2024 White Paper

Pathways to Improved Energy Storage Reliability

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Abstract

Energy storage systems are tasked with increasingly important roles in helping maintain grid stability and allowing accommodation of increasing amounts of renewable generation resources. Because of the relative infancy of storage technologies, these newer systems show gaps in achieving needed reliability and there is no firm understanding of long-term reliability, capacity degradation, and storage life. This paper explores the challenges in assessing reliability for the large span of storage technologies and current indications from reliability data. A framework for allowing more clarity in storage reliability is presented, along with survey results from EPRI members that highlight member needs in terms of reliability and emerging policy impacts. Potential solutions, which will be embodied in next-stage project efforts, are then listed.

Energy Storage Reliability Challenges

Over 15 GW[1] of energy storage has been installed in the United States alone, but it is difficult to firmly answer queries into how reliably these systems operate. Indications are that some storage systems are experiencing various issues and showing lower reliability compared to legacy electric utility assets. A wide variety of constituents—including utility executives who are directing substantial funding to procure storage capabilities, planners who are modeling storage in their resource mix, and operators who are using storage assets to manage the grid—are asking storage reliability questions, as well as technology developers and regulators and other entities that monitor systems and enforce grid reliability. To address these questions, EPRI is refining a framework to address storage reliability, based on experience with other utility assets and its experience monitoring storage system performance. This paper explores the challenges in assessing storage reliability, initial indications from system operations data, the variety of inputs and tools aligned to this framework, and a solution path to not only better understand storage performance and reliability but to also provide tools, guides, and results to improve these operational metrics.

Historic data from commercially oriented storage systems typically span less than five years, and there is little uniformity in the structure or extent of these operational

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[1] U. S. Energy Information Administrative. California Air Resources Board. Annual U.S. cumulative installed battery capacity (as of November 2023). https://www.eia.gov/todayinenergy/detail.php?id=61202

data. In contrast, reliability assessments of legacy utility assets are possible because of the availability of more than 30 years of operational data from a wide variety of equipment and manufacturers. With these robust legacy data, detailed equipment failure rates, failure mechanisms, prescribed maintenance procedures, and a firm understanding of asset life are tangible. However, there is a lack of energy storage operational data for the technologies in play that would provide similar, statistically valid answers to reliability questions. Furthermore, energy storage systems are deployed through various ownership models, including power purchase agreements (PPAs) or third-party-owned and -operated models. In these cases, important operational data are not always accessible to operators or off-takers.

Contrasting the assessment of storage reliability to legacy utility assets reveals numerous obstacles. The assessment of storage reliability is not only challenged by the lack of data (which are not uniform across systems) but is further complicated by the rapid technology growth and continued introduction of a wide variety of technology solutions and products. The most common storage technology currently being deployed is lithium ion, which itself appears in a variety of chemistries and configurations, each of which has distinct operational characteristics and supporting systems. Additionally, these features are continually evolving as manufacturers pursue better performance and lower cost. Aside from lithium ion, other emerging battery technologies have almost no track record of grid operations at scale. Additional complexities arise from integrating new storage control systems, with a wide variety of targeted applications storage, into legacy utility control networks.

Framework for Energy Storage Reliability Research

EPRI is addressing these challenges and advancing its storage performance analytics capabilities to further encompass storage reliability. The overall framework for EPRI's research links performance analysis to reliability analysis, which then informs maintenance leading practices and asset management practices. This is a continuous, circular effort that is informed by field data and experiences to further enhance storage reliability and economics, as shown in Figure 1.

