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Review of Codes and Standards for Energy Storage Systems

Charlie Vartanian[1] · Matt Paiss[1] · Vilayanur Viswanathan[1] · Jaime Kolln[1] · David Reed[1]

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Abstract

Purpose of Review This article summarizes key codes and standards (C&S) that apply to grid energy storage systems. The article also gives several examples of industry efforts to update or create new standards to remove gaps in energy storage C&S and to accommodate new and emerging energy storage technologies.

Recent Findings While modern battery technologies, including lithium ion (Li-ion), increase the technical and economic viability of grid energy storage, they also present new or unknown risks to managing the safety of energy storage systems (ESS). This article focuses on the particular challenges presented by newer battery technologies.

Summary Prior publications about energy storage C&S recognize and address the expanding range of technologies and their unique characteristics. However, there remains significant need and opportunity for researchers to add to the knowledge base that informs the development of technical references and standards, and ultimately, the application of published standards for the effective and safe design and use of modern ESS.

Keywords Energy storage · Energy storage systems · Codes and standards · Energy storage safety

Introduction

For the past decade, industry, utilities, regulators, and the U.S. Department of Energy (DOE) have viewed energy storage as an important element of future power grids, and that as technology matures and costs decline, adoption will increase. This future was identified in the DOE Office of Electricity Energy Storage (DOE OE ES) Program Planning report [1], and the expected expansion of global adoption of energy storage is becoming a reality.

As technology costs decline, the proportional contribution of soft costs will grow unless deliberate actions are taken to manage them. Soft costs are associated with high engineering costs incurred for individual projects due to lack of standards. In addition, there is a foundational mismatch between technology advancements and the long-lead time for getting standards developed and ratified.

As cited in the DOE OE ES Program Plan, "Industry requires specifications of standards for characterizing the performance of energy storage under grid conditions and for modeling behavior. Discussions with industry professionals indicate a significant need for standards …" [1, p. 30]. Under this strategic driver, a portion of DOE-funded energy storage research and development (R&D) is directed to actively work with industry to fill energy storage Codes & Standards (C&S) gaps.

A key aspect of developing energy storage C&S is access to leading battery scientists and their R&D insights. DOE-funded testing and related analytic capabilities inform perspectives from the research community toward the active development of new C&S for energy storage. Examples of such perspectives include the challenges to creating C&S for newer storage technologies with limited operational track records and limited user experience. The C&S lifecycle from development through compliance is illustrated in Fig. 1.

Given the relative newness of battery-based grid ES technologies and applications, this review article describes the state of C&S for energy storage, several challenges for developing C&S for energy storage, and the benefits from addressing these gaps, which include lowering the cost of adoption and deployment.

Topical Collection on *Energy Storage*

✉ Charlie Vartanian
charlie.vartanian@pnnl.gov

[1] Pacific Northwest National Laboratory (PNNL), Richland, WA, USA

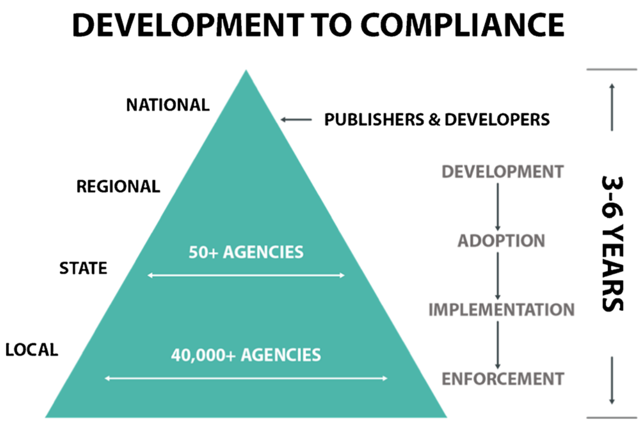

Fig. 1 C&S development timeline

Active Energy Storage C&S Development

Segments of C&S development activities can be grouped broadly under the areas of Performance, Reliability, and Safety. These activity areas map to the major stakeholder groups as represented by their respective Standards Developing Organizations (SDOs), shown in Fig. 2.

Key energy storage C&S and their respective locations within the built environment are highlighted in Fig. 3, which also identifies the various SDOs involved in creating requirements. The North American Electric Reliability Corporation, or NERC, focuses on overall power system reliability and generally does not create standards specific to equipment, so is not cited in Fig. 3 below. Likewise, this article focuses on safety and performance C&S for both energy storage equipment and complete ESSs, but not the overall power system.

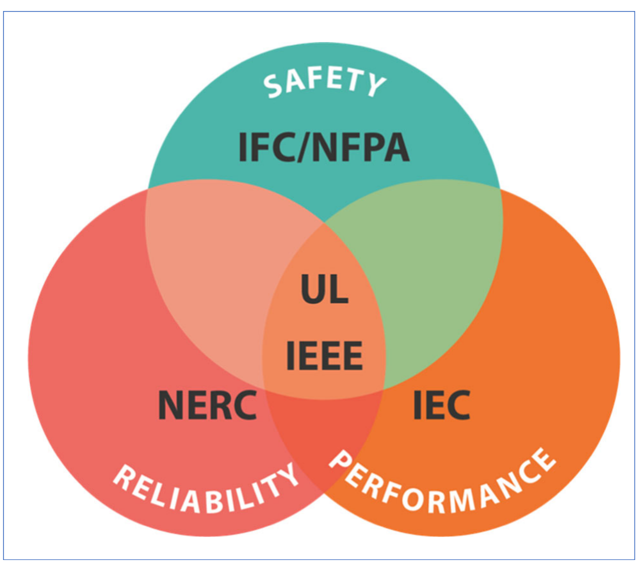

Fig. 2 Mapping C&S activity areas to standards developing organizations (NFPA, National Fire Protection Association, https://www.nfpa.org/; UL, Underwriters Laboratory, https://www.ul.com/, NERC, North American Electric Reliability Corp., https://www.nerc.com/Pages/default.aspx; IEEE, Institute of Electrical and Electronics Engineers, https://www.ieee.org/; IEC, International Electrotechnical Commission, https://www.iec.ch/)

