An Overview of Tools to Facilitate Documenting and Validating the Safety of an Energy Storage System Installation

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***Abstract*- This paper provides an overview of two energy storage system (ESS) compliance tools to help address the acceptability of the design and construction of stationary ESSs, their component parts, and the siting, installation, commissioning, operations, maintenance, and repair/renovation of ESSs within the built environment. These tools assist with the tasks of documenting and validating compliance with codes, standards, and regulations (CSRs) covering ESS safety, both the specific provisions that may address an ESS technology and its application or a situation in which the codes and standards may not provide specific provisions and the documentation and verification of the safety of the ESS are based on it being no more hazardous nor less safe than other ESS or similar technologies that are specifically covered in CSRs.**

***Keywords*- codes, standards, compliance, documentation, verification**

I. Introduction

Codes, standards, and regulations governing the design, construction, installation, commissioning, and operation of the built environment are intended to protect public health, safety, and welfare. These documents change over time to address new technology and safety challenges, so there is generally some lag time between the introduction of a technology into the market and the time it is specifically covered in model codes and standards developed in the voluntary sector. Development of a new code or standard can take 3 to 4 years from the initiation of the effort until the result is adopted. Typically, this takes on the order of 4 to 5 years and in some cases due to recent efforts to reduce the frequency of adoptions at the state and local level it could be over 6 years before new provisions covering ESS or other technologies are adopted. So, those seeking to deploy energy storage technologies or needing to verify an installation's safety may find it challenging to apply current CSRs to an ESS. Even when CSRs provide specific criteria, those deploying ESS technology must document compliance with the CSRs and those enforcing compliance must be able to verify it with their CSRs.

Under the U.S. Department of Energy's Energy Storage Safety Strategic Plan, developed with the support of the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability Energy Storage Program by Pacific

Northwest National Laboratory and Sandia National Laboratories, an Energy Storage Safety initiative with collaboration and involvement from many stakeholders has been under way since July 2015. One of three key components of the initiative involves CSRs affecting the timely deployment of safe ESSs. Their timely deployment is focused on how to document and validate compliance with current CSRs and in so doing validate that a proposed ESS installation is safe, as intended pursuant to the CSRs.

A task force was formed under the ESS Safety working group to address documenting and verifying compliance with current CSRs and through their efforts the Energy Storage System Guide for Compliance with Safety Codes and Standards [1] was developed and published in June 2016. In late 2016, another task force of stakeholders involved with the ESS safety initiative was formed, and through their efforts the Energy Storage System Safety–Plan Review and Inspection Checklist [2] was developed and published in March 2017. Acknowledgments of participants in each task force are included in each of the published documents.

As a result of the rapidly increasing demand to deploy stationary ESSs in the commercial and residential sector, the Energy Storage System Safety Working Group stakeholder involvement identified a critical need. The lack of guidance and resources to implement and facilitate new compliance processes in reviewing, documenting, and validating the safety of stationary ESSs is widespread throughout the United States (U.S.) and local jurisdictions that adopt and enforce national model codes and standards. Timely deployment of safe ESS is focused on how to document and validate compliance with current CSRs and, in so doing, validate that a proposed ESS installation is safe as intended pursuant to the CSRs.

Two ESS compliance tools were developed to help address the acceptability of the design and construction of stationary ESSs, their component parts and the siting, installation, commissioning, operations, maintenance, and repair/renovation of ESSs within the built environment. These tools assist with documenting and validating compliance with U.S. CSRs covering ESS safety, both specific provisions that may address an ESS technology and its application or a situation in which the codes and standards may not provide specific provisions and the documentation and verification of the safety of the ESS is based on it being no more hazardous nor less safe than other ESS or similar technologies that are specifically covered in CSR. These tools are not intended to replace codes and standards. They are intended to simplify and clarify CSR compliance supporting the safe deployment of ESS in the current environment. The following is an overview of each of the compliance tools, a compliance guide, and a compliance checklist, developed under the U.S. Department of Energy's Energy Storage Safety Strategic Plan, with the support of the U.S. Department of Energy's Office of Electricity Delivery and Energy Reliability Energy Storage Program by Pacific Northwest National Laboratory and Sandia National Laboratories.

II. Tool 1: Energy Storage System Guide for Compliance with Safety Codes and Standards

The Compliance Guide (CG) is intended to facilitate the timely deployment of stationary ESSs in accordance with existing safety-related CSRs and other governing (adopted) criteria that are based on voluntary sector standards and model codes that may not have been updated to specifically and prescriptively cover all ESS technologies or their intended applications. In this role, the CG is intended to address challenges related to documenting and verifying compliance with CSRs that have not been updated to more specifically address ESS technologies.

