

GSS® Design for Safety



Safety Feature Overview

- Multiple layers of safety features designed into the GSS[®] energy storage platform

System



- UL 9540, IEEE 1547, UL 1741SA compliance
- Electrical fault protection compatible and coordinated with downstream protection
- Fault current/voltage limited inverters with full electrical protection & isolation switches

Containers



- AEROS[®] controls monitors and ensures operation within safe limits and can disconnect power if needed.
- Automated fire suppression system on every GBS[®] battery container; additional safety feature options available. UL9540A test complete.
- Compliant with NFPA 70/70E, UN38.3, IEEE 693, IEC62040-1 and other international safety standards

Racks



- Compliant with UL1973 and IEC62619
- BMS provides functional safety, certified to IEC61508 Safety Integrity Level 2 (SIL 2)
- Automated switches (contactors) disconnect rack from the system if necessary
- High voltage fusing and ground fault protection

Modules



- Compliant with UL1973, IEC62619, and UN38.3
- Module monitors every cell bank voltage and module temperatures
- Integral module-level fuse

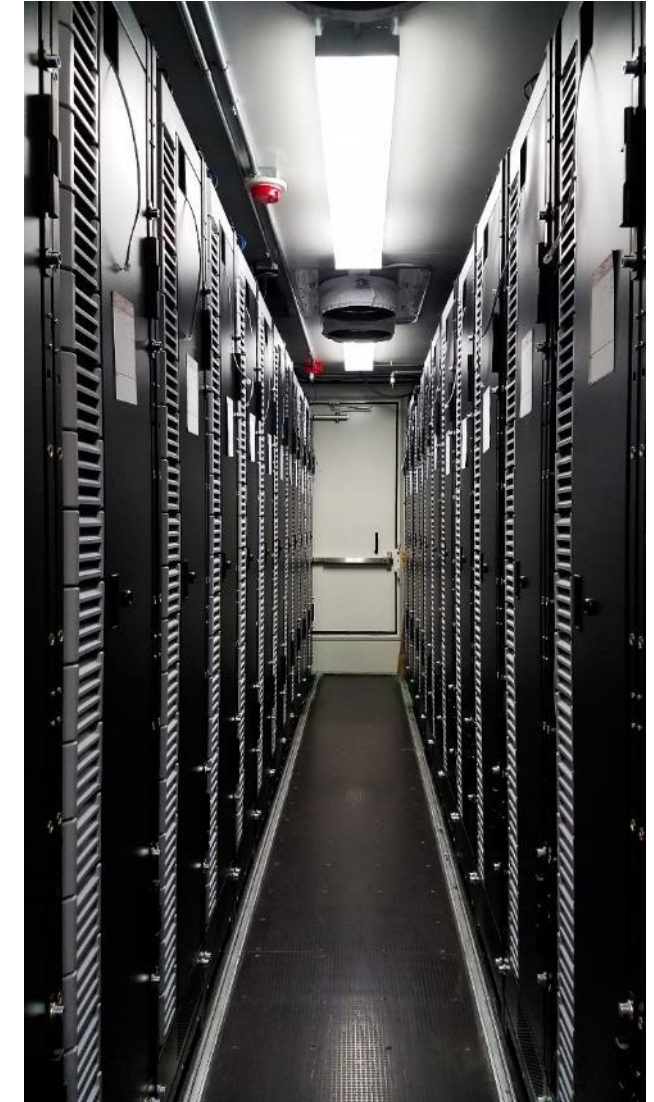
Cells



- All cells certified to UL1973, UL1642 and IEC62619 lithium ion cell safety standards
- All cells pass UN38.3 transportation safety test standards

GBS® Battery Container Safety Features

- AEROS® Controls software monitors and controls key components in the system
 - Ensures operation within safe parameters with access to thousands of voltage, current, temperature measurements, and employs multiple types of fault detection.
 - Operation outside normal conditions of voltage, current, temperature will cause AEROS® Controls to reduce power or under severe conditions (e.g. ground fault) immediately cease operation to prevent hazard.
- Enclosures are tightly controlled in temperature and protected against excess humidity, water and dust ingress/intrusion
- Enclosures are designed to survive or fail safely under extreme environmental conditions such as earthquake, hurricane, and flood.
- Safety features include:
 - Functional Safety Certified BMS (IEC 61508, SIL 2)
 - Thermal Runaway Propagation Prevention Panels
 - Sequenced High Voltage Fusing System
 - Ground Fault Protection System
 - Automated Fire Suppression System (Clean Agent + Water Spray)
 - Deflagration Ventilation
 - Battery Condition Annunciator for First Responders
 - Exhaust Ventilation
 - Video Surveillance Security System



Ground Fault Protection System

What Is A Ground Fault?

