Lesson Learned

Battery Energy Storage System Cascading Thermal Runaway

Primary Interest Groups
Generator Operators (GOPs)
Generator Owners (GOs)
Transmission Operators (TOPs)
Transmission Planners (TPs)
Resource Planning (RP)

Problem Statement
A fire started in a Battery Energy Storage System (BESS), resulting remote alarm triggering at approximately 16:55 PST. The utility, the maintenance provider, and fire fighters responded to the site. At approximately 20:04 PST, an explosion occurred that injured several firefighters and significantly damaged the BESS. A comprehensive investigation of the event was performed that identified the cause of the fire as being a cascading thermal runaway event that was initiated by an internal cell failure within one battery cell in the BESS.

Details
On the day of the event, the 2 MW/2 MWh BESS was performing a solar smoothing function (this entails charging during the daytime; absorbing solar energy produced from rooftop solar on the circuit) and discharging through evening load peak.

At approximately 16:54 PST, a battery cell in the BESS experienced a sudden drop in voltage during a charging cycle. Moments after, the voltage dropped and a battery cell went into thermal runaway. This event generated off-gassing and smoke that activated the smoke detection system, leading to the discharge of the fire suppression system. The initial cell's thermal runaway cascaded into neighboring cells and subsequently into the batteries contained within neighboring modules.

Figure 1 shows the general layout of the BESS. Figure 2 shows how a single cell failure propagated through one Module and consumed the whole rack, releasing a large plume of explosive gases. This could have occurred without a flame, explaining why the gases were not burned as they were emitted.

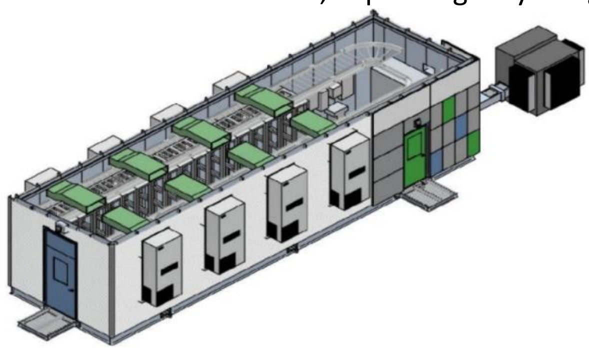

Figure 2: General layout of the BESS (Image credit: APS)

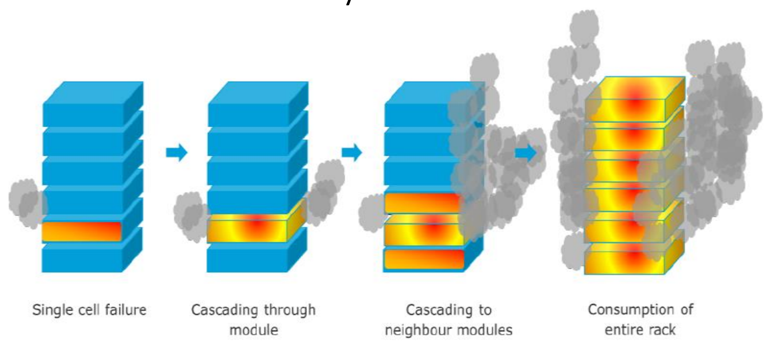

Figure 1: A single cell failure propagated through one Module (Image credit: APS).

Figure 3: BESS Exterior after event (image credit: APS)

A "clean agent" fire suppression system was built into the BESS and functioned as designed. However, the high temperatures generated by the thermal runaway and battery fire negated the agent's ability to suppress the fire.

Approximately three hours after initiation of the event, emergency responders opened the BESS side container door and approximately two minutes later, an explosion occurred.