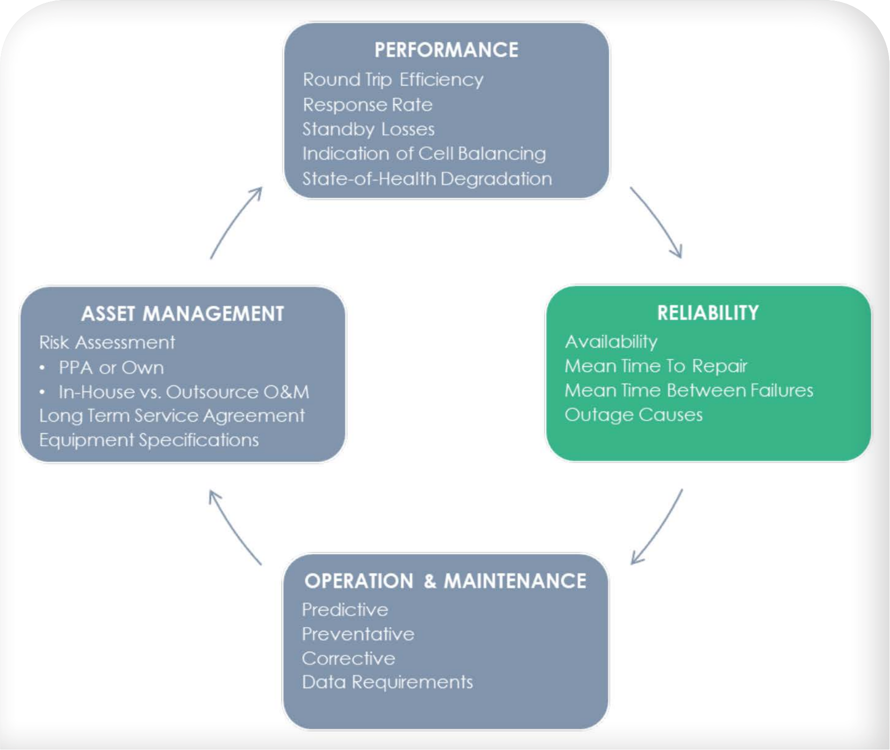

Figure 1. *Framework for research into storage reliability*

This refinement of a storage reliability framework draws on EPRI's extensive research and expertise in assessing the reliability of legacy assets such as generating units, transformers, and other equipment. It also leans on reliability research on similar inverter-based resource (IBR) data, and attendant policies and reporting requirements to allow for deeper understanding of storage system operational characteristics. The ultimate focus is on the individual components of these storage systems and their contribution to suboptimal system performance.

The intent of this effort, as shown in Figure 2, is to understand problematic components and to define better specifications, designs, level of component quality, software tools, and leading operational and maintenance practices to better ensure optimal performance. This framework also accommodates EPRI's current Energy Storage Roadmap, specifically the future state vision where energy storage asset and fleet reliability are **understood** and **achieved** through developed technology solutions and common industry approaches.

