Performance of Batteries in Grid Connected Energy Storage Systems

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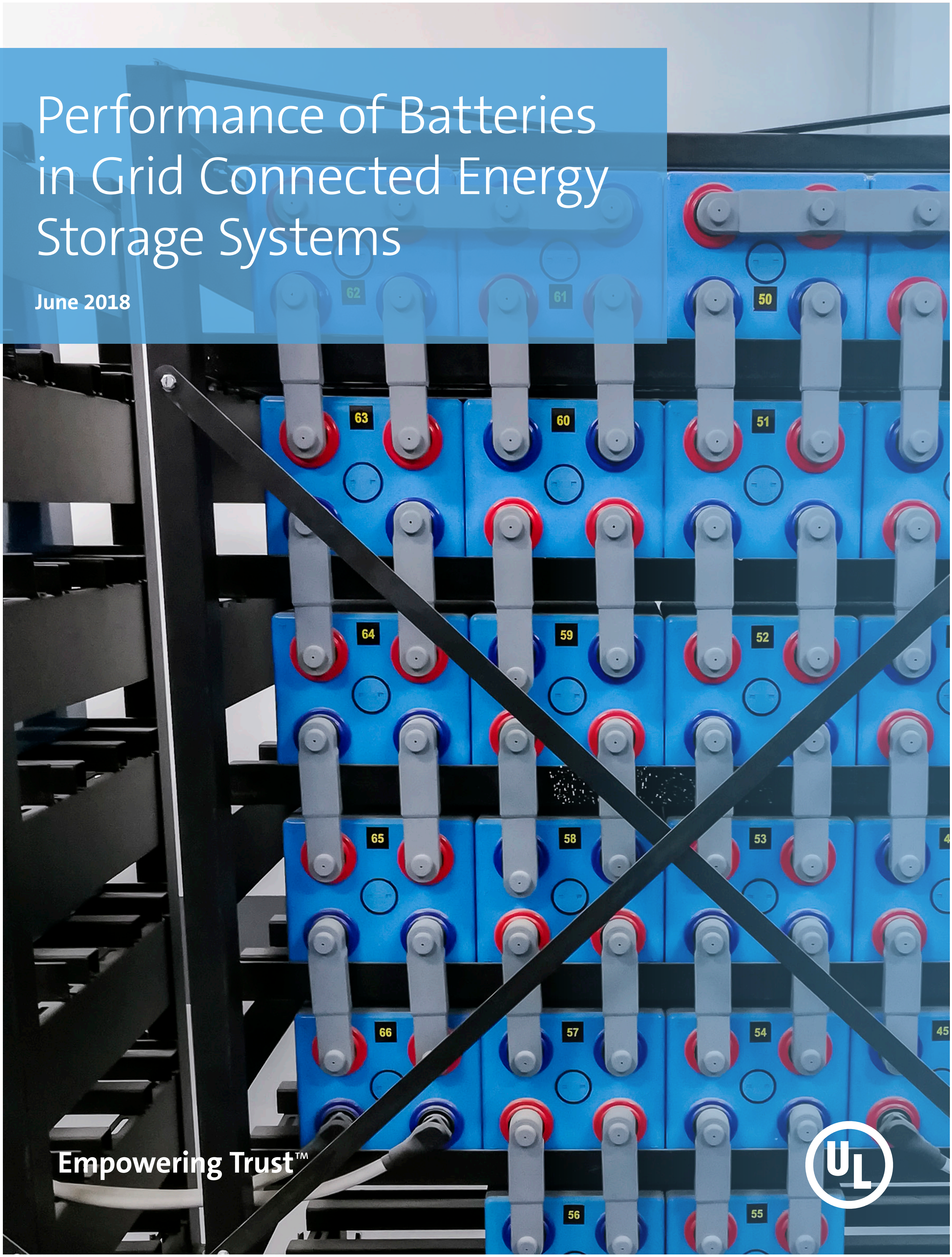

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Executive Summary

Energy storage systems (ESS) are being increasingly used for grid support, especially in regions with high renewable energy penetration. Common ESS applications include:

- Frequency or voltage regulation
- Peak shaving
- Renewables firming
- Power quality
- Energy arbitrage

Various ESS technologies and designs are available. Some are better than others for certain applications.