The CG provides 1) assistance to those who need to document compliance with current safety-related codes and standards in order to develop and deploy ESSs and 2) guidance for those responsible for approving and/or accepting ESSs or for verifying their compliance with the same codes and standards on an ongoing basis.

A. Energy Storage System Product and Component Review and Approval

Documenting or validating the safety of an ESS, either as a complete "product" or as an assembly of various components, involves a review of the product, its components, and the manner in which they are combined to create the product. An ESS resembles a product—either a self-contained piece of equipment or an assembly of matched components. The more the ESS is composed of component parts assembled in the field, the greater the reliance on codes and standards that address component installation, rather than complete system installation, as a basis for determining the safety of the ESS (e.g., the ESS "product" is essentially constructed in the field not at a factory). Fig. 1 is a flow chart showing the general process of documenting and validating the safety of an ESS product or component. If no available standards cover the ESS product or its components (or one chooses to not document safety to standards that are available), then alternative methods of evaluating and documenting safety will likely be needed. The various steps associated with reviewing and approving ESS products and components are described below and are covered in more detail in the CG.

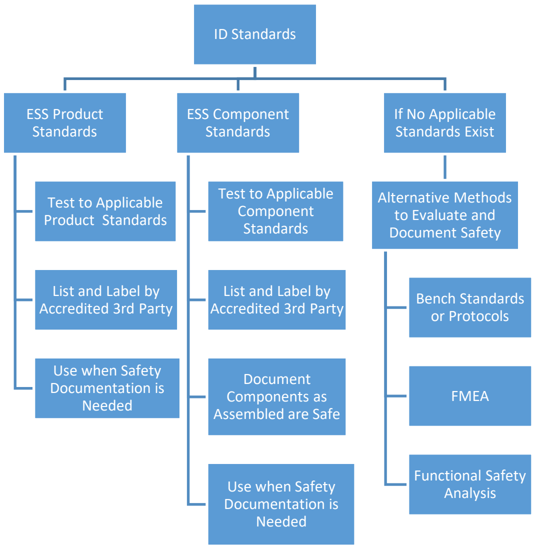

Fig. 1. Review and approval of Energy Storage System Products and their component parts.

1. Determine safety-related testing standards that are applicable to the ESS as a complete prepackaged system or to the components of an ESS when not a complete prepackaged system. These standards will either be included by reference in higher level existing codes and standards applicable to the built environment and or can be adopted and applied separately. Table I is a short list of some of the safety-related testing standards that could be used as a basis for testing and listing systems and system components. More detail about these and additional standards is provided in Appendix C (components) and Appendix D (systems) of the CG. In addition to the standards listed in Table I, specifications and related documents promulgated by utilities may address the acceptability of an ESS for location on or interconnection with the power grid. These standards include IEEE 1547 and may include others beyond those listed in Table I that are adopted by reference in the National Electrical Safety Code (IEEE C2).

Table I
Energy Storage System and Component Standards[1]

Title	Designation
Molded-case circuit breakers, molded-case switches, and circuit-breaker enclosures	UL[a] 489
Electrochemical capacitors	UL 810A
Lithium batteries	UL 1642
Inverters, converters, controllers and interconnection system equipment for use with distributed energy	UL 1741

resources	
Batteries for use in stationary applications	UL 1973
Second-use batteries	UL 1974 (proposed)
Recommended practice and procedures for unlabeled electrical equipment evaluation	NFPA[b] 791
Standard for interconnecting distributed resources with electric power systems	IEEE 1547
Recommended practice and procedures for unlabeled electrical equipment evaluation	NFPA 791
Outline for investigation for safety for ESSs and equipment	UL 9540
Safety for distributed energy generation and storage systems	UL 3001 (proposed)
Safety standard for molten salt thermal energy storage systems	ASME TES[c]-1 (proposed)
a. UL = Underwriters Laboratory b. NFPA = National Fire Protection Association c. ASME TES = American Society of Mechanical Engineers Thermal Energy Storage	

[1]International Electrotechnical Commission (IEC) and other non-U.S. CSRs are not identified in the short list of Table 1 or the more robust list in Appendix C and D of the CG. IEC and other non-U.S. CSRs are outside of the scope of this work.

