action was supportive or deleterious to ACE. This rule was not significant to system operations when there were few batteries on the system but became more so as battery capacity expanded.

Table 3 shows that as a result of these favorable market conditions, a large number of short-duration batteries were installed over 2013–2015, eventually accounting for an almost 50% share of market in 2017. But as more batteries saturated the market, as the rule changes discussed next were enacted, and as market prices also fell in response to other factors (for example, less extreme winter weather in 2016–2017), average revenues also fell dramatically. By the beginning of 2018, market prices and battery revenues had picked up a little, but three battery storage units had retired since the prior period in 2017—and market share declined to around 34%.

PJM Market Design Changes

Several problems began to emerge in the Regulation market in 2015, notably difficulty by system operators to control ACE under some operational conditions due to the growing number of batteries operating under the 15-minute energy-neutral signal. PJM organized a task force to evaluate further design changes. In late 2015, PJM capped the quantity of RegD resources that could be selected in particular hours, which largely stemmed the influx of new batteries.

In January 2017, PJM made several further changes to the Regulation market design. Of greatest impact to battery storage, PJM modified the energy neutrality of the RegD signal, so that it would be "conditionally neutral" over 30 minutes. As described by PJM, under conditional neutrality, PJM will try to maintain energy neutrality over this now longer period but "when required by system conditions, the RegD signal will dispatch resources outside of their anticipated energy capabilities."

Recent Regulatory Developments and Next Steps

In March 2017, ESA and several storage developers and operators filed complaints with FERC arguing that battery units were experiencing significant reductions in performance and increased operational costs; they requested that PJM remove the cap on

Table 3. Battery revenues and market shares in the PJM Regulation market: 2014–2018 Q1

Year	Average Battery Revenue ($/MW of Regulation provided)	Battery Share of Market (%)
2014	36.78	16
2015	27.07	27.6
2016	15.39	41
2017	13.70	46.5
Q1 2018	28.32	34.1

Source: Derived from PJM annual and quarterly State-of-the-Market reports.

new RegD supply and revert to the 15-minute energy-neutral signal until FERC decided otherwise. One storage operator disclosed that before PJM changed the timing of the RegD signal, "projects were within 10 percent of net neutral 75 percent of the time; after the signal redesign, they were within 10 percent of net neutral only 10 percent of the time and have experienced a decreased performance score of approximately 11 percent." Other operators found that under the new signal, energy throughput and mileage increased substantially compared to the prior signal, leading to more rapid battery degradation. These findings were cited in the second FERC order noted next.

In October 2017, PJM filed at FERC to formalize these and other design reforms—including the 30-minute conditional neutrality—and to more accurately substitute RegD for RegA procurement while maintaining system control, asking for an effective date of April 1, 2018.

In April 2018, FERC issued two orders responding to these filings. In the first order, FERC rejected PJM's proposal and, in the second, reviewed the ESA and storage developer complaints and set a technical conference to examine these contested issues. Subsequently, the parties requested and FERC agreed that the issues should be addressed through settlement. The resolution of these issues will provide an important signal for battery storage development because it highlights how sensitive such resources are to changes in wholesale market design, including operating signals, and market prices. For additional background, readers can also turn to the focus topics in the Annual Reviews, which have provided updates on this issue since 2015.

References

The relevant FERC docket numbers are EL17-64 (ESA complaint), EL17-65 (storage developer complaints), and ER18-87 (PJM filing).

Many relevant PJM documents can be found here: Regulation Market Issues Senior Task Force (closed), http://www.pjm.com/committees-and-groups/closed-groups/rmistf.aspx.

Section 15, *Energy Storage and Distributed Energy Resources in the United States: 2017 Annual Review of Policies, Markets, and Key Trends*. EPRI, Palo Alto, CA: 2017. 3002010961.

FERC Staff Report and Technical Conference on Distributed Energy Resources

On April 10–11, 2018, FERC held a technical conference on the participation of DER in the wholesale markets (under Docket Nos. RM18-9-000 and AD18-10-000). The conference materials include a previously issued staff report, *Distributed Energy Resources: Technical Considerations for the Bulk Power System* (February 2018), as well as transcripts and participant presentations. The staff report is focused on reliability impacts of DER and includes both literature review and modeling conducted by FERC to evaluate different aspects of DER operations and system impacts. For its power flow studies, FERC staff used EPRI's OpenDSS modeling tool and distribution feeder models; several EPRI reports were cited. With respect to potential reliability issues, the report identifies the following areas for improvement to ensure reliable integration of DER:

- The lack of DER data and the resulting implications for the operation, planning, and design of the bulk power system
- The need for coordination between the settings and capabilities of resources connected to the bulk power system and DER
- The need for improved modeling practices and capabilities for DER
- The effect of DER daily generation profiles on system unit commitment and ramping needs
- The effect of distribution-connected variable PV and wind output on day-ahead load forecasts

The technical assessment section of the paper concluded that the following topics require further investigation:

- The impact of the current common industry modeling practice of netting DER with load, which may mask the effects of DER operation
- DER capabilities for voltage and frequency ride-through during contingencies
- The potential for improved voltages due to the unloading of the bulk power system associated with the location of DER at or near customer loads
- Potential effects on systemwide transmission line flows and generation dispatch due to changing load patterns
- The sensitivity of voltage or power needs to different types of DER applications (that is, providing energy, capacity, or ancillary services)
- The need to develop planning processes that capture more detailed models of DER and allow for modeling of the interface between the transmission and distribution systems to enable information exchange and more accurate calculations of the DER impact on the bulk power system
- The advantages and disadvantages of allowing DER to participate directly in the organized wholesale electric markets

At the conference itself, key issues raised included most of those noted in the paper, including coordination between distribution utilities and the ISOs/RTOs, ensuring sufficient visibility of DER to the system operators and improved processes and agreements to support operational reliability, and the need to improve analysis of DER in planning. Participants from California, New York, and ISO-New England as well as several utilities discussed the progress made in their regions on these topics, some of which have been reviewed in previous issues of *Strategic Intelligence Update*.