- Battery systems are typically designed such that no power-carrying conductors are electrically connected to ground.
- A ground fault is when some part of the battery system makes electrical contact with a grounded metal structure.
- A single ground fault may not be dangerous, but a second one will result in a short circuit, creating hazardous conditions that could result in a fire.

How Can It Happen In A Battery System?

- The battery system is electrically insulated and isolated from ground at all points.
- If insulation breaks down anywhere in the battery system, from contamination, degradation, mechanical abuse, or other reasons, the potential for a ground fault increases dramatically.
- Once a first ground fault is detected, it is critical to prevent a second ground fault from occurring.



How Does NEC's Ground Fault Protection System Work?

- The NEC ground fault protection system identifies and mitigates ground fault driven short circuits – before they happen.
- The system not only continuously monitors insulation resistance, but also coordinates measurement over multiple insulation monitoring devices to ensure full protection over all battery zones in an entire site.
- Once a single breakdown in insulation is detected, the GFD system alerts AEROS®, which then disconnects and isolates all racks in the affected Battery Zone, and alerts operators of the potential hazard, who will locate the grounded point and repair it.

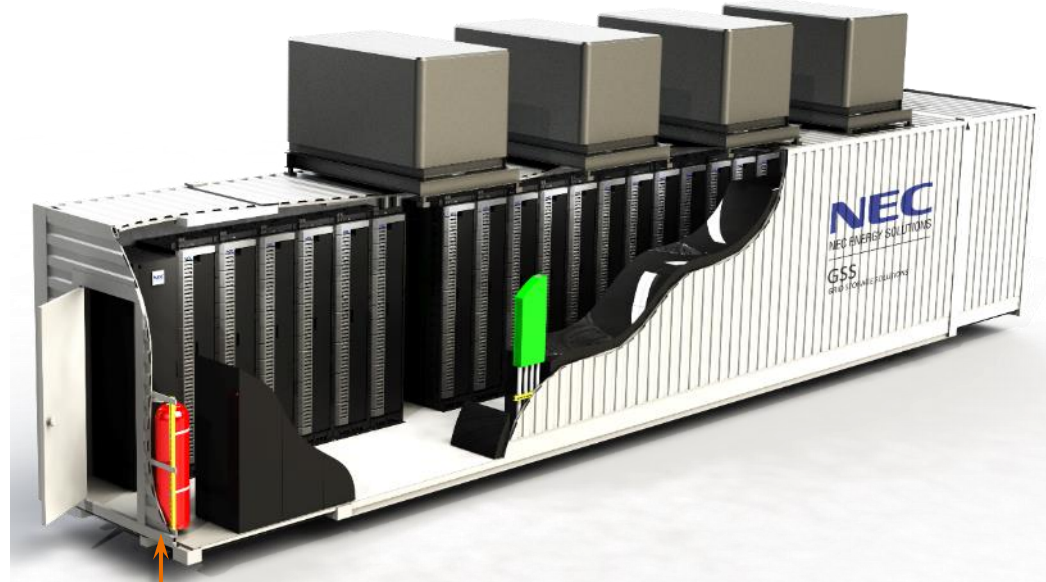
Automated Fire Suppression System (Clean Agent + Water)

What Is Clean Agent?