1. If relevant testing standards are not identified, they may be under development by a Standards Development Organization (SDO) or by a third-party testing entity that plans to use them as the basis for safety testing until a formal standard has been developed and approved by an SDO. Documents that precede formal standards developed by an SDO can be referred to as bench standards, protocols, outlines of investigation, or acceptance criteria. They can provide some guidance on testing until a formal standard is published. In many cases these initial documents form the initial draft of a standard developed by an SDO.
2. As a manufacturer of an ESS or component, conduct internal testing (e.g., self-testing) as required by the standards (or in accordance with bench standards, protocols, or acceptance criteria) applicable to the ESS or component. Then, based on the test results, determine whether the system or component design or construction need to be changed, implement those changes, and re-test/make changes until the system or component tests indicate compliance.
3. In conducting internal tests as a manufacturer, it is probable that those experiences will lead to questions about the test standard being used or suggested changes to improve the usability or accuracy of the standard.
4. Secure the services of an approved third-party testing agency that can test the ESS or component to determine if it complies with applicable standards.
5. When no standard is available with which to evaluate the safety of an ESS or component and a new standard is not under development, a bench standard or protocol may be available or could be developed by a third-party testing agency for use in assessing the acceptability of the system or component from a safety standpoint.
6. Prior to establishing any standard or bench standard, a failure modes and effects analysis (FMEA) could be prepared to document the safety of the ESS or its components from a reliability standpoint based on the application and use of IEC 60812, Analysis Techniques for System Reliability–Procedure for Failure Mode and Effects Analysis. Alternatively, consider the application of NFPA 791, which covers how to assess the acceptability of unlisted electrical equipment.
7. After an ESS or component has been found to comply with one or more appropriate safety standards, bench standards, protocols, etc., via testing by an approved third-party testing agency and their issuance of one or more relevant test reports, the test report can be used as documentation of system/component safety.
8. Secure the services of an approved third-party certification agency that can conduct ongoing monitoring of the continued production of the ESS or component as well as the manufacturer's quality control and manufacturing processes.
9. Through those services, the third-party agency is then in a position to authorize the manufacturer of the ESS or component to list the system or component as complying with the criteria (standard, protocol, etc.) used as a basis for safety testing and label it as such. This will depend on the scope of the safety testing conducted and the findings associated with the review of ongoing production and quality control processes.
10. Use the results from the activities above (testing and listing) when documenting compliance with safety-related codes and standards for any authorities having jurisdiction (AHJs).
11. After documenting or verifying the acceptability of the ESS as a system or individual system components, the safety of their application in, on, or around buildings and facilities must be addressed.
12. Looking toward an actual installation, those who are pursuing application and use of the ESS or components should identify the AHJs that have authority over ESS installation and the CSRs they have adopted to address its system safety.

B. Review the Energy Storage System as a Complete Product

When considering an ESS as an assembly of components, a standard for a complete "product" is likely to refer to various components and component standards within the ESS standard and then simply tie them together. One approach to assessing the safety of the ESS "product" is to confirm that the components meet relevant component standards and then assess the acceptability of their assembly as an ESS. Another approach is to consider the ESS "product" as a black box and how the entire ESS would function as an assembly of components, and then evaluate the ESS "product" against an appropriate standard covering resultant assembly of components. If the ESS "product" satisfies the provisions of the standard and related design criteria and performance metrics, then the components of the ESS would be considered to be in compliance with the standard. Through third-party certification programs, ongoing production of the ESS "product" would be inspected to ensure that subsequent production is identical to the ESS that was tested and found to comply with the standard. Those certification programs would also review and assess the administrative and quality control aspects associated with the manufacturer of the component. When a standard considers the ESS as a complete product, by default it considers performance of one or more components within the requirements of the standard, so the safety of the components is evaluated as a result of testing of the entire ESS.

Standards covering an ESS as a complete product, such as UL 9540, Outline for Investigation for Safety for Energy Storage Systems and Equipment, or ASME TES-1, Safety Standard for Molten Salt Thermal Energy Storage Systems, and the associated conformity-assessment activities to document and validate compliance would be of primary relevance to manufacturers producing an entire ESS "product." But ESS component manufacturers would want to be familiar with those standards to ensure their components comply with them when used in the ESS. Those who assemble a complete ESS "product" onsite from various components would likely have to document compliance on the basis of that standard, so they would benefit from using components that complied with relevant component safety standards. In addition, those who create an ESS "product" onsite by assembling various ESS components may also be more likely to have installation-related codes and standards that address the assembly of the components. Utilities, building regulatory agency staff, and others engaged in validating compliance would have an easier time approving ESS installations when the ESS "product" as a whole is validated as complying with applicable standards. In the absence of such standards, and until they are developed, it is more likely that approval of an ESS "product," whether prepackaged or assembled onsite from various components, would have to be pursued on a case-by-case basis working with the applicable parties involved in documenting and validating the safety of the ESS.

