Safe operating guidelines for electrical storage systems in developing countries

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Safe Operating Guidelines for Electrical Energy Storage Systems in Developing Countries

An Energy Storage Partnership Report

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Executive Summary

This guideline document outlines best practices for the safe operation of stationary energy storage systems in developing countries. It is not intended to be a stand-alone all-inclusive resource, but instead is a first point of reference for various users and developers including System Operators, Utilities, Project Developers, and Technology Providers. This document is intended to be technology agnostic, but inevitably does not fully cover all issues or potential energy storage systems. Therefore it is incumbent upon the reader to apply prudent engineering analysis and judgement to their particular situation.

The safety guidelines outlined herein follow the entire lifetime of an Energy Storage project, as it was seen in early ESS projects, that several issues and failures could have been avoided through more comprehensive safety analysis during the design and procurement stages. Where possible, examples of lessons learned and references to updated standards have been provided.

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In addition, the authors would like to acknowledge the work of the larger energy storage community, which has developed the many codes, standards, regulations, and guidelines upon which this document is based.

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List of Acronyms

AHJ	Authorities Having Jurisdiction
ASME	American Society of Mechanical Engineers
ANSI	American National Standards Institute
AS/NZS	Australian/New Zealand Standards
BESS	Battery Energy Storage System
BOS	Balance of System
CSA	Canadian Standards Association
CSR	Codes, Standards, and Regulations
CPUC	California Public Utilities Commission
EPC	Engineering, Procurement and Construction
ESP	Energy Storage Partnership
ESS	Energy Storage System
DER	Distributed Energy Resource
FAT	Factory Acceptance Test
GB/T	Chinese National Standards (Guobiao)
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
NFPA	National Fire Protection Association
NRC	(The) National Research Council of Canada
OSHA	Occupational Safety and Health Administration
PV	Photovoltaic
RFI	Request for Information
RFO	Request for Offers
RFP	Request for Proposal
RFQ	Request for Quotation
SCADA	Supervisory Control and Data Acquisition
SOW	Scope of Work
T&D	Transmission and Distribution
UL	Underwriters Laboratories
WBG	World Bank Group

1 Background

Energy storage is a rapidly expanding and evolving field, with installations of various kinds being built around the world. Due to the pace of the technology's emergence and the wide variety of systems, appropriate codes, standards and regulations for planning, procuring, operating, and decommissioning, these systems tend to lag behind what is being installed.

In some countries this has led to safety incidents, such as a series of fires due to a lack of environmental control, improper installation of components, an improperly integrated protection and control system, and battery protection system failure in South Korea (1). Similarly, a photovoltaic system in Myanmar experienced an event that resulted in combustion of the battery pack. An investigation into the incident was inconclusive as to the cause, although it could have been a result of overcharging, failure of a cell due to poor manufacturing, a short circuit in the battery system, or poor workmanship (2). Following appropriate codes and standards can help prevent these types of incidents from occurring, and ensure that if they do, there are procedures in place to limit their spread and avoid harming anyone in the vicinity.

This document presents an overview of safety lessons learned and best practices over the lifecycle of an energy storage system (ESS). For more detail, additional resources are referenced to provide more in-depth descriptions and templates that can be used throughout the various phases of a project's lifecycle.

While other documents developed by and for the Energy Storage Partnership (ESP) initiative will cover general best practices specific to each lifecycle phase, the objective of this document is to provide specific guidelines related to safe operation of energy storage devices, regardless of the energy storage system's project lifecycle. These include:

- Project Development and Planning
- Deployment and Commissioning
- Operation, Maintenance and Incident Response
- Decommissioning and End of Life.

More details on the safety considerations at each of these phases are outlined below; however, it is important to note that, in many cases, the requirements for operating an ESS system safely do not differ between developed and developing countries. Instead, early deployments of energy storage in developed countries have led to the development of many established guidelines which can reduce the cost and help ensure the success of initial deployments elsewhere in the world. As considerations specific to developing countries emerge, this document will be updated to reflect any changes required.

2 Project Development and Planning

In general, most energy storage projects go through two phases of planning: feasibility assessment and detailed engineering.

