Electrical Energy Storage Data Submission Guidelines

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ABSTRACT

Energy storage technologies are positioned to play a substantial role in power delivery systems. They are being touted as an effective new resource to maintain reliability and allow for increased penetration of renewable energy. However, due to their relative infancy, there is a lack of knowledge on how these resources truly operate over time. Data analysis can help ascertain the operational and performance characteristics of these emerging technologies. Rigorous testing and data analysis are important for all stakeholders to ensure a safe, reliable system that performs predictably on a macro level. Standardizing testing and analysis approaches to verifying the performance of energy storage devices, equipment, and systems when integrating them into the grid will improve the understanding and benefit of energy storage over time from technical and economic vantage points.

Demonstrating the life-cycle value and capabilities of energy storage systems begins with the data the provider supplies for analysis. After review of energy storage data received from several providers, it has become clear that some of these data are inconsistent and incomplete, raising the question of their efficacy for robust analysis. This report reviews and proposes general guidelines such as sampling rates and data points that providers must supply for robust data analysis to take place. Consistent guidelines are the basis of the proper protocol and ensuing standards to (a) reduce the time it takes data to reach those who are providing analysis; (b) allow them to better understand the energy storage installations; and (c) enable them to provide high-quality analysis of the installations. This report is intended to serve as a starting point for what data points should be provided when monitoring. As battery technologies continue to advance and the industry expands, this report will be updated to remain current.

CONTENTS

FIGURES

TABLES

1 OVERVIEW

As energy storage technologies promulgate, the need to accurately understand their reliability and performance has become paramount. Indications of storage performance are directly tied to performance warranties and grid reliability expectations; as storage becomes more prevalent, the grid will become more dependent on storage reliability to ensure overall grid reliability. When reviewing data from fielded energy storage systems, the data provided in many cases is insufficient or not accurate enough to perform reliability and performance analysis. This report addresses this gap by providing: 1) a list of required data points, 2) recommended sampling rates and accuracy, and 3) a recommended database structure to enable efficient analytics. If data can be supplied consistent with these guidelines, robust performance and reliability analyses can be performed. The guidelines in this report balance the needs for complete information with the cost of installing and maintaining the systems that collect, transport, and store these data. Therefore, the points and sampling rates are described in a posture to optimize the amount of data needed.

This report will serve to define guidelines for needed parameters (data points), and the accuracy and precision needed to calculate energy storage systems performance and reliability.

This report will answer the following questions:

- What data, and what degrees of accuracy and precision, are needed to validate vendor performance claims?
- Should safety related data (e.g. warnings and alarms) be processed differently from data related to performance and reliability?
- How should vendors control access to these data to protect the system and control proprietary information?
- Who among storage vendor, site owner and system operator should be responsible for data collection, transmission, and storage?

2

INTEROPERALITY STANDARDS

The framework under which storage data is acquired, stored and analyzed is an important consideration. Successfully performing data analysis requires communication between numerous devices and other actors such as system operators and analysts. IEEE Std. 2030.2 - 2015 - IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure [1], describes the types of entities that may need access to data generated by energy storage systems.

Many energy storage devices communicate in different protocols: Storage components can use CANBUS to internally communicate and MODBUS to communicate between devices. Utility control and data acquisition systems typically use DNP3 protocol in the US, and IEC 61850 internationally.

Standards that govern how devices communicate have been developed and are currently evolving to standardize approaches to interoperable communications. The standardization is based on IEC 61850 standards that govern how data is structured. This report has purpose in that it can inform new standards efforts and thereby promote and support a uniform stance on storage data and performance analysis. A key example is the opportunity to inform the IEEE 1815 working group that is incorporating recent efforts from the recently published DNP Application Note (DNP AN-2018) which describes how to use DNP3 with distributed energy resources (DER).

This report is therefore structured to provide guidance on energy storage resources, a subset of the DER classification. It will serve to inform further work on the IEEE 1815 DNP3.0 and IEEE 2686 draft BMS standards, in part, as well as standard specification updates produced by EPRI Energy Storage Integration Council (ESIC).

3
DATA RESPONSIBILITY

In framing the specific attributes of acquiring and analyzing data it is important to create a structure that assigns responsibility for the different project phases and elements placed. This structure should be thoroughly developed early in the project to allow for all stakeholders to understand roles and assignment and system requirements both in the design and operational phases. Table 3-1 shows a sample high level responsibility matrix that can serve as a template for this purpose.

Table 3-1 - Data Responsibility Matrix

Project Deliverable	Equipment Vendor	Integrator	Operator	Maintenance	Analyst
Data System Design	X	X	X	X	X
Installation	X	X	X		
Commissioning	X	X	X	X	X
Operation			X	X	X
Analysis			X	X	X

As is evident in even a high-level approach, all parties involved need to be intricately involved in the design process as well as the commissioning effort. Once the system is operable, the maintenance activities need to be well coordinated with data acquisition and subsequent analysis. Indeed, the analysis effort may, in itself, inform operational and maintenance activities.

4
OVERALL SYSTEM REQUIREMENTS

Before the data can be supplied, a database system must be in place (either physically or in a managed web service) for the data to be transferred to and stored. In most cases, sophisticated data historian software is preferred due to the tools that can be utilized for deep analysis. The system can be broken down into the following elements

1. Storage Unit – Includes all necessary points associated with the storage device(s), Power: Conditioning System (PCS), metrology, and all installed power meters. Specific data points collected for the storage unit(s) are discussed in Section 6.

2. Master Station Controller (the DNP3 outstation) - Data collection device must also have a backup connection to the primary with a speed of at least 10 Mbps, less than 200 ms of latency, and less than 5% packet loss.

