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Guidelines Developed by the Energy Storage Integration Council for Distributed-Connected Systems

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EPRI Project Manager

B. Kaun
S. Eckroad

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

SANDIA NATIONAL LABORATOROES
Albuquerque, New Mexico 87185 and Livermore, California 94550

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The Safety Subgroup of the ESIC System Development Working Group prepared this report.

Working group leadership and key contributors are listed below:

ESIC Safety Subgroup:

David Rosewater, Sandia National Laboratories
Steve Willard, EPRI
Ryan Franks, NEMA
Eva Gardow, FirstEnergy Service Corp.
David Conover, Pacific Northwest National Laboratory
Timothy Croushore, FirstEnergy Service Corp.
John Holmes, San Diego Gas & Electric Co.
Neeta Khare, Eos Energy Storage
Laurie Florence, Underwriters Laboratory LLC
Roberto Favela, El Paso Electric Co.

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ABSTRACT

Safety is critical to successful procurement of energy storage. Yet, safety aspects can be difficult to assess and it is easy to overlook at many stages in the integration process. To address these issues for distribution utilities, the Energy Storage Integration Council (ESIC) tasked the system integration working group to develop guidance for managing safety throughout the integration process. This document presents the results of a gaps analysis for safety in the energy storage integration process, provides guidance on managing safety throughout the project life cycle, and then lists reference codes and standards which could be useful in developing procurement documents. The gap analysis is first performed generally on the gaps in safety faced by the industry at large and then focuses more directly on gaps for utilities and integration on the distribution system. Guidance on safety in the energy storage integration process is organized by project stage from generation initial buy-in, through installation and operation, to decommissioning. Reference codes and standards are then organized by functional area. This document concludes with a list of all of the recommended documentation for ensuring safe deployment of energy storage.

The language in this guide narrowly refers to energy storage systems connected to distribution utility infrastructure. However, the guidance contained herein is likely to apply broadly to energy storage integration issues when connecting both to transmission infrastructure and behind the meter. This guide is expected to inform efforts to improve safety in the system integration process wherever it is helpful and to understand when and where the recommendations it offers may apply to a specific situation. Readers are advised that the document should be considered as informative rather than prescriptive.

Keywords
EPRI
Energy storage
Energy storage codes and standards
Energy Storage Integration Council (ESIC)

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1
INTRODUCTION

The Energy Storage Integration Council (ESIC) is a forum in which electric utilities guide a discussion with energy storage vendors, government organizations, and other stakeholders to develop reliable, safe, and cost-effective energy storage options for the utility industry. Through ESIC a number of working groups have been assembled to develop common approaches to critical components supporting the mission of ESIC, which is “to advance the integration of energy storage through open, technical collaboration, guided by the vision of universally-accessible safe, secure, reliable, affordable, environmentally responsible electricity.” The initial focus of ESIC is to find common solutions to definition and deployment for distribution system-connected energy storage systems, encompassing the utility scope from customer meter to 69kV.

Because safety throughout a project life cycle is a cornerstone to successful implementation and operation of energy storage systems, ESIC tasked its System Integration Working Group to develop guidelines for distribution utilities to address safety throughout the integration process.

Due to the varied nature of storage technologies, system designs, deployment environments, and function as well as placement within the electric grid, there is a wide set of safety codes, standards, and regulations (CSR) that may be consulted for applicable requirements. This list is continuously being updated to close gaps but has, so far, lagged deployment[1]. While methods exist for effective documentation and validation of safety, these methods are not necessarily uniform across jurisdictions of local authorities who rely on a variety of codes and standards to enforce safety, some of which may be out of date or incomplete. This has the potential to increase risks associated with ESS deployment. Developing common requirements for specific CSR criteria or alternative methods for validating safety, along with updating the applicable CSRs is seen as a key need. To reduce the risk to deploying energy storage, it is important that there be a well formulated and adequately funded research program with the goal of further informing local and national enforcement authorities and hence allowing wider and faster adoption. This document provides guidelines distribution utilities may need to understand and support ongoing research (Chapter 2), to understand and implement steps for meeting existing CSRs (Chapter 3), and to locate and access relevant resources (Chapter 4).

Non-uniform or out of date CSRs may degrade the effectiveness or relevance of decisions for a given project by the Authority Having Jurisdiction (AHJ) or administrative authority. Lack of clarity or availability of specific guidance on CSRs and other approval methods can lead to higher costs, longer schedules, and occasionally erroneous safety requirements imposed on deployments late in the integration process. Another source of inefficiency is that new energy storage technologies can require additional safety assurances not heretofore envisioned. Chemical and mechanical hazards that may be present in an Energy Storage System (ESS) and often necessitate an independent third party to adequately assess the safety features of the ESS

[1] Energy Storage Safety Strategic Plan, Department of Energy, December, 2014, Available, http://www.sandia.gov/ess/docs/other/DOE_OE_Safety_Strategic_Plan_Dec_2014_final.pdf

itself and its installation. With an expanding array of ESS technologies a lack of mature and robust ESS safety standards places challenges on the independent arbitration process to conduct the needed safety assessments that will facilitate market acceptance of these new technologies.

This document begins with an analysis of the existing gaps, both in the energy storage industry in general and in the utility specific integration process. A research-oriented plan to address each gap is then outlined in brief by first assessing ongoing work in the industry and second identifying specific tasks that the ESIC can undertake or support. Finally, this document presents current information on the process, steps and resources for ensuring that safety is included in the integration of energy storage.

This document should be considered as informative rather than prescriptive.

2
GAPS IDENTIFICATION

Energy storage is an emerging technology whose rapid deployment has outpaced codes, standards, and regulations that govern its procurement, application, and operation. This trend may continue simply because CSRs cannot anticipate the results of energy storage R&D. CSRs are written using experience from what is being deployed and hence can lag new technologies and create gaps. Identifying and addressing gaps will, over time, help protect stakeholders by reducing the risks associated with deploying energy storage. This section presents an analysis of these gaps from two perspectives. First, from the general perspective to identify gaps that are present from the energy storage vendor and developer standpoint , and second, from the perspective of the distribution utility or consumer standpoint to identify gaps that may be unique to their integration process.

2.1. General Gaps

The Department of Energy (DOE) published the Energy Storage Safety Strategic Plan in December 2014[1]. This document identified three key gap areas broadly impacting the industry: science-based safety validation techniques, incident preparedness, and safety documentation. These gaps are interconnected areas that may be bridged together to achieve a desired future state. A brief description of each gap area is provided below including the assessed present state and desired final state for the industry.

2.1.1. Science-based Safety Validation Techniques

Safety validation techniques are the methods (testing, inspection, analysis, etc.) used to decide whether a deployment is safe. Validation could encompass the whole project lifecycle including technology development, manufacturing, system design, installation, construction, commissioning, operation, maintenance and decommissioning. The present state for technologies with up-to-date CSRs (e.g. vented lead-acid batteries) consists of systems and/or their component parts that are evaluated for safety as 'products' by independent third party testing and listing agencies. Then applicable AHJs rely on the guidance through test results and ensuing codes and standards developed from those agencies for review and potential approval of the installation. Presently systems are likely to have to be evaluated for safety during inspection, after all of the design choices have already been made and the system has been installed, due to the gaps associated with updating CSRs. This can lead to costly last-minute modifications and project delays. Building and electrical inspectors for the AHJ can be unfamiliar with the specific technology and the technology specific safety requirements. Hence the approaches used to review and potentially validate adherence to safety codes and standards can vary widely between AHJs. A mature market requires a uniform set of methods used to validate safety that is effective and efficient, thereby allowing for rarity of incidents and rapid deployment.

2.1.2. Incident Preparedness

As energy storage becomes more ubiquitous, certain incidents may occur that will inevitably require the intervention of first responders to protect lives and property. Emergency action plans and hazard/risk analysis have the goal of being able to minimize the hazardous effects of accidents when they do occur and reduce the risk to first responders. Presently, action plans are often insufficient to accomplish this goal and local fire departments are unaware of the hazards and safe procedures to use when responding to an incident. It is preferred that first responders be engaged early in the design and siting process, and that all hazards and risks be both minimized and well understood by all participants in the supply chain (i.e., including researchers, developers, vendors, integrators and consumers).

2.1.3. Safety Documentation

The current state of codes, standards, and regulations (CSRs) pertaining to grid energy storage components and deployments lag the pace of technological advancement and requiring that they be continuously updated. This is due to the current rapid pace of technology advancement contrasted to the relatively slow place of CSR development which can take many years to manifest changes. Given the variety and complexity that the available energy storage technologies have achieved, existing CSR may need to be updated and possibly new standards may need to be developed to ensure safe deployment. The desired final state is for technology specific, appropriate CSRs to ensure safety by enabling consumers of energy storage to apply a single set of codes and standards to address all safety related issues. For instance, a few system standards covering the design and construction of the storage technology could provide system level requirements and reference component standards which provide component level requirements. This hierarchical structure would enable customers to develop clear specifications and venders to pass on clear requirements to their suppliers and subcontractors.

2.2. Distribution Utility Gaps

The integration process for utility owned energy storage connected to the distribution system produces unique challenges and hence unique gaps to be addressed. This process, as it exists today, can be summarized by the 15 steps shown in Figure 2-1.[2] The complexity of the process is indicative of the fact that energy storage technologies have yet to reach the commercial stage of pre-designed, pre-packaged and catalog-listed products. In such a commercial stage, safety considerations will have been largely identified and addressed. In the meantime, the existing process is an inefficient model for managing safety in the deployment of energy storage. As such it produces gaps which then produce research questions that need to be answered both for current project deployments and for achieving full commercialization.

[2] In addition to those steps in the diagram, utilities will also need to perform and report on routine inspections to regulators.