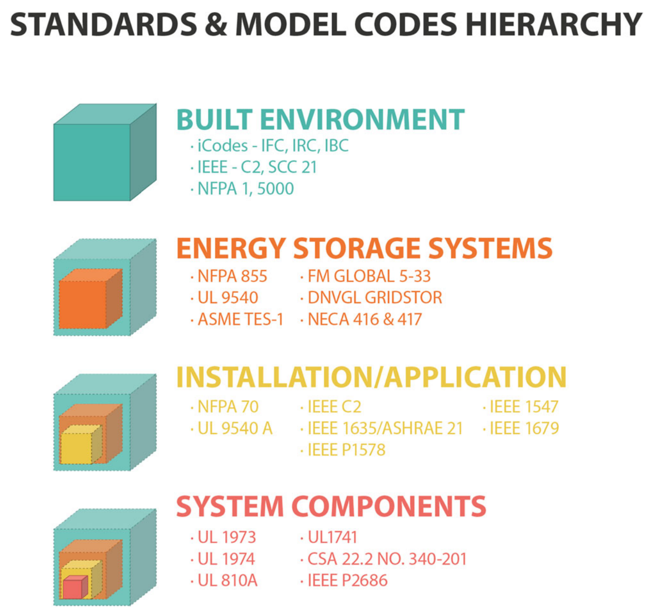

Fig. 3 C&S for energy storage systems and their respective locations in the built environment

Two specific examples of active C&S development are:

- UL 9540 Standard for Stationary Energy Storage Systems (ESS)
- IEC TS 62933-3-1 Electrical Energy Storage (EES) Systems–part 3-1: planning and performance assessment of electrical energy storage systems
- IEC 62933-5-2 Electrical Energy Storage (EES) Systems–part 5-2: safety requirements for grid-integrated ESS (expected publishment date in 2024)

These examples address energy storage performance and safety, respectively, and are discussed in the next section.

Safety Standards

As shown in Fig. 3, many safety C&S affect the design and installation of ESS. One of the key product standards that covers the full system is the UL9540 Standard for Safety: Energy Storage Systems and Equipment [2]. Here, we discuss this standard in detail; some of the remaining challenges are discussed in the next section.

UL 9540

The UL 9540-2020 product standard is the key product safety listing for stationary ESS. The current standard is the second edition (February 2020), and is a requirement for installation via reference by one of the two model Fire Codes in use in the United States: International Fire Code (IFC) and NFPA 1 Fire Code [3]. The IFC is in use or adopted in 41 U.S. states, the District of Columbia, New York City, Guam, and Puerto Rico [4]. The NFPA 1 Fire Code is adopted statewide in 19 states but used for construction in only 5 states. The IFC currently references standards cited in the Code in Chapter 80. In the current edition of the IFC (2021), the UL9540-2014 edition is cited. The significant changes from the first edition to the second include [5]:

- Scope now identifies applications with size and spacing requirements
- Performance criteria in accordance with UL 9540a fire test
- Construction to include non-combustible materials
- Critical safety controls to comply with applicable standards.

UL 9540a

Lithium ion (Li-ion) chemistry is the predominant battery technology, and all Li-ion cells are currently capable of thermal runaway and producing flammable gases. A key safety test cited in UL9540-2020 is the UL9540a-2019, "Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems" [6]. This document, now in its fourth edition (Nov 2019), outlines the test procedures to characterize the performance of cells, modules, and units/racks under possible worst-case thermal runaway conditions. The fourth edition includes performance criteria missing in previous editions.

Abuse testing starts at the cell-level test to determine if thermal runaway can be induced or if flammable gases are produced during the test. The test will identify gases that will be used in later testing to determine lower flammability limits and explosion studies. The testing sequence and requirements for further testing is based on the cell-level performance as seen in Fig. 4.

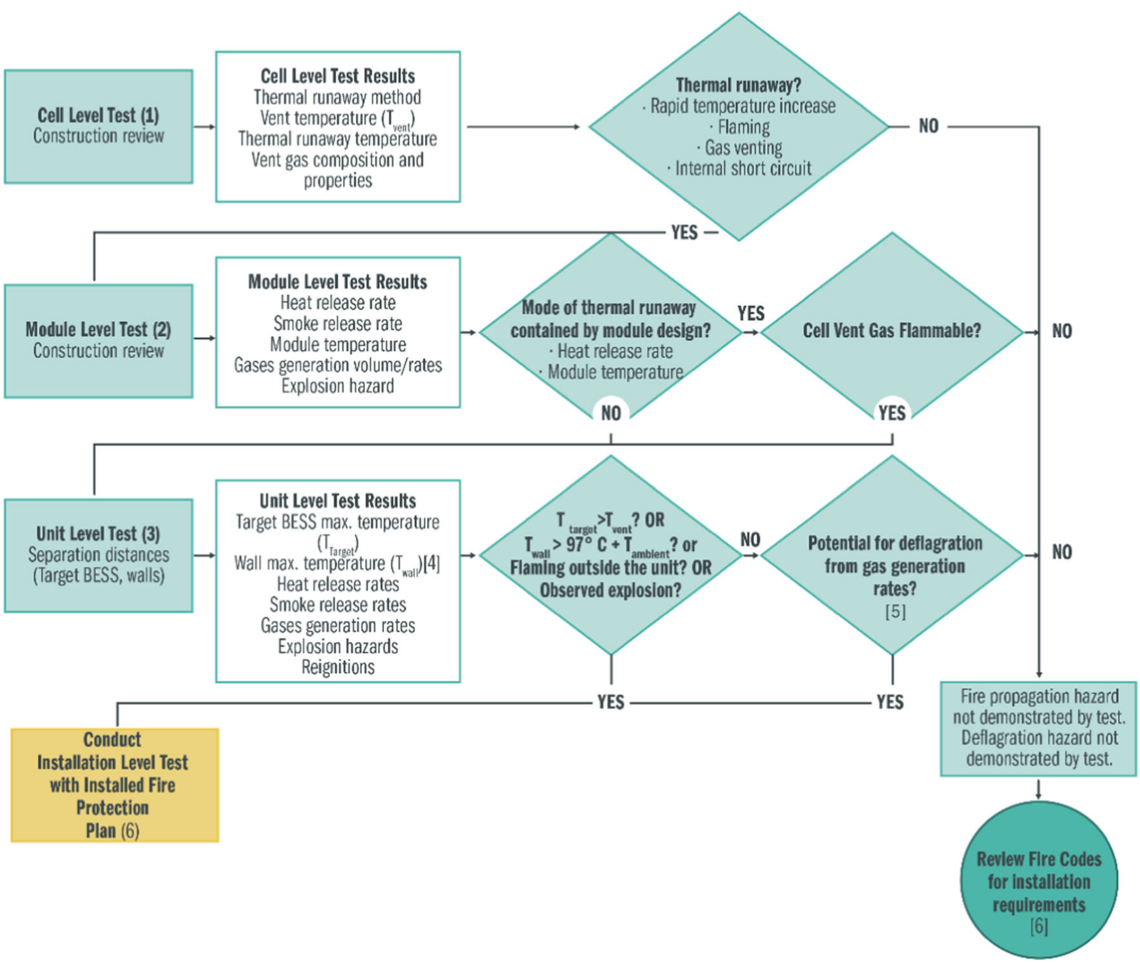

Fig. 4 UL 9540a test flow chart (used with UL permission) [7]