3. Data Transport - Primary link for the data collection to and from devices via high-speed wired or wireless connection with a speed of at least 10 Mbps for wired and 5 Mbps for wireless with less than 1% packet loss. Standard connections of this type include fiber optic, Category 6 or 5e ethernet, RS232, radio frequency and/or cellular. It should be noted that higher upload speeds may be difficult to attain in certain cell coverage areas. Strategies for lower cellular transmission rates need to be further researched.

4. Historian - Data collection software such as the historian (example: Mango), database, and operating system must be the latest version and kept up-to-date throughout the project. Data collection device must have an onboard memory of at least 60 days with the same resolution of that being collected.

5. Historian Access and Analytic Tools - Provider should also include Web Service Definition Language (WSDL) information as this defines how the analysts can connect and reach the necessary data. Ideally, this will lead to a machine-to-machine interface to securely access the web portal to retrieve the data automatically for a desired period. Depending on the data system, additional information like necessary Application Program Interfaces (API) may need to be provided for the provider and the analyst to interface the systems together. This should include a credential management plan to control access.

5
SAMPLING RATES OF DATA

For the system being monitored, there are three different kinds of sample rates. The first is the data acquisition system "sample rate" which is the rate at which the system samples a specific data point. The second rate, referred to as the "logging rate," is the reporting sampling rate which is the rate at which the logged data is to be transmitted to the analyst. The last sample rate, referred to as the "triggered rate," is the rate at which the system collects data during a triggered event. Triggered events are developed using a set of boundaries for a given data point which, if this boundary is violated, the system collects the data at its highest resolution. The required sample rate for triggered events will be addressed in the later revisions of this document. High sample rates are typically performed in sub cycle or greater than 180Hz to capture waveform data.

The data acquisition logging rate can typically range from 1 second to 1 hour and it is important to consider the optimal need balancing the quantity of data needed against the bandwidth and data storage available. Many power-based or basic voltage and currents are best obtained on 1 second basis to understand sub-component (battery cell) degradation and power characteristics. Energy based values such as kWh and measured temperatures do not necessarily need to be logged at intervals smaller than 15 minutes. Some databases and data historians apply sophisticated data compression algorithms, such as trending and down sampling, to save on information storage costs. When applied, these algorithms should not reduce data precision below the guidelines put forth in this report.

6
GENERAL SYSTEM DATA POINTS

The following sections describes the data points to be collected by the energy storage system (ESS) and specific technologies. These data points need to be collected to evaluate the performance, safety and longevity of the energy storage system. All data points need to be synchronously time stamped for accurate modeling and analysis.

6.1 Electrical AC

The AC data points are important as they inform the engineer/analyst the amount of power coming in and out of the entire energy storage system. With these data points, they can find important system statistics that indicate what the system is putting back into the grid as well as overall roundtrip efficiencies and capacity fade. Auxiliary load data is also collected to understand the parasitic loads associated with various technologies. Below are the listed data points.

NOTE: Common nomenclature is to use positive values for *discharging power*, negative values for *charging power* [2].

6.1.1 Considerations

When designing the data acquisition system and the surrounding infrastructure which will be used to collect and transmit the AC data, the following items should be considered:

1. Ownership of meters and responsibility for programming, reporting and maintaining data
2. Ability to capture events based on exceeding meter/parameter thresholds and how to transport, store and analyze. Some meters are capable of recording events on a sub-cycle basis and the quantity of data captured may be large. It may be best to store these events separately from the historian.

6.1.2 Data Points

This section lists the data points required for different types of analysis. The following key to map the points to the analysis is as follow: (^{P}) Performance – these data points are needed to measure system performance and how that changes over time, (^{R}) Reliability – these data points are needed to calculate system reliability, (^{Q}) Quality – these data points are needed to record power quality on the area electric power system. These points will be

If the ESS which the data is being collected from is a single-phase or split-phase system, all data will be collected from the line-to-neutral phase

1. ***AC Real Power (kW)^{P}*** – provide three-phase values except during event triggered which three-phase, line-to-line and line-to-neutral values. Refer to section 6.4 for event triggered data.

2. ***AC Reactive Power (kVAR)^{P}*** – provide three-phase values except during event triggered which three-phase, line-to-line and line-to-neutral values. Refer to section 6.4 for event triggered data.
3. ***AC Power Factor (pf)^{P,Q}*** – provide single phase and, if applicable, three-phase values
4. ***AC RMS Voltage (V)^{P,Q}*** – provide three-phase values except during event triggered which three-phase, line-to-line and line-to-neutral instantaneous values will be used instead of RMS. Refer to section 6.4 for event triggered data.
5. ***AC RMS Current (A)^{P,Q}*** – provide three-phase values except during event triggered which three-phase, line-to-line and line-to-neutral instantaneous values will be used instead of RMS. Refer to section 6.4 for event triggered data.
6. ***Total AC Charge Energy (kWh)^{P,R}*** – should be reported on a cumulative basis and ultimately have daily, monthly, annual, and lifetime sums for all energies available to compare with integrated instantaneous power measurements. This value will be reported for the three-phase system.
7. ***Total AC Discharge Energy (kWh)^{P,R}*** – similar to the Total AC Charge Energy (kWh)
8. ***Auxiliary Loads Real Power (kW)^{P}*** – if applicable, provide three-phase values except during event triggered which three-phase, line-to-line and line-to-neutral values. Refer to section 6.4 for event triggered data. If all auxiliary loads are single-phase or split-phase, the line-to-neutral value will be provided.
9. ***Auxiliary Loads Reactive Power (kVAR)^{P}*** – similar to the Auxiliary Loads Real Power (kW)
10. ***Auxiliary Loads RMS Voltage (V)^{P,R}*** – if applicable, provide three-phase values except during event triggered which three-phase, line-to-line and line-to-neutral instantaneous values will be used instead of RMS. Refer to section 6.4 for event triggered data.
11. ***Auxiliary Loads RMS Current (A)^{P,R}*** – similar to the Auxiliary Loads RMS Voltage (V)
12. ***Relay status^{R}*** – provide status of relay (1 = Closed, 0 = Open)
13. ***Breaker status^{R}*** – provide status of breaker (1 = Closed, 0 = Open)

In addition to the previous data points, the listed points below should also be provided for their relation to AC as indicators of power quality.