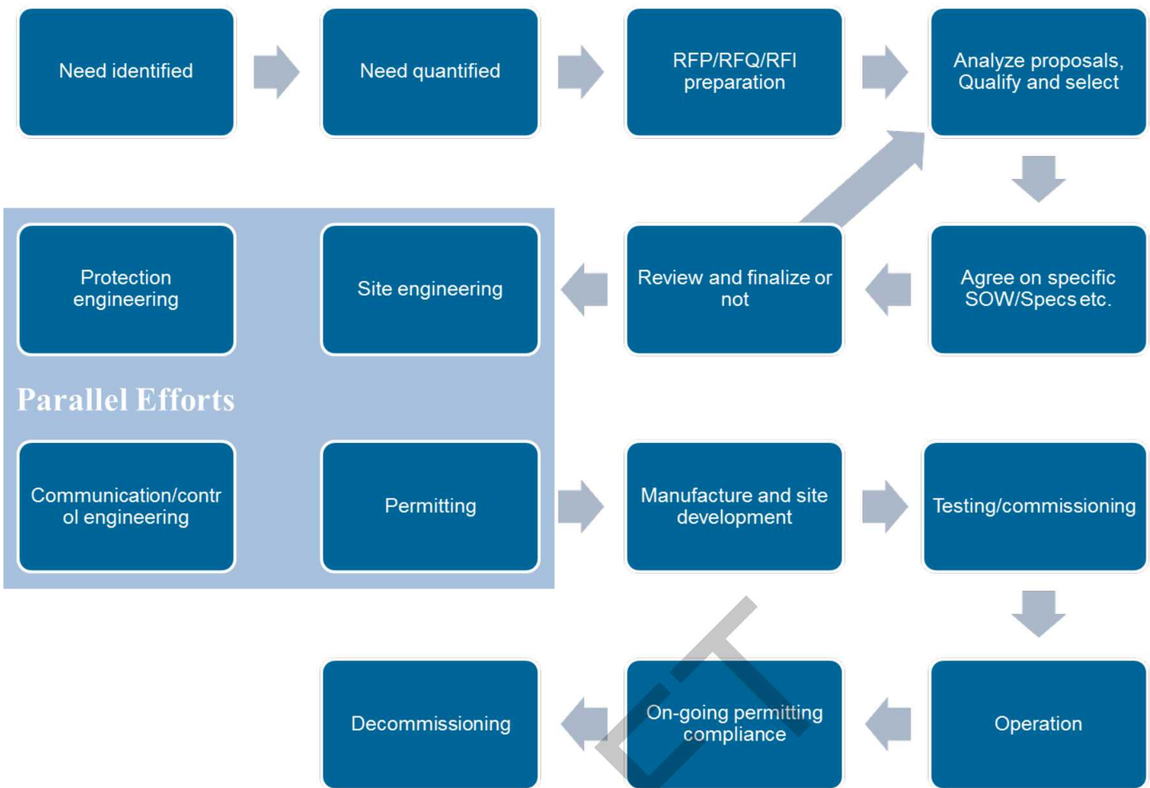

Figure 2–1
Generalized utility procurement process for energy storage (immature state)

A more mature procurement process, shown in Figure 2-2, requires only nine steps by combining and streamlining several steps from the model in Figure 2-1. The first two steps, where the need is identified, and then quantified, are combined as there are consistent metrics and processes for performing these tasks. Steps 3-6, RFP/RFQ/RFI preparation, analyze proposals qualify and select, agree on specific SOW/specs etc., review and finalize or not, are then combined as equipment vendors and utility customers settle into a set of standard products and options to choose from. Site engineering and permitting, are combined and streamlined as the regulators, inspectors and other AHJs become accustomed to standard products and options. Protection engineering and communications/control engineering are combined into one process step along with safety engineering.[3] That is because, as the hazards of new technologies are better understood and controls are developed for them, utility project managers will be able to select from a set of pre-validated designs/configurations for these subsystems. For the rest of the process, manufacture and site development, testing / commissioning, operation, on-going permitting compliance, and decommissioning, the steps remain the same even as they become more standardized and streamlined.

[3] Utility protection schemes would be performed during commissioning.

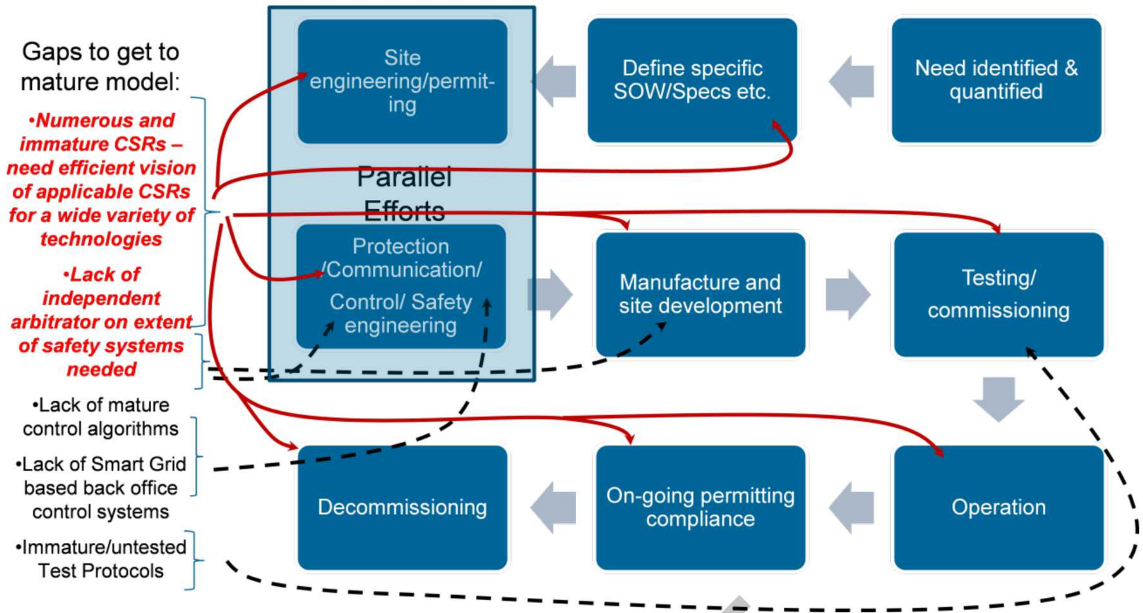

Figure 2–2
Generalized utility procurement process for energy storage (mature state)

In addition to the gaps identified in between the immature and mature procurement processes, there are gaps within the process steps themselves. In many cases safety requirements can be influenced by basic project needs (e.g. requirements for an underground substation are different from the similar sized above grade substations). These needs are often complex or simply not obvious, and detailed analyses of safety requirements are rare at this stage. The wide variety of technologies, chemistries, configurations, and deployment sites makes it difficult to align the currently available CSRs to specific storage projects. In many cases CSRs do not specifically address emerging technologies or chemistries. That is because the CSR development process is too slow to catch up to the rapid technology advances in energy storage that have been experienced in recent years. This makes the effort required to develop a robust specification which ensures safety more challenging for participants throughout the market supply chain. This gap also affects permitting as there is a lack of clarity for AHJ and inspectors to judge which CSRs apply to a given project, and how they are to be applied. This lack of clarity adds financial, operational and schedule risk to storage projects undertaken by the utility.

As the standards for this type of equipment mature, independent party testing can be performed and certifications can be issued more readily and cost effectively. While established testing organizations offer third party certification of energy storage systems today, there are risks inherent in their use of underdeveloped standards. In lieu of standards whose requirements have been developed based on a commonly accepted scientific understanding and methodology associated with the specific technology, a set of project specific safety criteria may be used. This can increase certification cost. There are also problems associated with the logistics of testing especially for energy storage systems that are very large or utilize unique technologies. In this regard, non-standard equipment also adds another layer of complication. Test labs can also be limited in their ability to conduct safety abuse testing at a representative scale due to equipment limitations and safety restrictions. Sufficient test capability (for example, the existence of equipment that can charge and/or discharge the storage device at its rated power) may not be located at any one test lab. Costs and logistics associated with providing samples for testing to various test locations add to the challenges of evaluating the energy storage system safety. As CSRs are updated testing laboratories may expand their capabilities to accommodate and optimize the prescribed safety testing regimen.

To summarize the results of this analysis, the gaps identified are as follows:

- Science-based safety validation techniques
- Incident preparedness
- Safety documentation (general CSRs)
- Lack of guidance for analyses of safety requirements during project inception
- Lack of standard energy storage products and options to choose from
- Regulators, inspectors and other AHJs are unfamiliar with energy storage
- Lack of protocols to enable to pre-validation of the safety of designs and design options
- The numerous and immature CSRs for distribution connected storage
- The lack of an independent arbiter on the extent of safety systems needed
- The lack of standard safety inspection and intervals

2.3. Plan to Address Gaps

This section provides a brief overview of the ongoing work in energy storage safety which is assisting in closing the gaps discussed above. The ESIC System Integration Working Group responsible for development of this safety document is focused primarily on identifying the research and implementation needs of the utility industry with respect to its use of energy storage. Another group that is working on safety issues, and one with which the ESIC group has coordinated its efforts, is that established by the U.S. Department of Energy (DOE). A review of DOE efforts is given followed by a review of efforts unique to each gap.