- A clean agent is a colorless, odorless, non-toxic, electrically non-conductive vapor. NEC uses Novec 1230 which is a fluoroketone, non-ozone depleting, and has a very low global warming potential (GWP 1).
- Novec 1230 suppresses fire by removing heat; it leaves no residue and requires no cleanup after discharge.
- Stored as a liquid, when discharged, the fluid quickly evaporates into a gaseous state.
- Clean agent is used as the first line of defense against incipient fires and helps rapidly contain thermal runaway events



Typical clean agent discharge



Clean Agent Cylinder

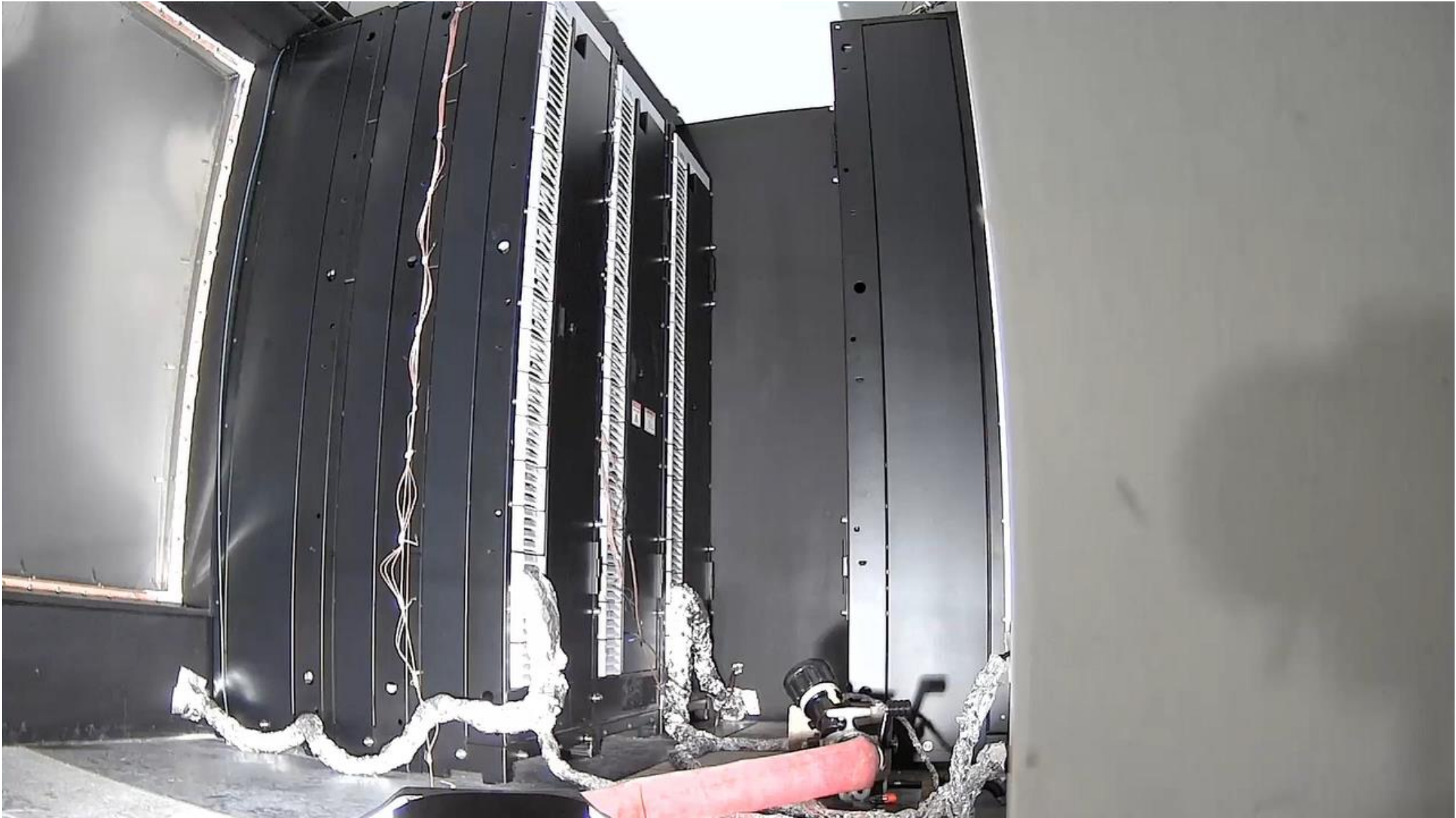
Not shown:

Fire System Control Panel
Fire Strobes (2 external, 1 internal)
Smoke Detectors
Linear Heat Sensor
Clean Agent Spray Nozzles
Water Spray Nozzles

How It Works

- A single detection of smoke or fire in the GBS will cause a signal to be sent to fire suppression system, strobe light operation, and horn sound at 60BPM. All contactors will open (switch to "Off" mode).
- A second detection will cause, horn sound at 120BPM, plus a time delay countdown (20 sec) which is displayed on the control panel. Upon expiration of time delay, the horn sounds steadily, and the fire suppression agent will be discharged, flooding the GBS container.
- Autodial notification to local fire and other authorities is available.
- In addition, UL 9540A testing has shown that clean agent combined with a standard water spray suppression system can fully extinguish lithium ion battery fires. A supplemental water spray system is available on all GBS units.

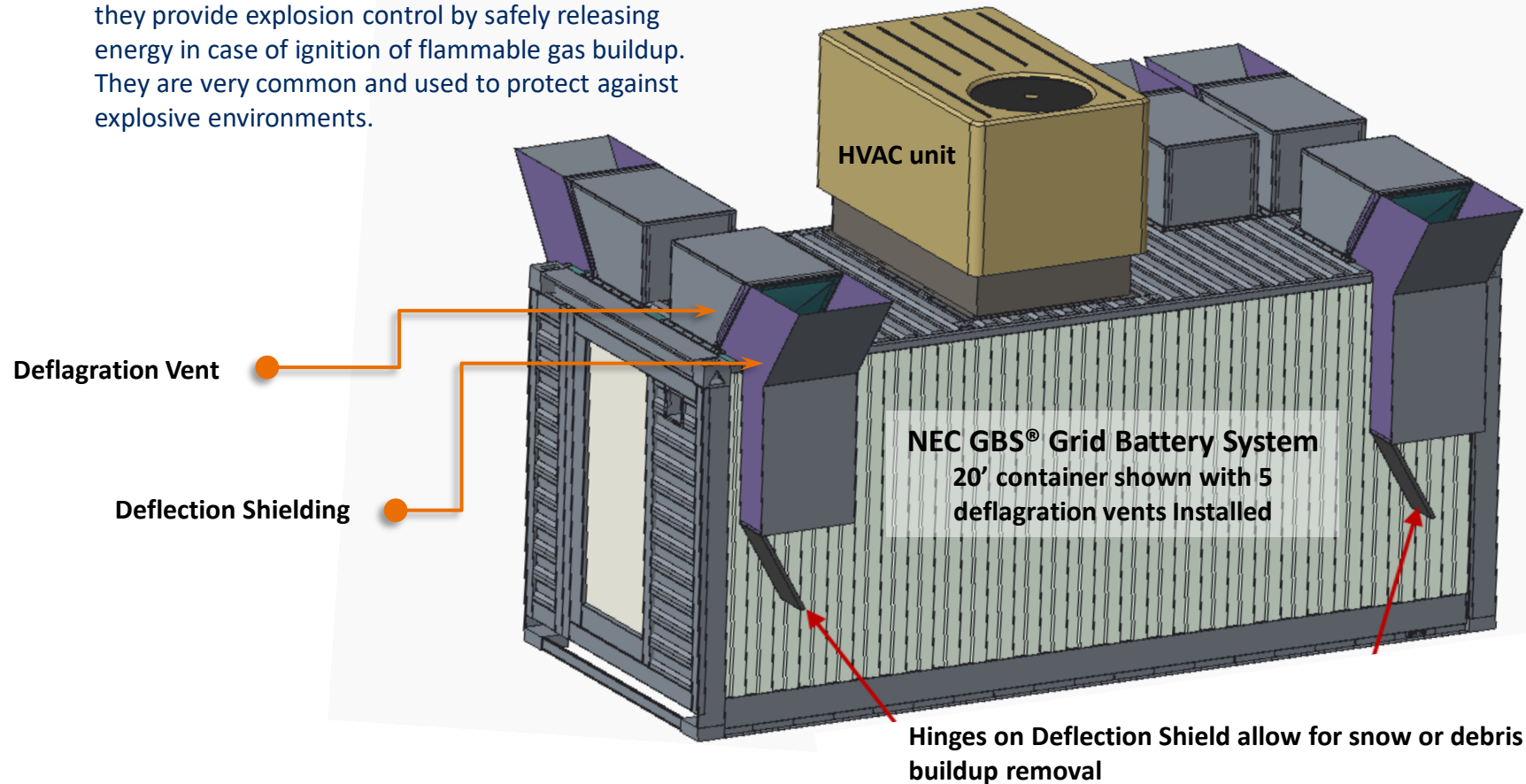
Automated Fire Suppression System Test: UL 9540A Installation Level Burn Test