C. Energy Storage System Installation Review and Approval

A review of the installation of an ESS covers what is involved in documenting or validating the safety of an ESS as installed in, on, or adjacent to buildings or facilities. This information does not cover the safety of the ESS as a complete "product" or the safety of the individual components of the ESS (as discussed in the previous section). It covers the installation of the ESS when tested and listed as a complete product or the assembly and installation of the components making up the ESS when the ESS is constructed onsite (as opposed to being a factory-constructed "product"). That said, the installation-related criteria that are part of the ESS "product" or component listing will also apply.

Installation provisions simply cover where and how the ESS interacts with its environment to ensure the surrounding environment is not adversely affected by an incident associated with the ESS and, in turn, that the ESS is not adversely affected by a natural or manmade incident associated with the surrounding environment. When an ESS has not been listed as a complete "product" and instead is an onsite assembly of ESS components, the installation provisions will have a greater impact on the ESS because they will address the acceptability of how the components are aggregated as an ESS onsite to construct the ESS.

The topics in Table II should be addressed when documenting and validating the safety of an ESS installation.

TABLE II
TOPICS ASSOCIATED WITH AN ENERGY STORAGE SYSTEM INSTALLATION

Topic	**Description**
Administration	The scope and purpose of the CSR and how it applies to new and existing ESS installations. These provisions will define what is covered in the CSR and how the provisions will apply to the ESS as a product or components and their installation.
References	Any other code, standard, or regulation document that is related to the installation of the ESS will generally be referenced and as such becomes part of the CSR in which is it referenced.
Definitions	All relevant terms are defined. They can be critical in "sorting out" what does and does not apply to an ESS installation and, if applicable, how the provisions are to be implemented.

ESS equipment and components	How to define the ESS (product, factory-matched components, field designed, and assembled) and what applies to documenting and verifying the safety of the ESS related to any design or construction that takes place offsite (e.g., as manufactured).
Siting	Location in relation to various aspects of the site (e.g., parking, roads, buildings, etc.), as well as criteria relevant to location in, on, or adjacent to one or more buildings.
Interconnection with other systems	Connections to communications, electrical inputs and outputs, and other energy-related systems on the site as well as any interconnections with an electric utility.
Ventilation, exhaust, and thermal management	Air flows, relative pressures, temperature and intake, and exhaust locations associated with the normal operation of the ESS.
Fire protection	Fire and smoke detection, fire suppression, containment of fire and smoke, smoke removal, containment of fluids and effluent from, firefighting operations, access/egress, and signage.
Commissioning	Validating the proper operation of the ESS and all control and emergency systems associated with the ESS.

D. Additional Resources in the Compliance Guide

The CG also covers frequently asked questions in order of when they are likely to occur along the timeline associated with the development and deployment of an ESS. Appendices augment the core materials provided in the body of the CG which include an overview of conformity assessment, a list of standards related to ESS components, entire ESSs, and installation of ESSs. Lists of related standards are subject to change as new codes and standards are developed and existing ones are updated; they are augmented by a monthly report compiled by Pacific Northwest National Laboratory (PNNL) that covers the ESS-related activities of 10 U.S. SDOs.

The ongoing development and deployment of ESS technology, anticipated use of the CG, and future availability of details associated with particular ESS technology installations, mean the CG can be further enhanced as technologies and practices evolve. The author welcomes suggestions for future enhancements of the CG.

III. Tool 2: Energy Storage System Safety – Plan Review and Inspection Checklist

The purpose of the Plan Review and Inspection Checklist (Checklist) is to help AHJs that are validating ESS installations recognize the issues they have to look out for. It could also serve those who have to document the safety of their ESSs installations (e.g., permittees). The Checklist augments the CG and acts as a stand-alone document that can be customized to meet more specific needs of stakeholders/users.

The Checklist is broken down into many sections (listed below) to streamline the plan review and inspection process. Refer to the actual Checklist for all provisions under each section. Figs. 2 and 3 are screenshots showing the Cover Page and ESS Technology Information of the Checklist (the first 2 bulleted items below). The complete Checklist is 30 pages long.

