A Primer on the Codes and Standards Governing Battery Safety and Compliance

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Batteries have greatly influenced the utility industry, and the evolution of battery chemistries has revolutionized their applications. With the emergence of new technologies and advancements in existing ones, standards committees and safety code writers are working to develop best practices and establish minimum safety guidelines.

These groups, comprised of volunteers from diverse industry segments, are actively involved in shaping the standards and model codes that govern battery usage and safety. Their efforts are aimed at keeping pace with the rapidly evolving landscape of battery technology and ensuring its safe and efficient implementation.

BATTERY APPLICATIONS

Batteries are used in a variety of battery energy storage (BESS) applications. Below is a list of common utility market applications and how batteries are used to support operations:

- **Grid Stabilization:** A stronger grid is required to support increased power requirements and demand. More devices are becoming electrified, including automobiles, and are demanding more energy. Energy storage can help stabilize the grid by providing energy back to the grid when the demand rises and store energy when excess power is available.
- **Renewable Energy:** Renewable sources of energy (solar, wind) generate electricity intermittently, and their outputs fluctuate with weather conditions. Batteries will store excess energy during periods of high renewable generation and discharge the batteries when generation is low. As a system, this provides a more consistent and reliable source of energy.
- **Micrograids and Off-Grid Systems:** Batteries help create micro grids that can operate independently from the main power grid. In remote areas together with renewable energies, batteries can provide electricity to communities without access to the central power grid.
- **Grid Resilience and Backup Power:** Batteries provide backup power during outages and emergencies. This includes substations that have powered switches, SCADA control systems and end users such as data centers, telecommunications companies, and other mission critical infrastructure for organizations.
- **Demand Response:** Batteries can be used where electricity consumers reduce their demand, following a request from their utility, during peak hours in exchange for incentives. This helps reduce peak loads while managing demand fluctuations and alleviating strain on the grid.
- **Peak Shaving:** Building owners can reduce their maximum hourly power requirement by knowing the load signature of the building and peak consumption intervals. Peak shaving lets these consumers use batteries to reduce electric charges from peak usage where price per kW is higher to off-peak usage where the price per kW is lower.
- **Electric Vehicle Integration:** As electric vehicles become more prevalent, their batteries can be used to store excess renewable energy and discharge it back to the grid during periods of high demand.

BATTERY TYPES & CHEMISTRIES

Over the years, lead-acid batteries have been the primary choice for utility batteries, enhanced with additives like calcium, antimony, and selenium. These additives were employed to optimize their performance in terms of service life, cycle life, and load profile, specifically tailored for various applications.

In environments with demanding conditions, where operating temperatures surpassed the capacity of lead-acid batteries, Nickel Cadmium batteries emerged as a crucial solution due to their wider temperature range. However, during the 1990s alternative technologies gained popularity and entered the mainstream. These included lithium-ion batteries, lithium metal polymer batteries, sodium-based (salt) batteries, flow batteries, and other innovative energy storage technologies.

Each battery type contains different chemistries that has proven beneficial for specific applications:

- **Lithium Ion and Lithium Metal Polymer Batteries:** These include battery chemistries such as Lithium Iron Phosphate (LFP) and Lithium Cobalt Oxide (LCO) which are commonly used in battery energy storage systems (BESS). They have high energy density, long cycle life and fast response times. Depending on the chemistry, some have higher deflagration potential than others causing fire code to regulate where they can be installed or impose additional site requirements. These batteries are typically used in energy storage applications including grid stabilization, renewable energy, microgrids, demand response, peak shaving, and backup power.
- **Flow Batteries:** These include chemistries such as Vanadium Redox Flow Batteries (VRFB) and Zinc-Bromine Flow Batteries (ZBFB). Flow batteries have advantages with scalability and long duration energy storage (several hours). They store energy in liquid electrolytes contained in separate tanks allowing decoupling of power and energy capacity. Flow batteries are great in applications for load shifting, frequency regulation, and grid backup power.
- **Sodium-Sulfur (NaS) Batteries:** These have high energy density and long-life cycle making them a good choice for large-scale energy storage. They operate at high temperatures (~300-340 degrees C) and use molten sodium and sulfur as active materials. They provide high output power and are used in grid-level applications to stabilize frequency, smooth renewable energy output, and provide backup power.
- **Lead-Acid Batteries:** Lead acid batteries have been used for decades due to low cost, high reliability, availability of materials and recyclability. Vented-lead acid (VLA) batteries have free flowing electrolyte, long life, and reliable performance. They are used in most substation and emergency power applications. Absorbed Glass Matt (AGM) and gel batteries are considered non-spillable batteries and have long cycle life with a tolerance to deep cycling. These batteries are used in smaller-scale energy storage, load shifting and emergency backup power.