2.3.1. DOE Energy Storage Safety Working Group

The DOE Energy Storage Safety Working Group (ESSWG)[4] has a mission to engage representatives of the stakeholder community having key competencies and an interest in energy storage system (ESS) development and deployment. The purpose for that engagement is to plan and execute paths forward to address safety gaps that were previously identified and prioritized by the Energy Storage Safety Core Team (ESSCT). These paths are needed to support the timely and safe deployment of stationary energy storage systems. It is envisioned that the ESSWG will enable the timely deployment of safe energy storage systems consistent with the December 2014 DOE OE Energy Storage Safety Strategic Plan by following the framework outlined by the ESSCT, which specifically prioritizes the work needed to address gaps in the knowledge associated with energy storage system safety, and carrying out safety related research, education and training, technical support, and codes/standards development activities. The activity will focus on the safety of all stationary ESSs, and projects to address the gaps will be organized and conducted through coordinated actions focusing on the priority gaps identified by the ESSCT in

[4] Stan Atcitty, "Energy Storage Safety Working Group," ESA Annual Meeting, Dallas TX, June 2015

each of three ESSWG areas: Safety Validation and Risk Assessment, Codes and Standards, and Safety Outreach and Incident Response. Each effort is led by a working group discussed below. More information on the ESSWG, along with how to join one or more of these groups, can be found here: http://www.sandia.gov/ess/sp_safetyplan.html.

2.3.1.1. Safety Validation and Risk Assessment Working Group

The focus of the work on the Safety Validation and Risk Assessment Research and Development working group is to provide a single location for information relevant to people and organizations engaged or with interest in R&D efforts in furthering adoption of ESS through addressing the safety of utility based storage and to maintain an updated, relevant, and prioritized list of work needed to help equipment suppliers and utility customers in understanding issues relevant to grid storage safety. Work will be focused on providing:

- Information on the R&D working group and planned webinar(s)
- Prioritized list of R&D topics
- List of relevant publications, patents and reports on grid storage safety and related topics
- List of upcoming conferences, registration deadlines, and abstract or paper deadlines
- List of funding opportunities in ESS safety related R&D

2.3.1.2. Codes and Standards Working Group

The focus of the work on codes and standards is to foster the development and deployment of codes and standards that effectively address energy storage system safety from initial design, though construction and commissioning to operations and any needed repair or replacement. This is accomplished in the short term by facilitating documenting and validating compliance with current codes and standards, recognizing that they may not have 'caught up with' the range of available storage technologies and intended installation scenarios. It is accomplished on a longer term basis through the updating of current codes and standards or development of new codes and standards to more effectively address safety related aspects of those technologies and intended installations. Over time these efforts would continue by providing information related to documenting and verifying compliance with codes and standards and ensuring codes and standards evolve in step with the evolution of storage technology and experiences associated with energy storage installations.

2.3.1.3. Safety Outreach and Incident Response Working Group

The goal of this working group is to outline and implement a plan to educate, engage, and train stakeholder communities on applying criteria and practices to ensure that systems are safe when placed into service and the first-responder community is equipped to respond, if there is an incident. To facilitate success, work on all activities will leverage past and current efforts by public and private sector organizations focused on ESS development and deployment. Web meetings are held monthly at first to address high priority challenges and opportunities. Work will proceed in close collaboration with stakeholder organizations and the other working groups. The high priority challenges are as follows:

- Provide guidance and information on ESS installation and protection design
- Provide guidance and information operational safety including thermal management
- Develop first responder training material for responding to an ESS fire
- Develop guidance and information on ESS safety analysis through energy storage websites, the ESS Handbook, and by offering safety analysis courses to developers and startups
- Promote first responder knowledge and confidence by developing a template for providing information to and working with local fire departments and by make safe methods available to first responder groups through demonstration (practice system fire), videos, guides, and courses.
- Provide links to educational material on cyber security on energy storage websites
- Provide guidance and information on the safe transportation/delivery of energy storage systems

2.3.2. Science-based Safety Validation Techniques

While the ESIC does not engage in scientific research, it is supported by EPRI which does engage in research designed to make energy storage more reliable, cost effective, and sustainable. As such, EPRI and associated ESIC activities are supportive of efforts by the DOE, ESS equipment vendors, and others to address this gap. Additionally, this gap will be addressed by providing guidance on how to work with the available validation techniques to improve safety in energy storage deployments.

EPRI's research program in energy storage has complimentary goals to those of the DOE and its national laboratories: Sandia National Laboratories and the Pacific Northwest National Laboratory. These goals include the development of a scientific understanding of the relevant safety issues associated with advanced energy storage technologies and identification of the practical steps that may be taken to validate safety designs and processes. Progress in achieving these goals will enable a more efficient adoption process for CSRs that must keep up with the rapid advances taking place on the ESS technology front. These research efforts include: fundamental science research on reducing hazards in prevalent technologies such as lithium-ion batteries, development of multi-physics models for simulation of failure conditions in energy storage devices, and system's safety analysis research that lowers cost and improves effectiveness of safety engineering in energy storage.[5]

2.3.3. Incident Preparedness

This gap will be addressed by providing guidance on working with local fire departments and first responder organizations to ensure that emergency action planning is sufficient. A list of

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[5] More information can be found at: http://www.sandia.gov/ess/saf_currwork.html, and http://energy.sandia.gov/infrastructure-security/energy-storage-new/batlab/. Reporting on current research results may often occurs at technical conferences and in technical journals. Conferences covering energy storage research include but are not limited to: Electrical Energy Storage Applications and Technologies, Battery Safety, Energy Storage Association Annual Meeting, Nattbat Annual Meeting, Energy Storage North America, and Next Generation Batteries. Technical journals with energy storage safety in their sated scope include but are not limited to: the Journal of Power Sources, the Journal of Energy Storage, and IEEE Transactions on Energy Conversion.

standards will also be provided that can be referenced when developing incident response procedures.

The New York City Fire Department's Bureau of Fire Protection update section 608 of the city fire code in 2014 to include flooded nickel cadmium, lithium-ion, and lithium metal polymer battery installations. This section includes requirements for room design, spill control, ventilation, smoke detection, and signage[6].

2.3.4. Safety Documentation (General CSRs)

This gap will be addressed by providing a categorized list of standards that may be applied at each stage of the utility procurement process. Further, ongoing participation in CSR updating efforts will be encouraged.

EPRI along with the DOE is working with Sandia National Laboratories and Pacific Northwest National Laboratory to develop and maintain a list of codes and standards related to energy storage. This list could assist in filling CSR gaps and informing all interested parties throughout the ESS supply chain about available CSRs. Below are links to more information on the DOE efforts related to CSRs.

http://www.sandia.gov/ess/saf_codes.html

http://www.sandia.gov/ess/docs/safety/Codes_101_PNNL_23578.pdf

http://www.sandia.gov/ess/docs/safety/ESS_Inventory_9-15-14_PNNL_23618.pdf

In 2015 the National Fire Protection Agency's (NFPA) research foundation began a project titled "Hazard Assessment of Lithium Ion Batteries Used in Energy Storage Systems[7]." This project has the stated goal of developing a hazard assessment of the usage of lithium ion batteries in ESS.

2.3.5. Lack of Standard Energy Storage Products and Options to Choose From

Consistent with EPRI's mission, the ESIC provides a collaborative forum for utilities, energy storage vendors, government organizations, and other participants to contribute to the commercialization process, such that energy storage will become a reliable, safe, and cost-effective option for the utility industry. To this end, the efforts of both EPRI and the federal government are addressing this gap. In addition to these efforts, this gap will be addressed by providing guidance and updates on the developments of relevant CSRs and templates of a generic safety specifications. This guidance will allow for more standardization across a wider array of technology offerings and for easier adoption in individual projects and, incrementally, more standardization in products.

[6] 2014 New York City Fire Code: http://www.nyc.gov/html/fdny/html/firecode/table_of_contents_2014.shtml

[7] Project Summary for NFPA Research Foundation Project titled "Hazard Assessment of Lithium Ion Batteries Used in Energy Storage Systems (ESS)," Available: http://www.nfpa.org/~/media/files/research/research-foundation/current-projects/hazardassessmentlithiumionbatteriesusedenergystoragesystems.pdf?as=1&iar=1&la=en

2.3.6. Regulators, Inspectors and Other AHJs are Unfamiliar with Energy Storage

This gap will be addressed by providing guidance on assembling the information needed to allow for front end communication with AHJs early in the project development process to allow for efficient project execution in terms of timing and budget as well as risk mitigation. The ESIC will also encourage a wide variety of stakeholders, with guidance from the DOE and other organizations, to address this gap through education and outreach to regulators and AHJs.

EPRI along with the US DOE and Sandia National Laboratories (SNL) are working with the Clean Energy States Alliance (CESA) to work with state and local legislators to better understand energy storage technologies - see http://www.cesa.org/.

2.3.7. Lack of Protocols to be Able to Pre-validate the Safety of Designs and Design Options

This gap will be addressed by a combination of guidance on developing a safety specification and stakeholder engagement in the CSRs development process. As safety specifications mature, protocols to validate systems and components to the specification will develop as well. Additionally, as energy storage products and options begin to settle as a result of the work of ESIC and other efforts, efforts related to defining CSRs will allow more efficient development of energy storage systems through sanctioned, front end, independent testing and certification that pre-validates system safety. With a uniform basis for testing and certification of systems, stemming from updated CSRs, the risk of ESS implementation can be greatly reduced.

While not considered applicable by utilities for equipment on the distribution grid and under utility ownership/control, a safety testing standard for energy storage systems developed by Underwriters Laboratories (UL) may be applicable for energy storage products connected on the customer side of the meter.[8]

2.3.8. The Numerous and Immature CSRs for Distribution Connected Storage

While the general CSRs are addressed under the safety documentation gap, the standards which are specific to distribution connected storage are of particular interest to the ESIC. These need to be prioritized and assessed for updating in future work.

