• This presentation shows how NEC has accomplished its record of keeping its products, customers and workers safe. We’ll show how safety begins at the product design stage, and some of the tools used to design safety into the products. Then, we’ll show some of the product features which make the product and its operation safe. We’ll show how NEC demonstrates the safety of the system through extensive certification and live testing. Finally, through the best teaching process ever, we’ll show by experience, what not to do, if one plans to make products safe and reliable for years to come.
Safety should be built into every part of product development from concept to commissioning. But most importantly, safety is DESIGNED INTO the product during the design stage, through the use of many tools and techniques, but most importantly the experience of having delivering successful installations.
Modeling the complete system from the electrochemical cell to the electrical interface at the grid, including auxiliary power systems, HVAC and the site controller algorithms allows engineers to properly size the various components for optimal performance and safe operation. NEC’s grand system model simulates the electrochemical functions within the battery cells, the electrical circuit dynamics, the cooling systems behavior, and the power conversion systems performance all while being operated under the control algorithms programmed into NEC’s AEROS site controller. Having this “digital twin” allows NEC to model a complete system’s reaction to a variety of contingency failures so that the proper protection systems can be designed for the real-world system to respond safely to any circumstance.
Thermal models of the physical structure are created for every new design, to show the effectiveness of the chosen HVAC system and architecture. This slide shows a color plot of the inside of a container while running at full power. The different colors show the different temperatures at various positions within the container. It’s important to keep temperatures between each of the battery modules close to each other so that they perform and age uniformly.
Many times, it’s impossible or impractical to test every aspect of the physical design, especially as the design is changing throughout the product development process. FEA analysis can show where the weak points in a physical structure, so that attention can be paid to those points throughout the design process. These screen shots show in vivid color, how specific areas of the structure are stress under extreme conditions, such as what would happen during an earthquake.
DFMEA and PFMEA are painstakingly long sessions where multi-disciplined engineers ask the question “How can this fail?” multiple ways and multiple times. This spreadsheet is an example of only a small portion of a more complete analysis. Typically, the entire system is broken down into components and subcomponents. For each subcomponent, the team brainstorms ways that it can fail, and estimating the probability of and severity of each failure. Scores are calculated for each, and the highest scoring failures stand-out in red. The next step in the process involves engineers thinking of ways that the failures can be mitigated. Either, the probability of the failure is reduced to an acceptable level, or the severity is reduced through some means. One example in particular which shows the value of this process, involves the control of the battery charging. As a result of the initial scores associated with overcharging lithium ion battery cells, NEC always implemented multiple redundant cell monitoring and over-charging protection in all of its battery storage systems.
As a result of extensive design, simulation and analysis, NEC’s GSS products are designed and built with multiple layers of protections from failures and unsafe conditions.

- **At the very basic level**, all **battery cells** have to have UL1642 and IEC62619 safety certification and of course pass the stringent UN38.3 transportation testing.

- **Modules** which physically protect and connect battery cells together also have to have UL and IEC safety certification. In addition, these modules monitor the cell’s voltages and representative temperatures and balance the cells’ SOC to an acceptable level.

- **Racks** which physically protect the modules and keep them operating in an acceptable temperature, voltage and current level have to conform to basic UL and IEC safety standards, but in addition are certified to the IEC61508 Safety Integrity Level 2 (SIL2).

- The **containers** or any chosen enclosure protects the racks and keep them operating in the proper temperature and humidity environment. This is vital to the safe and reliable operation of the batteries. In addition, the container will mitigate any catastrophic response to abusive conditions that could happen under multiple concurrent failures of lower level protection systems, by suppressing fires and deflagrating explosive gasses.

- **Finally**, the **site level controls** and installation keeps all of its components operating in an efficient and safe manner. Everything from average, peak power, state of charge and more are carefully managed to keep the system operating and safe for many years.
The first line of defense is good control, monitoring and environmental protection... but in case these fail, NEC uses additional layers of safety to backstop normal operational safety controls.

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 heat, 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)
- 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
- Cyber attack resistance
One of the things we learned while doing our failure analysis was the importance of ground fault protection.

**What Is A Ground Fault?**
- Battery strings are “Double Insulated”
- A ground fault is when one conductor connects to ground
- Concurrent ground faults = short circuit

**How Can It Happen In A Battery System?**
- Surface Contamination
- Materials degradation
- Mechanical stress
- Thermal Stress
- Human error
- Squirrels ...

**How Does NEC’s Ground Fault Protection System Work?**
- Detect faults BEFORE short circuits
  - Continuous monitoring
  - Coordinated monitoring on whole site
- Upon Detection...
  - Racks in affected zone are disconnected
  - Related power conversion is shut down
  - Operators and NEC AEROS Operations Center are notified

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The battery system is 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.

The battery system is electrically insulated and isolated from ground at all points.

If this 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.