2.1 Feasibility Assessment

At an early stage, it is important to consider specific safety requirements that may evolve as a result of the location, technologies, or environment being considered, as well as the costs that may be involved to either mitigate or eliminate safety issues. These may affect the feasibility of the project, or at a minimum, ensure that a sufficient budget is included to ensure safe operation of the system. Specific considerations include:

- Identifying the local authorities having jurisdiction (AHJ) and their safety requirements
- Establishing which minimum safety codes and standards should be applied absent effective AHJ requirements to ensure safe procurement, commissioning, operation, maintenance, and decommissioning
- Planning for local political, economic, social, and environmental factors that could affect safety risks
- Planning for current or future requirements when the project is considered critical infrastructure for national security or other reasons
- Identifying any first responder requirements or training needs required to ensure safe response to fires or other environmental contingencies.

These analyses will depend on the normal technical and economic feasibility study elements which would include at a minimum:

- A clear definition of the business case, including the primary and secondary use cases for the ESS
- Analysis of the technical requirements for the project, including load and generation profiles, system sizing, charge/discharge profiles, dispatch modes, and control requirements, etc.
- Screening of technologies to ensure they meet performance and safety requirements.
- Performing key stakeholder consultations to confirm all safety and social acceptance considerations have been identified
- Performing a detailed and unbiased economic analysis
- Identifying any non-standard or site-specific performance or safety considerations / requirements for inclusion in the detailed engineering and procurement phase.

2.2 Detailed Engineering and Procurement

In the detailed engineering and procurement phases, analysis of the considerations outlined in the feasibility phase produces a list of requirements to be implemented in the ESS (3). It generally consists of detailed engineering analysis which results in the development of a Request for Proposal (RFP) or Request for Offer (RFO), and a review of submitted proposals to decide which bid to accept. As in all stages of the lifecycle of an ESS, safety should be integrated into the process to ensure that risks are foreseen and managed well in advance, from the beginning of construction to decommissioning and end of life. This can start with the use of a standardized RFP / RFO template with well-defined terminology that will ensure that safety requirements are effectively communicated to groups bidding on the project and those supplying components. For more detailed information on RFPs, see the *Energy Storage Request for Proposal Guide 2017* (4). Specific considerations on safety during this phase include:

2.2.1 Detailed Engineering

The requirements for procurement and installation can include provisions that ensure the safety of the system over its lifecycle. They can be met in two primary ways: compliance with relevant Codes, Standards, and Regulations (CSRs), or if none exist, via a procedure such as a Failure Modes and Effects Analysis (FMEA) or Systems Safety Analysis (SSA).

Energy storage systems are a growing field, and as such, CSRs lag behind them. However, when trying to meet a safety specification for an ESS, if compliance with relevant, up-to-date CSRs can be proven, this can be taken as evidence of a safe installation. Where there is no relevant CSR, a safety analysis method can be used to bridge the gap. This is performed by an accredited third party that is selected by stakeholders. For more information on different methods, and guidance on where to find documentation specific to these analyses, see *Guidelines Developed by the Energy Storage Integration Council for Distribution-Connected Systems* (5).

2.2.2 Understanding the Local Economic, Political, Social and Cultural Environment

Communication with members of the community is important throughout the ESS lifecycle. During procurement, different AHJs will be responsible for signing off on different parts of the project. It should be known which AHJ is responsible for which part, and what tests, CSRs, or safety analyses they will use. To ensure all safety considerations are addressed, they should be clearly identified and assigned to accountable stakeholders. This can be captured in a Responsible, Accountable, Consulted, Informed (RACI) matrix to ensure interdependent or complex safety considerations are considered (6). When assigning roles, ensure that all those identified in the RACI matrix have the appropriate level of expertise and qualifications to ensure their complete and safe execution.

Risk to the public, customers, contractors and employees of the site also needs to be considered. Societal tolerance of risk varies around the globe, and can affect public acceptance of a project (7). Risk criteria can be established for a facility in a variety of ways. For specific information on different analysis methods and how to establish achievable risk criteria, please refer to *Chapter 6 - Regulatory Framework, Safety Aspects, and Social Acceptance of Hydrogen Energy Technologies* (8).

2.2.3 Understanding the Local External Conditions

Regional conditions, such as weather and seismic activity, will be different for every community, and should be considered during procurement of an ESS. A site that helps limit or avoid the possible effects of likely natural disasters can be chosen, and a plan that includes who has responsibility for monitoring for possible events, and what to do in case they occur, should be in place. This includes clear lines of communication and knowledge regarding who should be contacted and when. This should also include protocols on when a system should be shut down (9).