FERC also requested post-conference stakeholder comments and issued 47 questions for consideration. The complexity of some of these questions—which address transmission, reliability, and operational impacts of aggregated DER as well as the new processes for coordination discussed previously—leads us to conclude that it may be some time before FERC issues a final rule on aggregated

DER participation in the markets. A large number of stakeholder comments is expected as FERC continues its inquiries on this topic.

References

All materials are available on the FERC website under the relevant docket numbers. Technical conference materials can be found here:

ISO-New England DER Market Participation Models and Current Resources

As part of the FERC technical conference discussed previously, ISO-New England provided a description and tabulation of the DER of all types in its market—information that is not always easily organized in this way. This article describes how DER participate under wholesale market participation models as well as current and forecasted DER capacity.

Settlement-Only Resource Model

The Settlement-Only Resource (SOR) model is restricted to resources of 5 MW and under, which may be connected to the distribution network. The SORs, which include most small renewable generation (see Table 4), are *price-takers*—which simply generate in real time and have no bidding or scheduling obligations in either the day-ahead or real-time markets, nor are they subject to ISO dispatch or telemetry requirements. For SOR supply into the energy market, there is no minimum size requirement, but for offers into the capacity market, the minimum size is 100 kW. Because they do not have dispatch or telemetry requirements, they are not eligible to supply operating reserves, but they can provide frequency regulation if they also qualify under the ISO's Alternative Technology Regulation Resource (ATRR).

Demand Response Model

The Demand Response (DR) model has been implemented at ISO-New England since 2001, with full integration into the capacity market in 2010 along with modifications to allow for participation in the energy and reserve markets taking place in several steps from 2012 to 2018. There are two types of DR: passive and active. Passive DR, which do not respond to dispatch instructions (such as solar PV and energy efficiency) are nevertheless eligible for the capacity market. Active DR, which can respond to dispatch instructions and include active load controls and storage, are eligible as capacity resources and can also submit offers into the energy and operating reserve markets.

DER Capacity in 2018

ISO-New England estimates that 16% of its current wholesale market is composed of DER, which use the existing SOR and DR market participation models. Table 4, excerpted directly from the ISO-New England comments, shows the quantities of different DER under each participation model. As of January 1, 2018, ISO-New England counts 5,625 MW of DER, of which 4,093 MW participates in the wholesale markets using one of the current participation models.

New England DER Forecasts

ISO-New England conducts annual forecasts of DER within its footprint, using a transparent methodology. In its 2018 forecast of distributed PV, the ISO forecasts 6,841.3 MW by 2027. The

Table 4. New England Distributed Energy Resources as of 01/01/2018

Distributed Energy Resources Category	SOR Nameplate Capacity (MW)	DR Maximum Capacity (MW)	Total DER Capacity (MW)
Energy Efficiency	-	1,765	1,765
Demand Response (excluding behind-the-meter DG capacity)*	-	99	99
Natural Gas Generation	26	331	357
Generation Using Other Fossil Fuels	75	268	344
Generation Using Purchased Steam	-	19	19
Non-Solar Renewable Generation (for example, hydro, biomass, wind)	523	126	649
Solar PV Generation participating in the wholesale market	810	48	858
Electricity Storage	1	-	1
Solar PV Generation not participating in the wholesale market	-	-	1,532
Total DER Capacity	1,436	2,656	5,625
Total DER Capacity/Total Wholesale System Capability**	4.1%	7.5%	15.9%

** To avoid double-counting, demand response (DR) capacity reported here excludes any behind-the-meter DG capacity located at facilities providing DR. Registered DR capacity as of 01/2018 (MW): 684.*

*** System Operable Capacity (Seasonal Claimed Capability) plus SOR and DR Capacity as of 01/2018 (MW): 35,406.*

ISO also develops its own forecast of energy efficiency contributions to electric energy savings (MWh) and peak demand capacity (MW) in the region. This forecast tends to predict declining incremental energy efficiency contributions over time, a result that is contested by stakeholders. In addition, several states in the region—notably Massachusetts—have begun to implement energy storage policies (see Table 1), that include distributed storage projects.[7]

References

The ISO-New England comments, which include Table 4, are here:

7 The Massachusetts Advancing Commonwealth Energy Storage (ACES) Demonstration Projects, which include a number of distributed solar and storage projects, are listed in Table 4-7 in the 2017 *Annual Review.*

https://www.ferc.gov/CalendarFiles/20180410100927-Yoshimura,%20ISO%20New%20England.pdf.

ISO-New England, Final 2018 PV Forecast, May 1, 2018, https://www.iso-ne.com/static-assets/documents/2018/04/final-2018-pv-forecast.pdf.

ISO-New England, Energy Efficiency Forecast, https://www.iso-ne.com/system-planning/system-forecasting/energy-efficiency-forecast.

In Case You Missed It: Recent Industry News and Deployments

Tesla, Enphase Increase Price of Residential Energy Storage

In recent months, the cost of residential battery storage has seen a significant increase, with leading manufacturers Tesla and Enphase raising their prices. The rising prices have been driven by supply shortages as well as the rising market price of cobalt—a key raw material used by many battery manufacturers, including Tesla. Enphase uses lithium ion phosphate batteries and would not be impacted by cobalt prices. Despite the price hikes, battery storage technologies are becoming increasingly popular with Australian consumers, with residential battery storage installations expected to increase to 33,000 installations this year, up from 21,000 in 2017.