2.3.9. The lack of an independent arbiter on the extent of safety systems needed

At the present time there are independent organizations that conduct testing, listing, labeling and associated product and installation approvals. As mentioned earlier, there is a potential issue

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[8] UL 9540 Outline of Investigation for Energy Storage Systems and Equipment, available at: http://ulstandards.ul.com/standard/?id=9540. The scope of this standard is as follows: These requirements cover energy storage systems that are intended to store energy from power or other sources and provide electrical or other types of energy to loads or power conversion equipment. The energy storage systems may include equipment for charging, discharging, control, protection, communication, controlling the system environment, fuel or other fluid movement and containment, etc. The system may contain other ancillary equipment related to the functioning of the energy storage system. The ESS are intended for use in utility-interactive applications in compliance with the Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547 and the Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems, IEEE 1547.1 or other applications intended to provide grid support functionality. The ESS are to be installed in accordance with the national and local electrical codes and other applicable codes.

related to the lack of specificity to ESS and/or currency of the work of third party agencies (i.e., the “gaps” mentioned in Section 2.2). These organizations are often required to develop custom criteria to validate safety before testing can be performed and hence the requirements are not available until very late into the selection and integration process. As the more uniform CSRs are updated, the risks, costs and effort required to certify compliance of energy storage equipment to these CSRs will be reduced. This, in turn, will reduce the cost of certification programs and will hence enable more efficient independent testing and certification needed to address and demonstrate ESS system safety.

3
SAFETY GUIDANCE

The purpose of this section is to provide distribution utilities an understanding of steps involved in helping to ensure that any energy storage system they procure and install will adhere to applicable CSRs. This section introduces relevant safety related issues and provides criteria that utilities can apply in creating procurement documentation including specifications, commissioning manuals, safety inspections, and emergency action plans.

An overview is given of the practices the utility may consider adopting to ensure a safe energy storage deployment. It is important to minimize the need to make changes late in the process as these are generally more expensive, time consuming and less effective than necessary changes that are identified early. The intent of this section is to help stakeholders throughout the ESS market chain develop a complete package of safety related criteria. This package can be then be shared with all these stakeholders including utility management, utility commissions and/or insurance underwriters who are interested in how the utility has performed due diligence ensuring the safety of the equipment investment. The information in this section is organized to follow the five chronological phases of the life cycle of an energy storage project as laid out in the Integration Guidelines for Energy Storage: 2015[9]- Planning, Procurement, Deployment and Integration, Operations and Maintenance, and Decommissioning.

The scope of this section includes the safety of the system and its components as well as site development and installation of the system on the utility property. Safety of the system during the installation and initial commissioning can be ensured through contracts between the utility and the manufacturers, contractors, subcontractors, and engineers developing the system. Information on safe testing and commissioning practices are also included and would be applied by the utility to its own staff or to contractors retained to conduct these activities.

Note that the issue of system safety and development and implementation of safety related requirements would likely be undertaken administratively by a utility no different than any other utility implementation of technology (e.g. substation). As such, a utility likely has technical criteria and procurement, programmatic, and contracting administrative processes, such as distribution standards, in place. Utilities could use pre-existing materials and processes as a basis for energy storage system deployment using the information in this section to enhance and amend those materials. This document provides guidance on both those general requirements that could be included in all projects (e.g. risk analysis and incident preparedness) and those that are likely to be specific to the technology type, application environment, and other project specific factors. It is intended that this information be used by utilities in creating procurement specifications, processes, and procedures that will ensure a safe life cycle for energy storage deployments.

[9]Integration Guidelines for Energy Storage: 2015 *A Project Management Handbook for Distribution-Connected Energy Storage Developed by the Energy Storage Integration Council*," EPRI, 2015

3.1. Addressing Safety in Planning

It is often the case that the earlier safety is considered in a project, the less expensive it is to ensure compliance to applicable CSRs. This is because safety critical changes are much easier to make when the project is still on paper and not installed or operational. Utilities may address safety during the initial conceptualization of the energy storage project. This applies both to projects that are managed by the utility and to projects that are managed by a third party, engaged by the utility, through the procurement of equipment or services. Addressing safety at this stage, even to a minimal extent, will inform the development of the safety specification and ensure a more cost efficient and timely project.

One of the first steps in developing initial buy-in is identifying and quantifying the need for energy storage. When assessing the identified need for services on a given electrical system, the utility may consider the environments where an energy storage device could be installed. Factors such as population density, available footprint, local weather, electrical power constraints, proximity to the nearest fire station, and availability of water may be accounted for when evaluating a feeder or site. If there are insufficient resources or non-ideal conditions at any one site, multiple sites can be considered for smaller systems with aggregated functionality. Identified needs could include a short list of unacceptable outcomes that can be designed against. Many unacceptable outcomes can be derived from environmental and safety regulations such as those from the Environmental Protection Agency (EPA) and Occupational Safety and Health Administration (OSHA). These include events such as arc flash or blast in excess of the available worker PPE, or chemicals spilling into nearby river in excess of EPA regulations. Additional unacceptable outcomes can be derived from the associated level of financial risk or potential for loss of reputation such as in the event of a fire that spreads to nearby structures. Understanding these boundaries helps to contextualize specifications and make safety requirements meaningful. Unacceptable outcomes could be included in the background sections of procurement specifications.

3.2. Addressing Safety in Procurement

Along with information about physical dimensions, performance, and cost, a set of requirements to procure and install an energy storage system and then operate that system could also include requirements that ensure that the system is safe and that its operation over time remains safe. The requirements could also address potential safety related incidents and the specific actions that must be taken if they should occur (discussed primarily in Section 3.2.3.). The specification affords the utility an opportunity to mitigate risk and will aid in ensuring that equipment supplied by third parties is safe, that the system is effectively commissioned and deemed safe, and that the utility can ensure is continued to be operated safely.

Fundamentally, a specification focused on procurement of equipment, products, materials, etc. is developed by listing all of the functional areas for what is being purchased, whether it is a service or a piece of equipment, and then matching those functions to quantitative or qualitative requirements. Where relevant, these requirements may also include specifics about the criteria by which functionality or performance is documented and verified. Safety critical functions exist throughout the process including in design, construction, commissioning, operations and maintenance, and decommissioning. These functions can be difficult to determine holistically and envision over the life span of the project, especially given the variety of energy storage technologies that are available. However, these functions and the associated performance requirements are captured in two areas that can be referenced for ease in developing specifications. The first and primary area is the field of codes, standards, regulations (CSR). Requirements in this section rely on mature CSRs as effective ways of reducing and eliminating risk. For example, a fire could occur if a circuit breaker fails to open under overcurrent, however, the certification of circuit breakers as complying with applicable safety standards and low failure rate of circuit breakers is an effective control to prevent a fire. Where the CSRs referenced in a specification are considered complete and up to date in addressing ESS safety, compliance with those documents would be considered evidence of a safe ESS installation.

The second area, which may be used wherever there is gap in the field of applicable CSRs, is an analysis of safety. Figure 3-1 depicts an intuitive diagram for how CSRs and Safety analysis combine to ensure safe operation. There are many techniques available for analyzing safety in complex technological systems including Failure Modes and Effects Analysis (FMEA) and Systems Safety Analysis (SSA). When applied correctly, a safety analysis can provide a complete picture of how a devices or system will operate under normal, abnormal, and foreseeable abuse conditions. This information allows project developers, designers and utility personnel to make informed decisions about what safety critical functions are needed and so can be useful in bridging the gaps in applicable CSRs. Additionally, safety analyses can be used to extend the applicability of related standards by demonstrating that the environmental and use conditions are similar (e.g. industrial battery standards applied to stationary systems).

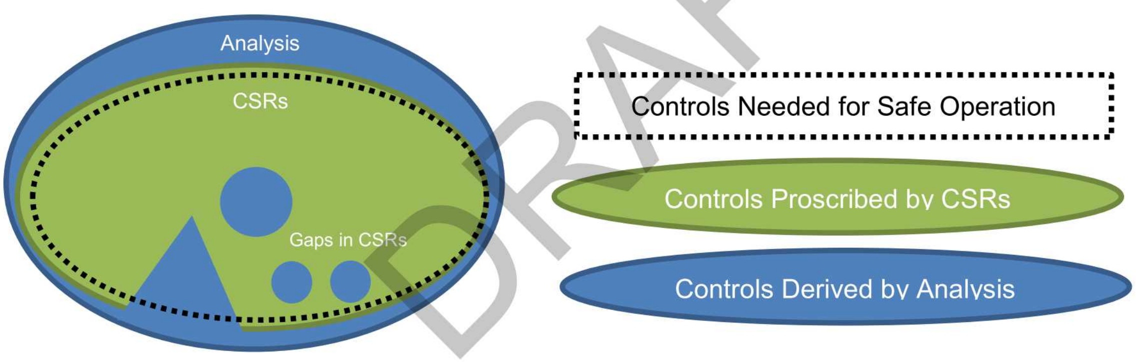

Figure 3–1
Illustration of how Gaps in CSRs can be filled by Safety Analysis

These two areas, CSRs and safety analyses, are closely connected and could both be included in a specification. Utilities may require energy storage supplier adherence to the applicable CSRs at the specific project site (e.g. state and/or local building codes), and the safety standards that will apply to all energy storage suppliers (e.g. IEEE1547). Standards that may apply to only a few technologies could be omitted as requirements if multiple technologies would be accepted. Section 4 of this guide provides many potentially applicable standards sorted by project stage which could be used as a reference when developing a procurement specification. As the field of CSRs has, and will necessarily continue to, lag the development of energy storage technologies, it is also recommended that utilities consider requiring a safety analysis be performed by energy storage suppliers. The results could be summarized and presented in the form of reports, designs, and project plans that can be followed throughout the integration process. The purpose of this analysis is to identify potential sources of safety incidents throughout the entire project life cycle and the methods that those incidents could be minimized or eliminated by engineering appropriate measures into the system design and project plan.

The following sections provide information and guidance on assessing the safety and reliability analyses. This assessment can be performed by an independent, third-party organization selected by the stakeholder(s) or an acceptable agent. An important consideration is that this third party be deemed to be qualified, through accreditation by appropriate agencies, to perform the assessment. Such accreditation would nominally be by a recognized accreditation body using appropriate U.S. or international standards which cover accreditation of safety analysis and risk assessment. Last, a section on guidance for incident preparedness is included to address potential issues that may arise in operation. This section provides guidance for developing emergency action plans which could be put in place before construction begins.