Resilience towards likely events should also be considered during this phase. For example, in areas with high seismic activity, measures should be taken to stabilize structures. For guidance on planning for specific types of weather and other natural hazards, please refer to the *U.S. Energy Storage Operational Safety Guidelines 2019* (10).

2.2.4 Understanding the Local Infrastructure Conditions

Depending on the nature of the system, an ESS may be reliant upon a variety of local infrastructures including power, fuel, transportation of goods by rail, road, or sea, and potable water. If a loss of infrastructure will affect the safety of the ESS or people in the vicinity, this should be accounted for in the emergency action plan for the site.

In addition, it is important to assess the potential local industrial partners (e.g. suppliers, shippers, machine shops, engineering consulting firms, etc.) and their relative capabilities and experience with the technologies. Where local suppliers with sufficient experience to execute the project as designed are not available, additional resources should be considered in order to mitigate the risks within the project.

3 Deployment and Commissioning

When an energy storage system has been manufactured and/or assembled at a project site, there are several typical steps that may be taken in order to ensure safe operation. These include:

- Factory Acceptance Testing (FAT)
- Site Acceptance Testing (SAT)
- Commissioning

3.1 Factory Acceptance Testing

Factory acceptance testing typically involves a verification of the essential functions and key performance attributes of a device or system in a controlled environment, most often at the manufacturer's site. These testing activities should follow a detailed test plan that is approved in advance by key stakeholders, has all results and exceptions formally documented, and is witnessed by the customer or other stakeholders (e.g. AHJ, first responders, utility partners, etc.).

The test plan can be provided by either the manufacturer or the customer. A manufacturer can propose their plan and the buyer can accept it as is, propose changes and improvements, or impose their own plan. The decision is typically dependent upon such factors as the nature of the equipment and the maturity of each party, etc. FAT activities in a controlled environment can be great opportunities for the following:

- Checking that all safety subsystems or devices are installed and functioning as required and specified
- Allowing stakeholders to learn how the ESS can and should perform, and how it is controlled
- Confirming that safety-related warning and fault threshold values are correctly programmed and documented
- Evaluating beginning of life (BOL) performance characteristics and ensuring the scope of supply is as per the terms of the purchase agreement. If / when any deficiencies are found, it is typically far easier, safer, and less costly to rectify such exceptions in the factory setting vs. at the project site
- Performing any CSR compliance or certification testing that may be beneficially performed in a controlled environment
- Verifying assembly quality, completeness of scope, and accuracy of any as-built drawings or other documentation that was specified as a contractual deliverable.

In addition to these points, it is prudent to ensure credibility and insurance protection from project vendors and any of their suppliers or subcontractors. The safe and reliable operation of the ESS is only as good as the weakest link in the supply chain, and risks or issues can often be identified and resolved during well-planned customer-witnessed FAT activities.

For larger ESS projects, where components are manufactured in multiple locations and shipped direct to site, it may become impractical to conduct a system-level FAT anywhere but at the project site. In that case, it may be possible to subdivide FAT activities for the key safety and performance criteria and evaluate them separately at multiple supplier facilities to help minimize risks once all equipment is integrated at the project site.

Further discussion and detail relating to device-type tests, FAT preparation and activities, and safety planning for FAT, SAT, and commissioning is available in Section 4 of the *ESIC Energy Storage Commissioning Guide* (11). The California Public Utilities Commission has also published an *SED Safety Inspection Items for Energy Storage* (12) report based on input from utilities, project developers, and equipment.

3.2 Site Acceptance Testing

Prior to installing and integrating the various subsystems or components associated with a utility-scale ESS, significant site construction or preparatory work is typically needed. A detailed SAT plan is recommended to be developed and followed to ensure key utility services (e.g. electricity, fuel, water, wastewater, specialty gases, communication links, security, etc.) are provided at the project site in the right locations, formats, quantities, and qualities. ESS installation steps should only commence after SAT results have been deemed acceptable to the owner or project developer, as the ESS safety systems rely on the interfaces provided at a properly engineered and prepared site. AHJ or third party inspections for site approval may also be required before equipment can be installed.

Some site-specific safety considerations to plan for or document as part of the SAT process are:

- First responder action plans, including signage for access routes, muster points, and emergency lighting
- Rules, procedures, and PPE provisioning for site access
- Emergency power-off interlock strategies for connected utilities or systems and fault condition annunciation and signalling
- Technician certification requirements
- Rigging instructions and access routes for equipment unloading or servicing (including load bearing limits of site surfaces).