EPRI Perspective: Residential energy storage has also become increasingly popular in the United States. In California, Self-Generation Incentive Program (SGIP) applications for residential energy storage have increased dramatically in 2017 and 2018. Favorable utility rates and long-term financing have made energy storage increasingly accessible to residential customers in California. A confluence of factors including raw material costs, installation costs, economies of scale, and increased demand highlights the importance of watching energy storage costs closely over the next several years.

Recently Published: *Energy Storage System Permitting and Interconnection Process Guide for New York City: Lithium Ion Outdoor Systems*

A consortium of New York entities published this guide in April 2018 to define the approval processes, including permitting and utility interconnection, relating specifically to Li ion systems in place in outdoor settings in NYC. (A guide for indoor installations is under development.) This document can be found here.

NFPA 855 First Draft Is Now Open for Review

The National Fire Protection Association (NFPA) has recently released its first draft of NFPA 855 Standard for the Installation of Stationary Energy Storage Systems. There was a first round of public input in late 2017 and the draft has substantial changes from what was initially disseminated. The current draft was released for public review on May 3, 2018, and NFPA will accept comments through July 12, 2018. Visit https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=855&tab=nextedition for links to review and provide comments. Following the period of public input, the 855 Technical Committee will meet in Salt Lake City and develop proposed revisions. Posted information indicates that a second draft will be posted on November 1 with final release scheduled for 2020.

EPRI Perspective: Storage safety codes, standards, and regulations are continuing to evolve to address the changing technology landscape as well as concerns that legacy fire suppression systems are inadequate to suppress battery fires. The impacts these new standards and guides have on storage permitting, placement, project costs, and timing could be significant. Recently published standards include UL9540, NFPA 1 (Fire Code), NFPA 70 (NEC- 2017), and the International Fire Code (IFC 2018). These standards, among others, were adapted or revised to include more specific information on lithium ion and flow battery technologies and frame new fire safety systems and their applicability to various storage technologies. It is important for members to understand the timelines and impacts related to modifications of these standards along with the opportunities to review and comment on standards as they evolve. Another consideration is the timing of adoption of these standards by local Authorities Having Jurisdiction. It is important to be aware of emerging codes and standards to understand potential project impacts. EPRI is addressing the evolution of these standards in a risk assessment framework through a safety guideline to be published this year through Project Set 94C and through efforts with the Energy Storage Integration Council (ESIC).

Salt River Project Residential Energy Storage Incentives

In May 2018, one of Arizona's largest public utility providers announced a new program aimed at offering residential customers support for installation and use of battery storage systems. Salt River Project (SRP) launched the program offering up to $150/DC-kWh for the first 4,500 customers over the next three years who purchase and install a lithium ion battery system, for a total cost savings of up to $1,800 per customer. Goals of the project include assisting customers with reducing their own demands from the grid system, looking at system performance in Arizona's desert environment, and studying how customers use these systems. SRP is hoping that this program will provide further insight into how battery storage systems affect customer energy use and grid usage.

EPRI Perspective: From a recent interview with SRP, EPRI has learned the utility has installed ~120–180 residential batteries to date, and has reservations for another 2,500+ as a result of SRP's ES incentive program. Virtually all of these distributed batteries will be affixed to solar. It's unclear, however, how many of the reservations will actually be deployed. In general, to the extent to which ESSs positively impact a utility is likely to be correlated to the incentives in place. Providers of residential PV plus energy storage often state that customers purchase ESSs with visions of "grid independence," "backup power," and security against rate changes. Once the systems are installed, customers are more likely to change their energy storage use profile based on financial incentives created by time-of-use rates, for example.

California Becomes First State to Order Solar on New Homes

In May 2018, The California Energy Commission voted in favor of requiring solar panels to be installed on new residential homes built after January 1, 2020. These standards fall under Governor Jerry Brown's goal to cut carbon emissions across the state by 40% by 2030. California has the nation's largest solar market, and the commission is hopeful that this housing mandate decision will provide an example of renewables implementation for other states to follow. With the state building around 80,000 new homes annually (approximately 15,000 currently including solar), and a typical home using 2.5–4 kW of panels, California can expect to see around 260 MW of added solar capacity per year to its energy portfolio. Critics warn, however, that this new solar rule may increase individual home prices by $10,000—a cost that would be offset by around $19,000 in energy and maintenance savings over a 30-year period.

EPRI Perspective: New housing developments with high penetrations of PV are likely to create new challenges for utilities in California. Localized penetrations of PV may create voltage, capacity, and reverse power flow issues and will add to California's famous duck curve. New opportunities to incentivize west-facing solar and behind-the-meter energy storage solutions may help mitigate some of these challenges. Opportunities for utility-sited storage will also exist.

South Australia's Grid Service Costs Slashed by 90% by Tesla Battery

A recent report presented at the Australian Energy Release Conference states that the Hornsdale Power Reserve (HPR) project with a 100 MW/129 MWh Tesla battery has reduced frequency control ancillary services (FCAS) market prices in the country by 90% during the first four months of the system's operation. It has been estimated to be a savings of $35M AUS for frequency ancillary services. The adoption of the HPR is just one of Australia's current undertakings to develop multiple large battery projects to manage the grid and implement more renewable energy technologies.

EPRI Perspective: Storage penetration has the potential to affect ancillary services prices in a dramatic way. As discussed in the section on PJM Regulation market updates, increased competition and battery market share resulted in a decrease in prices for frequency regulation services. In addition, the demand for frequency control is a small fraction of peak demand, so that market may saturate quickly. The HPR system has been operational only a few months, so there really aren't enough data to generalize the results. The article does not provide enough information to determine whether society received more value from price decline versus the contract cost to Tesla. However, this still shows an important source of storage value that would not be seen in a standard project valuation—similar to what StorageVET does. Societal value needs to be understood in order to comprehend the total rate impacts to end customers.