When choosing an ESS technology, it is important to understand how it will perform for the intended application and site. Early development of ESS performance capability criteria, metrics, and milestones is important. To address this issue there has been significant work on the development of protocols. For example, PNNL-22010 (Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems) was first published in 2010 and updated in 2016 to address new applications. In addition, recently published IEC 62933-2-1 (Electrical energy storage systems - Part 2-1: Unit parameters and testing methods - General specification) addresses ESS performance.

While the primary goal may be to determine the overall performance of a given ESS, each subsystem's operation should be validated for the intended application. There have been performance protocols developed for power conditioning systems, but there has been little in the way of performance programs developed for battery systems when used as part of an ESS for grid applications. Similar to the PNNL Protocol, methodologies and metrics to evaluate the performance and reliability of the battery system component of an ESS are needed. This evaluation should include general baseline metrics as well as application-specific ones.

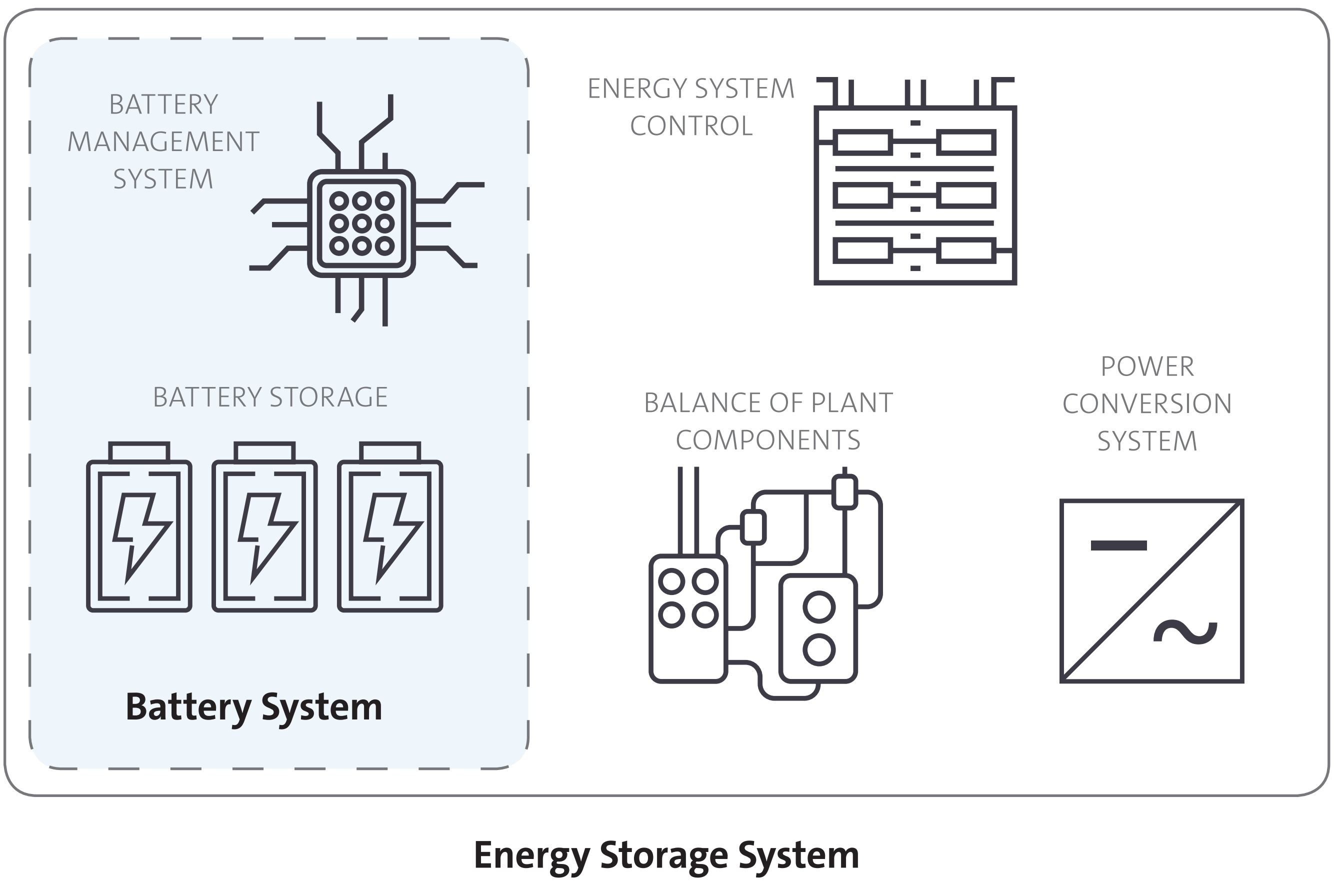
UL is pleased to present this paper for ESS designers, utilities, and other interested stakeholders about methods for evaluating and testing the performance and reliability of stationary battery systems used in grid applications.

