Siting and Safety Best Practices for Battery Energy Storage Systems

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Summary

The following document summarizes safety and siting recommendations for large battery energy storage systems (BESS), defined as 600 kWh and higher, as provided by the New York State Energy Research and Development Authority (NYSERDA), the Energy Storage Association (ESA), and DNV GL, a consulting company hired by Arizona Public Service to investigate the cause of an explosion at a 2-MW/2-MWh battery facility in 2019 and provide recommendations for mitigating this threat in the future. Exeter thanks Matthew Paiss (Technical Advisor, Battery Materials & Systems, Pacific Northwest National Laboratory) for his review of this document.

More detail is provided below, but briefly put, BESS should meet national codes and standards promulgated by the National Fire Protection Association (NFPA), the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE) and national laboratory standards. However, the DNV GL report concluded that the most commonly relied-upon standards for battery safety are insufficient to address the threat of thermal runaway (described herein) and explosion. The report recommends additional steps that should be taken, and these are included in the summary below. Finally, state and local building, fire, and zoning requirements should also be met.

For the purposes of CPCN review and approval, we recommend that future CPCN applicants with battery storage systems be required to submit plans for battery siting, safety, and decommissioning to the PSC, for review and approval, before construction begins.

- The siting plan should address: undergrounding on-site utility lines; maintaining the site free of vegetation; following noise, height, and setback requirements; fencing or enclosing the site; and installing screening or other measures to minimize visibility impacts.
- The safety plan should include: hazard detection systems; means of protecting against incipient fires; and ventilation and/or cooling strategies for protecting against thermal runaway, fires, and explosions. As a corollary, sound training must be provided to local responders so that they are equipped to handle any of these potential emergencies—which require substantially different tactics—as safely as possible. BESS should have plans to address extreme weather, earthquakes, or other environmental threats that may occur.
- The decommissioning plan should include: descriptions of the steps that will be taken, a cost estimate, a funding plan, and a contingency plan for handling damaged batteries.

Siting

NYSERDA published the Battery Energy Storage System Guidebook, most-recently updated in December 2020, which contains information and step-by-step instructions to support local governments in New York in managing the development of residential, commercial, and utility-scale BESS in their communities. The guidebook includes a Model Law which describes the recommended siting requirements for a BESS.

- **Utility lines**: Whenever possible, utility lines at the site should be installed underground. However, this does not apply to the main service connection at the utility company right-of-way or to new interconnection equipment.
- **Vegetation and tree-cutting**: A 10-foot buffer surrounding the BESS should be cleared of combustible vegetation. Beyond this, it is preferable to maintain any vegetation that is not fire-prone.
- **Noise**: Noise produced by the BESS and associated equipment must be kept below a 1-hour average of 60 A-weighted decibels (dBA), based on measurements taken at the outside wall of any nearby unaffiliated building that is in current use.
- **Setbacks**: Any setback requirements for primary structures in applicable zoning regulations should be applied to the BESS.
- **Height:** Any building height limits in applicable zoning regulations should be applied to the BESS.
- **Fencing/enclosure**: Unless secured within a dedicated-use building, all BESS components and mechanical equipment should be protected by a 7-foot-high fence with a self-locking gate.
- **Screening and visibility**: The BESS should be screened from adjacent properties using architectural features, earth berms, landscaping, or other methods that complement the character of the area without compromising BESS ventilation.

Safety

In addition to NYSERDA's BESS Guidebook, ESA issued the U.S. Energy Storage Operational Safety Guidelines in December 2019 to provide the BESS industry with a guide to current codes and standards applicable to BESS and provide additional guidelines to plan for and mitigate potential operational hazards. In April 2020, DNV GL issued its report focused on mitigating the risk of thermal runaway and battery explosions, McMicken Battery Energy Storage System Event Technical Analysis and Recommendations.[1]

In general, both ESA and NYSERDA recommend that a BESS and its subcomponents should meet the requirements of the applicable NFPA codes, ANSI standards, IEEE standards, and the Nationally Recognized Testing Laboratory standards for BESS and equipment (UL 9540, UL 1642, UL 1973, UL 1741, and UL 62109). These national codes and standards, and those referenced below, are defined in the appendix to this document. In addition to the national codes and standards, ESA and NYSERDA also concur that a BESS should meet the requirements of the building, fire, and zoning codes of the state and locality in which it is located. As noted earlier, DNV GL advocates for additional safety measures beyond those currently included in the most commonly used codes and standards.

The potential for thermal, weather, environmental, and other operational hazards varies significantly by the type of BESS technology. Nevertheless, the following recommendations from DNV GL, ESA, and NYSERDA serve as best practices in most scenarios at this time.