1. ***Flicker (Pst)^{Q}***
2. ***System Frequency (Hz)^{Q}***
3. ***Total Harmonic Distortion (dBm)^{Q}***

6.2 Electrical DC

DC data points are collected either from the power conversion system or from the battery management or monitoring systems (in battery-based systems). These data points allow insight on the performance of the energy storage technology behind the power conditioning system including items such as degradation and round-trip efficiency. Without access to DC measurements, accurate assessment of battery performance is not possible. There are energy storage systems such as pumped hydro or flywheels that do not have an electrical DC power and so may ignore collecting the following data points.

6.2.1 Considerations

When collecting DC data, the following items should be considered during the data acquisition design phase and collection.

1. Number of points needed for cells in a module to accurately get average, maximum values including temperatures. Amount of points should accurately provide a representation of behavior of all cells which data is not being collected. For large installations which multiple ESSs are being operated, sampling methods such as simple random, stratified random or cluster sampling can be used. The sample set should be representative of all ESSs in operation. It is recommended that, within each string, the highest cell value, lowest cell value, and average cell value are provided for relevant values such as voltage, resistance, and temperature.
2. Accuracy of sensors (see Section 8 below) and overarching BMS calculations
3. Processing that the BMS, to potentially compile points, does vs systems upstream such as a site controller or historian based analytic engine.

6.2.2 Data Points

1. ***DC Power (kW)^P*** – This value should be collected at the output of the ESS(s) and before the input of the PCS(s).
2. ***DC Voltage (V)^P*** – Depending on the technology being utilized there may be numerous DC voltages within the system. For an electrochemical based storage system, DC voltage needs to be acquired on all available levels including string, underlying racks, underlying modules and underlying cells in the modules. Figure 6-1 below maps the potential structure of an electro-chemical storage. For a 1MW system up to 40,000 cell measurements that may be available, research indicates that only a subset of these would be needed for degradation analysis. Any deviation of any cell reading outside normal boundaries should be reported via an alert/alarm, however:
    a. The Battery Bank points extract excerpt in Figure 6-1 is presented
    b. Mapping the more granular points (those below Bank level) currently requires manually applying descriptors to identify specific strings and associated racks, modules, and cells. The excerpt used is a subset of a much larger listing of Battery Bank point in the DNP

AN-2018 document[1]. ESIC participants indicated the need for a software tools that applies required descriptors in a more automated basis.

3. ***DC Current (A)***^{P} – All available current measurements should be acquired.
4. ***State of Charge (%)***^{P} – in certain instances SOC is available on a whole system and sub-system basis. All available SOC measurements should be acquired.
5. ***State of Health (%)***^{P,R} – this value is generally available on a system or BMS level. This reported value is a very important indicator of remaining life and should be verified independently through rigorous analysis that utilized sub-component DC voltage, current and internal temperature measurements
6. ***Total DC Discharge Energy (kWh)***^{R} – should be reported from start up on a cumulative basis and ultimately have daily, monthly, annual, and lifetime sums for discharge energies available to compare with integrated instantaneous power measurements.
7. ***Total DC Charge Energy (kWh)***^{R} – should be reported from start up on a cumulative basis and ultimately have daily, monthly, annual, and lifetime sums for charge energies available to compare with integrated instantaneous power measurements.
8. ***Temperature (°C)***^{P,R} – all temperatures available at the cell, module, rack and system levels should be reported. Typically, temperatures are measured on the module level or higher

Figure 6-1 is a flow chart of the parameters that are available at the various levels within a battery-based energy storage system. Current DNP3 mapping lists do not delineate to rack, string, module or cell levels. The data at the lower levels within the energy storage system allows for a better calculation of the system performance and reliability.

