TECH TALK
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BATTERY ENERGY STORAGE SYSTEMS (BESS) USING LI-ION BATTERIES

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Battery energy storage system made of shipping containers

This Tech Talk focuses on modular type BESS using lithium-ion batteries at industrial and commercial properties.

AT-A-GLANCE

- Battery energy storage systems (BESS) are an emerging technology that are becoming a popular component to a resilient and efficient electric strategy.
- BESS using lithium-ion batteries are susceptible to thermal runaway and have been involved in several serious fires in the last few years.
- The information in this Tech Talk may change as new research and information becomes available.

INTRODUCTION

BESS are becoming a popular component to a resilient and efficient electrical strategy for:

- Off grid locations
- Instantaneous response
- Network capacity for renewable locations equipped with intermittent power generation such as photovoltaic (PV) panels and wind turbines
- Grid balancing in lieu of synchronous condenser
- Back-up systems in lieu of a generator unit or spinning reserves
- Cost savings as energy arbitrage or curtailment avoidance

The cost to produce lithium-ion batteries continues to drop and several companies now offer BESS which can be located anywhere on the grid, at almost any size. These systems are quick to deploy and generally require less than six months to install. They are also flexible and can be easily expanded.

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Renewable energy power plants - photovoltaics, wind turbine farm and battery container.

It is expected that the use of BESS will increase substantially in the next few years. Like many new technologies, the property loss control advice for BESS is currently limited. The methods by which the units are designed, manufactured and assembled are different from one manufacturer to another. This makes it very difficult to develop property loss control guidelines that apply universally.

In 2017, the National Fire Protection Association (NFPA) began the development of NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems.* A 40+ person technical committee will publish the first edition of the standard in 2019-2020. Nevertheless, there have been technical discussions and presentations regarding the state of knowledge of BESS, which are shared in this document and should assist with the management of this hazard.

It must be clearly understood that there are currently no formal guidelines for the protection of BESS. The knowledge gaps include the following:

- No public fire test data demonstrating fire behavior
- Limited public fire test data related to large format batteries
- Limited incident data on large-scale (grid size)
- Methods of thermal runaway protection
- Post-fire incident response and recovery procedures

GENERAL INFORMATION

1. What is an energy storage system (ESS)?

An ESS works by capturing energy produced by both renewable and nonrenewable resources and storing it for discharge when required.

There are various types of energy storage systems and the common way of classifying an EES is by the type of energy used. The types include mechanical, electrochemical (battery), chemical, electrical, thermal and thermochemical.

Classification of Electrical Energy Storage Technologies

Mechanical	Electrochemical	Electrical
Pumped Hydro-PHS Compressed Air-CAES Flywheel-FES	Secondary battery Lead-acid/NaS/Li-ion Flow battery Redox flow/Hybrid flow	Capacitor Supercapacitor Superconducting Magnetic-SMES
Thermochemical	**Chemical**	**Thermal**
Solar fuels Solar hydrogen	Hydrogen Fuel cell/Electrolyser	Sensible/latent heat storage

2. What is an electrochemical ESS?

Electrochemical ESS uses batteries that generate electrical energy from chemical reactions. There are two types of batteries:

- Secondary batteries such as lead-acid, nickel-cadmium (NiCd) and nickel metal hydride (NiMH), metal air (Me-air), sodium sulfur (NaS), sodium nickel chloride (NaNiCl) and lithium-ion (Li-ion)
- Flow batteries, such as redox or hybrid.

Lithium-ion batteries offer good energy storage for their size, and can be charged and discharged many times in their lifetime. They are currently used in a wide variety of consumer electronics such as smartphones, tablets and laptops, but are also used in electric cars, some aircraft and BESS projects.

There are two types of BESS installations:

- Building types which are engineered and then built on site.
- Modular which are essentially plug and play containers that are added to generate the required energy (MWh). Modular units range in size from a 3 m by 3 m (10 ft. by 10ft.) package up to the size of a 12 m (40 ft.) long container and a rating of 0.1 MW up to 2 MW. Options are selected from a menu at the manufacturer level and the system capacity is sized by the number of individual modules.

LOSS EXPERIENCE

The loss experience involving lithium-ion BESS is limited, but these units have been involved in several fires since 2012.