3.2.1. Failure Modes and Effects Analysis (FMEA)

FMEA is a rigorous and systematic methodology for analyzing reliability and the impact of component failure on safety. It is a process by which system designers determine, for each system component, a probability and severity of failure. Table 1 shows several example FMEA calculations for a representative system's: BMS, Battery Cell, Battery Pack, and Inverter. For each component a series of failure modes is derived. Each failure mode is then attributed a Hazard Effect, Consequence, method of Prevention, and method of Detection. This is not a comprehensive list of all factors tracked in an FMEA. Rather, this provides a reasonable minimum set. These factors are then used to quantify the probability and severity of the failure mode. The product of the probability and severity provides a relative measure of risk associated with each component and failure mode.

Where precise actuarial data exist on component failure rates, probability can be determined quantitatively. In circumstances where these data are not available, such as in new technologies, experts may be able to make a qualitative determination of the likelihood of failure. Similarly, when there is significant data available on precisely how a component failed and the severity of that event (measured in down time of the equipment, cost to repair, or some other quantity), numerical data can be used where components without such data would rely on independent judgment. Components can be sorted by risk and design choices can be made to reduce project risk. The values reported for risk are relative within a given FMEA and are not directly comparable to other FMEAs on other designs. There are many standards available for how to conduct an FMEA[10] which could be considered when developing a procurement specification.

[10] IEC 60812: Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)

Table 1 Example Excerpt from an FMEA

System or Component	Failure Mode	Hazard Effect	Consequence	Prevent	Detect	Probability, Severity	Expected Value for Risk
BMS	system doesn't operate safely through normally expected temperature operating range	Fire	safety incident	BMS testing	independent temperature sensor	3,10	30
Battery Cell	group of failures	Fire	safety incident	abuse testing	fire alarm	3,9	27
Battery Pack	group of failures	Fire	safety incident	abuse testing	fire alarm	2,10	20
BMS	Battery damage due to BMS malfunction	Fire or loss of function	safety incident	fusing, inverter protection		2,7	14
Inverter	Inverter fails to detect/react to over temperature IGBTs	Loss of function	Power output de-rating	rely on supplier		3,4	12

3.2.2. System Safety Analysis (SSA)

The goal of a system safety analysis is to: 1 Determine how a design or project can be unsafe, 2 Make it safer through design and project plan choices, and 3 Communicate its degree or quality of safety to others, as shown in Figure 3-2. Analyzing risk using an FMEA adds considerable value for assessing the safety and reliability of an ESS as purchased from an ESS manufacturer or as designed and constructed by an external entity. However, not all safety related incidents will occur as a result of failure associated with an ESS or one of its component parts. Some incidents could occur as a result of events and conditions combining in unexpected ways (e.g. a safety system being turned off for maintenance and not reactivated for operation). Accidents may be caused by the interaction of the ESS to its installation environment (e.g. seismic event), or its operators (e.g. unsafe procedures). Because of these factors, a deeper analysis is needed to ensure safety of the integrated system throughout its operating life.

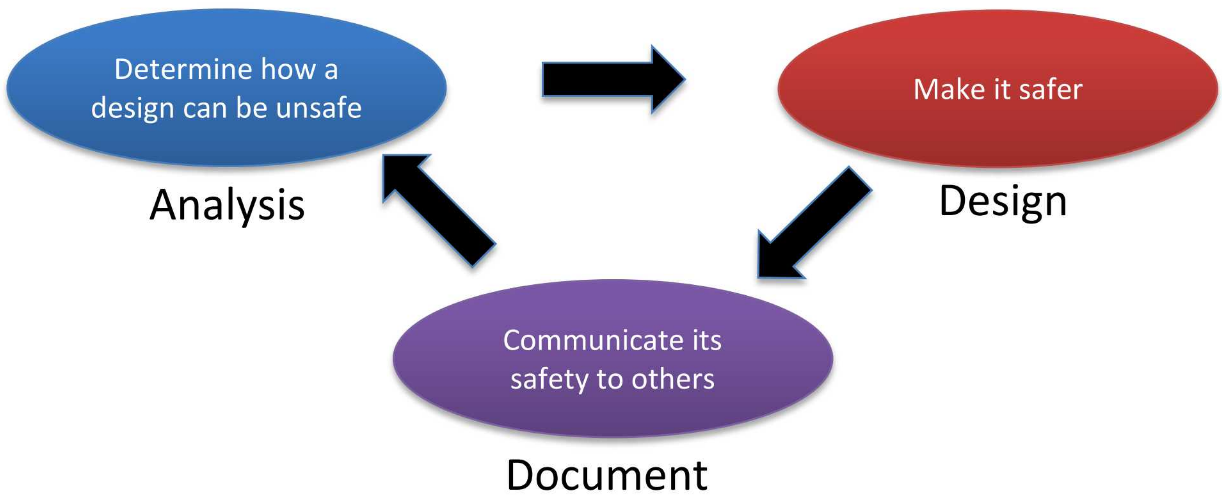

Figure 3–2
Structure of safety management in the installation process

There are many techniques used by different industries for performing an SSA including fault trees[11], event trees[12], HAZOP[13] and STPA[14]. These techniques have different advantages and disadvantages, depending on the system under evaluation, but they all try to foresee the conditions that could lead to accidents and engineer controls to prevent those conditions. Figure 3-3 shows a simple example of a Probability Risk Assessment[15] (PRA), which uses a combination of fault trees and event trees to estimate systematic risk. Changes to the components or structure of a system may reduce risk by reducing the probability and severity of failures, and failure propagation. This technique has the advantages of ranking incident scenarios by their relative risk and allowing designers flexibility to decide where to apply controls to reduce risk. Similar to FMEA, PRA also requires significant knowledge or data on the probability and severity of all component and system failure modes.

[11] IEC 61025 Fault tree analysis (FTA)

[12] IEC 62502 Analysis techniques for dependability – Event tree analysis (ETA)

[13] IEC 61882 Hazard and operability studies (HAZOP studies)

[14] N. Leveson, Engineering a Safer World, The MIT Press, January 2012, Available: https://mitpress.mit.edu/index.php?q=books/engineering-safer-world

[15] ISO/IEC 31010 standard for risk management

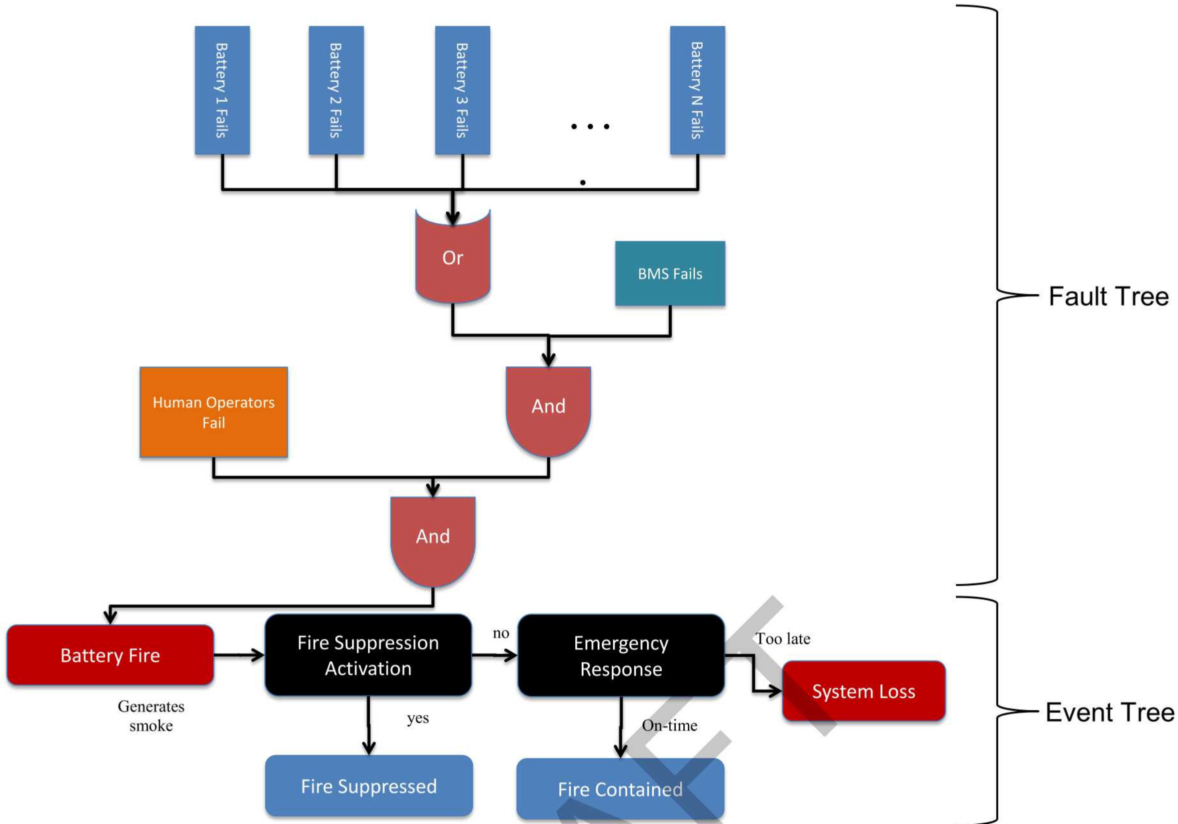

Figure 3–3
Example Probability Risk Assessment

Where actuarial data on component and system failures is unavailable or unreliable, Systems-Theoretic Process Analysis (STPA) provides valuable insight to ensuring safe system operation. STPA is a rigorous assessment of how the system enforces safety constraints on component interactions. For example, if available testing data shows that a type of battery is safe up to a high temperature limit, STPA enables designers to assess the effectiveness of all of the control loops which keep the batteries below that limit (e.g. temperature sensors, HVAC, fans, DC current limiting etc.). Figure 3-4 shows an example of an energy storage system safety control structure. The diagram is organized vertically by hierarchy such that utility grid operators (above) may be working with many manufactures (below) or a SCADA system (above) may control many energy storage systems (below). Each connection between components represents how those components interact (e.g. digital communication). Each component interaction possesses many safety constraints that, if violated, may result in an accident (e.g. technician using safety gear).