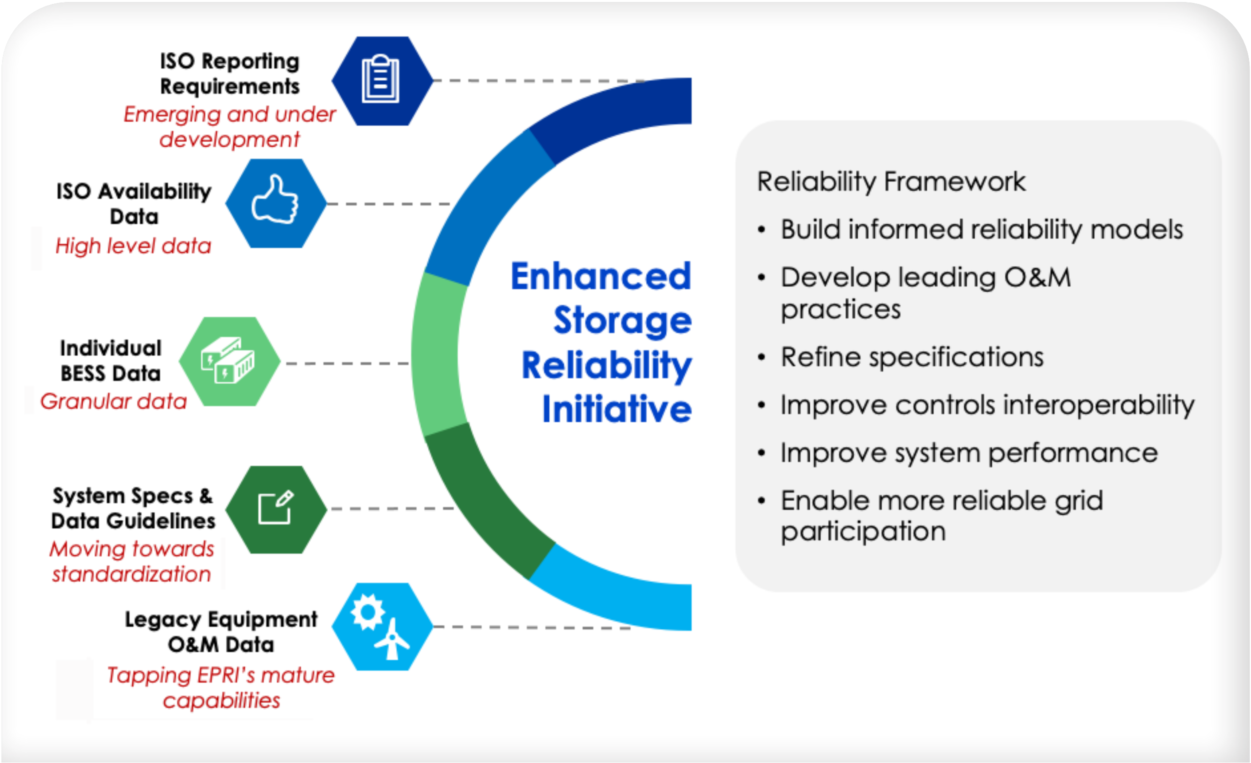

Figure 2. *EPRI energy storage reliability framework scope and objectives*

Broad Level Perspective—Initial Energy Storage Reliability Indications

Initial indications of storage performance, from a fleet perspective, can be found through investigation of daily outage and curtailed and non-operational data produced by independent system operators (ISOs). EPRI calculates unavailability from the data collected on a daily basis to allow visibility and insight into why a system is not participating in the market. EPRI has been collecting these data for more than a year from California Independent System Operator (CAISO) and has started collecting similar data from Electric Reliability Council of Texas (ERCOT). Closer examination of CAISO daily data in Figure 3 shows the types of resources and reasons for nonparticipation in the market over the past two years through the first quarter of 2024.[2]

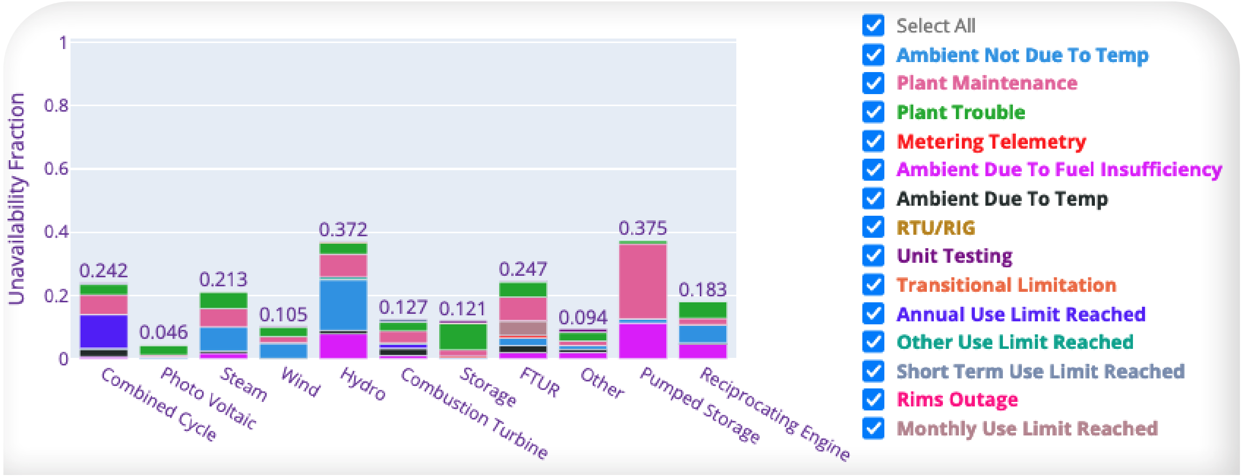

Figure 3. *CAISO curtailment and non-operational data dashboard*

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[2] Data source: CAISO, "Curtailed and non-operational generators in California and neighboring balancing authorities," https://www.caiso.com/market/Pages/OutageManagement/CurtailedandNonOperationalGenerators.aspx.