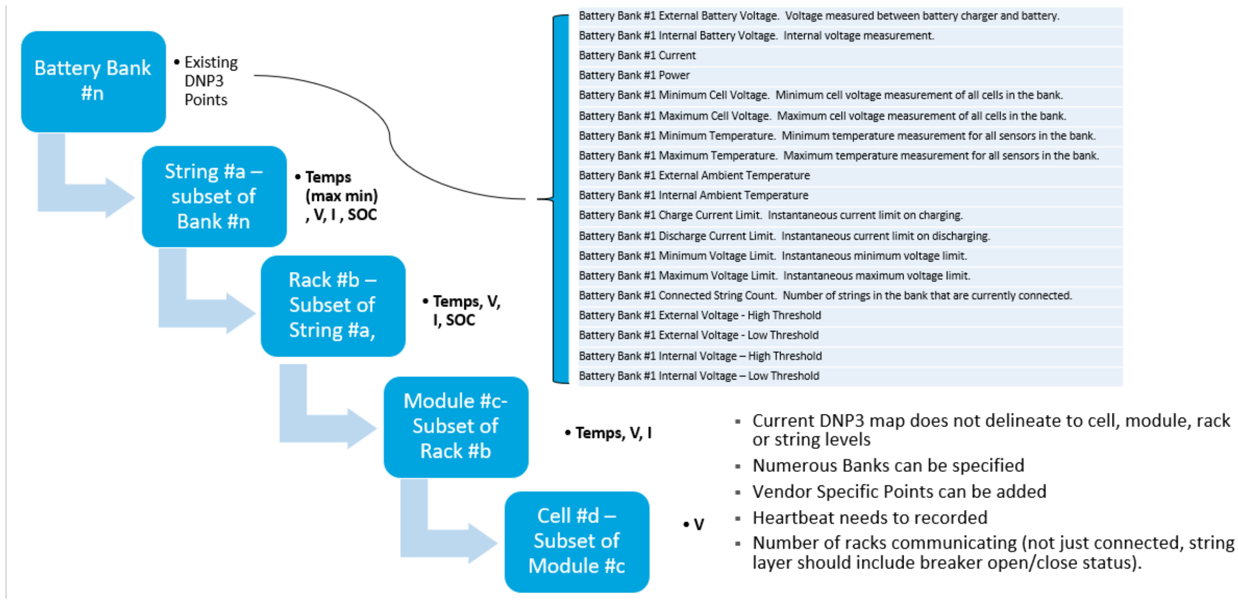

Figure 6-1: Flow chart for battery data points

6.3 Conditional

Environmental, energy market, and controller data points are useful because they allow the engineer to see the conditions the system is operating in and how these conditions affect the system. Financial market conditions like electricity price/cost are also included in this set as they help with the economic analysis of the system and its feasibility.

6.3.1 Considerations

The following are items that need to be considered when collecting conditional data.

1. Setpoints may be required to allow further understanding relating to data analytics. These would be classified as Analog Outputs according to the DNP AN 2018 document.

2. As many energy storage systems are sensitive to high or low temperature environments, it can be critical for maintenance personnel to responded quickly when internal heating/cooling fails. Prioritization of temperature threshold alarms is available at three levels and thorough analysis needs to be given to thresholds and associated priority of alarms.

3. Humidity measurements are also important in indicating the performance of environmental control systems. Both internal to system and ambient (outside) measurements are needed to ascertain internal conditions. Lack of proper control of internal humidity can lead to condensation of water vapor on surfaces that could lead to potential safety issues.

6.3.2 Data Points

1. ***Outside Temperature (°C)^{P,R}*** – This measurement is intended for installations in which the ESS is installed outdoors.

2. ***Outside Dew Point (°C)***^{P,R} – similar to the Outside Temperature, an indicator of humidity

3. ***Internal Temperature (°C)***^{P,R} – there can be numerous internal temperatures available. In an electro-chemical system, temperatures should be available down to the module level (typically 2 temperatures per module). All available internal temperatures should be acquired. Additionally, flags should be set to alarm if certain temperatures exceed safe operating limits.

4. ***Internal Humidity (%)***^{P,R} – this sensor is located within the interior of the storage system and attention needs to be paid to the accuracy of this sensor as it could serve as an indicator of condensation on interior surfaces.

5. ***Precipitation (mm)***^{P,R}

6. ***Wind Speed and Direction (mph)***^{P,R}

7. ***Electricity Price/Cost ($/kWh)***^{P} – if applicable and/or available, the electricity price will be provided if using Time of Use rates or Real Time pricing.

8. ***Power Request***^{P,R} – real and reactive power command to the ESS(s)

9. ***Charge/discharge schedule***^{P,R} – if the ESS is on a pre-determined dispatch schedule, this schedule will be logged and provided

10. ***Operating Mode***^{P,R} – ESS(s) have many modes of operations which needs to be collected to determine proper functionality and performance. This can include operating modes such as start-up, standby, load following, etc.

6.4 Miscellaneous Signals and Alerts

6.4.1 Considerations

Points listed in Section 6.4.2 are equally as important for the analysis of the system as they let the operators know when and where there is a problem. Stakeholders can see how the associated data is affected by the problem and/or if the data should be omitted. Some of the points in this section can be accessed through an analog or digital signal while others are accessed through manually maintained logs such as maintenance logs. The following is a list of considerations when determining other signals to collect for analysis.

1. Prioritizing which alarms to send through and other ones to alert that they have been triggered may need to be filtered to limit the number of data points.

2. There needs to be an indication if the system has lost data transfer connectivity.

3. Delivery of maintenance or other logs, either electronically or via hardcopy to the analysts needs to be discussed and determined. The frequency and format for how these logs need to be delivered also needs to be determined. Further research is being pursued on not only electronically capturing maintenance events but also determining best O&M practices through

application of artificial intelligence to the data base containing operational data.

6.4.2 Data Points

1. ***Events: Errors, Warnings, and Faults, Alarms*** ^{R,Q} – this category can be composed of numerous points and prioritization of what is reported may be necessary.
2. ***Maintenance Logs and Reports*** ^{R}
3. ***Communication Connectivity Disruptions*** ^{R,Q}

For event triggered data, the data shall be collected at the highest sampling rate possible (sub-cycle minimum sampling) with a waveform capture 1 minute, or more, before and after the event was triggered.

6.5 Technology Specific Points Required

The sections above provide guidance on which data points to collect for an agnostic energy storage technology and evaluating its performance. Sections 6.5.1 through 6.5.5 provides guidance on data points that need to be collected for specific energy storage technologies. These data points will allow analysis to be performed on the energy storage technology and not the power conditioning system and auxiliary loads. Additionally, depending on the energy storage technology, specific data points can be useful in evaluating the performance and the safety concerns.

6.5.1 Solid State Battery

The solid-state battery technology is one that has solid electrodes immersed in an electrolyte such as a lead acid or lithium-ion battery. Specific data to be collected for this technology is as follow:

1. ***Cell/Module/String DC Voltage (V)*** ^{P,R} – this can represent a significant amount of data, especially if every cell voltage were acquired (a 20MW/10MWhr Li-Ion system can have over 40,000 cells). A small subset of cell voltages in this case may be adequate to allow for thorough performance assessment.
2. ***Cell/Module/String DC Current (A)*** ^{P} – typically for electro-chemical storage systems current measurement is only available down to the module level. A small subset of cell/module currents in the case of a large ESS may be adequate to allow for thorough performance assessment.
3. ***Cell/Module/Rack Temperature (°C)*** ^{P,R} – a small subset of cell/module temperatures in the case of a large ESS may be adequate to allow for thorough degradation assessment.
4. ***Cell Resistance (Ohm)*** ^{P,R} – a small subset of cell resistance measurements in the case of a large ESS may be adequate to allow for thorough degradation assessment.