A. Energy Storage System Plan Review/Inspection Checklist Sections

- Cover Page (project name, address, facility owner, ESS owner, type of ESS, ESS owner, ESS operator)
- ESS Technology Information
- Pre-Inspection/Plan Review
- Self-Contained, Prepackaged ESSs
- Pre-Engineered ESSs
- Engineered and Field-Constructed ESSs
- Repairs to Existing ESS
- Additions to Existing ESS
- Renewal or Renovation of Existing ESS
- General Siting of ESS and Associated Equipment, Components and Controls
- Outdoor Installations of ESS and Associated Equipment, Components and Controls
- Rooftop Installations of ESS and Associated Equipment, Components and Controls
- Interior Installation of ESS and Associated Equipment, Components and Controls
- Interconnections with Other Systems
- Ventilation, Thermal Management and Exhaust
- Fire Protection – Fire and Smoke Detection
- Fire Protection – Fire Suppression
- Fire Protection – Fire Containment
- Fire Protection – Removal of Smoke
- Fire Protection – Containment of Fluids
- Fire Protection – Signage
- Commissioning

Energy Storage System (ESS) Plan Review/Inspection Checklist

Date: ____/___/_____

Project Name ____

Address ____

State: ________ County: ______________ Jurisdiction: ______________________

Facility Owner (owner of facility where ESS is installed): ____________________ I.C.E. #________

ESS Owner (owner of ESS if different than facility owner):____________________ I.C.E. #________

☐ New System ☐ Addition ☐ Renewal or Renovation ☐ Repair

System Manufacturer(s): ____

System Installer: ____

System Integrator (if one is involved in the project):____________________ I.C.E. #__________

System Operator: ______________________________ I.C.E. #________________

System Name: ____

System Address: ____

System Location (in relation to the primary electrical meter): ____________________________

Services Provided: ____

Fig. 2. Energy Storage System Plan Review/Inspection Checklist - Cover Page.

ESS Technology Information			
Type of ESS			
ESS chemistry (if electrochemical)			
Enclosure Type			
Footprint Area (ft.^{2})			
Weight (lbs.)			
Overall Dimensions L x W x H (ft.)	Length	Width	Height
Rated Continuous Discharge Power (kW)			
Input Voltage into the ESS (VAC)			
Output Voltage (nominal)(VAC)			
Frequency (Hz)			
Number of phases (input and output)	Input	Output	
Duty cycle (if applicable)			
Maximum short circuit current (A)			
Auxiliary (if applicable)	Input voltage (V)	Output voltage (V)	
Auxiliary (if applicable)	Current (A)	Frequency (Hz)	
Rated Discharge Energy (kWh)			
Minimum Discharge Time (min.)			
Maximum Discharge Time (min.)			
Operating Temperature Range (°F)			
Stored Energy Capacity (kWh)			
Self-discharge Rate (% energy loss/day)			
Liquid Capacity (Gal.) needed for secondary containment of flow batteries			
Special environmental ratings and limitations as applicable	Seismic	Indoor	Outdoor

Fig. 3. Energy Storage System Plan Review/Inspection Checklist – ESS Technology Information.

IV. CONCLUSION

The ESS industry is rapidly developing new chemistries, system types, and applications. The codes and standards that provide the benchmark for documenting and validating what is and is not considered safe are dynamic and regularly updated. Those documenting and validating ESS compliance must adjust to the ongoing changes. Hence, the CG and Checklist, as they exist today, have a limited "shelf life." They will need regular updating and enhancement as living documents over time. The ESS Plan Review and Inspection Checklist will be further enhanced to reflect the continuing evolution of ESS technology development and deployment, the anticipated use of the CG, and the future availability of details associated with particular ESS technology installations. It will be included in the ESS Guide for Compliance with Safety Codes and Standards and can be accessed at http://www.sandia.gov/ess. The author welcomes suggestions for future enhancements of this document.

The author also encourages all who have a stake in ESS safety to collaborate with the ESS Safety Working Group in the development and deployment of future versions of the CG and Checklist and to identify new resources that foster timely development and deployment of safe ESSs. The CG and Checklist will be updated in 2018 and will include codes and standards updates, new codes and standards development, case studies and new resources such as the ESS Safety Roadmap Focus on Codes and Standards monthly report. Furthermore, based upon feedback received from the ESS Safety Working Group, the CG will also include lessons learned and gaps in knowledge that require research and analysis that can serve as a basis for criteria in those codes and standards.

REFERENCES

[1] P. C. Cole and D. R. Conover, "Energy storage system guide for compliance with safety codes and standards," Pacific Northwest National Lab. and Sandia National Labs., Richland, WA and Albuquerque, NM, Rep. PNNL-SA-118870/SAND2016-5977R, Jun. 2016.

[2] P.C. Cole and D.R. Conover, "Energy storage system safety: Plan review and inspection checklist," Pacific Northwest National Lab. and Sandia National Labs., Richland, WA and Albuquerque, NM, Rep. PNNL-SA-124486/SAND2017-3066 R, Mar. 2017.