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 the AEROS® Controls system, 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.
One of the lessons we learned in our failure analysis is that even though we may reduce the possibility of an event from happening, certain outcomes are catastrophic, and possibly life-threatening. This causes us to include the option for a full fledged fire suppression system that responds appropriately to the conditions it senses. When all of the other redundant protections fail and a fire breaks out, the fire suppression system will effectively squelch the flames, limit the propagation and damage to a small subset of the whole system. The heart of this system is a Clean Agent discharge system.

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 and non-ozone depleting.
- 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.

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 the horn will sound at 60BPM. All contactors will open (switch to “Off” mode).
- A second detection will cause, the horn to sound at 120BPM. After a time delay countdown (20 sec) which is displayed on the control panel, the horn will sound 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.
Another thing we have learned in our failure analysis is that there is a possibility for explosive conditions to exist when everything goes wrong with the protection systems and a series of cells go into thermal runaway. Although we have reduced the probability of this effect, the severity of its occurrence is high enough that we designed Deflagration Venting into our 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.

Why Is It Needed?
- If all goes wrong with all of the redundant failure protections designed into the entire system, AND under certain abusive conditions, cells can overheat and release flammable gasses.
- If enough cells fail in this manner, an explosive condition can exist in an air-tight container.
- 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.

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.
When designing for safety, we not only think about the safe operation of the equipment, but of the safety of those who operate it and on rare occasions, respond to its alarm conditions. To that end, we have come up with a concept to reveal the condition and any hazards that may exist on the insides of an enclosure, to anyone who may be responding to an alert and approaching the container from the outside.

How It Works

- 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
- The Battery Condition Annunciator provides insight into the battery system status with time-stamped information about its condition

What It Does

- The AEROS control system is constantly communicating its status to the cloud, hosted by neces.com.
- Using a smart device, a first responder can access this information quickly and easily by navigating to NECES command site. This URL can be typed in or scanned from a QR code made available on or near the site. No special app needs to be downloaded. A web browser is all that is required.
- Critical battery condition information is communicated quickly and easily to the smart device.
Parameters such as battery temperature, state-of-charge, and fire suppression system status can help inform first responders of the hazard and guide their next moves.
The battery rack is proverbial the “soldier in the battlefield,” armed with concentrated energy, it responds with power and energy to the demands of the grid or other application to which it is assigned. But when it is told to do more than what its cells can safely handle, it will independently protect itself. Its brain is the Battery Management System (BMS), which diligently monitors the condition of each of the modules and takes action with its own disconnecting contactors in case of trouble.

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
- The BMS monitors 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.
The Battery Management System (BMS) Ensures Critical Functional Safety

**Voltage**
- Multiple level response and action
  - Fold-back, warning, protective action
- Multiple cell voltage measurement verification \([V_{\text{module}} = \text{sum}(V_{\text{cell}})]\)
- Multiple module voltage measurement verification \([V_{\text{string}} = \text{sum}(V_{\text{module}})]\)

**Current**
- Multiple level response and action
  - Fold-back, warning, protective action
- Hard short circuits open appropriate fuses

**Temperature**
- Multiple level response and action
  - Fold-back, warning, protective action
- Temperature Delta:
  - 10 °C difference from other modules → protective action

**Communications**
- Loss of communication between modules, racks, zones and AKUS results in protective action

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*Note: Every safety system has defined module functions.*

The BMS is the heart of battery safety – it ensures the battery cells inside operate within safe parameters! Without this, cells can be easily overcharged, overdischarged, overheated, overpowered, etc. resulting in thermal runaway and fire! The IEC 61508 Functional Safety Standard is the same standard governing proper operation of critical safety equipment in many industries, including power plants, aircraft, and automotive. It's likely the airbags, seatbelts, and anti-lock brakes in your car are certified to this standard! **Look for this certification to Functional Safety in EVERY battery management system.**

**Voltage**
- Normal cell voltage range is 3.00V – 4.20V
  - If cell voltage greater than 4.15V; power folds back to zero
  - If cell voltage greater than 4.25V; rack contactors are latched open
- Independent voltage measurement verification
  - Voltage measurement on cells is summed and compared to module voltage measurement
  - If the difference is greater than 0.25V, rack contactors are latched open
  - Same goes for the difference between the sum of the module voltages and the entire rack voltage.

**Current**
- The racks are protected from overcurrent in two ways: contactors and fuses
  - If the measured current exceeds a slow current limit; power is linearly folded back to zero
  - If the measured current exceeds a fast current limit (but less than that of a hard short circuit); the affected rack latches open its contactors
  - If a hard short circuit occurs, fast-blow fuses will open

**Temperature**
- The allowable cell temperature range is -30°C to +60°C.
  - If the measured cell temperature hits 53°C; power folds back to zero
  - If the measured cell temp hits 60°C; the BMS sends out an alarm message to the site controller
  - If the measured cell temp hits 65°C; the affected rack contactors are latched open and the BMS is shut down after a delay
- Temperature Delta:
  - If the measured temperature of any module differs by more than 10 °C from the average temperature of all the modules in the rack; the affected rack contactors are latched open

**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, such as a lack of communication; the affected rack contactors are latched open and shut the BMS is shut off after a delay
Battery modules are the muscle behind the rack’s power and energy. Each module contains a series and parallel combination of electrochemical cells which need to be maintained at their optimum condition in order for them to function effectively time and time again. To help keep each cell operating in its peak performance zone, a local electronic management system monitors, reports and balances the cells in accordance with specific direction from the rack’s BMS.