3.3 Commissioning Activities

In order to safely and reliably operate an ESS, it must be properly commissioned to verify all communications, control, and functions are operating as designed. Once this initial capability has been confirmed, the commissioning process must also validate an ESS's ability to provide the application-specific functions it was designed for. It is typically only after this final validation process has been completed that the ownership and control of an ESS is transferred to the owner / operator.

For large or complex projects involving multiple suppliers, it is essential that the demarcation points between subsystems or components and the associated divisions of responsibilities be explicitly defined and maintained to help ensure a complete and systematic commissioning process is completed.

The *ESIC Energy Storage Commissioning Guide* (13) provides a detailed review of typical ESS commissioning activities and includes example durations for each activity based on the experience of its authors from the utility, laboratory, and industry sectors. It describes commissioning considerations that exist throughout the lifecycle of an ESS project with safety-related recommendations, and reference checklists for typical ESS components or systems to help support a safe commissioning process.

The U.S. DOE's Sandia National Lab has also published a safety-focused overview of ESS commissioning activities for the California Energy Commission that is publicly available (14). It provides a summary of most topics described in the ESIC Commissioning Guide in a concise presentation format, and uses some alternate industrial jargon to describe the commissioning process that may be more common in certain jurisdictions.

Another reference that may be applicable for general facilities for, or ancillary systems to, the ESS is the *American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) Standard 202-2018 -- Commissioning Process for Buildings and Systems* (15) that describes a quality-based method to identify the minimum acceptable commissioning process for buildings and systems. It provides a framework for developing design documents, specifications, procedures, documentation, and reports, and includes example checklists, a systems manual, reports, and training plans.

4 Operation, Maintenance and Incident Response

ESS safety events occur not only as a result of the actions taken during normal operation, but also those occurring at all other stages of the project lifecycle. That being said, due to the amount of energy stored in a single location, there are risks of all types that will need to be monitored and dealt with on an ongoing basis through the development of proper operating procedures. This section has been separated into the aspects which fall within the longest duration of the ESS systems lifetime including:

- Normal Operation
- Maintenance
- Incident Response and Reporting

4.1 Normal Operation

During normal operation, the steps taken during earlier project phases will be applied. These include, but are not limited to:

- Development of an operations manual including all aspects of security and operations
- Ensuring redundancy of systems and implementation of fail-safe designs
- Ongoing monitoring of the ESS system, including clear warning systems and alarms
- Ensuring access to required technical experts during operation
- Ensuring security of the ESS system, both physically and as cyber-security
- Clear communication and training of staff and first responders, including regular emergency response drills

The requirements of each of these elements will vary by jurisdiction, as documents and steps have been outlined in other references such as those outlined in the *ESA Corporate Responsibility Initiative: U.S. Energy Storage Operational Safety Guidelines* (16).

4.2 Maintenance

The detailed design, deployment and commissioning phases of the project form the basis for ongoing maintenance. During these phases, maintenance plans, which include the required elements for both the ESS and the supporting infrastructure, should be clearly defined. The timing of these aspects should be based on time, level of usage, ESS manufacturer's suggestion and other local environmental factors. The maintenance schedule should include checklists that detail each component and auxiliary system and outline the required maintenance at each interval. A spare parts inventory and storage location(s) should be actively managed, with parts replenished once used.

These initial plans should then be supplemented with regular on-site inspection to look for abnormal issues related to:

- Restricted access or drainage

- Rust and deterioration
- Mechanical or electrical deterioration

It is important to communicate maintenance activities well in advance to both the users and the first responders, especially if they will require the system to be offline for some time.

Logs should be kept of all preventative maintenance and inspections completed as well as of any spare parts installed. Used components should be inspected to look for any signs of abnormal damage in conjunction with the manufacturer's instructions.

Further detail on maintenance standards and best practices can be found in the *ESA Corporate Responsibility Initiative: U.S. Energy Storage Operational Safety Guidelines* (17), *ESIC Energy Storage Commissioning Guide* (18) and the *ESIC Energy Storage Implementation Guide* (19).