Scope

This paper outlines important considerations for evaluating the battery system component of an ESS intended for grid support applications. These considerations include general and application-specific performance parameters to establish a battery system's ability to meet baseline performance goals. Important to these considerations are not only the methods of testing, but the knowledge and capability of the organization conducting these evaluations.

The devices under the scope of this document are battery systems, which are a component of an ESS that provides the overall storage mechanism. This document does not address the performance of the complete ESS, which is covered by several other documents such as the PNNL documented noted above. Figure 1 is a block diagram of the primary components of an ESS, which includes the battery storage devices and battery management system (BMS).

Figure 1 – Block Diagram of Energy Storage System Showing Battery System



Importance of Understanding the Battery System Performance

Why is it important to understand the performance of a battery system intended for ESS applications? Since the battery system is only a component of the overall system, why would determining its performance, including application-specific operating algorithms, be necessary? The answers have to do with the fact that the chosen battery technology is key to how the ESS will perform. For example, it may be important to the ESS that an integrated battery system provide enough energy for a particular application under the temperature and load conditions that it may be exposed to during its useful life. The typical ESS consists of a number of major components that are assembled and commissioned in the field. It is vital to the entities designing and integrating the various parts of the ESS to understand how these components will perform together to deliver the intended functionality. It provides them with assurance that the selected technologies, designs, and control logic will work as expected for the application.

It is also important when financing an ESS that there is evidentiary data available to support the performance and reliability assumptions of the battery system. This is needed as part of an overall project's risk and investment assessment. The financier or a third party typically performs a due diligence review as part of the assessment.

Third party performance data from a responsible test organization is also valuable to battery system manufacturers and other stakeholders trying to support marketing claims and spur investment for their systems. Purchasers of the battery systems can use the data when determining if the system is going to perform as the manufacturer claims. They can also use this data as supporting evidence when seeking investments for the ESS installations.

Understanding the Battery System

The first critical item to clarify is the set of battery system properties. Manufacturers of the battery system must provide a declaration of the attributes that address the baseline performance of the system. This information will be used in conjunction with specific performance parameters for the specific application(s) that the system will be used for.

The test version of the battery system must be representative of the full system intended for the application. The test version can either be a full-scale duplicate of the battery system or a scalable representative that is able to demonstrate the performance of the intended system when scaled to full size. It is important that the testing approach be discussed in advance with the appropriate stakeholder(s) to ensure agreement among all parties (financier, end user, developer, manufacturer, and independent third party) that the test plan is acceptable as a sufficient demonstration. The test report will describe the specific type of system tested as well as how it is scalable to the full battery system.

The full battery system will be described in detail in the final test report. More is noted in the Documentation section of this publication.

Base Line Key Performance Indicators

The battery system intended for an energy storage application needs to demonstrate general baseline performance parameters, which include the following:

- Discharge performance under various conditions
- Maximum discharge current
- Internal DC resistance, and
- Endurance under cycling and standby modes.

Depending upon the battery technology (e.g. flow batteries), evaluation may include the following:

- Net discharge energy under constant power (CP) discharge
- Maximum output power under CP discharge
- Maximum input power under CP charge, and
- Energy efficiency under CP cycling.

The baseline performance parameters provide a general understanding of the battery system's performance under constant discharge conditions and anticipated environmental conditions that can affect that performance. These results give a good generic footprint of the energy and power output of the battery system that is not application specific but is a good starting point for validating the battery performance.