[1] DNV GL, *McMicken Battery Energy Storage System Event Technical Analysis and Recommendations,* July 18, 2020, https://www.aps.com/-/media/APS/APSCOM-PDFs/About/Our-Company/Newsroom/McMickenFinalTechnicalReport.ashx?la=en&hash=50335FB5098D9858BFD276C40FA54FCE.

Thermal Runaway, Fires, and Explosions

In addition to standard fires, which require fuel, heat, and oxygen to continue burning, lithium-ion (Li-ion) battery cells can experience a chemical reaction known as thermal runaway, which does not require oxygen or a visible flame, if it occurs within a tightly packed cell assembly. If not addressed by system protection devices, this process can continue to drive up temperature and pressure until the battery cell ruptures, which in turn can release explosive gases. If thermal runaway propagates through a module, flammable gases may build up within the BESS, creating the conditions for an explosion to occur. Thermal runaway can also be caused by exposure to overheating from traditional fires.

It is important to note that a standard approach to minimizing conventional fires—turning off ventilation and using clean fire suppression agents to cool or starve a fire of oxygen—may worsen the threat of an explosion by allowing explosive gas concentrations to increase. Thus, DNV GL recommends that emergency systems and emergency response protocols be designed to extinguish fires *and* ventilate enclosures, as needed, before entry.

1. **Hazard Detection Systems**:
   a. BESS should include appropriate hazard detection systems, such as smoke and heat detectors, as well as gas meters, which would be monitored by control centers and alert operators to emergency situations.

2. **Thermal Runaway Prevention**:
   a. For Li-ion battery cells, there are several technologies, such as current interrupt devices (CIDs), ceramic-coated separators, and solid polymer electrolytes, that could prevent the overheating that leads to thermal runaway. (However, it may not be possible for a system owner to determine the presence of these technologies.)

   b. For battery systems, specialized heating, ventilation and air conditioning (HVAC) systems and the continuous monitoring of temperature, current, and voltage are effective in protecting BESS from thermal runaway.

   c. For enclosed BESS containers, protection from thermal runaway should also take into account external sources of heat, such as high ambient temperatures in the summer or wildfires encroaching on the site.

   d. The battery should include a failsafe protection that provides for forced shutdown, should all other countermeasures fail to prevent thermal runaway.

   e. The UL 9540 listing ensures BESS are designed to provide system-level thermal runaway mitigation through detection, suppression, and/or containment measures.

3. **Fire Suppression**:
   a. Sprinklers should be installed. NFPA 13 standards may not be adequate. Overhead pendant nozzles may not direct enough water into racks to prevent module-to-module propagation. Consideration should be given to in-rack suppression system designs.

   b. Because water is readily available and has useful cooling properties, it is a well-regarded tool for extinguishing Li-ion battery fires. However, it is important to assess whether water could react with the chemicals in a BESS. A water-based fire suppression system should be designed to avoid creating short circuits in adjacent equipment. Also, while it may be too costly to prevent any water used for fire suppression from exiting a BESS, consideration should given to minimizing run-off, since this liquid may contain toxic chemicals.

c. DNV GL notes that many BESS have a "dry pipe" system. This provides an exterior point of connection through which water can be directed into a BESS without opening the enclosure.

d. Gaseous suppression agents, such like FM-200 or Novec 1230, should be considered for use against incipient fires. (However, these cannot prevent and may not be able to stop thermal runaway.)

4. **Electrical Components**:

   a. BESS and its subcomponents and associated ancillary equipment should be in compliance with NFPA 70®, the National Electric Code® (NEC) and ANSI Standard C2, the National Electrical Safety Code® (NESC). Under these codes and in relation to the prevention and mitigation of a thermal event, BESS are required to:

      i. Have required working space clearances; and

      ii. Weatherproof enclosures for electrical circuitry.

5. **Ground Fault Protection**:

   a. Ground faults have the potential to cause fire or thermal runaway from high or continuous currents and pose a safety hazard due to overvoltages. In addition to proper insulation for all electrical equipment, additional protection is required for three-phase installations depending on the type of grounding.

      i. In systems that are grounded with little to no impedance (reactors, resistors), ground currents can be substantial. These systems should be designed to trip off-line automatically, in order to clear ground faults.

      ii. In systems that are ungrounded or have high levels of impedance, overvoltages pose a safety risk. Ensure that any overvoltages will be controlled with grounding banks, other forms of impedance grounding, or surge arresters. The electrical components at risk of overvoltage should also have phase-to-phase level insulation.

6. **Electrolyte Spill**:

   a. For lead acid and nickel-cadmium (NiCd) batteries that have acidic/basic (sulfuric acid or potassium hydroxide) aqueous electrolytes in liquid form, electrolyte spills should be contained by following IEEE 1578 standards. Flow batteries should be listed to UL 9540 and include secondary spill containment.