- Each module measures voltage on every series cell element and provides an independent voltage measurement at the module level
- The rack BMS reconciles cell voltage measurements and module voltage measurements by comparison to overall rack voltage
- Measures temperatures at representative 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
- Each module meets UN38.3 test and criteria for transportation safety
- Each module include a module-level safety fuse
This is something of an eye-chart, but we meant it that way. We are proud of this list, because it has taken us a long time and a lot of resources to accomplish it. These are the standards that we comply with and where applicable are certified to, related to safety, integrity, environmental conformance, and compatibility. It’s breadth shows that NEC has the experience to succeed in a global market all the while prioritizing the safety and health of our customers and the planet.
This slide shows the certifications grouped by subsystem ...

Slide updated 6/16/2017
LG Chem JH3 cell to IEC 62619:
https://www.certipedia.com/certificates/50345796?locale=en
LG Chem JP3 cell to IEC 62619:
https://www.certipedia.com/certificates/50356384?locale=en
... and by category.

LG Chem JH3 cell to IEC 62619:
https://www.certipedia.com/certificates/50345796?locale=en
LG Chem JP3 cell to IEC 62619:
https://www.certipedia.com/certificates/50356384?locale=en
Note: Internet connection required to view video

It doesn’t do any good to have a fire suppression system in place that you don’t know will actually work when it needs to. To that end, NEC has intentionally tested its fire suppression system against real-world conditions to make sure that it will do what it was intended to do in a real-world battery fire.

This video shows the test in which a cell is intentionally set into thermal runaway by applying heat to it. Then after a considerable amount of smoke, the fire suppressant is applied at which point the screen goes white.) The liquid dripping on the surfaces of the nearest wall is the fire suppressant in liquid form after being discharged, and before it completely evaporates. A second take at the event shows the same sequence with another camera. The results show that with NEC’s chosen fire suppression that a cell and ultimately a module in the midst of thermal runaway do not propagate from one rack to another.
This set of photos shows the racks before and after the burn test. The affected rack did not propagate thermal runaway to the neighboring racks while protected by NEC’s fire suppression system.
Real world experience is the best teacher. Sometimes it’s painful, but valuable nonetheless. NEC has been designing, building, installing and operating systems since 2009 and has learned its lessons along the way. Sometimes from our own experience, and sometimes by comparing notes with other integrators.

There are reports of several sites in the world which are built into containers without the proper dehumidification, filtering and cooling. Excessive air humidity and pollution cause all sorts of problems from corroded terminals, clogged air vents, and surface contamination. These conditions are unhealthy for the battery’s performance and can even cause catastrophic damage. This is especially true where high voltage DC is present. DC voltage drives ions across contaminated surfaces, eventually leading up to a short and fire.
Energy storage integrators need to eliminate personal safety hazards as well. For example, a one-way-out corridor can be a death trap if an unlucky person is at the end of the pictured aisle when a fire breaks out in a rack halfway down the aisle. Although it is known that UL rates wires with some safety margin, there is no reason to take chances. The insulation class of wires is tested with a nice smooth DC or AC voltage. When you add a high frequency component from the PCS switching, the breakdown voltage will decrease. In addition, over time, the insulation will degrade, losing its capacity to withstand high voltages. Mechanical abuse is one of the most common means to compromise wire insulation. Protect wire from damage during the installation and during operation. With so many ways to compromise insulation between high voltage conductors, one should never assume that there will not ever be a ground fault in the system at some point in a product’s service life. Install a ground fault detector (GFD) to eliminate the risk of having ground faults be part of a catastrophic short circuit.
Because most PCS implement a non-isolated single-stage conversion topology, grounding the output wye configuration will result in excessive CM noise on the DC bus. It is possible to filter this noise out with decently sized filters in the PCS, but these usually are expensive and as a result seen to be undersized or even optional by the PCS manufacturers. In addition, if there is just one ground fault on the DC bus, there will be excessive current flowing through that fault, the PCS and into the grounded transformer.

For very similar reasons, it is not recommended to tie the negative PV bus to ground and connect the output of its associated PV PCS directly to the output of an ESS PCS. A single fault to ground can lead to a short circuit even on the DC bus of the batteries.

Finally, to be sure there are no compatibility issues with your DC bus and the chosen PCS configuration, it is always a good idea to check the voltages between the bus and ground using a high quality oscilloscope and the appropriately sized voltage probes. This shows you how much voltage is on the bus under all conditions, so you can be sure that you rated the wire correctly.