STPA step 1 is performed by developing a list of all of the interaction's safety constraints (also called control actions or safety responsibilities) and then deriving how each interaction could violate its safety constraints (if a control action was needed and not provided, control was not needed and provided, control was provided too early or too late, or control was provided for too long or too short a time). STPA step 2 is performed by exploring how each safety constraint violation could be caused by developing a list of contributing causal factors and stringing them together in causal scenarios.

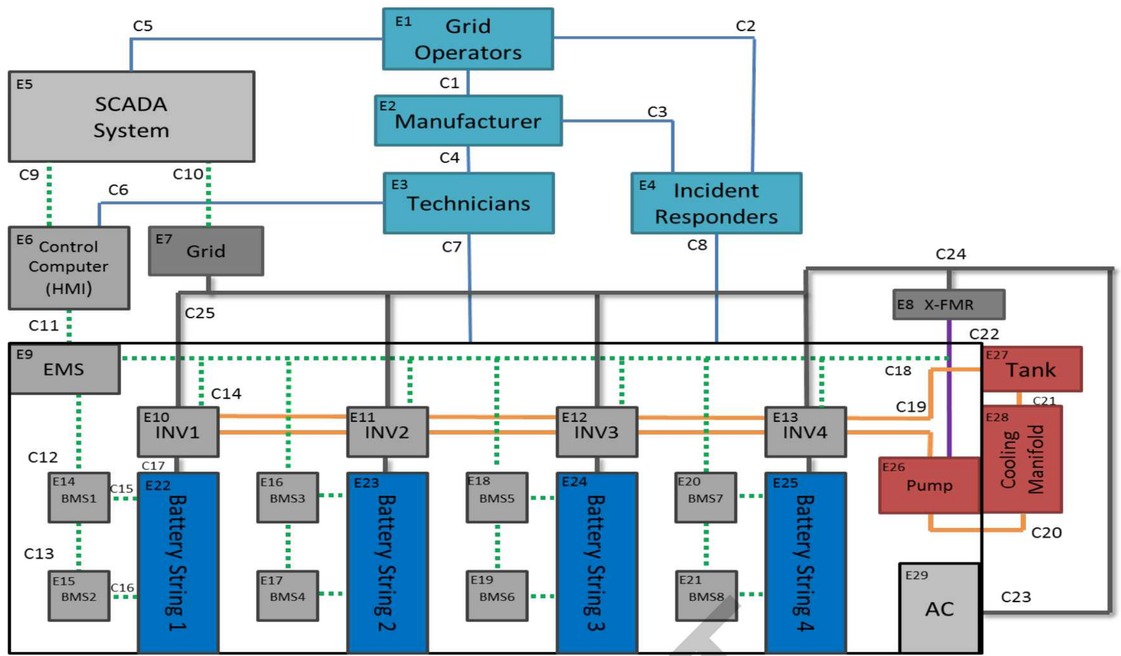

Figure 3–4
Example STPA System Safety Control Structure

A more extensive SSA, with larger fault trees or more pages of analysis, is often the result of a more complete process rather than higher risk. When interpreting an SSA it is important to be critical of the data that it relies on. Laboratory results are often used to predict field behavior where use environment can be drastically different. Designers could reference appropriate component and subsystem certifications wherever possible as this may provide the most reliable input to the analysis. SSA can be used to fill in the gaps in system certification only where appropriate CSRs are insufficient to ensure safety. As CSRs are updated, less emphasis will be needed on the SSA during integration as it will already be reviewed as part of system certification.

3.2.3. Incident Preparedness and Training Requirements

As ESS grow in prevalence, occasional incidents may occur which require human intervention to control. Utility staff and/or their agents as well as outside agency staff or volunteers (e.g. first responders) may be required to act to protect lives and property. The ability for those personnel to respond to an incident associated with an ESS involves two key topical areas: training, and development of an action plan.

For those personnel who are called on during emergency situations an important consideration is appropriate training to recognize and respond to all reasonably foreseeable incidents that may occur at the site of an energy storage installation, whether the incident source is the system itself or something external (e.g. wildfire or flood). It is recommended that stakeholders throughout the ESS market chain require the energy storage supplier make available all necessary emergency action information related to their system. This information could also be included in the operations and maintenance manual. This emergency action information will contain salient information for preparing for incidents and could be used by the utility and other stakeholders, such as local responders, to prepare a site specific, emergency action plan. Stakeholders include all applicable governmental and private sector entities that would be affected by an incident associated with the energy storage system. Including all stakeholders, both locally and others in the market chain, in the process will ensure that all affected parties can be made aware of an incident and are able to act accordingly. The action plan could address possible incident scenarios starting during construction and commissioning and continuing through operation and decommissioning. This could include a call/email list for all those who need to be informed of a situation potentially including: emergency personnel, operators, owners, regulators, and many others. Actions for these parties may include urgent responses, such as responding to a medical emergency, or non-urgent responses, such as performing an incident investigation. This plan could account for all reasonable accidents that could occur at the project site possibly including but not limited to medical emergencies and incidents associated with fires, chemical spills, explosions, shocks and mishandling of the system or materials related to the installation.

The incident training manual could allow utility personnel and their contractors, as well as first and second responders, to understand the likely incident scenarios associated with the energy storage installation and appropriate actions to take to for each scenario. It could include, at a minimum, emergency shutdown procedures, a Materials Safety Data Sheet (MSDS) or Safety Data Sheet (SDS) along with any first-aid requirements. Steps and actions listed in the incident training manual could be consistent with the Occupational Safety and Health Administration (OSHA) hazard communications standard[16] (HCS).

3.2.4. Other Safety Considerations

There are a number of established and emerging technologies designed to address specific hazards within energy storage systems. This section will elaborate on some specific technologies that could be considered during the procurement process. The content of this section is intended to identify areas where good engineering practice is important and to provide information regarding the development of good practices. It is not intended to be prescriptive as to design or operation, since the individual stakeholders must make the final decisions as to proper methods for its installation.

- While it is often beneficial to design a closed system for heating and cooling efficiency, pressure relief valves could be considered to prevent a hazardous buildup of pressure. Closed systems can lead to oxygen starvation which can cause a backdraft if sufficient heat builds up for a fire. In systems where an explosion hazard may exist, deflagration venting[17] could be considered as well.
- Fire suppression systems may be an effective control for component fire potential. Claims on effectiveness could be supported with some combination of testing, analysis, and/or simulation. However, it is important to consider the material that may experience a fire when selecting the type of system to be used. In the case of lithium-ion batteries, sufficient heat can be generated internally to sustain or reignite a fire if extinguished by an oxygen starvation system. In these cases a water suppression system may be considered if properly designed to remove enough heat from the cells that the exothermic chemical reaction can be slowed or

[16] OSHA 29 CFR 1910, Available: https://www.osha.gov/dsg/hazcom/

[17] NFPA 68: Standard on Explosion Protection by Deflagration Venting

stopped.[18] It is important to be critical of claims on the effectiveness of a given suppression design.

- It is important to consider both normal and unexpected operating conditions in the design of the contactors. Inverter based systems often require large capacitive filters on their DC bus to reduce the magnitude of the AC current (noise) component. These capacitors draw significant current when first connected to a battery or other DC source; thus, all inverters come with a pre-charge circuit. This circuit allows the input capacitors to be resistively coupled to battery voltage thereby reducing the in-rush current. Abnormal conditions during pre-charge include voltage spikes, incorrect contactor switching, and battery short circuit. If the contactors in this circuit open unexpectedly while pre-charging the capacitors, they can fuse and cause an inverter fault requiring extensive repair or, in rare cases, an inverter fire.
- Impressed current systems or sacrificial anodes may be used in environments where corrosion could affect system operation or safety. Essentially, they work by holding the system at a somewhat positive potential to slow the rate of chemical reaction with this environment. Impressed current systems accomplish this through the use of a DC power supply or rectifier. Sacrificial anodes accomplish this by providing an anode of an appropriate chemical to produce a negative potential as it reacts with the air or soil.
- When an energy storage system contains large volumes of liquid, it is important to consider secondary containment. Recommendations can be adapted from stationary battery standards for flooded lead acid batteries which stipulate that secondary containment be sufficient to contain and allow for the safe disposal of either 30% of the total volume or 100% of the largest single container, whichever is greater[19].
- Cyber security may be considered as a safety issue for internet connected systems, SCADA connected systems, and even stand-alone systems. This involves an analysis of what access to system information and system control could produce a hazard. For example, changing BMS parameters could lead to reduced system life or fire through the improper enforcement of safety constraints. The National Institute of Standards and Technology publishes a general cyber security framework[20] which may be applied to energy storage systems and installations.
- Energy storage technologies that contain or produce hydrogen gas are subject to the appropriate controls for this hazard. Examples of these controls can be found in section 500 of the National Electrical Code (NEC), and NFPA 2: Hydrogen Technologies Code those other standards may be more appropriate for specific technologies.