Deflagration Ventilation Systems For Battery Containers

What Is Deflagration Venting?

- Deflagration vents protect against explosion hazard; they provide explosion control by safely releasing energy in case of ignition of flammable gas buildup. They are very common and used to protect against explosive environments.



How Does It Work on a Battery Container?

- Based on gas composition measured during actual lithium-ion battery fire tests, deflagration venting safely releases pressure buildup from ignition of flammable gas.
- NEC battery deflagration vents are sized and designed in accordance with NFPA 69 and Section 911 of the International Fire Code (IFC), and several are used per container to provide full protection.
- Depending on specific installation location, deflection shields can be used to redirect energy in a safe direction

How It Helps

- Testing has shown that flammable gases are released during lithium-ion battery fires, overcharging, or other abuse situations. A buildup of these gases creates an explosion hazard. Deflagration ventilation can control and reduce this hazard.

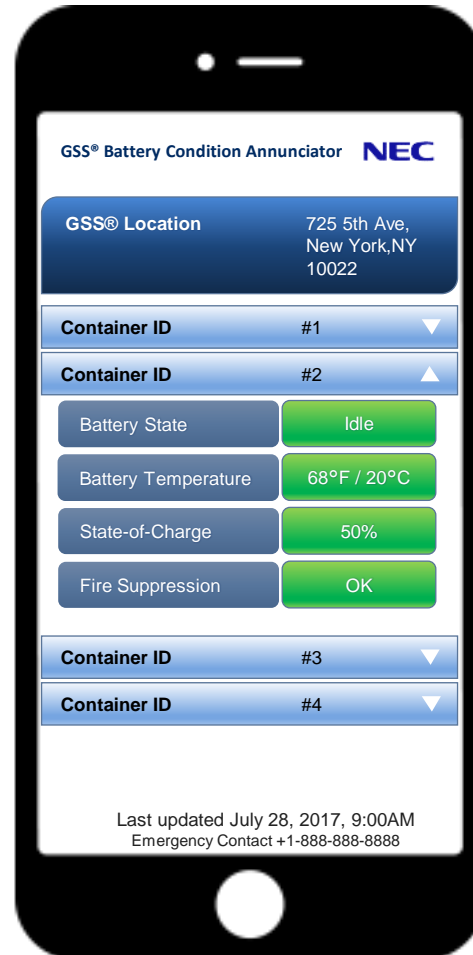
Battery Condition Annunciator

What It Does

- Critical battery condition information is communicated quickly and easily to first responders
- Parameters such as battery temperature, state-of-charge, and fire suppression system status can help inform first responders of the hazard

How It Helps

- When first responders arrive at an incident, it may be unclear whether the source of hazard is the battery unit or not by simple visual means
- Annunciator provides insight into the battery system status with time-stamped information about its condition



How It Works

- The annunciator collects information from AEROS® and provides it via a website which can be accessed on a smartphone or tablet
- Quickly access the information by scanning a 2D barcode/QR code or visiting the website. Barcodes and web address can be found at nearby control panels and on the container's outside surface.
- Annunciator will display essential information pertinent to the specific storage systems onsite and their safety condition.
- This information can be used by subject matter experts to advise on the best course of action; whether it is safe to leave, to further investigate, or to stand clear and allow the system to do its job.