The UL9540a testing sequence follows:

- Cell level

  Tests are conducted on individual sample cells for thermal runaway and flammable gas production. Cells not capable of thermal runaway or producing flammable gases can be marked "For use in Residential Dwellings." While current Li-ion technologies are not capable of meeting this high bar of safety, other emerging technologies may meet this criterion in the future. For technologies lacking inherent safety based on cell-level characteristics, safety testing and evaluation must take place for product sub-systems that include multiple cells, e.g., multi-cell modules.

- Module level

  This test outfits a single module with heaters around individual cells to induce fire propagation from heated cells to target cells. This test determines the level of propagation and fire/explosion hazards.

- Unit or rack level

  This is a module-level test with full rack/unit to determine fire propagation and evolution of fire/explosion hazards.

- Installation level

  If unit-level testing identifies fire propagation outside of unit, a fire suppression system is required and tested in conjunction with additional unit-level test. This test determines the effectiveness of a fire suppression system to mitigate fire propagation outside of target unit/rack.

A typical 9540a test report includes a summary of the cell, module, and unit-level performance. A graphic example of a cell-level test report (Fig. 5) shows the various data points obtained, such as cell temperature at venting versus thermal runaway, vent gas properties, gas composition, and time/temperature curves.

Safety Bottom Line

The utility industry is actively involved in the development of best practices for the safe deployment of ESSs. Best practices learned from recent failures include early detection as well as designing features that prevent fire propagation. While

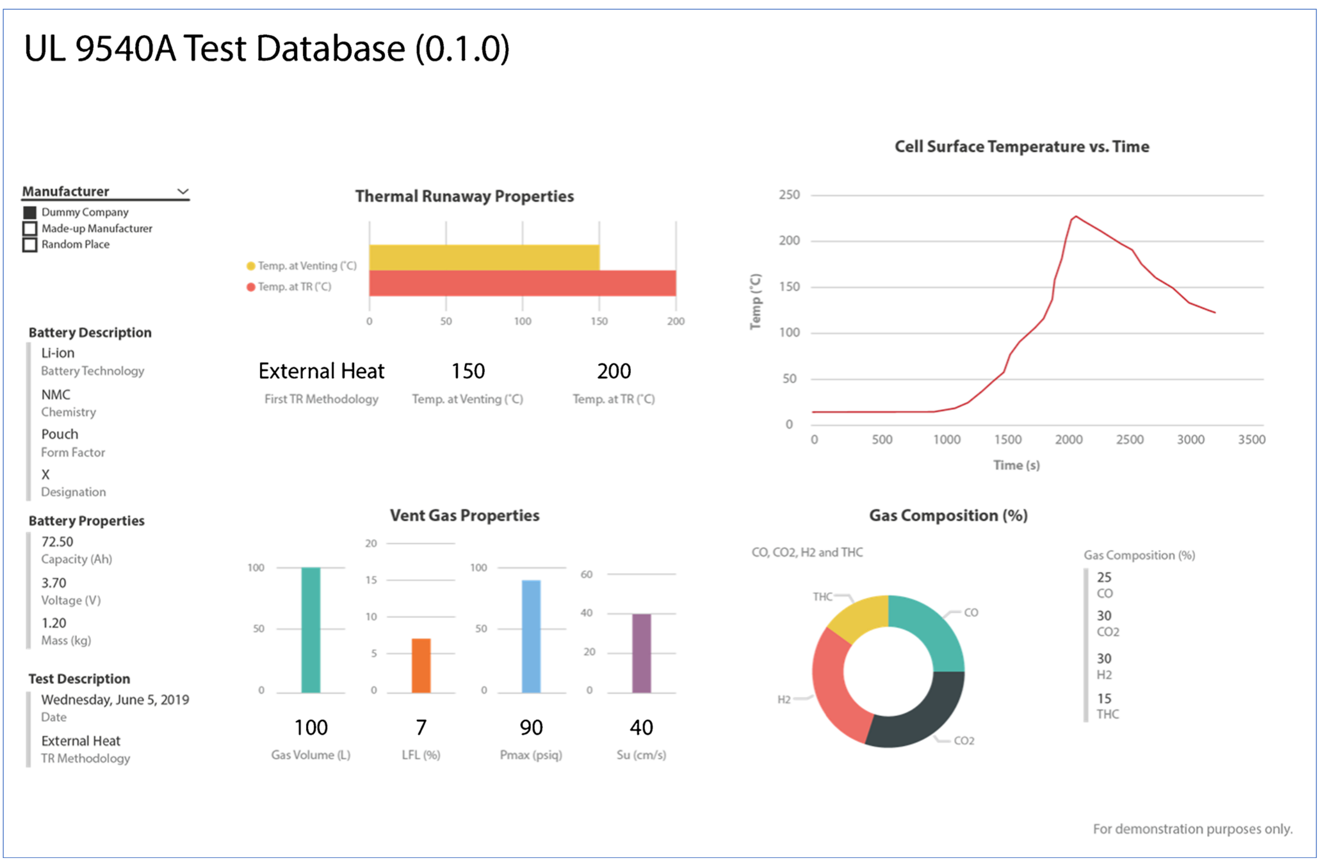

Fig. 5 Sample 9540a cell-level test report (used with permission of CUNY SMART DG Hub) [8]

eliminating the chance of a single cell failure may not be possible, the key is to design features that ensure propagation to other cells is minimal. Should a larger event occur, preventing an explosion is the next critical step. Deflagration vents (blow-out panels) can direct the flame front and pressure wave in designed directions.

