A Guide to Lithium-Ion Battery Safety

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What is safety?

- Safety is not absolute!
- ...or intrinsic (to batteries)

- Safety is relative and is expressed statistically
Definitions

- **safety** – ‘freedom from unacceptable risk’
- **hazard** – ‘a potential source of harm’
- **risk** – ‘the combination of the probability of harm and the severity of that harm’
- **tolerable risk** – ‘risk that is acceptable in a given context, based on the current values of society’
Safety statistics – IEC 61508

■ “Functional safety of electrical/electronic/programmable electronic safety-related systems”

■ Safety Integrity Levels:

<table>
<thead>
<tr>
<th>SIL</th>
<th>High demand or continuous mode: probability of dangerous failure per hour</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>≥ $10^{-6}$ to $&lt; 10^{-5}$</td>
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<tr>
<td>2</td>
<td>≥ $10^{-7}$ to $&lt; 10^{-6}$</td>
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<tr>
<td>3</td>
<td>≥ $10^{-8}$ to $&lt; 10^{-7}$</td>
</tr>
<tr>
<td>4</td>
<td>≥ $10^{-9}$ to $&lt; 10^{-8}$</td>
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Good safety philosophy

- Safety events cannot be entirely eliminated
- Reduce the probability of a safety event
- Minimize the level / severity of that event
- Limit the consequences of the event
Lithium-ion hazard categories

- Overcharging
- Overtemperature
- Mechanical abuse
Lithium-ion basics

- Safety characteristics vary by Li-ion electrochemistry
- Overcharged (delithiated) positive can become unstable
- Passivation layer (SEI) can break down above 100°C

Battcon 2008 – “Understanding Lithium-Ion Technology”
Overcharging

- The most serious of Li-ion safety events
- ...but also the least likely
- Would require very high voltage
  - Around 65V for a 48V system
  - Around 160V for a 125V system
- Multiple layers of control
  - Reliable charging systems
  - Alarm management
  - Battery-level switches
Overtemperature

**Causes**

- High ambient temperature
- \( I^2R \) heating from duty cycle
- Internal short circuit
Mechanical abuse

- Crushing or penetration of cells
- Can cause short-circuiting and overtemperature
- Most likely during transportation and installation
  - Shipment in partially charged state
- Roadside cabinets could be hit by a vehicle
  - Partial protection from cabinet structure
Selling safety

- Frequent promotion of ‘single-shot’ safety solutions
  - Electrochemistry
  - Ceramic-coated separators
  - Thermal-management devices

- Electrochemistry
  - Lithium iron phosphate
  - Lithium titanate
  - Each has pros and cons
  - No intrinsic safety!

“Prius fire forensics” report
Holistic safety – the four pillars

The Four Pillars of System Design & Safety

Materials and Process Control
- Particle contamination of incoming materials
- Particle and humidity control
- Process validation/control

Choice of Chemistry
- Cathode: LiNiCoAlO₂
- LiFePO₄
- LiNiMnCoO₂
- Anode
- Others

Cell Design
- Current interruption
- Venting
- Thermal Mgmt

System Design
- Electronics
- Software
- Mechanical
- Architecture

User Requirements
Cell design – venting

- Relies on gas pressure buildup within cell
- May also have a circuit-interrupt function
Effects of cell venting

- The severity of a thermal runaway event can be limited if the chain is interrupted.
System design – module

- Avoid heat propagation from a cell in thermal runaway
  - Air gap
  - Thermal insulation
  - Phase-change material

- Module mounting must allow for management of vented gas

One cell (not shown) forced in runaway
Layered approach to safety management
- Measurement and detection
- Cell balancing
- Switches (contactors; MOSFETs)
- Algorithms
- Alarm management
Case study – Boeing Dreamliner

- First large commercial jet with Li-ion batteries
- Two incidents of battery fires grounded the fleet for months
- Extensive NTSB investigation
Dreamliner battery design

JAL APU Battery Cells

Exemplar Battery  JAL Event Battery

NTSB
Dreamliner cell construction

Electrodes

Cell construction

- Negative terminal
- Positive terminal
- Positive electrode
- Negative electrode
- Rupture plate
- Separators
- Case
Dreamliner battery fix

787 Dreamliner battery changes

The battery consists of eight lithium-ion rechargeable cells connected in series.

Cells
Wrapped with electrical isolation tape

Containment
Sealed steel box eliminates possibility of fire. Added weight: 68kg

Source: Boeing/Graphic News

Vent line
Any vapour is vented overboard within 1.5 seconds.

Pressure vent

Insulation
Improved separation between battery cells - with ceramic-plated spacers between cells.

Battery locations in the plane

787 Dreamliner battery changes
Standards and specifications

- Two approaches
  - Specify safety design features
  - Specify functional safety under application conditions

- Specifying functional safety is far better
  - Allows use of standards
  - IEC 61508 – SIL level
  - Telcordia GR-3150

- IEEE Std 1679 provides framework for evaluating safety and other functionality of new technologies
Summary

- Recognize that safety is never absolute
- Holistic approach through “four pillars” concept
- Safety maxim: “Do everything possible to eliminate a safety event, and then assume it will happen”
- Properly designed Li-ion batteries can be operated confidently with a high degree of safety
Thanks for listening...

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