7. **Ventilation**:

    a. Lead-acid and NiCd batteries produce gases during normal charging. Li-ion batteries do not. Adherence to standard ventilation codes will address the production of gases during regular operating conditions. For BESS that are located inside a building, storage venting systems should take building ventilation systems into account so that any hazardous gases are not drawn into other rooms, putting building occupants at risk.

       To address gas production under abnormal (thermal runaway) conditions, a system should be designed to provide a series of safeguards progressing from fire suppression, to ventilation, to explosion mitigation. For example, if smoke is detected, and a so-called clean agent suppression system is present (for example, Novec™ 1230), the agent will be released to help suppress an incipient fire by lowering oxygen levels and/or temperatures in the enclosure. If heat is still detected after the clean agent has been introduced, this is an indication that thermal runaway may be occurring, and secondary suppression and emergency ventilation systems should be activated. Finally, if high concentrations of explosive gases are detected, DNV GL typically recommends the use of deflagration panels, which are designed to open in the event of an explosion, thus decreasing its severity (see next bullet as well).

8. **Explosion Study**:

    a. For BESS within a container or enclosure, a (manufacturer-provided) UL 9540A test report on the battery can be used to determine what gas constituents would be expected during thermal runaway and what gas levels are likely to be explosive. This information is used by fire protection engineers to design a deflagration prevention system NFPA 69 (exhaust) or deflagration venting system NFPA 68 (blow-out panels), or a combination of both.

First Responder Training and Status Assessment Tools

It is imperative that first responders be included early in the planning of BESS installations and given the training and real-time information necessary to gauge conditions at a battery facility and respond accordingly. Training should include any jurisdictions that may be asked to assist the primary fire department. Periodic update trainings should be given to address turnover. DNV GL states that training materials can be created by the system integrator or the engineering, procurement and construction (EPC) contractor for all those who would benefit.

- **Procedures:** Establish a protocol for extinguishing, ventilation, and entry, in that order.
- **Roles:** Establish a hierarchy and specific responsibilities for operations and maintenance (O&M) personnel, emergency responders, and staff of the owner organization.
- **Qualified Support Personnel:** A trained individual, knowledgeable on the BESS, should be made available to fire department personnel in the event of an incident to support the timely turnover of the site to a knowledgeable person for hazard monitoring.

- **Training:** Provide training to the relevant fire department(s) before and during project commissioning. Include information on the range of hazards that may be present, how to assess conditions inside a BESS, and what steps to take.
    - Explicitly address explosion risks, indicating what gases may accumulate on site and how to detect and ventilate them.
- **Complementary Training:** Train appropriate members of the owner's organization and any third-party contractors working on the project.
- **Informational Technologies:** Set up a remote display for first responders to monitor trending metrics such as state of charge, module temps, ambient temps, gas levels, etc. This station could also contain exhaust ventilation controls and the dry pipe fire department connection. Battery management systems should be provided with auxiliary backup to ensure communications in the event that an emergency triggers isolation of the entire BESS.

Extreme Weather, Geological, and Environmental Hazards

For potential extreme weather events, natural disasters, and environmental hazards, the BESS site should be secured and have plans in place to prevent or mitigate dangerous situations that could impact personnel or damage equipment and the surrounding environment.

- **Monitoring, preparation, and response strategies**: Each BESS should have plans to monitor and mitigate extreme weather and natural disasters. These plans should provide communication protocols for all key parties, identify which personnel should remain on site, and specify shutdown protocols.
- **Designing resilient systems**: BESS should be designed to withstand environmental hazards that may arise in the area. Examples of design resiliency include:
    - Isolating electronics;
    - Designing physical enclosures, buildings, and drainage systems so that they meet local building code requirements regarding wind speed, snow load, snow shed, standing water, and flashfloods;
    - Seismic hardening sites in earthquake-prone regions as per local building codes and IEEE 693;
    - Shielding equipment from lightning strikes and/or affixing lightning rods to taller structures as per NFPA 70, NFPA 780, CSA C22.1, or IEEE C2, as applicable;
    - Controlling temperatures and protecting against excess humidity, salinity, and dust; and
    - Designing enclosures to prevent animals and plants from entering.