EPRI has developed further analyses that sort and group the data by specific trouble codes and asset type. Figure 4 shows that, of all the resources represented, storage typically has the highest unavailability when the plant trouble cause code is isolated.[3] CAISO defines *plant trouble* as when "plant equipment fails or is in danger of imminent failure resulting in a curtailment of dispatchable capacity."[4]

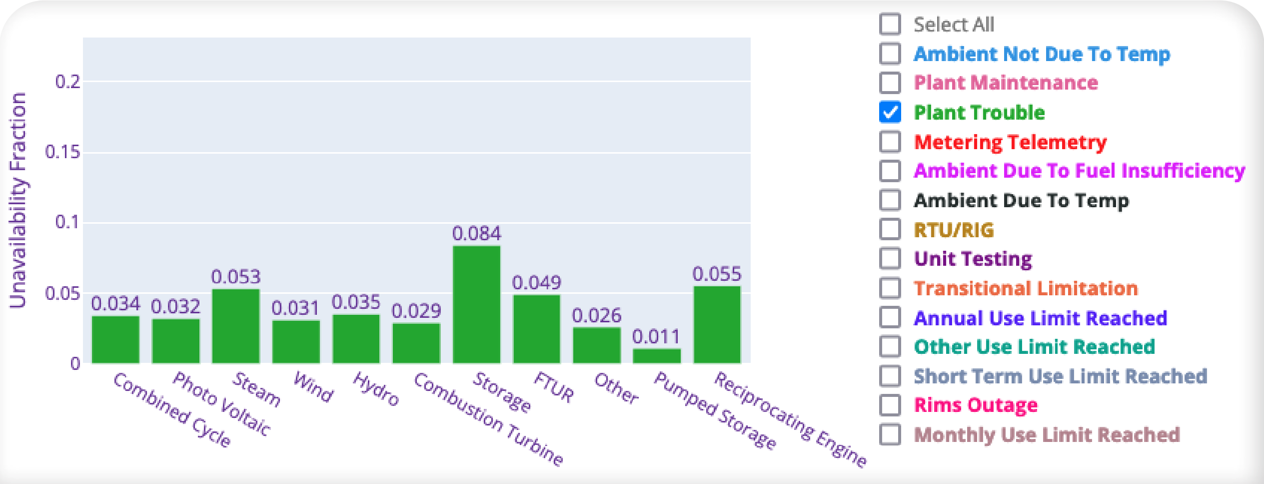

Figure 4. *CAISO system unavailability by source type*

Based on these data, storage has typically experienced almost three times the amount of plant trouble when compared to other IBRs. Diving into the unavailable cause codes for specific systems, Figure 5 shows that unavailability over time is not only due to plant trouble but also metering/telemetry issues and maintenance.

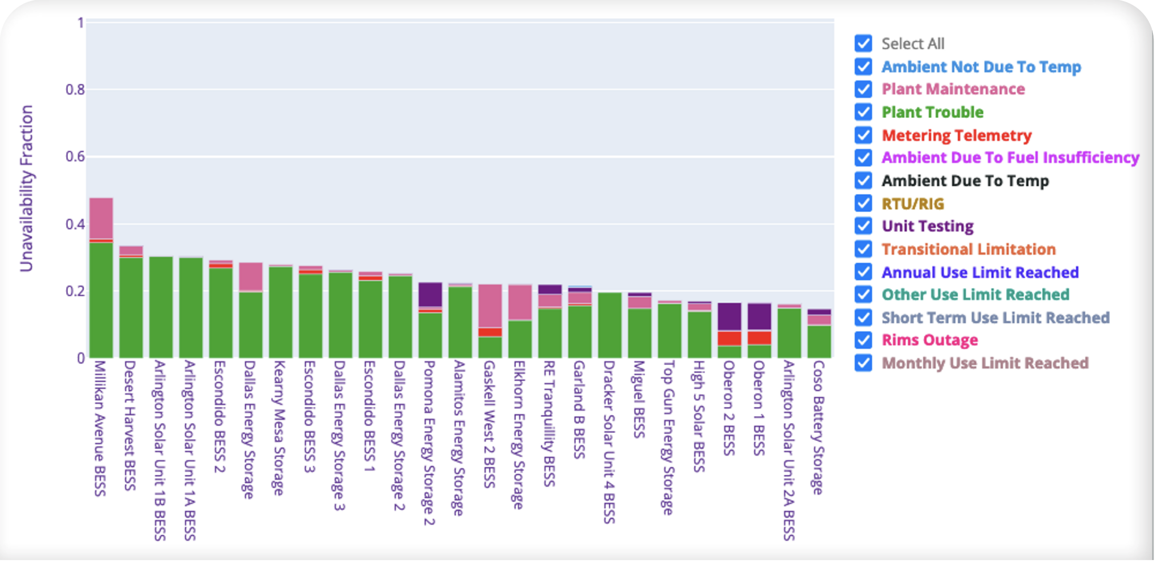

Figure 5. *CAISO specific storage resource unavailability—highest 25 underperformers*

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[3] There are indications that a unit may flag trouble code if state-of-charge level precludes charging or discharging from the ISO requests—this is still considered a negative impact to availability or a contributor to unavailability.