3.3. Addressing Safety in Deployment and Integration

When an energy storage supplier has been selected and detailed project development begins, it is important that this process be conducted in a way that ensures safety. There are many regulations

[18] Aircraft Installed lithium Battery Hazard Analysis , Federal Aviation Administration, May 12th, 2015

[19] IEEE 1578: Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management

[20] Framework for Improving Critical Infrastructure Cybersecurity, Version 1.0, National Institute of Standards and Technology, February 12th, 2014, Available: http://www.nist.gov/cyberframework/upload/cybersecurity-framework-021214.pdf

concerning, transport, worker safety, inspection, and commissioning some of which can be found in Section 4.3. Utilities could apply the requirements in these documents to the jurisdictions, materials, and operations within their scopes. However, where these CRSs have not been updated to address new energy storage technologies, there may be gaps that could delay project permitting and hence project implementation. Those enforcing compliance (AHJs) may require documentation that the design is no more hazardous nor less safe than similar designs that are specifically addressed in those documents. A risk analysis, including an FMEA and SSA, can offer evidence supporting this assessment and could be considered as an alternative to documenting compliance with specific CSRs. Inspections can in many cases be performed to verify 'compliance' with an approved SSA. For example, if a SSA identifies that an emergency shutdown switch, fire suppression, and a minimum offset distance are needed for a specific installation, then the AHJ can inspect the system to verify that the installation indeed has an emergency shutdown switch, fire suppression, and a sufficient offset distance.

One key aspect to ensuring a safe installation is commissioning, which entails verification that the ESS and all associated controls, detection devices, shutoffs, etc. are functional and will operate under all anticipated conditions. In view of this the utility could require the energy storage supplier to provide a defined set of commissioning requirements for the utility and AHJs to review and approve. This commissioning procedure could be sufficient to verify all design requirements from the SSA, the applicable CSRs, and the utility's specification have been met in order to fulfill the contractual obligations of the procurement. This will include both performance requirement, such as power and capacity, and safety requirement such as emergency shut off operation. Operator training requirements could be included as well as verification of the required data interconnections. Inspection is performed to verify the installation adequacy of the equipment, commissioning then verify that the equipment operates as expected. In addition the commissioning plan may address the following issues.

- Documentation of completed Control Assurance Plan (CAP). Verification that safety critical control points are within compliance. CAP could include accuracy and delay compliance thresholds, recorded values, and testing interval. Simulated out-of-range inputs could be used to verify appropriate input or signal sanitization. The CAP could also stipulate data recording requirements and how stale data is handled for each point.
- Documentation of completed Measurement Assurance Plan (MAP). Verification that safety critical measurements are within compliance. The MAP could include accuracy and delay compliance thresholds, recorded values, and testing interval. Simulated out-of-range measurements could be used to verify appropriate alarms and warnings before operation. MAP could also stipulate data recording requirements and how stale data is handled for each point.
- Internal or External Communication Loss. If there is a loss of safety critical measurement or control, the system could gracefully shut down (e.g. loss of temperature measurement). If measurement or control is not safety critical (As determined in the FMEA and System Safety Analysis) then the system can continue to operate (e.g. loss of connection to off-site data backup).

When the system has passed inspection and is ready for commissioning, depending upon the common practices of the stakeholder, a new tag may be applied. Once commissioning has been completed and accepted by the utility, a final tag may be applied to denote the transfer of ownership and responsibilities to the utility or their designated agent. This system of tags may be especially helpful for keeping track of installation, inspection, and commissioning for large installations that can have multiple parts at each stage of this process. Due to the risk inherent in this critical step the utility may consider retaining the services of an accredited third party agency, recognized by the utility and appropriate AHJ (as required) to conduct the commissioning activities and document the proper operation of the ESS as a condition for utility acceptance.

3.4. Addressing Safety in Operations and Maintenance

The utility could establish criteria to address safety during the operation and maintenance of the system. These criteria could include plans for inspecting, servicing, repair and renovation as well as any addition to the system (e.g. installation of additional storage capacity). The utility procurement specification could require that the energy storage supplier deliver a complete operation and maintenance manual. This manual could provide instructions for all required operating and maintenance activities, the timing for these activities, and who will perform them. Ideally the manual could be in electronic form and automatically prompt utility personnel and/or their agents to initiate, perform, and document required actions after the system is commissioned and placed in operation. This manual could also include conditions under which the system will have met end of warranty, service life, and operational life.

3.5. Addressing Safety in Decomissioning

After the system has reached the end of its operational life, the utility may wish to decommission the system, disposing of or recycling materials. For this reason it is recommended that the energy storage supplier be required to develop a decommissioning and disposal plan for utility approval. This plan could explain the procedure for decommissioning, including any hazards this may present, as well as the steps to disconnect the system from external automated control systems. It could elaborate who is responsible for disposal and recycling, what costs this will incur, how articles could be packaged for disposal, and who is responsible for shipping the materials to the disposal or recycling site.

4
REFERENCE CODES, STANDARDS, AND REGULATIONS

This section provides a list of reference CSRs which may apply to or be useful for the integration of energy storage to the distribution system. It is intended that these documents can be referenced with the materials in Section 3 when preparing specifications and other documents necessary planning, design, construction, installation, commissioning, operations, maintenance and decommissioning of ESS. Additionally, these documents may be of use providing for safety of personnel and property during these activities and responding to incidents that may occur that are attributable to or could affect the system. Figure 4-1 shows the structure of this Chapter as organized by functional area. It is noted that the following is a partial list, subject to change, and that a review by stakeholders of all potential CSR sources for applicability is recommended.

Figure 4–1
Structure of safety CSRs by Functional Area

4.1. Energy Storage System Components

Safety criteria for ESS components (e.g., battery, inverter, controls, etc.) are intended to ensure the design and construction of each individual component meets the relevant safety-related metrics. The supplier of each component could design and construct the respective component to the standard and subject it to whatever testing is required by the relevant standard for that component. If the component satisfied the provisions of the standard and related testing criteria, then the individual component could be considered in compliance with the standard. The manufacturer of the component could retain an independent, accredited third party testing agency (as defined above) to test the component to relevant safety standards, unless the utility wanted to conduct those tests themselves. If the component is determined to be compliant, the independent third-party certification programs would inspect ongoing production to ensure that subsequent components are identical to that of the component that was tested. In addition, those certification programs would also review and assess the administrative and quality control aspects associated with the manufacturing of the component.

Standards covering ESS components are of primary relevance to component manufacturers in deploying the component and to utilities in specifying and procuring safe components. Manufacturers of complete ESS “products” or those that assemble an ESS on site from various components would benefit when using components that are shown to comply with relevant standards. This will potentially facilitate AHJ approval during inspection. Component standards and the associated conformance testing also provide significant data for use during an SSA. Utilities engaged in validating compliance have an easier time approving ESS installations when the components are validated by an accredited third party (e.g., independent testing lab or research organization) as complying with applicable standards. Note that the standards covered in Section 4.2 for an entire ESS "product" could concurrently address the acceptability of the components to the degree that such standards addressed the safety of the individual components in the ESS.

Table 4–1
Standards for Energy Storage System Components

Energy Storage System Components	Standard
Molded-Case Circuit Breakers, Molded-Case Switches, and Circuit-Breaker Enclosures	UL 489
Electrochemical Capacitors	UL 810A
Lithium Batteries	UL 1642
Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources	UL 1741
Batteries for Use in Stationary Applications	UL 1973

4.2. Energy Storage System (Complete)

Considering ESS as an assembly of components, a standard for a complete ESS "product" is likely to refer to various components and component standards. The complete ESS standard then simply ties together lower level requirements with industry best practices for safe system design. One approach these standards take is to specify that the components meet relevant component standards and specify documentation as to the acceptability of their combination as a safe ESS. Another is to consider the ESS "product" as a black box and evaluate the entire ESS against a holistic standard. If the ESS "product" satisfies the provisions of the standard and related testing criteria and metrics, then the components of the ESS is considered in compliance with the standard. A standard for the product would provide both prescriptive design and construction requirements as well as testing requirements for specific issues with certain allowable limits.

Those issues would include but not be limited to:

- Documentation of thermal management system adequacy
- Documentation of thermal abuse limits
- Documentation of adequate enforcement of thermal limits (including below freezing)
- Documentation of electrical shock and arc flash hazards, required clearances, etc.
- Documentation of electrical abuse limits
- Documentation of adequate enforcement of electrical limits
- Documentation of mechanical abuse limits (vibration, and shock)
- Documentation of adequate enforcement of mechanical limits
- Thermal run away propagation prevention adequacy

A complete system standard will document the safety of the ESS as a delivered product and its intended uses. Third-party certification programs inspect the initial design and ongoing production of the ESS to ensure compliance is both established and maintained. In addition, certification programs would review and assess the administrative and quality control aspects associated with the manufacturer of safety critical components. A system standard will reference and impose the requirements of applicable component standards. This will help the customer determine whether the operational environment imposed by the system is consistent with predictable and safe component behavior. For example, a system standard would establish requirements for installation and operation of batteries and would require that batteries comply with manufacturing standards ensuring safe operation under those conditions. Both utilities and energy storage system providers could be familiar with the applicable system level standards and the component standards they reference. When possible, the utility specification document could require energy storage suppliers comply with the applicable complete ESS standard from Table 4-2. As such, Energy storage suppliers would benefit from using components that complied with relevant component safety standards. Utilities and energy storage providers could clearly list what system level standards were consulted for their design and what component level standards are referenced, as this can help those reviewing ESS safety for deployment. As the applicable standards can lag technology and hence be insufficient to ensure safety, a holistic SSA could be considered during reviews of alternative means for standards compliance.