Inside the Battery Rack

BMS Module



Battery Modules*



Battery Rack*

How The BMS Works

- The BMS continuously monitors voltage, temperature, and current readings and reports them upstream to AEROS®
- If the BMS senses a deviation from normal operating conditions, it first warns upstream controllers, but ultimately it will independently isolate the rack to prevent hazardous conditions
- Each BMS has automated control of two separate contactors (high power switches) to disconnect the individual rack from the DC bus if necessary. These contactors mechanically default open (off) if the control links to the contactor or BMS power is lost.

Battery Rack Safety Features

- BMS is certified to the IEC 61508 Functional Safety Standard, Safety Integrity Level 2 (SIL 2), ensuring autonomous, fundamental, and critical safety at the most basic level of the entire energy storage system
- Hundreds of voltage and temperature measurement points per battery rack, including both Battery Rack and Battery Module measurements
- Each rack is protected by a fuse, positioned outside of the BMS, to supplement contactor operation for overcurrent protection and sequenced to operate properly in conjunction with module-level fuses
- Each rack has independent active air-flow control to maintain the proper air temperature for the batteries in each rack

*Note: A Battery Rack is comprised of multiple Battery Modules and one BMS Module.

The Battery Management System (BMS) Ensures Critical Functional Safety

- NEC-designed BMS is certified to IEC 61508 Functional Safety Standard, Safety Integrity Level 2 (SIL 2)
- BMS keeps all batteries and cells within the proper parameters

Voltage

- Normal cell voltage range is 3.00V – 4.20V
 - If cell voltage greater than 4.15V; power foldback to zero
 - If cell voltage greater than 4.25V; open affected rack contactors and latch
- Independent voltage measurement verification
 - Voltage measurement on cells is summed and compared to module and rack voltage measurement
- If difference is greater than 0.25V, open affected rack contactors and latch
 - Voltage measurement on modules is summed and compared to rack voltage measurement
- If difference is greater than 0.2V, open affected rack contactors and latch

Current

- Overcurrent protection in two ways; contactors and fuses
 - If measured current exceeds slow current limit; linear power foldback to zero
 - If measured current exceeds fast current limit (but is not a hard short circuit); affected rack open contactors and latch
 - If hard short circuit occurs, fuse will open

BMS Module*



Temperature

- Allowable cell temperature range is -30°C to +60°C.
 - If measured cell temp hits 53°C; power foldback to zero
 - If measured cell temp hits 60°C; BMS sends out alarm
 - If measured cell temp hits 65°C; open affected rack contactors and latch + power-off BMS to prevent any current flow
- Temperature Delta:
 - If measured temperature of any module differs by more than 10°C from the average temperature of all the modules in the rack; open affected rack contactors and latch

Communications/Software

- Battery modules communicate to the Rack BMS which then communicate up to a Zone (a Zone is a collection of racks) controller
- Hardware watchdog feature monitors in real-time the behavior of the BMS hardware and software
- If any BMS misbehavior; open affected rack contactors and latch + power-off BMS to prevent any current flow
- If there are communications interruptions between any module and the zone controller; open affected rack contactors and latch

*Note: Every Battery Rack has its own BMS module.

The Battery Modules

- Electronics provide measurement and balancing functions

- Each module measures voltage on every series cell element and provides an independent voltage measurement at the module level
- Measures temperatures at select locations



- Module-level balancers maintain cells at equal state-of-charge to reduce overcharge or overdischarge risk
 - Lithium-ion cell chemistry is not “self-balancing” and can easily be overcharged and cause a thermal event
- Meets UN38.3 test and criteria for transportation safety
- Module-level safety fusing included

Extensive GSS® System Certifications and Compliances

Full testing and independent certification / evaluation assures safety and lowers deployment risk

Safety	
UL 9540	Safety for Energy Storage Systems and Equipment
UL 9540A	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage
UL 1973¹	Batteries for Use in Light Electric Rail Applications and Stationary Applications
UL 1642²	Standard for Lithium Batteries
IEC 62619³	Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for secondary lithium cells and batteries, for use in industrial applications
UN 38.3	UN Recommendations on the Transport of Dangerous Goods Manual of Test and Criteria
IEC 61508⁴	Functional Safety of Electrical/Electronic/Programmable Electronic Safety-related Systems
IEC 62040-1	Uninterruptible power systems (UPS) – Part 1: General and safety requirements for UPS
CE – Conformity	CE Marking - European Conformity, Safety and EMC
NFPA 70E	Standard for Electrical Safety in the Workplace
NFPA 70	(NEC) National Electric Code (whenever applicable)
ANSI/IEEE C-2	National Electrical Safety Code (NESC)
ANSI/IEC 60529	Degrees of Protection Provided by Enclosures (IP Code)
IEC/UL 60950-1⁵	Information technology equipment - Safety - Part 1: General requirements