Endurance testing provides a rough estimate of the battery system's life over a number of cycles and can provide a way to estimate lifetime for the intended application. Measuring internal resistance can also provide a marker parameter that can be re-measured and compared to help estimate the state of health of the battery system.

It is important to consider the effects of parasitic loads from the balance of plant components on the overall performance of the battery system. These effects can be included as part of the general parameters to gain an understanding of their impact on the system in addition to similar measurements in the application specific tests.

As part of this determination of baseline parameters, the test battery sample is to be visually examined and charge/discharge cycled to determine that it is operating in accordance with specifications prior to testing.

Application Specific Key Performance Indicators

For various grid applications that the battery system is expected to be exposed to, the following parameters are measured during endurance testing using the particular application-specific algorithm:

- Battery system energy at ambient temperature
- Battery system energy efficiency during endurance testing at various ambient conditions
- Heat losses during endurance testing
- Energy requirements during idle states, and
- Maximum time to start up.

The parameters noted above are examples of information that demonstrates important performance characteristics necessary to understanding the performance of a given battery system when operated in accordance with application-specific algorithms.

Considerations for Selecting a Third Party Provider

It is important that those interested in having battery systems assessed for performance and reliability also carefully consider the provider they choose to conduct the evaluation and testing.

To start, the test equipment used for performance testing of battery systems must be of sufficient capability in order to conduct the intended performance tests on the test battery; it must also be calibrated in accordance with ISO 17025 requirements for laboratory operations. This capability includes choosing equipment that allows measurements to have sufficient accuracy (including tolerances) in accordance with laboratory norms for the parameters being measured.

The test facilities where testing is to be conducted must have adequate controls for the environment, power availability, and power quality so that testing can be conducted in accordance with the test performance criteria. It is also recommended that the facility be a national or internationally recognized testing laboratory meeting known accreditation criteria for the country or region such as a NRTL in the USA or IEC CB Scheme in Europe.

The test facilities must have standard operating procedures (SOPs) for the safe handling and testing of battery systems. Personnel conducting testing of the battery systems must have a thorough understanding of the test procedures for performance testing of the battery systems and an understanding of the laboratory SOPs for the safe handling and testing of battery systems. The battery system SOPs must include procedures for the safe handling, operating, testing, transport and storage of battery systems at the laboratory facilities.

The staff technical competency of the third party provider should be assessed, as they should have an established track record in evaluating and testing battery and energy storage systems. Product listings for safety are an early and easy indicator of the provider's ability to deliver results on important technical matters.

Documentation

Documentation is critical to providing the information necessary to establish the performance of the battery system. The documentation should be thorough enough to give an accurate picture of what was tested, how the system performed, and how that performance related to what may be seen in the field application of the battery system. The type of documentation detail needed is noted below and includes information such as a complete description of the test item and its comparison to the final assembled (full) battery system. Other system documentation such as manufacturer's construction diagram(s), schematics, system specifications, test data, etc. are also important. The more thorough and complete the information provided in the documentation, the better the overall understanding of, and confidence in, the battery system performance for the intended energy storage application.

Thorough documentation will require a cooperative effort from the entity seeking third party performance evaluation, the laboratory, and the organization providing the service. Although the documentation may be stored in one or more secure databases, all documentation of test results is the property of the entity seeking the evaluation.

Battery and Application System Information

As noted earlier, a complete description of the full battery system as well as test battery system is to be documented. This description is to include the manufacturer's name, model or part number, battery technology, internal electrical configuration (i.e. parallel and series combinations of cells and internal modules or stack size and configuration for flow battery), complete electrical ratings including power in kW, charging and discharging characteristics, internal resistance, tank configuration and sizes (for flow batteries), complete footprint (i.e. physical dimensions with all components in place - in meters), weight in kg, and date of manufacture. Additional critical information such as the type designation, hardware and software version, and so on, must also be documented.

Further, information on the internal cells or stack are to be provided including specifics of the technology, cell format, electrolyte, electrical rating of the cell or stack, and how many are contained within a full battery and within the test battery.

A complete description of the balance of plant components such as cooling systems, controls including

BMS, pumps, etc., are to be included. This also holds true for any special circuits, protection or other devices required in order to conduct testing and operate the test battery and any balance of plant components. The report must also identify the equipment that the ESS is intended to be directly connected to (e.g. the inverter, the dc-dc converter, etc.)