Hydrostor to Convert Old Mine Site in Australia into CAES Plant

In April 2018, Toronto-based company Hydrostor, developing adiabatic compressed air energy storage (A-CAES) technology, announced plans to construct a 5 MW A-CAES system in an existing mining cavern in South Australia—its second facility using underground caverns. A-CAES technology involves compressing and storing ambient air in an underground cavern. The air can be heated and expanded when electricity is desired, powering a generator. This process increases efficiency within power generation systems and does not require additional heat sources. The facility will participate in energy time shift, frequency regulation, inertia, and black start services. The plant is expected to be operational by early 2019, with plans to add 5–10 MW of solar capacity. Hydrostor's first cavern facility is a 1.75 MW, 7 MWh project now under construction in Ontario, Canada.

EPRI Perspective: EPRI has been tracking the development of Hydrostor's technology in the bulk storage research area. Hydrostor's core technology innovation is in the thermal subsystem. Its distinction from traditional CAES is that it can be installed almost anywhere and is not restricted to mine sites or salt domes. For more information, Hydrostor technology was evaluated in Strategic Intelligence Update, November 2017 and Bulk Energy Storage Interest Group: 2017 Webcast Summary.

ARPA-E Long-Duration Storage Funding Opportunity

The Advanced Research Projects Agency for Energy (ARPA-E) recently took proposals for a R&D funding opportunity to develop technologies for long-duration energy storage, called the DAYS program ("Duration Addition to ElectricitY Storage"). Proposals were due on July 2, 2018. The opportunity sought technologies suitable for electricity in/electricity out storage facilities that can discharge at full rated power for 10-100 hours – dramatically longer than systems now being installed. The focus on very long durations is motivated by the anticipation of very high renewable generating capacity in the future, leading to very low cost electricity available for storage. Consistent with ARPA-E's mandate, the opportunity also sought high-risk technology approaches that are distinct from those currently being designed for 8 to 10 hour systems. The call was open for projects ranging from development of individual technology components to demonstration of a complete, sub-scale storage system, and anticipates funding awards of $500,000 to $10 million. Although this funding opportunity was focused on technology development and not demonstration projects, ARPA-E stated its interest in a subsequent phase of the program to fund demonstration of innovative storage technologies. Funding awards are expected in September 2018. (A link to the full announcement is here.)

EPRI Perspective: EPRI is participating in multiple proposals to the DAYS program in partnership with technology developers, including to contribute technoeconomic analysis and tech-to-market guidance.

Younicos Launches Energy Storage Rental Business Model

In March 2018, Berlin-based energy company Younicos debuted its Energy-Storage-As-a-Service program, which allows customers to rent storage devices instead of purchasing them outright. Customers pay a rental fee along with mobilization and demobilization charges to rent individual systems for a two-to-four-year period. Storage devices are housed in moveable containers, shipped to sites, operated by Younicos, and moved when conditions change. The company has plans to launch multi-month contracts in the future. Analysts believe that this type of service demonstrates a trend toward differentiation in energy business models, with companies offering financial incentives for customers to invest in their products.

EPRI Perspective: StorageVET could be used to understand the potential benefit of this business model over a more traditional utility ownership. Although this business model is not explicitly handled in StorageVET, the financial results could be modified to fit the model. A key component in the analysis would be to understand any dispatch limitations in the rental agreement.

Deployment Announcements

Project	Status	Notes
Microgrid with 30 MW/1.4 MWh battery in Australia	Operational	Integrated with existing gas turbines to provide spinning reserve and backup power; Kokam was the integrator and battery provider, and ABB provided microgrid controls. Kokam Press Release
Orsted's 20 MW storage in Liverpool, UK	Planning permits in place; expected operational by end of 2018	Orsted's first battery storage project; NEC Energy Solutions is supplier of battery energy storage system, Shaw Energi is supporting execution; ESS will provide services to National Grid. Orsted's Press Release
200 MW battery in Midlands of Ireland	Announced; timeline not yet given	Lumcloon Energy to partner with Hanwha Energy Corporation and LSIS on two 100 MW storage projects; system will be used to provide frequency response to balance the grid.
30 MW solar plus 20 MWh storage in Tibet	Operational	Plant run by China Shoto, part of Shuandeng Group; expected life is 10 years; sixteen 40 ft containers of lead carbon batteries. China Soto Press Release
32 MW virtual power plant (VPP) in Belgium	Operational	REstore's 32 MW VPP includes an 18, 22 MWh Tesla system; VPP is providing primary frequency response and participating in the real-time balancing market. REstore Press Release
750 kW solar plus 500 kWh storage system in Oahu, Hawaii	Expected completion 2019	EnSync Energy Systems signed a 20-year PPA with Michaels Development Company to supply solar plus storage at a housing development; storage equipment will be connected by EnSync's DC-Link Technology that allows for sharing of the energy between customers. EnSync Press Release
20 MW solar plus 10 MW storage in Arizona	Operational	NextEra Energy and Salt River Project (SRP) worked together on the Pinal Central Solar Energy Center integrating a 20 MW PV plant with battery and 10 MW lithium ion system; SRP will purchase all energy produced at the plant under a 20-year PPA; plant is owned and operated by subsidiary of NextEra. SRP Press Release
SRP 10 MW, 40 MWh stand-alone storage	Under construction	AES, Fluence to supply storage, Mortenson is EPC; storage will be used for peak capacity and to support the integration of variable renewables. Fluence Blog
Pumped hydro plus batteries in Bavaria	Operational	Engie built a 12.5 MW Siemens lithium ion system at a pumped hydro site; battery to provide balancing services.
8.96MW/9.8MWh battery at former German coal-fired power station	Operational	Daimler and Mercedes-Benz Energy's new storage facility will serve as "live replacement parts storage" for its third generation electric vehicle fleet while also providing primary balancing power to German market. Daimler Press Release
10MW, 42MWh storage at existing Texas solar plant	Announced, estimated completion late 2018	Vista Energy contracted with integrator, FlexGen to integrate a 10MW/42MWh lithium ion storage system at the existing Upton 2 Solar Power Plant; When installed it will be Texas' largest storage facility. FlexGen Press Release