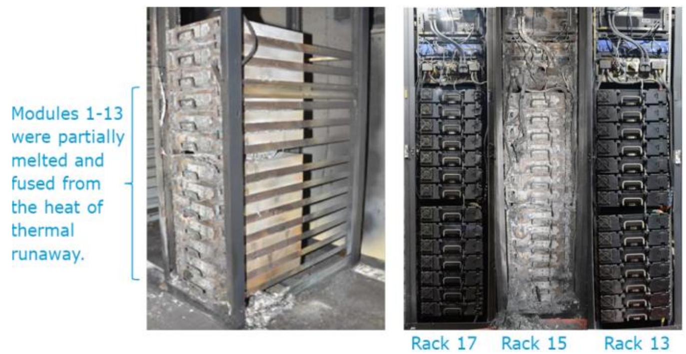

Figure 4: All modules in Rack 15 were severely damaged by thermal runaway while leaving nearby racks mostly intact (image credit: APS)

An extensive investigation of this event was led by the involved entity that included emergency responders, vendor partners, forensic experts, and nationally recognized research institutions. The investigation uncovered the following five main contributing factors:

- Internal failure in a battery cell initiated thermal runaway
- Lack of thermal barriers between cells led to cascading thermal runaway
- The fire suppression system was incapable of stopping thermal runaway
- Flammable off-gases concentrated without a means to ventilate
- Emergency response plan did not have an extinguishing, ventilation, and entry procedure

Corrective Actions

The primary hazard during a BESS incident is flammable gas in an enclosed space. Planning, training and design modifications will reduce this risk. The following are actions the entity took:

- Improve training, emergency response planning, and procedures for first responders, operations, and maintenance personnel that account for the risks and hazards of cascading thermal runaway, including flammable gases and how to enter systems after a failure.
- Work with suppliers, industry experts, and standards bodies to improve battery safety and limit potential risk in the following areas:
  - Minimize or eliminate cell-to-cell and module-to-module heat transfer to stop thermal runaway.
  - Implement fire detection and suppression system designs that will fully manage a thermal runaway.
  - Implement design changes incorporating monitoring and remote reporting of flammable gas concentrations and implement ventilation systems to mitigate.

Lesson Learned

NERC Lessons Learned normally provide anonymity for the entities involved in the source events. However, in this case, the entity wished to be known in order to expedite the dissemination of information by providing access to their complete investigation report that contains much more detail and photos and can be found at: www.aps.com/mcmicken

The potential for and impact of the contributing factors to this event were not well known at the time this BESS was commissioned, so these risks were not addressed in the design of that system even though it was constructed according to the standards at the time. Energy storage is a vital (but maturing) technology and entities need to consider these findings and the risk of similar events in their own storage implementations. Standards and regulations have developed slower than the technology and still need some improvement. As a result of this event, the NFPA 855 standard is making progress and now addresses several of these learnings.

Until NFPA 855 has been finalized, entities owning BESS should consider:

- The key to managing risk associated with the installation of a BESS focuses on a hazard mitigation analysis. This will identify gaps along with the appropriate control measures like design modifications, suppression, and training.
- The fire services should not be seeing a BESS for the first time when 911 is called. Consideration should be given to developing a pre-incident guide which will serve as the mutual platform for future training of utility personnel and the fire services.
- Conduct training, familiarization tours and exercises with your local fire department. The approach laid out in previous NERC Lesson Learned 20190202 "Substation Fires: Working with First Responders" can be used as a template.

NERC contacted an industry substation fire expert who had additional suggestions:

- A registered fire protection engineering firm should perform a hazard mitigation analysis that includes a review of the UL 9540a test data.
- As a best practice, consider following NFPA 68 guidelines for the installation of deflagration venting on future BESS installations.
- Discontinue use of clean agents as a method of suppression.
- Install a fire alarm control panel in a remote location in the facility to allow fire department to monitor conditions without being in harm's way.
- The panel should have also flammable gas monitoring capabilities along with a purge control feature.
- Install a class 1 /division 1 purge system.
- The design of the BESS container should consider garage type doors that would facilitate suppression operations without having to enter the container
- A fire protection engineering firm should also produce a Pre-incident guide (NFPA 1620) that outlines the hazards and response tactics that should be employed during an incident.
- Training should be provided. This will guide both the utility and fire services as to the appropriate actions when responding to low frequency high hazards events, such as BESS emergencies.
- Prior to placing a BESS in service, a familiarization tour should be conducted with local fire services along with any specialized units, such as hazmat, who may respond during an incident.
- Consider conducting an annual exercise with the members of the first response community to validate the plan or identify gaps.

NERC's goal with publishing lessons learned is to provide industry with technical and understandable information that assists them with maintaining the reliability of the BPS. NERC is asking entities who have taken action on this lesson learned to respond to the short survey provided in the link below.

Click here for: Lesson Learned Comment Form

For more Information please contact:

NERC – Lessons Learned (via email)

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