The key to preventing a deflagration is gas management. Exhaust venting of an enclosed space is the objective, yet the move toward smaller cabinet-style enclosures with less open volume makes this more challenging. Lower open-air volume translates to a flammable gas exceeding the 25% lower flammability limit much faster. Innovative exhaust methods will be needed, in addition to retrofitting options for existing enclosures.

Performance Standards

Pacific Northwest National Laboratory (PNNL) and Sandia National Laboratories, sponsored by DOE OE ES, have led multiple industry working groups to develop ESS performance protocols for various grid services [9]. A total of eight grid services were considered, with duty cycles ranging from volatile (frequency regulation), constant power (peak shaving), and a combination (microgrid). The ESS was considered a black box with power exchange between the ESS and the grid being measured. From the working groups, performance metrics such as round-trip efficiency, ramp rate for real and reactive power, stored energy capacity at various percent of rated power, energy capacity stability, and standby energy loss were developed. Duty cycle specific performance metrics, such as reference signal tracking and peak continuous power for various durations, were also developed.

The national laboratories are also actively engaged with national and international SDOs to develop ESS performance standards. SDOs working on the standards include NEMA, IEEE, and the IEC. The DOE ESS performance protocol was directly incorporated into a NEMA Standard published in 2019 [10], while parts of it are included in IEC Standard 62933-2-1 and IEC Technical Specification 62933-3-1 [11]. The national laboratories also collaborated with the Electric Power Research Institute's Energy Storage Integration Council (EPRI ESIC) to develop test procedures for evaluating the performance of ESSs [12]. ESIC also developed a detailed technical specifications document that utilities and end users can use to specify their ESS [13], and an energy storage implementation guide to help end users throughout the life of the ESS from commissioning to decommissioning [14].

The effort by IEC TC 120 was the first to develop an ESS standard and technical specification considering the ESS as a black box. In the standard IEC 62933-2-1 [15], three classes of ESSs were defined:

- Class A, with volatile duty cycles with respect to power
- Class B, for energy intensive applications, and
- Class C, which combines Class A and Class B duty cycles, such as storage for microgrids.

Continuing work on technical specification IEC TS 62933-2-2 [16] focuses on applications and performance testing, including specific duty cycles as described in the DOE-OE protocol, Revision 2. Performance metrics such as round-trip efficiency, ramp rate, response time, and reference signal following were defined, and the method to determine them was described to enable end users to provide performance specifications per the metrics defined in the standard.

Another technical specification by TC120 [11] was developed to address multiple grid services, the power conversion system, and grid integration issues in more detail. Some of the DOE-OE performance protocol duty cycles were included so that end users can evaluate various ESS using these generic duty cycles.

IEC TC120 also published a standard on definitions for Electrical Energy Storage Systems (EESS) [17]. This standard used several definitions from the DOE-OE performance protocol, such as duty cycle round trip efficiency, electrical energy storage system, ramp rate, rated power/energy and self-discharge. As a part of TC120, IEC also has working groups developing safety and environmental standards for EESS who have published technical specifications [18] and are working on an EESS safety standard [[19] and a technical report on environmental issues [20].

The standards and technical specifications discussed above provide utilities and end users unique resources to compare various ESS technologies on an equitable basis in terms of performance, environmental compliance, and safety.

It is important to treat the ESS as a black box for a direct comparison independent of battery technology. However, the performance of DC and AC storage components should be monitored separately to fully assess ESS performance. Hence, work continues toward the development of chemistry-specific standards. Some examples of ongoing work in IEC for transportation and stationary storage include the following technical committees and working groups:

- IEC TC 21: Secondary cells and batteries
- IEC TC21 JWG 82: Secondary cells and batteries for renewable energy storage
- IEC TC21: Traction and stationary batteries
- IEC TC 21 JWG 7: Flow battery systems for stationary applications.

Draft IEC standards for various battery chemistries are listed below.

High temperature sodium-based batteries

- IEC 62984-3 ED1–high-temperature secondary batteries–part 3: sodium-based batteries-performance requirements and tests.

Flow batteries

- IEC 62932-1: 2020 International Standard-flow battery energy systems for stationary applications–part 1: terminology and general aspects. Published February 18, 2020.
- IEC 62932-2-1: 2020 International Standard-flow battery energy systems for stationary applications–part 2-1: performance general requirements and test methods. Published February 18, 2020.
- IEC 62932-2-2: 2020 International Standard-flow battery energy systems for stationary applications–part 2-2 Safety requirements. Published February 18, 2020.

Lead acid batteries

- IEC 62193–Lead-acid batteries for propulsion and operation of lightweight vehicles and equipment–general requirements and methods of test
- IEC TR 61431–Technical report in draft stage–guide for the use of monitor systems for lead-acid traction batteries
- IEC TR 61044 ED3–Technical report in draft stage–opportunity-charging of lead-acid traction batteries
- IEC 63193–International Standard in draft stage–lead-acid batteries for propulsion of lightweight means of locomotion–general requirements and methods of test.

For Li-ion, high-temperature sodium-based batteries, and redox flow battery systems, work is ongoing to develop recommended practices that focus on definitions, performance, degradation, safety, life cycle cost [21], and additional chemistry-specific recommended practices.

While it may appear that each SDO is on a parallel path, there is considerable coordination with IEC among various technical committees to ensure consistency and to identify areas of overlap at an early stage. Similarly, the IEEE effort considers developments in IEC to avoid duplication and to use information developed within the IEC standards rather than reinvent the wheel.

While the above standards provide a method to evaluate performance and safety of ESS, they do not provide ESS specifications that utilities can use for procurement purposes. As stated earlier, EPRI ESIC has developed detailed energy storage specifications which utilities can use to specify ESS characteristics. The utilities, in their request for proposals, can specify which standards apply to meet the technical specifications. In other words, the technical specifications developed need to be used in conjunction with applicable standards for procurement. Performance and safety metrics that apply to all storage technologies as described in IEC TC120 can be supplemented with technology specific metrics as detailed in the corresponding standards.

As discussed earlier, technology-specific and technology-neutral standards describe performance metrics and methods to evaluate them for various duty cycles or grid services. The standards also specify ambient conditions such as temperature, relative humidity, and barometric pressure.

GAPS in C&S for Energy Storage

Gaps in C&S are a significant barrier to the adoption of energy storage. A potential gap in the 9540a test is the ability to accurately measure flammable gases at the module and unit level tests. This is based on both sensor accuracy and the size of the test and large volume of exhaust air needed to safely conduct the test.