4.3 Incident Response and Reporting

An Emergency Response Plan, which describes how any incidents will be responded to in order to safely shut down and address immediate safety issues such as fire, chemical, or electrical issues, must be created. Guidelines for the plan have been included in the *Energy Storage Association's Energy Storage Corporate Responsibility Initiative Emergency Response Plan* (20). It should include safety information for the ESS provided by the supplier, and should include any foreseeable incidents that could occur over the lifecycle of the system. Actions can include immediate responses such as a medical emergency, or non-immediate responses such as incident investigations. Safety considerations due to environmental events or a loss of infrastructure should also be accounted for. Particularly important are fire hazard mitigation strategies, which are detailed in the *ESIC Energy Storage Reference Fire Hazard Mitigation Analysis* (21) and *NFPA 855* (22).

Relevant personnel should be trained to recognize and respond to emergencies, and a call list should be in place for who to contact in the case of various incidents. First responders should be specifically trained for ESS-related hazards, including shut down locations to safely de-electrify the system, and fire and explosion risks that arise from lithium batteries. Particularly important codes to follow regarding proper electrical interconnection and wiring are the IEEE 1547 (23), CSA 22.1-15 (24), and UL1741 (25). The responsibility for monitoring and responding to different events should also be decided upon and recorded when the plan is formulated (26). For more information on setting up a robust emergency action plan, see the *Guidelines Developed by the Energy Storage Integration Council for Distribution-Connected Systems* (27).

After an incident, it is important to develop a detailed report to determine the root cause of the failure. The content for these reports is outlined in the *ESIC Energy Storage Safety Incident Gathering and Reporting List* (28). Ideally the results from these reports would be made public, either through a stand-alone report or by inclusion in one of the databases of lessons learned outlined in Section 6.1.

5 Decommissioning and End of Life

5.1 Decommissioning

The decommissioning stage of an ESS can arise for many reasons. Whether it be that a defined project end date is reached, the ESS is no longer required, or the ESS has reached its end of life, a sound decommissioning plan will help ensure this phase of the ESS lifecycle proceeds smoothly and safely.

End of life conditions and criteria, such as a capacity or round-trip efficiency threshold (29), must be defined during the project planning stage. These conditions should be carefully considered to ensure that they meet the requirements for maintaining an ESS that is safe and reliable.

A decommissioning plan must be prepared before any decommissioning activities begin, and should ideally be considered from the outset of ESS project planning. It is recommended that a decommissioning plan be included in a Request for Proposals, as discussed in the *ESIC Energy Storage Request for Proposal Guide* (30), and clearly define which parties are responsible for decommissioning the ESS. The plan should be a living document that is updated as technologies, experience with ESS, and relevant codes and regulations evolve over the project lifecycle.

With respect to safety, the decommissioning plan should include a risk management assessment, a safety plan, and an environmental assessment, and should take into consideration ESS component recycling and/or disposal. More detailed breakdowns of these and other aspects of an ESS decommissioning plan are outlined in the *ESIC Energy Storage Commissioning Guide* (31) and the *ESIC Energy Storage Implementation Guide* (32).

5.2 ESS Component Recycling and Disposal

Most energy storage systems include a variety of materials that must be disassembled and disposed of in accordance with national and international standards. The risks regarding disassembly, recycling and disposal primarily surround the transportation of used materials and the final disposal or recycling process. It should be noted that in many jurisdictions, extended producer responsibilities for ESS components will apply, and are not necessarily limited to cell materials, but also Balance of System (BOS) components. The costs and contracts regarding such responsibilities should be outlined during the planning phase of the project, and are generally outside the scope of this document due to the variance in applicable regulations worldwide.

Although each technology and embodiment will be specific to the manufacturer or product developer, of particular importance for Li-ion-based ESS is the proper handling of Li-ion batteries during disassembly and transport. Improper handling and disposal of these materials could result in fire, explosion, and/or a release of hazardous materials into the environment. Several codes and standards regulate Li-ion battery transportation, and disposal / recycling should be referenced and followed as applicable, including:

- *Recycling and Disposal of Battery-Based Grid Energy Storage Systems* (33)

- *ESA Corporate Responsibility Initiative: U.S. Energy Storage Operational Safety Guidelines 2019* (34)
- *ESA End-of-Life Management of Lithium-ion Energy Storage Systems* (35)
- *UNECE. Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria: Sixth Edition. 2015* (36)
- *CFR Title 49 - Transportation* (37)
- *U.S. Environmental Protection Agency (EPA) Resource Conservation and Recovery Act* (38)

5.3 Recommissioning

An ESS may require recommissioning following certain events, such as changes in operational requirements and/or major upgrades or replacement of components or firmware. Recommissioning consists of a series of tests used to ensure that an ESS continues to operate as intended. Generally, recommissioning tests can follow the same guiding principles as outlined for the initial ESS commissioning outlined in Section 3, although perhaps at a reduced scope depending on the nature of the recommissioning-triggering event.