Table 4–2
Standards for Complete Energy Storage Systems

Energy Storage System Type	Standard
Stationary Energy Storage Systems with Lithium Batteries – Safety Requirements (under development)	IEC 62897
Flow Battery Systems For Stationary Applications – Part 2-2: Safety requirements	IEC 62932-2-2
Recommended Practice and Requirements for Harmonic Control in Electric Power Systems	IEEE 519
Standard for Interconnecting Distributed Resources with Electric Power Systems	IEEE 1547
Recommended Practice and Procedures for Unlabeled Electrical Equipment Evaluation	NFPA 791-2014

4.3. Installation

The installation of an ESS, as pre-packaged equipment, a matched set of components, or a mix-matched assembly of components involves two key topical areas: procedures and physical requirements. Procedures cover worker safety, transportation, handling, and functions associated with the act of installing the ESS and its component parts. Physical requirements cover the safety of the final installation in terms of the surrounding environment, buildings, and other systems, electrical protection, access, egress and other safety-related issues. The information below first lists those standards and related documents associated with the installation procedures and then those standards and related documents associated with the installation physical requirements. An overarching guiding standard covering this topic is IEC 62935 Planning and Installation of

Electrical Energy Storage Systems. This standard could be referenced in the specification with the intent of augmenting it on an issue by issue basis using safety analyses and the other standards listed in Table 4-3.

Table 4–3
Standards for Energy Storage Project Design, Deployment, and Operations

Energy Storage Installation	Standard
Transportation Testing for Lithium Batteries	UN 38.3
Safety of primary and secondary lithium cells and batteries during transport.	IEC 62281
Shipping, receiving and delivery of ESS and associated components and all materials, systems, products, etc. associated with the ESS installation.	DOT Regulations
Worker safety	Federal and state OSHA
Competency of Third Party Field Evaluation Bodies	NFPA 790
Fire and smoke detection	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Fire suppression	NFPA 1, NFPA 13, NFPA 15, NFPA 101, NFPA 850, NFPA 851, NFPA 853, NFPA 5000, IBC, IFC, state and local codes
Fire and smoke containment	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Fire alarm	NFPA 72
Protection of Electronic Computer/Data Processing Equipment	NFPA 75
Clean Agent Fire Extinguishing Systems	NFPA 2001
Ventilation, exhaust, thermal management and mitigation of the generation of hydrogen or other hazardous or combustible gases or fluids	NFPA 1, IEEE/ASHRAE 1635, IMC, UMC, state and local codes
Egress (operating and emergency)	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Access (operating and emergency)	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Working space	OSHA 29 CFR 1910.305(j)(7) and OSHA 29 CFR 1926.441 (if applicable), NFPA 70E, Article 320
Physical security	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Illumination (operating and emergency)	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Fire department access	NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes

Table 4-3 (continued)
Standards for Energy Storage Project Design, Deployment, and Operations

Energy Storage Installation	Standard
Anchoring and seismic protection	NFPA 5000, IBC, state and local codes
Buildings, enclosures and protection from the elements	IEC 60529, UL 96A, NFPA 5000, IBC, state and local codes
Signage	ANSI Z535, IEEE C-2, NFPA 1, NFPA 70E, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Emergency shutoff	IEEE C-2, NFPA 1, NFPA 101, NFPA 5000, IBC, IFC, state and local codes
Spill containment, neutralizing and disposal	NFPA 1, IPC, UPC, IFC, IEEE1578, state and local codes
Electrical safety	IEEE C-2 (National Electrical Safety Code), NFPA 70E, FM Global DS 5-10, DS 5-1, DC 5-19
Communications networks and management systems	IEC 61850, DNP3, Modbus
Seismic Requirements, Design, and Testing	IBC (International Building Code), CBC (California Building Code), OSHPD, IEEE 693, ACI 318-05, ACSE 7-10

4.4. Commissioning

The commissioning of an ESS occurs after installation and inspection to ensure it operationally complies with the applicable codes, standards, rules, and regulations in addition to any contractual obligations for performance of the ESS (e.g., efficiency, delivered power, availability, life, etc.). Essentially, commissioning ensures that the system operates as expected. Once commissioned, the system can be accepted by the utility and ownership is transferred as needed. The system is then operated, maintained and renovated as stipulated in the procurement contract. Table 4-4 lists those standards and related documents that could be referenced in an ESS specification imposing requirements on commissioning. The utility could require that the energy storage supplier develop a commissioning plan to be approved by the utility.

Table 4–4
Standards for Energy Storage Commissioning

Energy Storage Commissioning	Standard
Recommended Practice for Commissioning of Fire Protection and Life Safety Systems	NFPA 3
Building and Systems Commissioning	ICC 1000

4.5. Operation and Maintenance

The operations and maintenance of an ESS involves two key topical areas: qualification of operators, and the operations and maintenance (O&M) manual. Qualification of operators involves training and certification associated with those personnel who will be working with the ESS. The O&M manual dictates the processes and technical requirements for working on ESS during operation as well as the schedule and instructions for maintenance. Table 4-5 first lists those standards and related documents associated with ensuring the competency of those personnel performing operations and maintenance and then those standards and related documents associated with the operations and maintenance activity itself.

The energy storage supplier and utility may consider re-commissioning the system on a regular basis to verify the safe operation, control, and shutdown of the system under normal and incident response situations. In order to ensure efficient operation the customer may consider requiring that the energy storage provider develop a qualification program to train operation and maintenance personnel to be approved by the utility. These technicians could be utility personnel, energy storage provider personnel, or personnel of a third party contracted to perform these functions. The utility, in cooperation with their insurance underwriters and management, could determine the degree to which training and certification is required for technicians.

Table 4–5
Standards for Energy Storage Operations and Maintenance

Energy Storage Operations and Maintenance	Standard
Hazardous materials storage, handling and use	NFPA 400
Standard on Maintenance of Electrical Equipment	NFPA 70B

4.6. Incident Preparedness

The ability to respond to an incident associated with an ESS involves two key topical areas: procedures, and automated systems. Table 4-6 first lists those standards and related documents associated with ensuring the competency of those personnel doing response and then those standards and related documents associated with facilitating the response activity itself.

Table 4–6
Standards for Energy Storage System Incident Preparedness

Incident Preparedness	Standard
Standard for Technical Rescuer Professional Qualifications	NFPA 1006
Standard for Fire Fighter Professional Qualifications	NFPA 1001
Standard for Fire Department Occupational Safety	NFPA 1500
Standard System for the Identification of the Hazards of Materials for Emergency Response	NFPA 704
Guide for Substation Fire Protection	IEEE 979
Fire Fighting	Emergency Planning and Community Right-to-Know Act (EPCRA)
Fire and Explosion Investigations	NPFA 921
Fire Safety Concepts Tree	NFPA 550

5
QUICK REFERENCE FOR CITED DOCUMENTS

Safety Package Document List	Developed by	Reviewed by	Details of What to Include
Documentation of need for ESS	Utility Procurement	Utility Management	Section 3.1
Documentation of early stage safety considerations	Utility Procurement	Utility Management	Section 3.1
Procurement specification and project scope	Utility Procurement	Utility Management	Sections 3.2 and 4
Applicable standards and compliance package	ESS Provider	Utility and/or Third Party	Section 4
Failure Modes and Effects Analysis (FMEA)	ESS Provider	Utility and/or Third Party	Section 3.2.1
System Safety Analysis (SSA)	ESS Provider	Utility and/or Third Party	Section 3.2.2
Commissioning plan	ESS Provider	Utility and/or Third Party	Sections 3.3 and 4.4
Qualification program to train operation and maintenance personnel	ESS Provider	Utility and/or Third Party	Sections 3.2.3 and 4.6
Operation and maintenance manual	ESS Provider	Utility and/or Third Party	Sections 3.4 and 4.5
Incident training manual	ESS Provider	Utility, Third Party, and Other Stakeholders	Sections 3.2.3 and 4.6
Site specific emergency action plan	ESS Provider	Utility, Third Party, and Other Stakeholders	Sections 3.2.3 and 4.6
Decommissioning, disposal and recycling plan	ESS Provider	Utility and/or Third Party	Section 3.4

6
GLOSSARY

Below is list of acronyms used in this document, for a complete list of terms and definitions see the Energy Storage Association (ESA) Glossary of Terms available: http://energystorage.org/energy-storage/glossary

Acronyms

AC	Alternating Current
ACI	American Concrete Institute
AHJ	Authority Having Jurisdiction
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BMS	Battery Management System
CAP	Control Assurance Plan
CBC	California Building Code
CESA	Clean Energy States Alliance
CSR	Codes, Standards, and Regulations
DC	Direct Current
DOE	Department of Energy
DOT	Department of Transportation
EPA	Environmental Protection Agency
ESA	Energy Storage Association
ESIC	Energy Storage Integration Council
ESS	Energy Storage System
FMEA	Failure Modes and Effects Analysis
HAZOP	Hazards and Operability Analysis
HCS	Hazard Communications Standard
IBC	international building Code

IEC	International Electrotechnical Commission
IEEE	International Electrical and Electronic Engineers
IFC	International Fire Code
MAP	Measurement Assurance Plan
MSDS	Materials Safety Data Sheet
NEC	National Electrical Code
NESC	National Electrical Safety Code
NFPA	National Fire Protection Agency
NIST	National Institute for Standards and Technology
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
OSHPD	Office of Statewide Health Planning and Development
PNNL	Pacific Northwest National Laboratory
PRA	Probability Risk Assessment
RFI	Request for Information
RFP	Request for Proposals
RFQ	Request for Quotations
SCADA	Supervisory Control and Data Acquisition
SDS	Safety Data Sheet
SNL	Sandia National Laboratories
SOC	State of Charge
SOW	Scope of Work
SSA	System Safety Analysis
STPA	Systems-Theoretic Process Analysis
UL	Underwriters Laboratory
UN	United Nations

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Electric Power Research Institute
3420 Hillview Avenue, Palo Alto, California 94304-1338 • PO Box 10412, Palo Alto, California 94303-0813 • USA
800.313.3774 • 650.855.2121 • askepri@epri.com • www.epri.com