Grid Interconnect	
UL 1741 (SA)	Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources for Distributed Resources
IEEE 1547	IEEE Standard for Interconnecting DR with EP
G59	Recommendations For The Connection Of Generating Plant To The Distribution Systems Of Licensed Distribution Network Operators (UK)
Other regions	Other interconnect standards as may be required

¹ Testing complete, pass/fail to be determined by permitting authorities

² Applicable to battery modules and battery racks only

³ Applicable to battery cells only

⁴ Applicable to battery cells, modules and battery racks only

⁴ Evaluation performed on Battery Management System (BMS) only, in support of UL 1973, UL 9540 and IEC 62619 certification

⁵ Applicable to AEROS Controls Unit only

⁶ Applicable to battery rack BMS only

Seismic and Enclosure Integrity	
ANSI/IEC 60529	Degrees of Protection Provided by Enclosures (IP Code)
IEEE 693-2005	IEEE Recommended Practice for Seismic Design of Substations

Electromagnetic Compatibility	
FCC 47 CFR Part 15 subpart B class A	Radio Frequency Devices (Federal Communications Commission, CFR)
EN 55011	Industrial, Scientific and Medical (ISM) Radio-Frequency Equipment - Electromagnetic Disturbance Characteristics - Limits and Methods of Measurement
IEC/EN 61000-6-2	Electromagnetic compatibility (EMC) - Part 6-2: Generic standards – Immunity standard for industrial environments
IEC/EN 61000-6-4	Electromagnetic compatibility (EMC) - Part 6-4: Generic standards - Emission standard for industrial environments
IEC/EN 61000-6-5	Electromagnetic compatibility (EMC) - Part 6-5: Generic standards - Immunity for equipment used in power station and substation environment
IEC/EN 61000-6-7⁶	Electromagnetic compatibility (EMC) - Part 6-7: Generic standards - Immunity requirements for equipment intended to perform functions in a safety-related system (functional safety) in industrial locations

Environmental	
EU Battery Directive	2006/66/EC of the European Parliament and of the Council of 6 September 2006 on batteries and accumulators and waste batteries and accumulators and repealing Directive 91/157/EEC
RoHS	2011/65/EU Directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment (RoHS)
Proposition 65 (CA)	Proposition 65 Safe Drinking Water and Toxic Enforcement Act of 1986
China RoHS II	Management Methods for the Restriction of the Use of Hazardous Substances in Electrical and Electronic Products Order No. 32 (China RoHS II)
REACH	Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH)

Safety Standards in Energy Storage System Hierarchy

Cell:

UL 1642
UN 38.3
IEC 62619



Module:

UL 1973
UN 38.3
IEC 62619



PCBA:

UL Construction

Battery Rack:

UL 1973, NFPA 70 and 70E
UN38.3
IEC 61508(BMS), IEC 62619

FCC 47 CFR Part 15 Subpart B Class A
IEC 61000-6-2, 4, 5, and 7
EN 55011

CBC/IBC and IEEE 693



System:

UL 9540 / 9540A
NFPA 70 and 70E
UN38.3
IEC 60529, IEC60950-1 (Controls), IEC 62040-1
IEEE C-2 (National Electrical Safety Code)
IEC 62040-1

FCC 47 CFR Part 15 Subpart B Class A
IEC 61000-6-2, 4, and 5
EN 55011

CBC/IBC and IEEE 693
IEC 60529
AMERICAN BUREAU OF SHIPPING Certificate of
CARGO CONTAINERS

UL 1741 SA
IEEE 519
IEEE 1547



Legend

Battery Safety

Electromagnetic Compatibility

Seismic and Enclosure Integrity

Grid Interconnection