[4] CAISO, Business Practice Manual for Outage Management, July 2023, https://bpmcm.caiso.com/Pages/BPMDetails.aspx?BPM=Outage+Management.

Policy Perspectives

Another perspective on storage reliability comes from assessments of storage misoperations and the resulting impact on the overall network. NERC recently published a disturbance report[5] that focused specifically on impacts to CAISO from large battery systems that did not correctly operate within the market environment in 2022. These instances were attributed, in part, to unreliable ride-through, poor commissioning, lack of adequate monitoring, data quality, and data inconsistency.

An additional policy impact stems from emerging performance reporting requirements. NERC recently issued requirements for solar generation, which includes storage elements for hybrid systems.[6] These NERC requirements spell out specific cause codes for a variety of outage types and performance indices. Future efforts at NERC are forecasted to cover storage in more detail and further impact how storage operations and outages are reported.

Utility Perspectives

In developing the storage reliability framework, EPRI surveyed the storage arena to assess how reliability is being addressed. EPRI-member utilities that own, operate, or off-take from over 4 GW of storage throughout North America and Europe were surveyed. Most of these systems are large (>10 MW) and connected to high-voltage transmission. This effort aimed to uncover which actors, asset management systems, and policies are in place; what reliability parameters are being used in performance guarantees and warranties; and how required storage performance is being enforced. Key findings include the following:

- Most systems discussed were lithium ion based, mostly lithium iron phosphate and nickel manganese cobalt chemistry, in front of the meter, and serving at the transmission level.
- Many systems are owned by third parties that are held to performance guarantees (MW capacity and, in some cases, MWh throughput, as well as availability based).
- Benchmarking reliability analysis is needed, including failure rates, failure modes, associated costs, and engineering analysis for key components of wind, solar, and battery technologies. Benchmarking is most valuable when many similar systems, across many utilities, are assessed.
- Utilities would like to be able to interrogate ISO reliability data on specific vendors and specific battery types and for specific abnormal weather events.
- These systems are dispatched through various methods including utility generation desks, setpoints sent from the corresponding ISOs, and power operations desks.
- Availability seems to be the leading parameter used to gauge reliability and enforce performance. Some members are using weighted-by-component availability calculations to penalize for partial outages where the power or energy rating of a given component penalizes the whole system ratings if that component is not operational. Response time, MWh throughput, and MW power delivered are also monitored and featured in performance guarantees. Targeted availability is around 96–97% with some contracts allowing seasonality where with different targets.
- Tracking of reliability also includes response of systems to market dispatch, accounting for lost opportunity costs from less than optimum performance in markets, and equivalent forced outage rates similar to NERC-defined outage reporting for traditional generating units.
- There is a substantial lack of clarity in how derated performance is attributed to lower reliability. Derated output of systems is common and attributed to many causes, including component or subcomponent failure, inverter derates, ambient conditions, improper control settings or operation. Derating can affect how a system reports daily availability to market monitors (ISOs) and operators and complicates overall system availability calculations.
- Inverters and thermal management systems seem to be the chief contributors to unavailability. Inverter issues stem from componentry and firmware and communication issues.

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[5] NERC. 2022 California Battery Energy Storage System Disturbances, https://www.nerc.com/comm/RSTC/Documents/NERC_BESS_Disturbance_Report_2023.pdf.

[6] NERC, GADS Solar Generation Data Reporting Instructions, January 1, 2024, https://www.nerc.com/pa/RAPA/PA/Pages/Section1600DataRequests.aspx.