In the residential ESS space, this testing has criteria that does not allow fire to extend outside of the unit, which will be challenging for some manufacturers. Because the current fire codes do not require 9540a testing for residential installations that meet the size & separation requirements, a gap in safety exists. This has resulted in fire damage to structures in several residential installations due to the lack of fire testing that guides safe design & installation practices. In addition to a risk of fire, there is also the risk of flammable gas production. The testing criteria states that "concentration of flammable gas does not exceed 25% LFL (lower flammability limit) in air for the smallest specified room installation size." This would require the manufacturer to identify the minimum space a particular battery could be placed in, and this is not currently provided in existing product specs.

Standards that measure battery performance and determine state of health are also lacking. Note that state of health estimation is performed by periodic reference performance tests. However, there is no process for the battery owner to maintain the original and last performance test to assess the fade of capacity or performance.

A better understanding of performance and life expectancy is needed to access the risks of an ESS project. For example, consider an e-bike owner who has charged their bike to 100% and heads out for a ride. The distance they can travel is constantly changing based on how hard they pedal or how many hills they encounter; the difference in terrain can influence battery degradation. For that user, knowing how far they can ride at any time and under any road conditions over the life of the battery is valuable information. The same is true for an owner of an ESS who is using it for a variety of grid services. A commonly acceptable state-of-health standard would enable a secondary market for used batteries that may have completed their first use (such as transportation batteries) and still have some value for secondary use for grid services. A clear understanding of remaining life is necessary to enable the valuation.

Education for end users is needed to teach proper use of the standards that verify the technical specifications. For example, there are ESSs that do not require reference performance tests, which makes estimating the state-of-health difficult. Identification of the right standard is crucial—a Li-ion DC battery module specification needs to be verified by a standard for Li-ion battery modules, while an ESS specification needs to be verified by an ES performance standard.

A good understanding and standardization of battery management systems (BMS) would add efficiency to battery-based ESS (BESS) design and operations. Standardizing how BMS track key performance metrics is also very important to achieve an adequate performance and life from the total BESS. While this is especially true for Li-ion BESS, other battery chemistries also have complex BMS that play a crucial role in performance and life. A reliable BMS is critical to battery safety by ensuring the battery operates in a safe envelope with multiple layers of protection. There is an immediate need for standardization in this area. The IEEE Working Group P2686 "Battery Management Systems in Energy Storage Applications" is leading efforts to write a recommended practice for BMS [22], and the Canadian Standards Association is developing a Li-ion BMS standard.

Frequency regulation duty cycles are different from balancing area to balancing area based on regional specific operating procedures and market designs. It would be useful to provide prototypical frequency services profiles by balancing area or by wholesale power markets (e.g., Independent System Operators (ISO) in No. America).

Hierarchically, the Energy Storage Management System (ESMS) is above the BMS. The ESMS manages the total system (battery, inverter, and balance of plant) versus the BMS focus on DC module and rack sub-systems of a BESS. The ESMS also communicates and controls the interface with the dispatching entity (e.g., building management system, ISO/Utility Automatic Generator Control), and controls multiple BESS units within a single ES project border/fence line. While current standards describe duty cycles corresponding to various grid services, no uniform way exists to develop and implement an ESMS to operate the ESS for specific well-defined grid service, e.g., frequency regulation. In addition, the ESMS preserves the flexibility to accommodate future stacked storage applications, i.e., more than one grid service application at a time. This is a challenge because the strategy to operate the ESS depends on site-specific conditions. There remains a need to develop a site ESMS standard for a suite of use cases. IEEE is working to develop an ESMS standard with a target publication date of 2023.

Finally, standards to estimate standby losses for seasonal energy storage are lacking. With increasing penetration of renewables, the demand for long-duration storage is expected to grow. The ability to quantify standby losses for days to months of storage is key to successful deployment of seasonal storage.

Energy Storage C&S Development Impacts and Challenges

Gaps in C&S development can lead to a variety of impacts.

- Poorly written requirements can lead to unenforceable code. For example, a technical requirement written to say, "Shall have thermal runaway mitigation" could appear in an installation or fire code. This puts the jurisdictional authority in the difficult situation of understanding the technical details to verify all situations and ensure compliance. The requirement would be better managed in a product safety standard such as UL 9540.
- C&S can be overly restrictive for newer technologies that have yet to demonstrate a history or data set of safe performance.
- Industries or manufacturers seeking to obtain exemptions from the code can erode adoption of the code as jurisdictions amend certain sections or, in some cases, the entire code. This situation defeats the ability to ensure safe ESS installations on a consistent basis.
- Providers of risk management tools have difficulty pricing and providing their products, including warranties and performance bonds.
- Financial providers charge risk-premium cost adders or are unable to provide financing at all.

At the bottom line, gaps in energy storage C&S increase the cost (the "-" net cost portion of the graph in Fig. 6) and time needed to deploy energy storage projects, while also limiting the scale of viable projects. In Fig. 6, the curves from A to C correspond to an environment where C&S are well developed (less time to reach + net cost, or benefit) to a less developed C&S environment resulting in relatively more time for a deployed project to reach positive net economic benefit. The negative-to-positive change in slope corresponds robust C&S versus weaker C&S being available to all stakeholders, with projects going into service and delivering net positive returns sooner versus later, respectively.

Impacts due to gaps in C&S affect all scales of energy storage, from permitting and installing residential scale energy storage products through the design, financing, construction, and commissioning of very complex engineered ESSs connected to large-scale electric grids. The DOE sponsored an effort to gather input from traditional risk products and finance providers serving more established technologies (e.g., wind, gas generation) to identify how the energy storage industry can access critical tools needed for 100 MW or larger scale projects. The resulting report, published in 2019, is a "best practice guide" [23] that includes guidance [24], pp. 293–311] on how energy storage C&S can help facilitate the use of risk and financial tools needed for the development of larger ESS projects. Another financial example comes from the