6.5.2 Flow Battery

A flow battery is a type of rechargeable battery where rechargeability is provided by two chemical components dissolved in liquids contained within the system and most commonly separated by a membrane [3]. Specific data to be collected for this technology is as follows – additionally a sample points list from a recent flow battery project is presented in Appendix A:

1. ***Cell/Module/String DC Voltage (V)***^{P} – this can represent a significant amount of data, especially if every cell voltage were acquired for a large system. A small subset of cell voltages in this case may be adequate to allow for thorough performance assessment.
2. ***Cell/Module/String DC Current (A)***^{P} – this can represent a significant amount of data, especially if every cell voltage were acquired for a large system. A small subset of cell currents in this case may be adequate to allow for thorough performance assessment.
3. ***Cell Temperature (°C)***^{P,R} – a small subset of cell temperatures in the case of a large ESS may be adequate to allow for thorough degradation assessment.
4. ***Cell/Module/Stack Resistance (Ohm)***^{P,R} – a small subset of cell/module/stack resistance in the case of a large ESS may be adequate to allow for thorough degradation assessment.
5. ***Anolyte Flow(s) (gal/min)***^{P}
6. ***Anolyte Tank Pressure(s) (psi)***^{P}
7. ***Anolyte Tank(s) Level (gal)***^{P,R}
8. ***Catholyte Flow(s) (gal/min)***^{P}
9. ***Catholyte Tank(s) Pressure (psi)***^{P}
10. ***Catholyte Tank(s) Level (gal)***^{P,R}
11. ***Stack State of Charge (%)***^{P}
12. ***Reported State of Health (%)***^{P,R}

6.5.3 Flywheel

A flywheel is an energy storage system that consists of a spinning mass attached to a shaft that converts mechanical energy into electrical energy. Specific data to be collected for this technology is as follow:

1. ***Speed of Flywheel (RPM)***^{P}
2. ***Vacuum Pressure (psi)***^{P,R}
3. ***System Temperatures (°C)***^{P,R}
4. ***Vibration Sensor*** ***(m/s²)***^{P,R}

6.5.4 Compressed Air

Compressed Air Energy Storage (CAES) consists of storing energy in the form of air and releasing the air into a turbine connected to a generator producing electricity. As these are rather complex systems the amount of sensed points can be quite large. Publicly available reports such as Reference Design Description and Cost Evaluation for Compressed Air Energy Storage Systems, EPRI TR1021939 detail typical system designs and illuminate the potential complexity of these types of system. General data to be collected for this technology is as follows:

1. ***Inlet Air Pressure (psi)^{P}***
2. ***Outlet Air Pressure (psi)^{P}***
3. ***Speed of Turbine (RPM)^{P}***
4. ***System and Ambient Temperatures (°C)^{P,R}***
5. ***System Fuel Consumption (MMBTU/per kWh or similar)^{P,R}***
6. ***System Emissions Data (ppm)^{P,R}*** – this value is the cumulative emission in ppm between samples. This can be many points depending on the various types of emissions that are produced.

6.5.5 Pumped Hydro

Typically found at the utility scale is pumped hydro. Pumped hydro consists of pumping water from one reservoir to another reservoir at a high altitude and then releasing the water from the higher reservoir through a turbine and generator to produce electricity. Like CAES, these systems can be quite large with numerous points requiring monitoring. General data to be collected for this technology is as follow:

1. ***Reservoir Water Height (ft)^{P}***
2. ***Water Flow from Higher Reservoir to Lower Reservoir (gal/min)^{P}***
3. ***Water Pressure from Higher Reservoir to Lower Reservoir (psi)^{P}***
4. ***Water Flow from Lower Reservoir to Higher Reservoir (psi)^{P}***
5. ***Water Pressure from Lower Reservoir to Higher Reservoir (gal/min)^{P}***
6. ***Water Pump Speed (RPM)^{P}***
7. ***System Temperatures (°C)^{P,R}***
8. ***Turbine Inlet Pressure (psi)^{P,R}***
9. ***Turbine Outlet Pressure (psi)^{P,R}***

6.6 Sample Points List – General Energy Storage3 Phase System

Table 6-1:. System Data Points [2]

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
AC Real Power	kW	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
AC Reactive Power	kVAR	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
AC Power Factor		≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
AC RMS Voltage	V_{RMS}	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
AC RMS Current	I_{RMS}	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Total AC Discharge Energy	kWh	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Total AC Charge Energy	kWh	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Auxiliary Load Real Power	kW	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Auxiliary Load Reactive Power	kVAR	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Auxiliary Load RMS Voltage	V_{RMS}	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Auxiliary Load RMS Current	I_{RMS}	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Relay Status	Binary	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	1=Closed 0=Open
Breaker Status	Binary	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	1=Closed 0=Open
Flicker	pst	≥500 Samples/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
System Frequency	Hz	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
THD	dBm	≥500 Samples/Cycle	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
DC Power	kW	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
DC Voltage	V	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
DC Current	I	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
State of Charge	%	≥1 Sample/Second[2]	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
State of Health	%	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Total DC Discharge Energy	kWh	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Total DC Charge Energy	kWh	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Outside Temperature	ºC	≥1 Sample/Minute	≥1 Sample/Minute	≥ 1 Sample/15 minutes	value, max, min, avg
Outside Dew Point	ºC	≥1 Sample/Minute	≥1 Sample/Minute	≥ 1 Sample/15 minutes	value, max, min, avg
Internal Enclosure Temperature	ºC	≥1 Sample/Minute	≥1 Sample/Minute	≥ 1 Sample/15 minutes	value, max, min, avg
Internal Enclose Humidity	%	≥1 Sample/Minute	≥1 Sample/Minute	≥ 1 Sample/15 minutes	value, max, min, avg
Precipitation	mm	≥1 Sample/Minute	≥1 Sample/Minute	≥ 1 Sample/15 minutes	value, max, min, avg
Wind Speed and Direction	(mph, cardinal direction)	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
Electricity Price/Cost	$/kWh	Sample rate associated with price data	Sample rate associated with price data	Sample rate associated with price data	Value
Power Request	(kW,kVAR,kVA)	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Charge/Discharge Schedule	(time vs kW)	≥1 Sample/5 Minute	≥1 Sample/5 Minute	≥ 1 Sample/15 minutes	Schedule
Operating Mode	integer	≥1 Sample/5 Minute	≥1 Sample/5 Minute	≥ 1 Sample/15 minutes	integer value related to operating mode
Events: Errors, Warnings and Faults		≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	Value
Maintenance Logs		Per manufacturer	Monthly	Monthly	Tablature Report
Communication Conductivity Disruptions	integer	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	1=Online 0=Offline