Particular care should be taken when planning recommissioning tests following firmware upgrades. Firmware upgrades may result in a loss of system tuning parameters, and may require re-testing of interconnection procedures, control functions, performance related functions and IT and cyber security procedures. Further information on recommissioning an ESS following firmware upgrades can be found in the *ESIC Commissioning Guide* (39).

Planning for recommissioning, including identifying which parties are responsible for recommissioning, defining specific recommissioning-triggering events, and selecting the scope of recommissioning tests, should ideally be considered during ESS procurement (40).

In some cases, an ESS may have been decommissioned due to the end of a project, even though it had not yet reached the end of its operational lifecycle. These ESS may be moved to a new location and recommissioned there. In these cases, recommissioning should follow the same guiding principles as outlined for the initial ESS commissioning in Section 3.

6 Lessons Learned and Updates to Codes, Standards and Regulations

6.1 Lessons Learned

Several documents have compiled lessons learned through investigations of ESS incidents and through surveys of ESS stakeholders. These lessons serve as a tool to help the industry avoid repeated mistakes. Several examples of lessons learned are shown below.

	Lessons Learned
MOTIE Report (41)	There should be careful investigation of ESS components. For example, examining battery cells for defects will help to avoid cell failures.
	There needs to be careful consideration of the ESS environment with respect to moisture and/or temperature control.
	Proper care during ESS installation is required. For example, batteries should be properly stored prior to installation, and careful installation will avoid incorrect connections and wire shorts.
	Proper care integrating different ESS components that may originate from different manufacturers is crucial.
Myanmar Battery Incident Report (42)Error! Reference source not found.	There should be careful investigation and testing of ESS components according to relevant standards. For example, examining battery cells for defects will help to avoid cell failures, as well as applying battery pack standards such as IEC 62619.
	Proper care during installation is required. Careful installation will avoid incorrect connections, loose materials and wire shorts. Factory Acceptance and Site Acceptance Tests should be completed in order to catch manufacturing issues.
McMicken Battery Investigation (43)	Following a thermal event, flammable gases can build up in the ESS, resulting in explosion. Mitigation strategies should be considered.
Japan Transport Safety Board Report (44)	There needs to be careful consideration of temperature control.
	There should be careful investigation of ESS components. For example, examining battery cells for defects will help to avoid cell failures.
	Safety testing should be carefully planned to simulate actual operation conditions so that effects of potential incidents are not underestimated.

PCTEST Battery Incident Root Cause Analysis (45)	There should be careful investigation of ESS components. For example, examining battery cells for defects will help to avoid cell failures.

Where possible, additional lessons learned should be gathered and made public to ensure that failures in ESS systems result in changes to codes, standards, and regulations. This ensures both increased safety of ESS systems over time, and the continued social acceptance of ESS deployments around the world.

6.2 Codes, Standards and Regulations

An ESS project consists of different stages such as engineering, manufacturing, site engineering, site installation, site decommissioning, and so on. Figure 1 shows the project stages in the NRC's CSR database website. Codes and standards are excellent tools to ensure that critical items are not overlooked during each project stage. They help insurers manage risk, help the AHJ evaluate the safe installation and integration of the systems, and help integrators trust component manufacturers and suppliers. Similarly, they are good tools to understand the required standard of care. Therefore, compliance with codes and standards reduces risk related to ESS installations and increases confidence in the technologies. In fact, after 23 ESS fire incidents in Korea, the investigation findings drove the Korean government to establish Korean Industrial Standards (based on international standards), adopt Industry Standards, and lead the discussions on setting international standards (46).