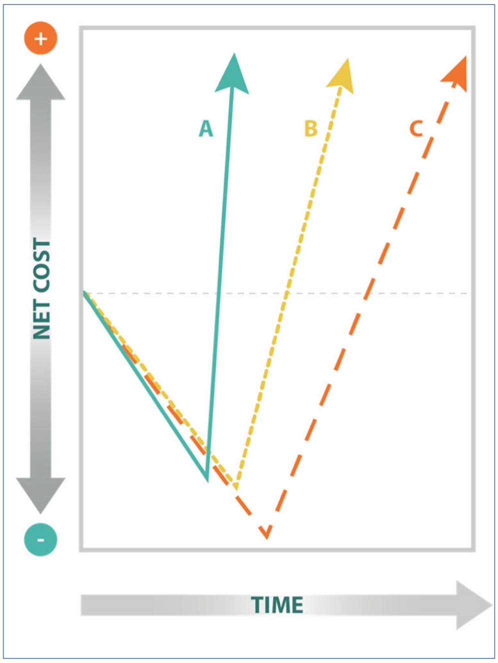

Fig. 6 Closing C&S gaps decreases time and money for ES project development

experiences of solar photovoltaic (PV) installation. The PV cells have traditionally been the largest cost component of an installed PV system, but with the rapidly declining cost of the cells, soft costs (i.e., permitting, siting, balance of plant, installation) are now the dominant cost. Robust C&S can reduce soft cost components by streamlining the integration of ancillary technologies and permitting procedures.

The need to close the gaps in energy storage C&S is motivating SDO communities to collaboratively work to meet the challenges. Several specific challenges and industry efforts to address them are discussed next.

Selected Energy Storage Safety C&S Challenges

Filling gaps in energy storage C&S presents several challenges, including (1) the variety of technologies that are used for creating ESSs, and (2) the rapid pace of advances in storage technology and applications, e.g., battery technologies are making significant breakthroughs relative to more established resources including photovoltaic and traditional fossil-fired generation. The discussion below puts these selected challenges into the context of specific technology-driven issues from the perspective of safety C&S and performance C&S.

Energy Storage Safety C&S and Technology Challenge

The challenge in any code or standards development is to balance the goal of ensuring a safe, reliable installation without hobbling technical innovation. This hurdle can occur when the requirements are prescriptive-based as opposed to performance-based. Using the deflagration prevention topic discussed earlier, an example might be a requirement for deflagration protection to ensure that a battery cabinet does not explode or cause significant personal or property damage as a result of a catastrophic failure. The language might specify an exhaust system compliant with NFPA 69 be installed, with language that states that buildup of flammable gases above 25% of the lower explosive limit (LEL) not be permitted to occur, and leave the "How" to accomplish this up to the system designer. The system could be designed with no doors, or with constant ventilation, or with an igniter to ensure gas buildup does not occur. Each system may not be NFPA 69 compliant yet meet the performance criteria. Whereas providing a system designed to NFPA 69 may require very large fans to activate faster than the gas production is generated. This is a real challenge in cabinet-style ESS enclosures as identified earlier. Achieving gas accumulation above 25% of LEL could occur very rapidly and incorporating an active exhaust system capable of maintaining safe gas levels may be challenging in meeting the requirements of NFPA 69.

One challenge to moving further toward performance-based versus prescriptive-based standards is a lack of operating experience with some of the newer battery technologies. A potential solution is for a public-funded entity to replicate the type-testing performed by nationally recognized testing laboratories (e.g., UL) for commercial clients (product manufacturers), with the intent of providing publicly available data to assist manufacturers in understanding safe design best practices. Another long-term benefit of disseminating safety test information could be baselining minimum safety metrics related to gas evolution and related risk limits for creation of a pass/fail criteria for energy storage safety testing and certification processes, including UL 9540A.

This selected example of an energy storage C&S safety challenge highlights a more general challenge to energy storage C&S—diversity of technologies. As Fig. 7 and Fig. 8 show, Li-ion batteries are the most prevalent form of battery-based ESSs being deployed today. The challenge described above is driven in part by this market reality. However, great care must be taken to address industry needs for energy storage C&S today, without closing off or inadvertently limiting access to and use of the expanding range of energy storage technologies. For example, flow batteries, which are discussed in the section on energy storage performance C&S above, may have a different risk profile where gas evolution and management is not a driving safety risk factor.

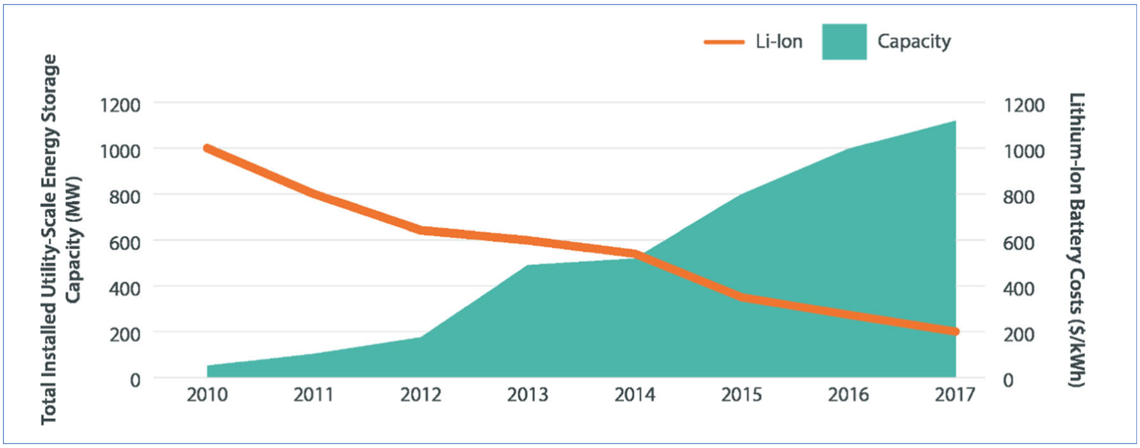

Fig. 7 Installed Li-ion ESS capacity Increase vs. cost decline [24]

Energy Storage Performance C&S and Pace of Technology Development Challenge

The pace of change in storage technology outpaces the following example of the technical standards development processes.

All published IEEE standards have a ten-year maintenance cycle, where IEEE standards must undergo and complete a revision process within ten years from the standard's approval to retain an active standard status. [26], p. 7]

Non-SDO industry groups are helping to meet this pacing challenge. SunSpec Alliance[1] and Modular Energy Storage Architecture Alliance (MESA)[2] are examples of non-SDO industry entities that are issuing specifications that can be used now and refined over time for use or reference by formal SDO-published standards in the future.

MESA is an industry association that focuses on the development of communication specifications for utility scale ESSs. The membership includes utilities, technology suppliers, and integrators. Together, the members work to develop interoperable solutions by specifying the communication protocols and implementation requirements that will allow the management of ESSs and control of the advanced capabilities they can provide.