Photos, diagrams, drawings and schematics should be provided to give a complete description of the full battery and test battery under evaluation.

Additionally, documentation must include a description of the intended energy storage application(s) (e.g. peak shaving, frequency regulation) and the performance parameters required from the system in order to meet the intended energy and power application needs.

Performance Testing Documentation

The performance testing documentation must identify the parameters of the battery system that were tested and also clearly identify how testing of the test battery system was determined to be representative of a complete battery system.

The report should also in detail describe the entity conducting the testing and the location of the laboratory where the testing has taken place. If more than one laboratory is utilized for testing, each facility is to be described together with what testing was done at which lab. The report shall also note the capability of the test facility to carry out the test parameters. Within the test data, the pertinent environmental conditions impacting the testing results are to be documented. The report should provide information on the particular test equipment used and provide details on the calibration status of that equipment.

The report is to include sufficient details of the testing to provide a clear understanding of how the system was tested including test methods used, assumptions, data measurements, calculations, and observations and conclusions necessary to understand the battery system performance. Photographs, illustrations and chart recordings necessary to clarify the testing should be included as determined necessary by the laboratory conducting the testing.

Any special handling necessary during testing or modification to the battery system during testing is to be documented in the report. Finally, the report documentation should include the results of all testing, how the testing results were recorded, and laboratory ambient conditions as well as any conclusions regarding the test results.

Conclusion

Energy storage systems are becoming a critical part of the energy infrastructure, serving as support for various grid applications. Battery systems are increasingly becoming the technology of choice for ESS. To support the growing and more widespread use of battery systems, it is important to evaluate in advance how they will perform for their intended application.

Relevant battery system properties and performance parameters should be established and verified via a well-documented test program endorsed by the key stakeholders. A robust third party program that evaluates battery systems and their capability to provide the desired performance within the ESS application is important for ensuring that the storage industry will thrive in today's energy market.

Acronyms

The following acronyms are used in this document.

- **BMS** – Battery Management System
- **CB** – Certification Body
- **CP** – Constant Power
- **ESS** – Energy Storage System
- **IEC** – International Electrotechnical Commission
- **NRTL** – Nationally Recognized Test Laboratory
- **PNNL** – Pacific Northwest National Laboratory
- **PV** - Photovoltaic
- **SOPs** – Standard Operating Procedures

Definitions

The following definitions of terms that are used in this document.

- **Ambient Temperature** - Considered to be a temperature in the range of 25 ±5°C (77 ±9°F).
- **Battery System** - Consists of a multi-cell/module battery assembly and all controls and circuitry and components that are required for the safety and operation of the battery
- **Energy Storage System** – Equipment that stores that energy in some form that can be converted to usable electrical energy when needed for local grids or in parallel with an electric utility or for both.
- **Flow Battery** - A rechargeable battery that stores its active materials, in the form of liquid aqueous electrolytes, external to the battery.
- **Full Battery System** – Battery system that is anticipated to be used for an energy storage system that includes all components.
- **Test Battery** – Battery system that is scalable to a full battery system that is used for testing to represent a full battery system.

References

The following documents are critical to understanding the methods and procedures for determining performance of battery systems addressed within this document. The latest edition of the documents below are to be utilized for this document.

- **PNNL 2010:2016**, Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage System
- **IEC 62933-2-1**, Electrical energy storage (EES) systems - Part 2-1: Unit parameters and testing methods - General specification
- **IEC 61427-2**, Secondary cells and batteries for renewable energy storage - General requirements and methods of test - Part 2: On-grid applications
- **IEC 62620**, Secondary cells and batteries containing alkaline or other non-acid electrolytes – Secondary lithium cells and batteries for use in industrial applications
- **IEC CDV 62932-2-1**, Flow Battery Systems for Stationary applications - Part 2-1 Performance general requirement & method of test (under development at the time of this publication)
- **IEC 1679**, Recommended Practice for the Characterization and Evaluation of Emerging Energy Storage Technologies in Stationary Applications
- **IEEE 1661**, Guide for Test and Evaluation of Lead-Acid Batteries Used in Photovoltaic (PV) Hybrid Power Systems
- **ISO 17025**, General requirements for the competence of testing and calibration laboratories

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