Energy Storage and Distributed Generation Program Activities

Recent Publications and Webcast Recordings

	Title
94D	EPRI Capacity Value of Storage Update Webcast* Bulk Energy Storage Interest Group (BIG) Webcast*
94E	Grid Interactive Microgrid Controller Evaluation for Resilient Communities: Laboratory Testing, Field Testing, and Performance Evaluations [3002010909]
Other	Supplemental – Integrating Energy Storage System with Photovoltaic Generation: Analysis within Los Angeles Department of Water and Power (LADWP) Service Territory to Meet SB801 Requirements: Interim Report** [3002013007] Entergy New Orleans Solar Power Plant: Research Highlights** [3002014079]

*Webcasts recordings are available at the EPRI Member Center P94 Meeting and Events tab
**Denotes publicly available

Active Collaborative Supplementals

Energy Storage Analysis Finding, Designing, and Operating Projects [3002011930]

Energy Storage Implementation Practices: Building Organizational Capability for Deployment [3002012514]

Energy Storage Performance and Reliability Data Initiative [3002011755]

This section includes notes from recent conferences and meetings attended by EPRI staff. Visit the event websites for more specific information about speakers and session topics. Opinions, statements, and claims by companies have not been vetted by EPRI and are not a reflection of EPRI's position on certain topics, but they are documented to reflect what was heard during presentations and conversations with the exhibitors.

Energy Storage North America (ESNA) Solar+Storage Summit, Regional Event

March 27 | San Diego, CA

ESNA's Solar+Storage Summit featured presentations geared toward solar installers and integrators. The following are notes from the sessions.

Business Case and Value Proposition for Behind-the-Meter C&I Solar+Storage Applications in California

- Engie notes that in territories where NEM does not exist, storage can result in an increase of solar sizing by 20–25%.

Business Case and Value Proposition for Behind-the-Meter Residential Solar+Storage Applications in California

- Main selling points for residential solar (as defined by specific providers of residential solar + storage) include backup power, energy independence, hedge against rate changes (future proof solar savings).
- Demand and time shifting still confuse the average customer at this time, but that customer will use the battery for these purposes after the initial sale. Sunrun noted that most customers come for the backup power and stay for time-of-use (TOU) reductions. Cinnamon Energy Systems says that talk of arbitrage causes the customer's eyes to glaze over, whereas backup power gets people excited. Topics like backing up the fridge, hot water heater, EV, and heat are all exciting.

Business Case and Value Proposition for Low-Income and Multi-Family Solar+Storage Applications in California

- SDG&E filed $2M proposal with the CPUC to offer up to 4 MW energy storage (no MWh component to proposal) to homeless shelters, nursing homes, and low-income housing. SDG&E wants to offer energy storage at $1.20/Wh and is investigating 24 sites with cap of $75K per project. SDG&E recognizes that low-income individuals are exempt from TOU, but building owners are mission-driven and may share savings with their renters.
- SCE is investigating a new tariff for multi-family homes, which account for 19% of homes in their territory. These customers have few, if any, programs to assist them at this time.

How to Succeed in the Self-Generation Incentive Program (SGIP)

- There has been a large uptick in residential storage applications. Prior to 2017, nonresidential systems had higher applications rates than residential. In 2017 and 2018, SGIP received more than five times as many residential applications compared to nonresidential.
- Initially most residential systems were installed as part of a Tesla and Southern California Edison pilot project, but that is no longer the case.

IEEE PES T&D Conference

April 17–19 | Denver, CO

The overall theme of the conference presentations relating to DER—specifically solar PV and energy storage—centered on the impact of declining inertia stemming from the retirement of synchronous-based generators and the growing amount of inverter-based resources. There was a lot of discussion on the potential of storage providing primary vs. fast frequency response to address this change. Other topics touched on the role of DSO vis a vis an ISO as well as the impacts of upcoming revisions to the IEEE 1547 standard to accommodate smart inverter functionality. Specific sessions of interest are noted next.

Applications of Energy Storage in Power Delivery Systems: Real-Life Experiences

A variety of utilities relayed experiences with storage in this session. Duke, National Grid, and Entergy highlighted their various storage projects. The key lessons learned displayed by these utilities included:

- Controls must be fast and reliable
- Looked for solutions that are scalable and interoperable
- Understand your use cases (don't try to do volt control on a feeder with stiff voltages)
- Develop process and methodologies for repeatable projects
- As complexity increases, so does O&M
- Thermal management (HVAC) is the Achilles heel of storage reliability
- Don't ignore standby losses: they can rise to 15–25% per day

EPRI Perspective: Many of the lessons learned that were highlighted in these presentations are being experienced by many storage owners. EPRI has initiated research through its Energy Storage Performance and Reliability Data Initiative in which field data and experiences are guiding development of a mature storage reliability database.