- Lack of interoperability between control systems is a concern. A complicated control hierarchy exists in most cases. Utility dispatch controls need to integrate to battery site energy management systems, which in turn govern component controls including the battery management systems, which monitor the batteries, safety systems, and environmental control systems. Many different vendors attempt to integrate with each other, and few follow standard architectures, such as the Modular Energy System Architecture, which is evolving into IEEE Standard 1815.2.[7]
- Mean time to repair (MTTR) and mean time between failure (MTBF) data are useful but require regimented documentation of activities, reasons, actors involved, and time stamps to ascertain. Legacy asset management systems require adaptation to the nuances of storage componentry and a variety O&M assignments.
- Many systems are serviced and maintained through long-term service agreements, which vary in duration. The most common approach is to trigger these agreements when the system is operative, after commissioning, with a three-year, or potentially longer, term.
- Some owners are developing in-house O&M capabilities to some extent or contemplating doing so.
- Some utilities are endeavoring to bring at least a portion of maintenance in house to ensure adequate timely response (MTTR). This adoption requires access to manufacturer-based software and tools and specific training on the particulars of battery systems that differ from utility assets.
- Some utilities have developed in-house in-depth analysis tools to assess MTTR and MTBF on a component and system level, but they need access to component reliability statistics from a broader reach, sourced from other than just their own fleet.
- Independent assessments of how different duty cycles affect battery life are needed because some vendors have not shared their analyses, if they are available.
- Enhanced specifications are needed to ensure improved reliability. Specifications of auxiliary systems, chiefly climate control systems, which have been noted as unreliable, are a key target for improved specifications.
- There are long backlogs for some storage system components, and, in some cases, specifications have to be relaxed to keep a project on track. The current backlog for some utility side equipment (transformers, switchgear, and so forth) can be around four years.
- Assessment of performance and reliability data, with the aim of finding indications of emerging safety issues, would be of great benefit.

Path Forward/Solutions

As an extension of EPRI's storage independent performance assessment effort, focus will be added on storage reliability. This forthcoming project intends to accumulate more discrete storage system and associated component-level data and then develop initial models that identify the reliability impacts and their causes, with the caveat that certainty of the results is gained through continuous accumulation of data. This effort in turn will allow development of new resources and refinement of existing resources to enable improved reliability. Perceived efforts include the following:

- Continued ISO data monitoring, refined to allow searches by vendor and equipment types
- Allowing benchmarking of systems and components through development of a storage component-based reliability database, populated initially with existing data from similar components in other IBRs and common electrical equipment (used in integration and protection) as well as acquired field data
- Assessing heating and cooling systems, malfunctioning controls, along with inverters, which are chief contributors to unavailability, for improvements
- Developing a basic storage system reliability modeling tool that is adaptable to various technologies. Where component data are insufficient, documented assumptions will be used. Results will then both further identify data gaps and incentivize data contributions from owners and vendors.

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[7] MESA Standards Alliance, "MESA-DER Becoming IEEE 1815.2 Standard." https://mesastandards.org/mesa-der-std/.

- Continued interaction with NERC and other standard revision efforts, such as IEEE 762 revisions,[8] with regard to storage reliability reporting requirements
- Accommodating required data from the preceding efforts into an enhancement of the EPRI Energy Storage Integration Council (ESIC) O&M reporting tool
- Application of initial modeling to individual systems, which will allow for calibration and further identification of data gaps
- Feeding results to ESIC-related activities centered on enhanced specifications, commissioning plans, and data guidance
- Development of leading O&M practices that address reliability gaps

Conclusion

Energy storage is assuming a critical role in utility operations and maintenance of grid reliability. There are indications, however, that the reliability of storage systems needs to be improved to allow beneficial contributions to overall grid reliability. EPRI has decades of experience assessing grid equipment reliability and leading operational practices. It has also established leading energy storage performance data collection and analysis capabilities, hosted in its Data Science Platform, which has strict data governance policies in place. Through extension of these capabilities and further accumulation of performance and reliability data, a more rigorous approach to understanding storage reliability will allow for more reliable operation of energy storage assets. This approach needs to identify the weak links in storage systems and identify corrections, leading operational practices, and refined tools that allow for these reliability gaps to be bridged.

[8] This revision adds storage to the existing standard that defines terminology and indexes used to report generation reliability and availability. See IEEE 762, Standard Definitions for Use in Reporting Electric Generating Unit Reliability, Availability, and Productivity, https://standards.ieee.org/ieee/762/6856/.

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