SAFETY STANDARDS

Every battery type has specific guidelines for installation, operation, and maintenance, which can be found in the manufacturer's installation and operations manual. To ensure consistency and best practices across the industry, the IEEE PES Energy Storage and Stationary Battery Committee (ESSB) develops standards documents that cover the characterization, selection, operation, and recommended practices for batteries. In addition, the National Fire Protection Association (NFPA) produces standards documents that focus on electrical safety in relation to batteries. These standards serve as valuable resources for industry professionals and help promote safe and efficient battery usage.

Building and fire codes mandate that batteries undergo testing according to UL standards or other internationally recognized standards. UL 1973 is a safety standard specifically designed for batteries used in electric vehicles (EVs) and hybrid electric vehicles (HEVs). This comprehensive standard covers a range of critical aspects, including electrical, mechanical, thermal, and environmental considerations. Its primary objective is to minimize the potential risks associated with fire, explosions, and other hazards.

In the context of Energy Storage Systems (ESS), including BESS, UL 9540 and 9540A standards have been developed. UL 9540 is the original standard, while 9540A represents the updated version. These standards outline the requirements and guidelines for safe and efficient ESS operation. Fig 1 provides a visual representation of the specific requirements outlined in these standards. Adhering to these UL standards ensures that battery systems meet the necessary safety criteria and helps mitigate potential risks in various applications.

Requirement	Description
Electrical Safety	Electric shock, short circuits, and overcurrent conditions
Fire Safety	Thermal management, containment, and suppression systems
Environmental Testing	Temperature extremes, humidity, and vibration
Installation Requirements	Proper installation including electrical connections, ventilation, and clearances for safe operation.

Fig 1

While UL standards are recognized across North America, other regions have similar standards such as IEC 62619 and 62485. Other industry specific standards may cover abusive environments such as Telcordia (Bellcore) Testing Standards.

MODEL CODES

In addition to the UL standards and other international standards, model building codes play a crucial role in ensuring the safety of battery systems. Notably, the International Building Code (IBC) includes provisions for the seismic design of battery racks and cabinets. This ensures that these structures can withstand seismic events and maintain the integrity of the battery systems.

Similarly, model fire codes such as Chapter 12 of the International Fire Code (IFC) and the National Fire Protection Association (NFPA) 855 focus on establishing safety requirements specifically for BESS. These codes serve as comprehensive guidelines that address various aspects of BESS safety.

These model codes are widely adopted by states and are sometimes supplemented by local municipalities. Local authorities have the flexibility to make state-adopted codes more stringent, although they cannot relax the requirements, resulting in what is known as a local modified code. A notable example is New York City's FDNY B-28 Fire Code, which incorporates additional provisions from the National Fire Protection Association (NFPA) 855 while complying with the city's adopted International Fire Code (IFC).

To further ensure compliance with the codes, most states and local governments establish minimum system sizes to comply with code and set maximum limits for BESS installations. These size requirements and limitations are crucial for meeting code compliance and are often depicted in guidelines such as Figure 2.

Minimum to Comply

Battery Technology	IFC Chapter 12 – Min to Comply
Flow Batteries	20 kWh
Lead-Acid Batteries	70 kWh
Lithium-Ion Batteries	20 kWh
Nickel Metal Hydride Batteries	70 kWh
Nickel- Cadmium Batteries	70 kWh
Other Battery Technologies	10 kWh
Other Electrochemical Energy Storage Systems	3 kWh

Fig 2

Minimum to Comply

Battery Technology	NFPA 855 – Min to Comply
Lead Acid Batteries	70 kWh
Ni-Cad/Ni-MH, Ni-Zn	70 kWh
Lithium-Ion Batteries	20 kWh
Nickel Metal Hydride Batteries	70 kWh
Sodium Nickel Chloride	20 kWh or 70 kWh if tested to UL 1973
Flow Batteries	20 kWh
Other Battery Technologies	10 kWh
Batteries in one-and-two family dwellings/townhouses	1 kWh