Power System Reliability with High Penetration Renewables Resources: Challenges and Opportunities

- NERC presented new recommendations centered on network-based inverters associated with large PV systems. The issue at hand is the instability that could be created when numerous inverters trip due to system disturbances. The recommendations are centered on replacing current functionality with a ride-through capability to prevent large-scale resource loss.
- PJM furthered the discussion on how storage can help mitigate this issue, especially in assisting steam generators to trim voltage and frequency excursions, because the fossil units are not likely to respond quickly enough. PJM also noted that distributed resources currently contribute 37% of the total frequency response-based units, but demand response capacity has been declining since 2006.
- TVA discussed similar network-based issues, pointing specifically at the impact of inverter-based generation on the bulk power system dynamics and short-circuit performance of inverter- vs. fossil-based units. It also re-emphasized that current protection schemes are well-suited to the emergent resource mix.

EPRI Perspective: A noted gap in many of the discussions pointed to the need for distributed resources to be better aligned with current protection schemes or be better able to adapt. A general theme was that inverter-based resource vendors need to better understand how utilities protect their networks and tailor their offerings appropriately to the realities of system protection schemes. EPRI is conducting numerous studies and modeling efforts to better understand how new inverter-based resources can appropriately align to protection schemes and, alternatively, how the future protection schemes can be modified to better accommodate these new resources as well as the specific role that energy storage can effectively play in these scenarios.

Energy Storage Association (ESA) Annual Conference and Expo

April 18–20 | Boston, MA

The 28th Annual ESA Conference was held in April 2018 in Boston, Massachusetts. See the conference agenda for full session descriptions and speakers.

Grid Modernization Keynote

- Fluence claims up to 30% balance of system (BOS) cost reduction in DC-coupled system compared to AC-coupled system.
- Solar Massachusetts Renewable Target (SMART): Proposed "adders" or additional incentives when storage is installed with the solar PV.

EPRI Perspective: It is not clear what components are included in Fluence's BOS cost reduction calculations, but GTM estimates that BOS makes up approximately 44% of the total installation costs for a 4-hour system. This could mean a 13% reduction in total project installation cost. Cost savings may be attributed to factors such as lower inverter costs, shared infrastructure build-out, or less auxiliary equipment.

Keynote by Bruce Walker, Assistant Secretary of Office of Electricity and the Acting Assistant Secretary of Cybersecurity, Energy Security, and Emergency Response (CESER)

Assistant Secretary Walker kicked off with a discussion of the newly established CESER office within DOE, which will include energy storage, as an important resilience asset. He discussed five initial goals of this new office:

- Goal #1: Execute an initiative to work with the Puerto Rico Electric Power Authority (PREPA) to ensure a more resilient system for the islands, including Puerto Rico and the U.S. Virgin Islands. He mentioned a goal of N-1-1-1 level resiliency and more effective usage of NOAA modeling for wind and solar output forecasting.
- Goal #2: Bring lessons learned from the Puerto Rico experience and apply to the full U.S. power system, as applicable. Improve

situational awareness and real-time data availability, involving Canada and Mexico.

- Goal #3: Leverage best available operating strategies today. He mentioned an upcoming funding opportunity announcement (FOA) for $25M to "fix cybersecurity."
- Goal #4: Deploy widespread synchrophasors to improve transmission system monitoring to add to the 2,500 already deployed.
- Goal #5: Deploy energy storage for power system stability and to advance national security through mitigation of physical and cybersecurity risks. He further noted that the objectives for high-priority deployment will be Department of Homeland Security Tier 1 and 2 critical facilities, which include the water and wastewater infrastructure, communications, and banking sectors. He stated: "storage provides opportunity, not only to mitigate, but eliminate, cyber-risk."

A Developer's Primer on Launching Solar+Storage Projects for Residential Properties

- APS is receiving ~30 storage interconnection requests per month. Storage is being primarily used for backup and does not have a data connection. Arizona is offering a rebate of $1800. Storage is always installed with solar by an integrator as a resilience upsell.
- Germany has ~90,000 residential storage systems operating at 500 MW. Pure economics suggest that solar only is the best return, but early adopters are driven by desire to self-consume PV due to falling feed-in electricity tariff (FiT).
- Average system size:
  - Sunrun: 8 kW PV, 5 kW/10 kWh BESS, four critical loads
  - Sonnen: 12 kWh in U.S.; 5.5 kWh in Germany

Getting Down to Business in the C&I Sector

- EDF Distributed Solutions has several business models: sell and operate, shared savings, and lease guarantee. Its biggest challenge is project financier risk avoidance.
- Engie plans to transition from BESS only to solar PV plus BESS; Engie's business models are similar to EDF's.
- ENEL X is moving customer acquisition efforts to Ontario; NYC, NJ, and MA currently challenging to sell C&I.

What You Need to Know to Tackle and Execute Solar+Storage Projects

- Cypress Creek's biggest challenge: PJM market constructs do not clearly define solar plus storage (FERC Order 841 may help).
- RES's biggest challenge: How to best package system to reduce costs.
- Borrego's biggest challenge: Interconnection criteria for various utilities.

Utilities Reveal Key Lessons on Storage

- National Grid provided several lessons learned on site preparation, including 1) plan communications integration at the early design stage so that relevant site requirements can feed into the site plan (for example, routing conduits efficiently), 2) deposit full documentation at the project site in a weather-rated cabinet—useful for later reference by field staff ("as-built document cabinet"), 3) size concrete pads with ample workspace (that is, with wide margins around cabinets/enclosures) to provide level work space for personnel and their tools.
- Doosan highlighted when sizing storage capacity on solar plus storage projects (that is, ratio of MW storage to MW solar), keep in mind whether the primary functions of the storage facility are related to the PV power capacity. If primary functions are frequency control and voltage support/balancing, these are dynamic functions not directly related to PV output.