Table 6-2.: Technology Specific Data Points

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
SOLID STATE BATTERY					
Cell/Module/String DC Voltage	V	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Cell/Module/String DC Current	I	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Cell/Module/Rack Temperature	ºC	≥1 Sample/Second	≥1 Sample/5 Seconds	≥ 1 Sample/15 minutes	value, max, min, avg

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
Cell Resistance	ºC	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
FLOW BATTERY					
Cell/Stack/String DC Voltage	V	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Cell/Module/String DC Current	I	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Cell Temperature	ºC	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Cell/Module/Stack Resistance	ohm	≥1 Sample/Second	≥1 Sample/5 Second	≥ 1 Sample/15 minutes	value, max, min, avg
Anolyte Flow(s)	gal/min	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Anolyte Tank Pressure(s)	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Anolyte Tank Level(s)	gal	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Catholyte Flow(s)	gal/min	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Catholyte Tank Pressure(s)	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Catholyte Tank Level(s)	gal	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
FLYWHEEL					
Speed of Flywheel	rpm	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Vacuum Pressure	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
System Temperature(s)	ºC	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Vibration Sensor	m/s^2	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
COMPRESSED AIR					
Inlet Air Pressure	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Outlet Air Pressure	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Speed of Turbine	rpm	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
System Temperature(s)	ºC	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
System Fuel Consumption	(MMBTU/kWh)	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
System Emission Data	ppm	≥1 Sample/15 Minutes	≥1 Sample/15 minutes	≥ 1 Sample/hour	value, max, min, avg
PUMPED HYDRO					
Reservoir Height	ft	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Water Flow from High Reservoir to Low Reservoir	gal/min	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Water Pressure from High Reservoir to Low Reservoir	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Water Flow from Low Reservoir to High Reservoir	gal/min	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg

Data Point	Units	Sample Rate Minimum	Power Application Report Out Minimum	Energy Application Report Out Minimum	Values
Water Pressure from Low Reservoir to High Reservoir	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Water Pump Speed	rpm	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
System Temperature(s)	ºC	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Turbine Inlet Pressure	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg
Turbine Outlet Pressure	psi	≥1 Sample/Second	≥1 Sample/Second	≥ 1 Sample/15 minutes	value, max, min, avg

For the stated minimums in Table 6-1 and Table 6-2, if the Report Out can be provided at a faster rate, then the faster rate is desired and the provider shall provide the data at this rate.

7
DATA QUALITY AND TRANSMISSION

After the data is measured and logged, it shall be sent to the analyst by the provider in 24 hours or less. If the data from a time period is aggregated into a single file, like daily data, then the provider should have 24 hours from the last sample to make the data available for the analyst.

When the data is transmitted it should be sent in a timestamped-row, column format where one of the columns documents each row's unique timestamp with all other columns relaying measurements and status values for the corresponding timestamp.

It may be necessary to create multiple files for logging data within a given interval. Each file may logically represent a subsystem within the larger storage system (e.g. data from controllers, meteorological stations, container, racks, modules, cells, etc.). The files should abide by an intuitive naming scheme. For instance, each file name should contain the date, a short descriptor for what subsystem it represents, and, if there are numerous files produced in a day, a number designating which file it is for that day. An example for a group of files under this naming scheme might look like:

- Bank1_20190111_1.csv
- Bank1_20190111_2.csv
- Bank1_20190111_3.csv

A "data details" document should accompany the first set of data set (and any subsequent changes to the reported data) and should provide the following information to support the interpretation, storage, and analysis of the data. This includes:

- A short description of the data in each column
- Corresponding units
- If the data point is an enumerated type, provide all possible values with a description of what the values represent

If a software/firmware update will in any way affect the way data is logged by the system, then the vendor must alert the operator of the expected changes. If new data points will be added to the log files, the columns should be appended to the end of the file. A new "data details" document should also be provided by the vendor for added visibility into the changes.

To ensure privacy and protection of proprietary information, a possible non-disclosure agreement (NDA) can be signed between the analyst and the provider of data. This combined with the read-only access for the analyst will ensure that data will not be shared with anyone else and the provider can remain confident that their information will remain private.

Should the provider, upon review, find that the data quality is compromised due to any planned or unplanned outages, they should request or initiate repair of the system within 24 hours to ensure the smallest down time. In addition, the provider shall tag the data loss interval in a log provided to the analyst. To combat data loss due to network issues or outages, the vendor shall implement on site data storage, and 60-day backup, where compiled data can be pulled from later once connection is reestablished.

The system also needs to account for daylight savings time in cases where revenue meters automatically adjust. Data should be timestamped using methods such as Universal Time Coordinated (UTC) or similar.

8
SENSOR AND COMPUTATIONAL ACCURACY

Inaccurate sensors lead to poor quality data and hence inaccurate analysis and misleading representation of system condition. Inaccuracies can also be introduced through calculation routines where significant digits are truncated or the equations used are inaccurate in themselves.