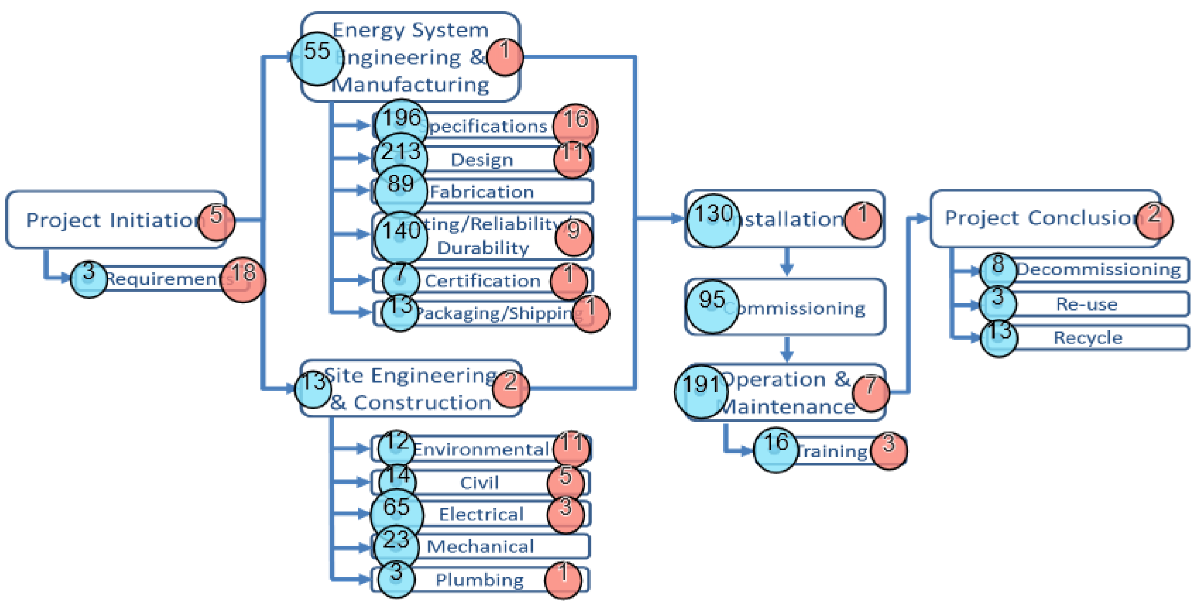

Figure 1: Project Stages in the NRC's CSR Database Website

Activities during each project phase should be compliant with applicable local codes, standards and regulations (CSR). If local CSRs do not yet exist, AHJ and/or project developers may be able to de-risk their project by adopting appropriate international CSRs that have been carefully adapted for a specific project. This strategy should not be considered a substitute for a formal and comprehensive framework of local CSRs to ensure safe ESS installations in the longer term. Applicable ESS codes and standards are published by many Standards Development Organizations around the world, such as but not limited to IEEE, ANSI, IEC, NFPA, CSA, UL, OSHA, ASME, AS/NZS, CPUC, and GB/T, etc.

Standards manage safety from the bottom up, which means they ensure that components comply with safety requirements found in component standards to deem them safe for use as part of the system (as long as they are used within their ratings). Similarly, system enclosures, installations and buildings must also comply with safety requirements. Therefore, the codes, standards and regulations landscape is vast and complex (to cover all components, as well as the buildings and installations). However, some standards created in North America and Europe include a comprehensive list of requirements which help users to understand the CSR landscape, at least locally. For example, in North America the *Bi-national (US and Canada) Standard UL 9540* (47), which is non-technology specific, references more than 60 documents such as UL 1973 for batteries, UL 1741 for inverters, ASME B31 for power piping, ASME Boilers and Pressure Vessels for boiler and pressure vessels, ASHRAE 62.1 for ventilation, and so on (48). In Europe, the *DNV GL's "Gridstor" RP0043* and *Recommended Practice: Safety, Operation and Performance of Grid Connected Energy Storage Systems* (49), which is intended as a comprehensive best practices checklist, compiles a list of requirements as well.

The *Bi-national Standard (US and Canada) for Energy Storage Systems and Equipment UL 9540* covers the complete energy storage system including flywheels, batteries and other types of energy storage, the power conversion system, control system, ancillary equipment, protection systems and more. The purpose of the *Bi-national Standard (US and Canada*) UL 9540A (Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems) is to formally record the battery fire characteristics during a Thermal Runaway (TR) event. This information is useful for facility designers, integrators, AHJs, and emergency personnel (50). In this standard, TR tests are performed at different levels such as cell level, module level, unit level, and even at the installation level to check fire protection system effectiveness, gas release rates, heat and fire propagation, and explosion hazards, etc. The UL 1973 *Batteries for Use in LER and Stationary Applications* covers different types of batteries including lead acid, Lithium-ion, nickel, sodium beta, flow batteries, capacitors, and hybrid systems (51). UL published a standard to sort and grade used battery packs, modules and cells to be repurposed from other applications to ESS (*Standard for Evaluation for Repurposing Batteries UL 1974*).