Energy Storage Integration Council (ESIC) General Meeting

In addition to participating in the conference activities, EPRI also organized an ESIC General Meeting at National Grid's Waltham headquarters. Notes from the ESIC meeting can be found on the ESIC collaboration website (collab.epri.com/esic).

The Battery Show: Europe 2018

May 15–17 | Hanover, Germany

The Battery Show Europe is a trade fair featuring manufacturers and service providers focused on advanced battery technologies.

Key takeaway from the Exposition Hall: Many companies are working to address battery thermal management and longevity issues as well as fire safety and thermal runaway. Paradoxically, some companies are filling interstitial areas between cells with thermally conductive adhesive for better heat distribution; others are filling with insulating foam to prevent thermal runaway propagation. Competing design objectives need to be balanced for battery pack design.

- Primary sponsor Paraclete has technology to address issues with silicon anode limitations. Silicon anodes have the potential to offer significant improvements in energy density but have historically had significant issues with cycling and durability due to material expansion during charge/discharge and fracture of the silicon when in contact with electrolyte. Paraclete has developed technology to mitigate silicon fracture—a new SEI layer forms when crack begins. CEO Jeff Norris indicated that most silicon anodes will fail after fewer than 50 cycles, and Paraclete claims 300–600 cycles >80% at 100% DOD with a similar cost to graphite anode. Paraclete's business model is to work with cell chemistry developers to develop tuned blends to incorporate silicon into their technology.
- LORD has developed "liquid dispensed gap fillers" (under trade name *CoolTherm*) of thermally conductive adhesives to draw heat from individual cells and promote uniformity. LORD indicated that its technologies have historically been very expensive and low quantity, but now their materials are being incorporated into several automotive designs—including Tesla. They noted lifetime characteristics are important for increased car-sharing applications that experience heavier duties.

- Diabati is a Belgian company using artificial intelligence to develop optimized heat transfer designs for many applications, including battery and motor cooling, which it claims can increase cooling performance by 30%.
- H.B. Fuller has developed flame-retardant encapsulation foam (thermal insulation) to stop propagation of thermal runaway. It should be noted that this is the opposite approach to LORD's heat conductive adhesives.
- Cape Bouvard Technologies is an early-stage Australian company working on a design that incorporates thick metal foils bent into custom shapes to serve both structural and thermal management functions with higher pack energy densities.
- Solvay is a French company developing several Li-ion chemistry enhancements, including fluorinated additives for Li-ion electrolytes to improve cycling performance of NCA/LCO with graphite, LiTFSI electrolyte salt that demonstrated higher cycling and lower degradation under storage (that is, improved calendar life), and ionic liquids based on TFSI for high-voltage Li-ion electrolytes.
- RIVA showed a modular LFP Li-ion grid system (AC) of 0.75 MW/1.36 MWh (usable)/1.7 MWh nominal under the trade name *Power-MRack*. It claims >90% RTE with a footprint approximately the size of a 20-ft container. Highlights include a "contactless connection of the battery cells to the battery case by means of induction—they can be removed and replaced during operation, safely and without prior electrical knowledge ('hot-swappable')," according to RIVA's marketing materials.
- Umicore is a leading supplier of cathode materials to the battery industry. Umicore uses its recycling stream for cobalt, nickel, and lithium to remanufacture, but it is a relatively low percentage of the total volume produced. It noted that design for disassembly and remanufacture is highly variable across manufacturers.

GTM Forum: Energy Storage vs. Gas

May 21 | New York, NY

The major challenge for storage as peaking capacity discussed in this conference was market design—designing markets to send the right price signals so that the optimum amount of each resource (renewables, fast response gas peakers, storage, transmission, and so on) is procured using scarce capital. This is a question of fundamentally changing market structures to internalize the full set of values that storage and every other resource can provide. There is concern about how long market redesign can take and the number of stakeholders that must be satisfied to do so, but the general agreement among speakers seemed to be that it is necessary.

Following is a summary of the key points in each session. A detailed agenda with speakers can be found on the GTM website.

Economics of Peaker Plants

- Interesting statistics presented:
  - 84% of peaker plants have a capacity factor under 10%.
  - 73% of peaker plants generate for less than 8 hours per start.
  - In California, the median capacity factor is 6% (twice the national average) for 3.6 hours (much less than national average).
  - By 2025 in SCE territory, only 223 hours in the year when CA's peakers are utilized at >25% and only 17 events lasting >4 hours.
- GTM's major claim was that 32% of gas peakers are "at risk" from 4-hr storage by 2022.

EPRI Perspective: GTM's analysis does not consider the expected decommissioning times for all the peakers in the current fleet, and it is worth noting that there were some issues with the analysis. The comparison between energy storage and gas peakers was done on a gross cost basis, neglecting differences in lifetime and other value streams. If these effects were included, the percent of peakers at risk to storage would be higher. It was assumed that a storage system could replace a peaker if its energy capacity is greater than or equal to the average energy content of the peaks (the energy delivered by the gas peaker it is replacing). In reality, this storage system would be unable to completely cover approximately half of the peaks it was called for. GTM also used LCOE to compare storage to peakers for a different analysis and quoted costs of energy storage in $/kW and $/kWh without providing the duration of the storage systems or even the general scale.

Fireside Chat with GE

- It's not clear to GE if wind + storage will be able to claim tax credits.
- GE won't likely make systems below 1 MW because it anticipates much system customization.
- GE thinks that energy storage investment should be directed toward flexible, modular implementations that benefit from being interchangeable with other technologies (that is, PCSs that can work with different energy storage media).
- Many cells don't come with reliable cycle life information. Because GE and others are warrantying 20-yr systems, they need to better understand degradation.