1. KAHUKU, HAWAII WIND FARM - 2012

This location is a 10 MW battery system used to store electricity from 12 wind turbines (a total of 30 MW), smoothing out spikes and low spots in wind power production. The BESS is a 1,000 m^2 (10,000 ft^2) metal building with 12,000 batteries mounted in racks to a height of 2 m (6 ft.).

This wind farm went online in the beginning of 2011. Less than two months later, a small fire started in one of the inverters, destroying the dynamic power module. Less than two months later, a second inverter caught fire.

On August 3, 2012, a fire started at the wind farm during the night. The fire department notification was delayed for more than seven hours after the fire began. They used dry chemical to try to extinguish the fire but failed. Firefighters faced thick smoke, toxic fumes and other hazards.

The loss amount is estimated to be between $10 and $30 million.

The site had been previously visited by Underwriters Laboratories (UL) with reports of leaking batteries, substandard maintenance and issues with the operation of the site.

2. FLAGSTAFF, ARIZONA 1.5 MW BESS CONTAINERIZED SYSTEM - 2012

In February of 2012, the Arizona Public Service Company began testing a new 1.5 MW BESS that was part of a solar energy system. The BESS resembled a shipping container and used lithium-ion batteries. A fire started on November 26, 2012 and caused significant damage to the $3 million installation. The fire did not affect the nearby substation. The exact cause of the fire is not known.

3. FRANKLIN, WISCONSIN BESS UNDER CONSTRUCTION - 2016

On August 10, 2016 a fire occurred in the BESS located in Franklin, Wisconsin. The BESS was under construction at the time and utilized lithium-ion batteries. The fire started in one of the battery manufacturer's DC power and control compartments, not the batteries themselves. The fire department arrived quickly on the scene and controlled the fire by an initial application of alcohol-resistant, aqueous film forming foam and 500 gpm hose streams. A fire suppression system had been installed in the BESS, but was not fully functional at the time of the fire. Damage estimates are between $3 and $4 million.

4. DROGENBOS, BELGIUM 1 MW BESS CONTAINERIZED SYSTEM – 2017

On November 11, 2017, a fire started in one of the containers associated with the 1 MW BESS located in Drogenbos, Belgium. The firefighters arrived quickly and rapidly extinguished the fire, preventing spread to the adjacent containers. The French multinational utility ENGIE, was in the process of commissioning the lithium-ion battery system at the time of the fire. The BESS was equipped with a fire detection and extinguishing system, but it failed to contain the fire. The cause of the fire is not known at this time.

WHAT ARE THE HAZARDS?

The hazards associated with BESS are not fully known or understood at the present time, but based on existing loss experience, there appears to be three different causes of a fire event:

- Thermal event: External heating associated with a failure of the ventilation system or improper design
- Electrical event: Internal short circuit due to internal cell defects, overvoltage charging or a defect on the internal resistance
- Mechanical failures: Physical damage to a cell which may have occurred during the manufacturing or installation process, as well as damage caused by vibration or expansion

These events can lead to thermal runaway, which is a chain reaction leading to a decomposition reaction of the cell that spreads to adjacent cells. Once thermal runaway starts, it is difficult to stop. The main consequences are:

- Exothermic reaction with heat release

- Release of flammable and toxic gases, such as carbon monoxide (CO), hydrogen chloride (HCl), hydrogen fluoride (HF), hydrogen cyanide (HCN), benzene and toluene. The gases are generated within the cell enclosure before venting.
- Intense fire due to the fact that the cells are constructed primarily of plastic. It is important to note that re-ignition can occur long after the fire is fully extinguished.

Even when the fire is extinguished, stranded electrical energy is observed. It is a unique hazard that can make an incident unsafe for long periods of time (from hours and days to weeks). Thermal runaway can cause re-ignition long after the fire is fully extinguished. Re-ignition always involves an external electrical, thermal or mechanical stimulus, which is the cause of the thermal runaway. Based on loss history, the batteries do not reignite on their own once they are properly cooled. This is why it is important to understand the differences between cooling and extinguishing.

ARC RECOMMENDATIONS

The following recommendations can greatly reduce the potential for property damage and resulting business interruption caused by BESS fires. As soon as a project is considered, contact ARC to discuss your specific needs.