Additional Design Elements

- **Site Access**:
  - O&M workers should have ready access to the site at all times and regardless of the BESS's operating state.
- **Lighting**:
  - For indoor BESS, emergency lighting based on building codes should be available to facilitate any emergency response activities or unscheduled maintenance.
- **Signage**:
  - Signage should meet ANSI Z535, NFPA 70, and NFPA 855 standards.
  - Signage should list: the type of technology associated with the BESS; potential and specific hazards; Personal Protective Equipment (PPE) requirements; the type of suppression system installed in the area of the BESS; 24-hour emergency contact information; information related to the disconnection and emergency shutoff of the BESS; evacuation routes; and muster points.
  - The BESS signage should be clearly displayed on a light-reflective surface. A clearly visible warning sign concerning voltage should be placed at the base of all pad-mounted transformers and substations.
- **Cybersecurity:**
  - BESS developers should rely on experienced suppliers who can ensure the integrity of all equipment and routinely update security software.
  - Only vetted, trained personnel should have access to the BESS. Likewise, connections between the BESS and other web-based systems should be kept at a minimum.

Decommissioning

Decommissioning is especially important for Li-ion batteries, given that they contain hazardous materials. Indeed, under the Resource Conservation and Recovery Act (RCRA), used Li-ion batteries are considered hazardous waste that must be disposed of in accordance with U.S. Environmental Protection Agency (EPA) rules. Damaged Li-ion batteries that have not been fully discharged present a stranded energy hazard and are still considered batteries. The decommissioning process must take into consideration the full discharge of all power prior to being considered hazardous waste. It should be noted that even if a contract places the onus for decommissioning on a third-party operator, RCRA holds the owner of hazardous waste liable for its proper disposal.

One possible example to draw from is NYSERDA's sample decommissioning rule, which was developed to provide local governments with an option to adopt it as a local requirement. Under the sample rule, the decommissioning plan must include descriptions of the steps that will be taken, a cost estimate, a funding plan, and a contingency plan for handling damaged batteries.

APPENDIX

Applicable Safety Standards and Codes for BESS

- **ANSI Z535 (Standards for Safety Signs and Colors)**: Provides the specifications and requirements to establish uniformity of safety color coding, environmental/facility safety signs and communicating safety symbols.
- **IEEE 693 (Recommended Practice for Seismic Design of Substations)**: Provides seismic design recommendations for substations, including qualification of different equipment types.
- **IEEE 1578 (Recommended Practice for Stationary Battery Electrolyte Spill Containment and Management)**: Provides descriptions of products, methods, and procedures relating to stationary batteries, battery electrolyte spill mechanisms, electrolyte containment and control methodologies, and firefighting considerations.
- **NFPA 13 (Standard for the Installation of Sprinkler Systems)**: Addresses sprinkler system design approaches, system installation, and component options to prevent fire deaths and property loss.
- **NFPA 69 (Standard on Explosion Prevention Systems)**: Provides requirements for installing systems for the prevention and control of explosions in enclosures that contain flammable concentrations of flammable gases, vapors, mists, dusts, or hybrid mixtures.
- **NFPA 68 (Standard on Explosion Protection by Deflagration Venting):** Addresses the installation and use of devices and systems that vent the combustion gases and pressures resulting from a deflagration within an enclosure, so that structural and mechanical damage is minimized.
- **NFPA 70 (National Electrical Code (NEC))**: Provides the benchmark for safe electrical design, installation, and inspection to protect people and property from electrical hazards.
- **NFPA 704 (Standard System for the Identification of the Hazards of Materials for Emergency Response)**: Presents a simple, readily recognized, and easily understood system of markings (commonly referred to as the "NFPA hazard diamond") that provides an immediate general sense of the hazards of a material and the severity of these hazards as they relate to emergency response.
- **NFPA 780 (Standard for the Installation of Lightning Protection Systems)**: Provides lightning protection system installation requirements in buildings to safeguard people and property from fire risk and related hazards associated with lightning exposure.
- **NFPA 855 (Standard for the Installation of Stationary Energy Storage Systems)**: Provides the minimum requirements for mitigating the hazards associated with BESS.
- **UL 1973 (Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications)**: Provides requirements for battery systems as defined by this standard for use as energy storage for stationary applications such as for PV, wind turbine storage or for UPS, etc. applications.

- **UL 1642 (Standard for Lithium Batteries)**: Provides requirements for primary, i.e., non-rechargeable, and secondary, i.e., rechargeable, lithium batteries for use as power sources in products.
- **UL 1741 (Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources)**: Provides requirements for inverters, converters, charge controllers, and interconnection system equipment intended for use in standalone (not grid-connected) or utility-interactive (grid-connected) power systems.
- **UL 9540 (Standard for Energy Storage Systems and Equipment)**: Provides requirements for energy storage systems that are intended to receive electric energy and then store the energy in some form so that the energy storage system can provide electrical energy to loads or to the local/area electric power system (EPS) up to the utility grid when needed.
- **UL 62109 (Standard for Safety of Power Converters for Use in Photovoltaic Power Systems)**: Provides requirements for the design and manufacture of power conversion efficiency (PCE) for protection against electric shock, energy, fire, mechanical, and other hazards.