Surviving the Coming Storage–Natural Gas Collision

- NRG identified effective deployment of scarce capital as the biggest challenge for the climate change problem. The best solution probably involves both gas peakers and energy storage. The way to allocate capital effectively is to design markets to send the right signals that internalize the costs and constraints imposed by reliability criteria.
- NRG believes that requests for proposals should define the characteristics of what is needed and then let the proposals identify the best solution rather than identifying the technology up front.
- USAF prefers that a third party own and operate the storage for reliability and resilience.
- There is a lot of inconsistency in how utilities consider storage in their IRPs.
- The consensus was that storage can take off if the right market signals are sent.

Finding the Inflection Point: Expectations for the Economics of Storage Peakers

- There was not consensus among panelists as to whether storage is currently competitive.
- LCOE is not used to drive investments or determine what ratepayers pay but is widely used in analysis.
- New gas peakers are not being built in ISO/RTO areas—only in vertically integrated areas. Are the markets not capturing as much value from peakers as vertically integrated utilities can? Or is there something else driving this?
- Fluence claims that 4-hr storage can compete with peakers on an up-front cost basis with peakers ($1000/kW). Some places are building reciprocating engine peakers for their flexibility, but these come in at $1600/kW and aren't as flexible as storage.

Fireside Chat with Strategen

- Strategen believes that capacity—not energy—is what's going to cost ratepayers in Arizona over the next 15 years.
- In MISO, west-facing solar panels could be implemented to serve the peak cleanly without storage, although perhaps storage will be required as the renewable penetration there grows.
- For meeting peak load cleanly, there must be a risk-sharing mechanism between ratepayers and utilities (TOU pricing, demand charges, and so on). Flat billing is another option and gets utilities on board with energy efficiency programs, but there still needs to be risk-sharing somehow.

Should Natural Gas Owners Be Worried? (Panel)

- National Grid noted that in the ongoing electrification effort, the role natural gas plays in serving end-use energy is often undervalued. During a cold snap, the natural gas system can supply the equivalent amount of power to every electric power plant in the U.S. running flat-out. It would take a lot of investment to switch all of this power and energy to electricity. The speaker noted that natural gas can be produced from renewable energy and stored. This could be a solution.
- Commonwealth Bank of Australia noted that banks don't take technology risk. Risk must go down and the scale must come up for the banks to really engage. Energy storage will be a bank market before it's a bond market.
- Moody's Investors already sees storage as a viable alternative to gas peakers. The risk of stranded assets is nothing new, so it doesn't present an issue for banks as long as they are comfortable with the risk profile. Moody's Investors doesn't think technology risk exists for lithium ion batteries—the technology is well-understood, and we should instead think of merchant risk from unpredictable markets, financial risk from degradation based on the systems' operations, and so on. The better the use cases for storage are understood and defined and the more this understanding drives dispatch constraints, the better. This is different from gas peakers, which are well-understood and unconstrained.

FERC Order 841: The Outlook for Markets

- MISO's second highest concern for stakeholders in 2017 was addressing storage integration, behind addressing fast response AGC signals.
- NYISO currently considers energy storage as part of its energy-limited resources (ELR), a category that also includes NOx-limited gas turbines. It will be moving storage to its own category and may increase or decrease the current 4-hr duration limit for providing capacity. The move will also allow storage to qualify for all the value streams it can provide at once.
- PJM currently has a 10-hr duration limit for capacity resources. It will look into changing that for storage as a result of FERC Order 841.

EPRI Events

August 20–23: *Electrification 2018*, Long Beach, California

September 17–19: *PDU Advisory*, Atlanta, Georgia

October 16–18: *Energy Storage STUDIO and ESIC*, Charlotte, North Carolina

2018 Industry Conference Calendar

July 9–12: *Grid Evolution Summit*, Washington, DC

July 10–12: *Electrical Energy Storage North America*, San Francisco, California

September 11–13: *The Battery Show*, Novi, Michigan

September 24–27: *Solar Power International*, Anaheim, California

November 6–8: *Energy Storage North America (ESNA)*, Pasadena, California

December 11–12: *GTM Energy Storage Summit*, San Francisco, California

EPRI Contacts

Erin Minear
Strategic Intelligence Project Manager
eminear@epri.com
650.855.8706

Ben Kaun
Program Manager
bkaun@epri.com
650.855.2208

Haresh Kamath
Sr. Program Manager, Distributed Energy Resources
hkamath@epri.com
650.855.2268

Andres Cortes
acortes@epri.com
650.855.8616

Giovanni Damato
gdamato@epri.com
650.855.8588

Miles Evans
mevans@epri.com
650.855.2031

Aditie Garg
agarg@epri.com
650.855.2085

Evan Giarta
egiarta@epri.com
650.855.8619

Peggy Ip
pip@epri.com
650.855.8624

Karen Larsen
klarsen@epri.com
650.855.8741

Arindam Maitra
amaitra@epri.com
704.595.2646

Matt Pellow
mpellow@epri.com
650.855.8773

Ram Ravikumar
rravikumar@epri.com
650.855.8559

Robert Schainker
rschaink@epri.com
650.855.2104

Morgan Smith
mdsmith@epri.com
650.855.2226

David Stevens
dstevens@epri.com
650.855.7909

Joe Thompson
jthompson@epri.com
650.855.2587

Nick Tumilowicz
ntumilowicz@epri.com
650.445.3081

Eva Ulett
eulett@epri.com
650.855.7943

Brittany Westlake
bwestlake@epri.com
650.855.2103

Steve Willard
swillard@epri.com
505.366.7230

Rebecca Wingenroth
wingenroth@epri.com
610.777.8919

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303 USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com