MESA has developed and manages two specifications: MESA-DER [27] (formerly MESA-ESS) and MESA-Device/SunSpec Energy Storage Model [28]. MESA-DER addresses communication between a utility's control system and distributed energy resources (DERs), including ESSs. MESA-Device specifies standardized communications between components within the ESS.

MESA-Device Specifications/SunSpec Energy Storage Model addresses how energy storage components within an ESS communicate with each other and other operational components. MESA-Device specifications are built on the Modbus protocol.

The MESA Standards Alliance and the SunSpec Alliance have developed a joint testing and certification program for the MESA-Device specification [29]. Vendors can now receive certification via third-party authenticators, ensuring their products meet the requirements of this specification and will be interoperable with other certified components of ESS. Compliance with the MESA-Device specification ensures greater interoperability among the components of the ESS (the inverter, power control system, and energy source (e.g., Li-ion battery) across the spectrum of distribution-connected DER-scale ESS to large-scale transmission-connected ESS.

The MESA-DER specification is built on the IEEE Std. 1815 (DNP3) protocol [30], with further specificity prescribed in the DNP Application Note (AN2018-001), which describes the DNP3 Profile for communications with DERs. The MESA-DER specification addresses how utility and other grid SCADA communicate with DERs and ESS, including configuration management and operational states, and the profile of the DNP Application Note (AN2018-001) [31] based on the IEC 61850-7-420 information model for advanced DER functions [32]. This includes all the functions defined in IEEE 1547-2018 [33], California's Utility DER Electric Rule 21 Interconnection [34], and the European ENTSO-E DER interconnection requirements (2016) [35], as well as additional functions specifically applicable to ESS.

The use-by-reference of MESA specifications by Standards IEC 61850 and IEEE 1547-2018, respectively, are examples of industry-group non-SDO products being used to accelerate development of formal SDO-published Performance Standards for ESSs and their major sub components. However, a remaining challenge is third party verification and certification (e.g., UL Listing) of compliance with MESA and other industry specifications. Where MESA

[1] https://sunspec.org/

[2] http://mesastandards.org/

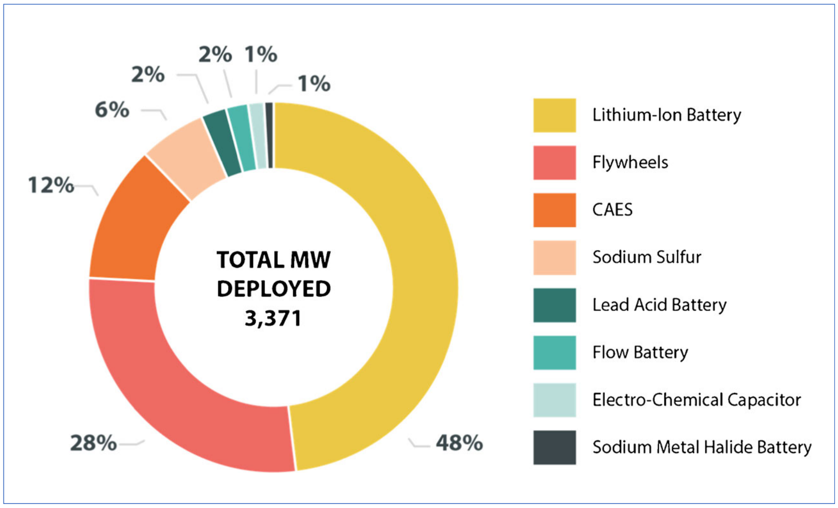

Fig. 8 Installed energy storage technology breakdown excluding pumped storage as of 2018 [25]

specifications are incorporated in a formal SDO standard, the certification processes for referencing the formal standard can be leveraged. IEEE 1547-2018 is an example.

UL 1741 [36], based on the IEEE Std. 1547.1-2020 test method [37], is a means for third party verification of compliance with IEEE 1547-2018 performance requirements, and by extension the portion of MESA that is referenced in IEEE 1547-2018. Specifically, IEEE 1547-2018 cites SunSpec Modbus, which incorporates portions of the MESA-Device specification, is one of three protocols that meet the communications protocol requirements. The SunSpec/MESA Device Profile applies this protocol; however, the IEEE 1547-2018 Standard only addresses a subset of performance requirements specific to interconnection of distributed resources (including ES) with distribution systems. Thus, the UL 1741 listing as a form of certification of ES performance is not comprehensive.

To address this challenge, MESA Alliance, with support from DOE, expanded its mission to address certification procedures and processes for MESA's industry (non-SDO) specifications. The MESA Testing and Certification Work Group was started in 2020 to cover certification of the MESA-Device and MESA-DER specifications.

Conclusions

Energy storage has made massive gains in adoption in the United States and globally, exceeding a gigawatt of battery-based ESSs added over the last decade. While a lack of C&S for energy storage remains a barrier to even higher adoption, advances have been made and efforts continue to fill remaining gaps in codes and standards.

Key challenges presented in this article include the tension between the deliberative slow speed of the formal standards development process relative to the rapid rate the underlying storage technologies change, and the diversity of technologies to which any standard will apply. A theme in discussions for solution is the application of impartial science-based input to the standards development process. Examples of this approach have been presented in this article, including the adoption of DOE-funded national laboratory work on energy storage performance metrics in IEC performance standards. The article also offers ideas on extending impartial science-based support for continued C&S development. For example, public entities replicating confidential product fire safety testing for the purpose of wider public data dissemination and use to baseline minimally acceptable risk and risk mitigation could be formalized later in published C&S.

Several other gaps in C&S associated with the specification and certification of ESS still remain. It will be crucially important for the continual cost decline of ESS to fill the gaps that will make the specification of a new ESS as common as the specification of a diesel generator or another common grid asset. Furthermore, to improve the risk exposure for investors of this technology and to enable a second market for storage devices, more transparency in remaining life and state-of-health standards and best practices are necessary.

While some energy storage devices, e.g., Li-ion battery technologies, have already become commodity products with a continually declining unit cost, C&S will help to drive down soft costs related to planning, purchase, financing, deployment, commissioning, operations, and de-commissioning.

Declaration

Conflict of interest The authors declare no competing interests.

Human and Animal Rights The article does not contain any studies with human or animal subjects performed by any of the authors.