8.1 Meter Accuracy Standards

Of primary interest is the accuracy of the electrical metering. The key data elements associated with performance analysis center on these meters. Temperature measurements are also important, but the accuracy requirements may not be as arduous. Revenue grade accuracy has been the traditional nomenclature used to describe the accuracy of meters used in utility settings. These levels of accuracy should be utilized for storage performance measurement, though the level of revenue grade accuracy needs to be established for a given project. Standards that govern the accuracy of electric meters follow:

8.1.1 United States Based

- ANSI C12.1-2014 - National Standard for Electric Meters – Code for Electricity Metering which covers the testing and installation of the meter [3]
- ANSI C12.20-2015, American National Standard for Electric Meters for Electricity Meters – 0.1, 0.2 and 0.5 Accuracy Classes. This revision introduced a new 0.1 accuracy class. Previous versions had a 0.5 accuracy (error rate <0.2%) and 0.2 accuracy (error rate <0.1%). The new 0.1 accuracy class dictates an error rate <0.05%. [4] [5]

8.1.2 International

Similar to the ANSI Class structure the International Electrotechnical Commission (IEC) standards applicable to meter accuracy follow: [6]

- IEC 62053-21 Class 1
- IEC 62053-22 Class 0.5, 0.2, and 0.1 (ed. 2)

8.2 Temperature and Humidity Sensors

The National Institute of Standards and Technology (NIST) lists numerous standards that govern the accuracy for a variety of thermocouple configurations. Of key importance is the calibration of thermocouple that is required after certain time durations. NIST Special Bulletin 250-35 details techniques for recalibration. As storage systems age it is necessary to understand that temperature sensor accuracy may deteriorate and require recalibration or replacement.

There are a variety of humidity sensors available with a wide range of available accuracy. It is important to understand not only the needed accuracy but also any drift that may be experienced overtime. In containerized systems understanding humidity may be important with respect to prevention of condensation on surfaces that are cooler than the dewpoint of the surrounding air. This should be a key consideration in humid environments with regard to O&M practices and when open doors can introduce humid air.

8.3 Impacts of Various Accuracies on Energy Measurement

It should be noted that Round Trip Efficiency (RTE) may be independent of meter accuracy since any error that scales with the power reading will not affect RTE calculations, because it will reduce/increase the charging energy as much as the discharging energy. Other important measurement parameters can be affected through differences in accuracy and the incumbent error introduced into the measurement. Figure 8-1 below highlights the cumulative difference or error that could be presented over 10 years for cumulative energy discharged from a system rated at 1MW/2MWh and discharging an expected 50MWh/year. Error deviation also affects the state of charge calculation which can propagate to reducing the state of health calculation ending the life of the system prematurely.

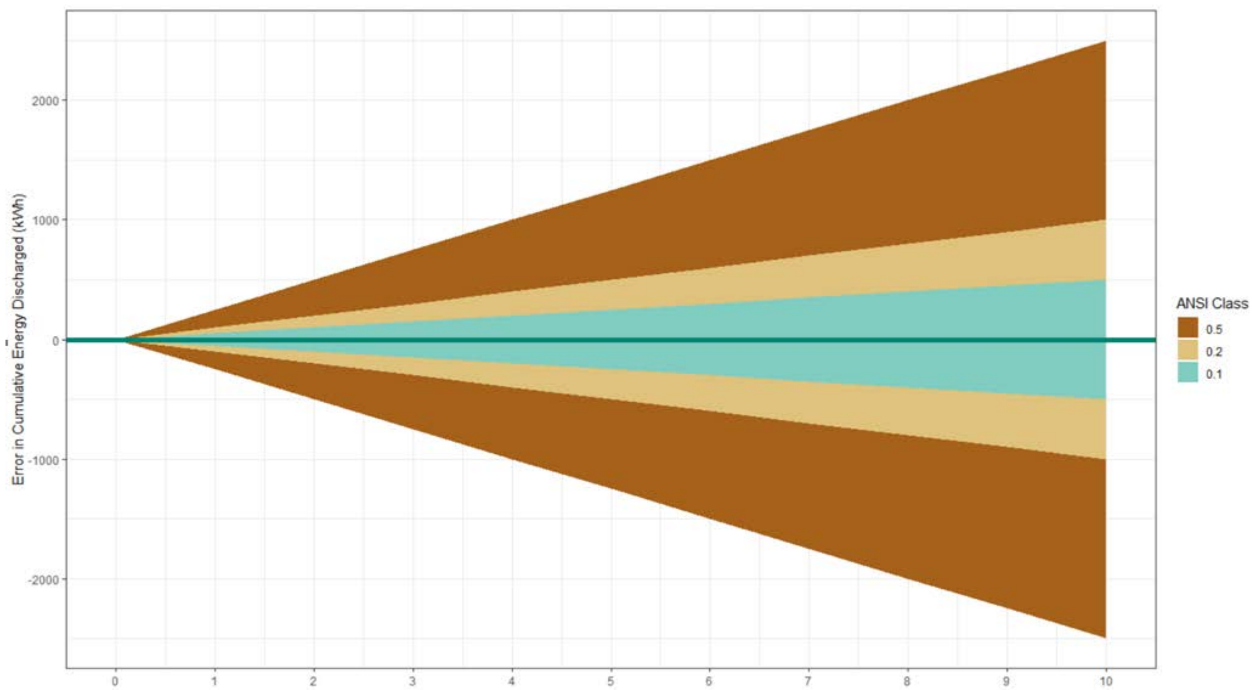

Figure 8-1 50MWh/year Cumulative Energy Error for ANSI 0.1, 0.2 and 0.5 Class Meters

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The relative expanse of the error experienced in Figure 8-1 above would be expected to broaden significantly with use of less than revenue grade metering.