The US has the NFPA 855 standard for the *Installation of Stationary Energy Storage Systems* which specifies risks around fires in energy storage systems, including siting, separation between components, ventilation systems, detection and suppression systems, and signage, etc. (52). This code also includes procedures for standard operations and emergency response (53). An ESS emergency response plan example was created by ESA, which can be used as a template for the creation of an ESS emergency response plan (54).

The Norwegian DNV GL's *Recommended Practice for the Safety, Operation and Performance of Grid-connected Energy Storage Systems* (RP43) (55) covers risk management recommendations regarding the battery safety systems design (devising a safety strategy that addresses critical components such as cells, subsystems such as modules, and so on), planning the factory acceptance tests, having design rules at multiple points in the product life cycle, and testing the interoperability of components, etc.

The International Electrotechnical Commission has developed, or is developing, relevant safety standards such as the *IEC 62937, Safety Considerations Related to the Installation of Grid Integrated Electrical Energy Storage (EES) Systems*, *Flow Battery Systems for Stationary Applications*, *IEC 62932-2-2 - Safety Requirements*, *IEC 62619 - Safety Requirements for Large Format Secondary Lithium Cells and Batteries for use in Industrial Applications*, *IEC 62620 - Secondary Lithium Cells and Batteries for use in Industrial Applications*, and *IEC 62897 - Stationary Energy Storage Systems with Lithium Batteries – Safety Requirements* (56).

Government and private entities also spend considerable resources creating documents to help people navigate through the complex CSR domain. For example, the SNL / PNNL monthly Codes and Standards updates reference a comprehensive list of codes and standards including recent and planned updates (57). Other documents include the *U.S. DOE OE Energy Storage Systems Safety Roadmap* (58) and the National Research Council of Canada's extensive web-based CSR inventory (https://gateway.eme.nrc.ca/). This searchable NRC website informs all ESS stakeholders involved in the complete ESS life cycle (from engineering to recycling) of more than 500 existing Canadian and international CSRs. This website also includes information on 47 Canadian ESS installations and is a platform that hosts data from many ESS, bioenergy and hydrogen refueling sites. The website is intuitive, and multiple filters can be used to very efficiently locate data.

Most safety standards include construction criteria and normal use and abuse tests, and require a safety analysis such as a Failure Mode and Effects Analysis (FMEA) that is completed to address hazards that could be unique to the system in question and that are not addressed by the standard. International documents exist that describe how to implement these analyses, such as the *IEC 60812:2018 Failure Modes and Effects Analysis / Failure Mode, Effects and Criticality Analysis* (FMEA and FMECA) (59) and the *IEC 61025:2006 Fault Tree Analysis*. (60)

Current automatic safety systems may comprise complex microelectronics and software. Functional safety is the valuation of the safety of a system as a result of the use of microelectronics and software to automatically protect the system, and is a very important part of the overall safety. There are also standards to evaluate programmable electronic safety-related systems such as the *IEC 61508 Functional Safety of Electrical / Electronic / Programmable Electronic Safety-Related Systems* (61).

Current Gaps in Codes, Standards and Regulations

Due to the time required to develop CSR for new technologies, gaps currently exist for the evolving energy storage sector. For example, the NFPA 855 code requires three foot separation distances between battery arrays, unless Large Scale Fire Testing (LSFT) to standards such as the UL 9540A confirms that smaller separation distances do not result in fire propagation between battery systems (62). However, industry is not aware of data that corroborates the adequacy of the three foot separation distance, which may impose excessive costs to indoor installations (63). Therefore, it is important to perform fire tests and analysis to improve fire code separation distances with objective data. A second part of the NFPA 855 code that may require more testing and analysis is related to the maximum energy allowance (in the absence of LSFT tests) for lithium-ion energy storage systems, which currently sits at 50 kWh per rack and 600 kWh for the entire system. Industry would like to base this number on the ability of systems to prevent failure propagation (64).

One gap that industry has raised about the UL standard 9540A is that systems do not necessarily pass a test. Instead, this standard provides a standard methodology for testing and reporting, and the results may need interpretation by an AHJ to decide on the project. One concern is that the AHJ may not have the required experience to make decisions based on the complex reports that may be generated when tests are performed in accordance with the standard, and this may lead to additional very expensive safety features (65). Another gap raised by Stephan Lux et al. (66) is that a standardized test specific to Lithium-ion battery charge controllers does not currently exist.

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