1. Fire department

- Invite the fire department to your property to discuss BESS hazards. An adequate emergency response is the key to avoiding an uncontrolled fire. Keep in mind that some fire fighters will not fully understand the hazards and may assume that lithium-ion batteries are the same as lithium batteries.
- Key questions to discuss with the fire department include:
  - What is the main difference between extinguishing and cooling?
  - How to handle a damaged battery?
  - How to manage the flammable and toxic gases?
- Plan training exercises with the fire department when the system is commissioned.
- Standard Operating Procedures (SOP) & Standard Operating Guidelines (SOG) are of major importance and should be updated and tested on a regular basis.

2. Construction and location

- Install BESS outdoors a minimum of 20 m (65 ft.) from important buildings or equipment. Maintain a minimum of 3 m (10 ft.) separation from lot lines, public ways and other exposures.
- Within the module, maintain a minimum of 1 m (3 ft.) separation distance between enclosures for all units up to 50 kWh when not listed, or up to 250 kWh when listed.
- Install a thermal barrier where the minimum space separation cannot be provided.
- If the BESS must be located indoors, install in a 2 hour fire rated cut-off room, which is accessible directly outdoors for manual firefighting.
- Restrict the access to competent employees or sub-contractors.
- Ensure enclosures are noncombustible.

3. Material, equipment and design

- BESS should be tested in accordance with UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*. This standard evaluates thermal runaway, gas composition, flaming, fire spread, re-ignition and the effectiveness of fire protection systems. Data generated can be used to determine the fire and explosion protection requirements for a BESS.
- Place capacitor, transformer, and switch gear in separate rooms according to best engineering practices.

4. Ventilation and temperature control

- Install adequate ventilation or an air conditioning system to control the temperature. Maintaining temperature control is vital to these batteries longevity and proper operation as they degrade exponentially at elevated temperatures.
- Ensure ventilation is provided in accordance with the manufacturer's recommendations.
- Install and maintain the ventilation during all stages of a fire. Ventilation is important since batteries will continue to generate flammable gas as long as they are hot. Also, carbon monoxide will be generated until the batteries are completely cooled through to their core.

5. Gas detection and smoke detection

- Install a very early warning fire detection system, such as aspirating smoke detection.
- Install carbon monoxide (CO) detection within the container or BESS room.

6. Fire protection and water supply

- Install sprinkler protection within BESS rooms and ideally within BESS containers. The sprinkler system should be designed to provide 12.2 l/min/m^2 over 232 m^2 (0.30 gpm/ft2 over 2500 ft^2). Water has been proven to be the best agent to fight a fire involving lithium-Ion batteries. It is important to note that other extinguishing agents, such as aerosols or gaseous extinguishing systems, will extinguish the fire, but they do not provide cooling like water. Insufficient cooling allows a hot and deep seated core to remain. The heat will rapidly spread back through the battery and reignite remaining active sections. This is the primary reason ARC recommends the use of water for fighting the fire and cooling the batteries.
- Implement a procedure for battery submersion in the pre-emergency plan performed by the fire department. Submerging batteries in water (preferably outdoors) after they burn has proven to be effective at cooling the batteries and neutralizing the thermal threat. They will continue to release gases,

mostly carbon monoxide, but also flammable gas such as hydrogen. Therefore, never submerge several batteries in a confined space without adequate ventilation.

- Ensure that sufficient water is available for manual firefighting. The ability of the fire department to control a fire involving a BESS depends on the presence of an adequate water supply and their knowledge of the hazards. The following should be considered:
  - An external fire hydrant should be located within 100 m (330 ft.) of the BESS room or containers.
  - The water supply should be able to provide a minimum of 1,900 l/min (500 gpm) for at least 2 hours.

7. Maintenance

- Follow original equipment manufacturer recommendations for the inspection, testing and maintenance of BESS. In addition, ensure that the following are completed:
  - Measure the internal resistance of the cells. Replace the cells when a dramatic drop is detected. Keep in mind that the internal resistance is mainly independent of the state of charge, but increases as the battery ages. Therefore, it is a good gauge of predictable life.
  - Perform infrared scanning at least once per year.
  - Check for fluid leakage.
  - Implement electric terminal torqueing procedures to maintain connection integrity.

REFERENCES

- NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems,* 2020 edition currently under development

- UL 9540, *Standard for Energy Storage Systems and Equipment*

QUESTIONS OR COMMENTS?

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Tech Talk is a technical document developed by ARC to assist our clients in property loss prevention. ARC has an extensive global network of more than 100 property risk engineers that offers tailor made, customer focused risk engineering solutions.

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