9 DNP AN-2018-001 REVISION/INPUT

As this guideline develops it is important to inform relevant standards that are under modification and address storage performance measurement. This section serves to define needed tools for implementation and inform potential modifications to DNP Application Note AN2018-001 Version 2019-01-15 - DNP3 Profile for Communications with Distributed Energy Resources (DERs).

The current version is quite comprehensive in detailing the data points, protocol and settings required for communication to DERs, however there needs to be recognition of the large number of points within the storage system that would require external monitoring for independent performance assessment.

9.1 Need for Data Mapping Tools

It is important to recognize the level of effort needed to define and map the data points between sensors, computers and the historian. As such it is recommended that software tools that enable rapid and efficient mapping be developed in conjunction with further development of the Application Note as it emerges into the IEEE 1815 Standard. These types of tools will also allow for more discreet identification and data labeling for specific points within the battery system. is also pertinent. Key features of these tools could entail

- Drop down menu selection of discreet points
- Automated labeling of points to allow for discreet identification of individual sensors as to their physical location

9.2 Further Input to the Application Note/IEEE 1815

The current version of the application note is limited in defining subcomponents of the battery system. Following are suggested modifications, which will need to be modifiable as related safety and performance standards evolve:

9.2.1 Binary Inputs

- Status of fire suppression system
- Status of safety ventilation system
- Status of Gas and Smoke detectors, if applicable
- Container door status

9.2.2 Counters

Recognize that system meter and site meter may not be the same.

9.2.3 Analog Inputs

- Add number of battery strings, racks.

- Modules and cells – appended to Point Index numbers A125-A127 – the current point index only enumerates number of meters, inverters and batteries.

More definition is required to differentiate meter #1 through "m" as listed in the DNP AN2018. Simple numerical labeling of the meters and other points can lead to less than efficient analysis and further description may be needed to better identify the physical location of each meter. This same comment applies to

- DER Unit
- Inverter
- Battery Bank

It is also necessary to add, as mentioned previously, data points #1- "m" for the following discreet subsystem

- Battery string – including available DC current and voltage
- Battery rack - including available DC current and voltage, status (on or off line) and temperature
- Battery module - including available DC current and voltage, and temperature
- Battery cell - in including available DC voltage, and temperature (if available)
- Currently there is no mention of humidity measurements. Relative humidity or dew point needs to be added for outside (ambient) and inside container measurements.

10 CONCLUSION

While this guideline for providing data does not guarantee perfect analysis, it serves as a starting point to enable communication on the types and quality of data available from energy storage systems. Ultimately, if the data is collected in a consistent manner across a large number or storage systems, accurate evaluation and comparison will be possible and allow for even more efficient integration energy storage technologies.

Robust data, provided via these guidelines, can benefit all stakeholders and facilitate meaningful analysis and independent verification of storage performance. This analysis capability can lead to impactful conclusions that help improve the performance of energy storage systems as well as improve O&M practices. As noted throughout this guideline, there are numerous areas that need more research. Numerous activities will help inform subsequent versions, including sessions under the auspices of EPRI's Energy Storage Integration Council (ESIC) and IEEE Energy Stationary Storage and Batteries (IEEE ESSB). These forums are open to all and information on participation can be found at www.epri.com/esic or www.ieee.org.

11 REFERENCES

[1] *IEEE Std. 2030.2 -2015 - IEEE Guide for the Interoperability of Energy Storage Systems Integrated with the Electric Power Infrastructure.*

[2] DNP Users Group, "DNP3 Application Note AN2018-001 - DNP3 Profile for Communications with Distributed Resources," January 2019. [Online]. Available: https://www.dnp.org/Resources/Document-Library?folderId=1261. [Accessed March 2019].

[3] Energy Storage Association, "Energy Storage Technologies," 17 01 2019. [Online]. Available: www.energystorage.org.

[4] American National Standards Institute, "ANSI C12.1-2014 - Code for Electricty Metering".

[5] American National Standards Institute, "ANSI cv12.20-2015 - Electricity Meters - 0.1, 0.2, and 0.5 Accuracy Classes".

[6] Schneider Electric White Paper, "Regulating accuracy impacts of changes in ANSI C12.1 and ANSI C12.20".

[7] International Electrotechnical Commission.

12
GLOSSARY

Below is list of acronyms used in this document.

Acronyms

A	Amperage
API	Application Program Interfaces
CAES	Compressed Air Energy Storage
dBm	Decibels referenced to Milliwatts
ESIC	Energy Storage Integration Council
ESS	Energy Storage System
Ft	Feet
Hz	Hertz
kW	Kilo Watts
kWh	Kilo Watt Hour
kVAR	Kilo Volt-Amperes Reactive
NIST	National Institute of Standards and Technology
Pf	Power factor
Psi	Pounds per square inch
Pst	Perceptibility
RPM	Revolutions per Minute
Sandia	Sandia National Laboratories
V	Voltage
WSDL	Web Service Definition Language
AHJ	Authority Having Jurisdiction
BMS	Battery Management System
CSR	Codes, Standards and Regulations
CT	Current Transformer
DER	Distributed Energy Resource
EMI	Electromagnetic Interference
EPRI	Energy Power Research Institute
ESIC	Energy Storage Integration Council
ESS	Energy Storage System
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
kVAR	Kilovolt Ampere Reactive
LVRT/HVRT	Low/Hight Voltage Ride Through
Ms	Milliseconds

MVAR	Mega Volt Ampere Reactive
PCC	Point of Common Coupling
PCS	Power Conditioning System
PNNL	Pacific Northwest National Laboratory
PT	Potential Transformer
SCADA	Supervisory Control and Data Acquisition
SOC	State of Charge
SOC	State of Health
THD	Total Harmonic Distortion
ANSI	American National Standards Institute

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