References

1. Energy Storage Program Planning Document. In: U.S. Dept. of Energy Office of Electricity. February 2011.
2. UL Standard 9540. ANSI/CAN/UL Standard for Energy Storage Systems and Equipment.. Underwriters Laboratories. February 2020. https://standardscatalog.ul.com/ProductDetail.aspx?productId=UL9540
3. National Fire Protection Association. NFPA 1, Fire Code. 2021. https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1
4. International Code Council's country adoption information web page. https://www.iccsafe.org/international-code-adoptions/
5. UL 9540 Second Edition: Understanding the Impacts of Requirement Changes. Underwriters Laboratories, CT 26157086-0520. 2020. https://www.ul.com/insights/ul-9540-second-edition-understanding-impacts-required-changes
6. UL 9540A. Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems. Underwriters Laboratories. November 12, 2019.
7. UL 9540A Data Utilization Guide For NYC: Flow Charts. City University of New York (CUNY) Digital Hub. https://nysolarmap.com/media/2041/fire-safety-testing-data-analysis-supplement-for-nyc-outdoor-ess_v1.pdf
8. Smart Distributed Generation Hub (Smart DG Hub). City University of New York for the U.S. Dept. of Energy. https://nysolarmap.com/solarplusstorage/
9. Conover D, et al. Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems. Pacific Northwest National Laboratory and Sandia National Laboratory for the U.S. Dept. of Energy Office of Electricity. PNNL−22010 Rev. 2 / SAND2016-3078 R. 2016, https://energystorage.pnnl.gov/pdf/PNNL-22010Rev2.pdf
10. Standard for Uniformly Measuring and Expressing the Performance of Electrical Energy Storage Systems" NEMA Standard ESS 1-2019, National Electrical Manufacturers Association, 2019
11. IEC Standard TS 62933-3-1. Electrical Energy Storage (EES) systems–part 3-1: planning and performance assessment of electrical energy storage systems–general specification. International Electrotechnical Commission
12. Westlake B and Thompson J. Energy Storage Integration Council (ESIC) Energy Storage Test Manual. 3003013530, Technical Update. December 2019.
13. Kaun B, et al. ESIC Energy Storage Technical Specification Template v3.0. EPRI Product 3002013531.
14. Minear E. Energy Storage Integration Council (ESIC) Energy Storage Implementation Guide. 3002013533, Technical Update. March 2019
15. IEC Standard 62933-2-1. Electrical energy storage (EES) systems–part 2-1: unit parameters and testing methods–general specification, Ed. 1.0, 2017-12.
16. IEC Standard 62933-2-2. Electric Energy Storage Systems–part 2-2: unit parameters and testing methods–applications and Performance testing. International Electrotechnical Commission
17. IEC Standard 62933-1. Electric Energy Storage Systems–part 1: vocabulary. International Electrotechnical Commission
18. IEC Standard TS 62933-5-1:2017. Technical specifications–electrical energy storage (EES) systems–part 5-1: safety considerations for grid-integrated EES systems–general specification. International Electrotechnical Commission
19. IEC 62933-5-2: 2020 PRV (Pre-release version). Electrical energy storage (EES) systems–part 5-2: safety requirements for grid integrated EES systems–electrochemical based systems. International Standard, International Electrotechnical Commission.
20. IEC Standard TR 62933-4-200/Ed.1. Greenhouse gas (GHG) emission reduction by electrical energy storage (EES) systems. International Electrotechnical Commission.
21. IEEE Standard 1679. IEEE recommended practice for the characterization and evaluation of emerging energy storage technologies in stationary applications. 2010. https://standards.ieee.org/standard/1679-2010.html
22. IEEE Draft Standard P2868, approved project scope (PAR). IEEE recommended practice for battery management systems in energy storage applications. , September 27, 2018. https://standards.ieee.org/project/2868.html
23. Energy Storage Best Practice Guide. Developed by the Advancing Contracting in Energy Storage (ACES) Working Group, Richard Baxter, Executive Director, ACES Working Group. December 2019.
24. Twitchell J. A review of state-level policies on electrical energy storage. Curr Sustain/Renew Energy Rep. 2019;6:35–41. https://doi.org/10.1007/s40518-019-00128-1.
25. Mongird K, et al. Energy storage technology and cost characterization report. Pacific Northwest National Laboratory for the U.S. Dept. of Energy. PNNL-28866. 2019, https://energystorage.pnnl.gov/pdf/PNNL-28866.pdf
26. IEEE-SA Working Group Chair Quick Reference Guide. IEEE Standards Association 1602-01, 2016, p.7.
27. MESA-ESS(DER) draft specification, Modular Energy Systems Architecture (MESA) Alliance. 2018. http://mesastandards.org/mesa-downloads/
28. MESA-Device specification, Modular Energy Systems Architecture (MESA) Alliance. http://mesastandards.org/mesa-device/
29. Verifying MESA Device Specification Compliance Using SunSpec Modbus Certification with the MESA Profile. Modular Energy Systems Architecture (MESA) Alliance. 2020, http://mesastandards.org/wp-content/uploads/2020/09/MESA-Device-Certification-Guide-Final-Draft.pdf
30. IEEE Standard 1815: IEEE Standard for Electric Power Systems Communications-Distributed Network Protocol (DNP3). 2012. https://standards.ieee.org/standard/1815-2012.html
31. DNP Application Note AN2018-001. DNP3 Profile for Communications with Distributed Energy Resources. DNP Users Group. January 2019.
32. IEC Standard 61850-7-420:2009. Basic communication structure–distributed energy resources logical nodes. International Electrotechnical Commission.
33. IEEE 1547-2018: IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces. 2018. https://standards.ieee.org/standard/1547-2018.html
34. California Interconnection guidebook: a guide to interconnecting customer-owned electric generation equipment to the electric utility distribution system using California's electric rule 21. California Energy Commission, P500-03-083. September 2003.
35. ENTSO-E Network Codes. European Network of Transmission System Operators for Electricity (ENTSO-E). 2016.
36. UL Standard 1741. Inverters, converters, controllers and interconnection system equipment for use with distributed energy resources. Underwriters Laboratories. January 2020.
37. IEEE 1547.1-2020: IEEE Standard Conformance Test Procedures for Equipment Interconnecting Distributed Energy Resources with Electric Power Systems and Associated Interfaces. 2020. https://standards.ieee.org/standard/1547_1-2020.html