Fig 2

HAZARDOUS MITIGATION PLAN (HMP)

The model fire codes outline essential safety requirements for both safeguarding BESS and ensuring the protection of individuals. It is strongly advised to include the items listed in the Battery Safety Requirements table (Fig 3) in your Hazardous Mitigation Plan (HMP) for battery system. These items encompass the following:

- Identify the hazards: Fire, explosion, chemical risks, electrical hazards, environmental impacts.
- Assess the risk to your site: Identify the consequences to the above risks.
- Safety Measures: Implement safety measures to prevent or mitigate hazards.
  - Designing engineering controls to prevent and mitigate hazards.
  - Creating the operating procedures.
  - Develop a training program.
  - Assess the fire system for the battery technology.
  - Assess the ventilation, gas detection and environmental controls.
  - Document the Emergency Response Plan (ERP).
  - Document all maintenance activity and inspections.
- Document and communication: Maintain detailed safety inspection records, training sessions, hazards, safety procedures, and emergency response protocols.
- Perform an ongoing improvement plan: Update the site based on codes & standards updates and safety inspection findings.

Battery Safety Requirements

Item	Code/Regulation/Standard	Description Explosion Control
Explosion Control	IFC section 1207.6.3 NFPA 855 section 9.6.5.6	Batteries with high deflagration rates are required to install prevention systems and venting.
Safety Caps	IFC section 1207.6.4 NFPA 855 section 9.6.5.4	Required to prevent flame from entering a battery.
Exhaust / Ventilation	IFC section 1207 6.1 NFPA 855 section 4.9, 9.6.5.1 IEEE 1635/ASHRE 21	Required for all batteries that could gas. Explosive gasses need to be kept within 25% of the Lower Explosion Limit. This may Include a Hazard Mitigation Analysis (HMA) to determine gassing levels per IEEE 1635/ASHRE 21. Hydrogen detection may be a part of the HMA to connect to an exhaust fan and annunciate and alarm condition.
Spill Control & Neutralization	IFC section 1207.6.2 NFPA 855 sections 9.6.5.2, 9.6.5.3 IEEE 1578	Prevents free-flowing electrolyte from creating an unsafe condition.
Thermal Runaway	IFC section 1207.6.5 NFPA 855 section 9.6.5.5	Required for lead-acid, Ni-Cad, Ni-MH, Lithium-ion, and other technology types that could go into thermal runaway.
PPE	OSHA 1926.441(a)(5) NFPA 70E article 320	Eye protection, face shields, acid resistant apron, acid resistant gloves.
Eyewash	OSHA1926.441(a)(6) ANSI 358.1	Primary eyewash devices must be installed with all aqueous batteries.
Shrouds & Shields	OSHA 29 CFR 1910.308 (a)(7)(IV) OSHA 29 CFR 1910.333(a) OSHA 29 CFR 1910.333(c)(5) OSHA 29 CFR 1910.335 NFPA 70E	Shrouds and shields shall be installed on all connections with dangerous voltage to protect people from incidental contact.
Signage	OSHA 29CFR 1910 IFC section 1207.4.8 NFPA-1 section 52.1.18.1 NFPA 855 section G.1.4.2 NFPA 70e section 310.5 (B) ANSI Z535 ANSI 358.1	Warning signs are required to notify of dangerous voltage, hazard identification (type of technology), emergency contact, emergency shutdown, fire suppression system installed.

Fig 3

Adhering to these guidelines and incorporating them into a Hazardous Mitigation Plan enhances the safety and reliability of a battery system and effectively manages potential risks.

CONCLUSION

Battery technology has undergone significant advancements since the 1990s, introducing a range of new and exciting chemistries to cater to the increasing demands of the power grid.

As these technologies start to materialize in practical applications, ensuring safety becomes crucial for their successful operation. This involves the establishment of safety testing standards and the implementation of site and personal safety protocols.

It should be noted that not all battery chemistries are suitable for every application. Therefore, engineers must carefully consider the distinct characteristics, maintenance requirements, and operational prerequisites of each technology before implementation. Additionally, regulatory bodies responsible for enforcing safety measures will adapt model codes to incorporate specific attributes relevant to their respective states or municipalities.