Substation Battery Systems Present & Future

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Agenda

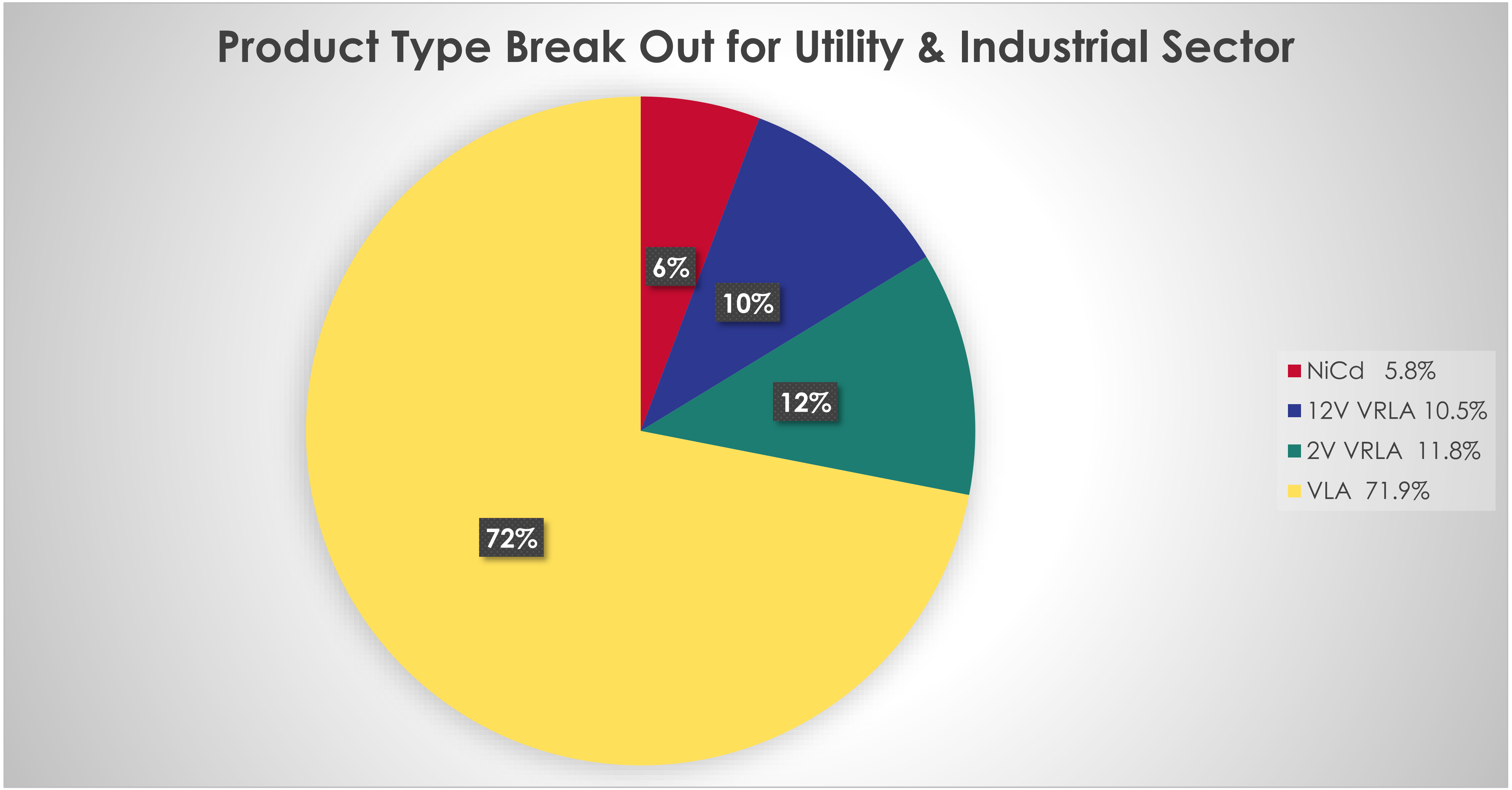
- Purpose of batteries
- Common battery types found in substations
  - Advantages & disadvantages of battery types
- Sizing and selection
- Think outside the box – alternative technologies

Utility applications

- Utilities (Switchgear & Control)
  - Consists of Utility Generation, Transmission, Distribution, Manufacturing (Industrial UPS), and Oil & Gas sectors
  - Designed to provide power backup for switches, circuit breakers, motors, monitors and communications equipment used for protecting electricity generation, distribution, transmission, and industrial applications
  - Prefers VLA (flooded) products for substation usage; although, seeing increasing trend for VRLA when space constrained
  - Prefers VRLA products for communications application

BATTERY SALES MIX

Industrial sector



Purpose of batteries

- Once AC power is lost, batteries pick up the load until the generator starts or until power is regained

- Benefits of using batteries
  - Immediate response (compared to generator)
  - Do not require fuel source to be replenished
  - Noiseless
  - Only emissions are Oxygen & Hydrogen – no Carbon or Nitrous emissions

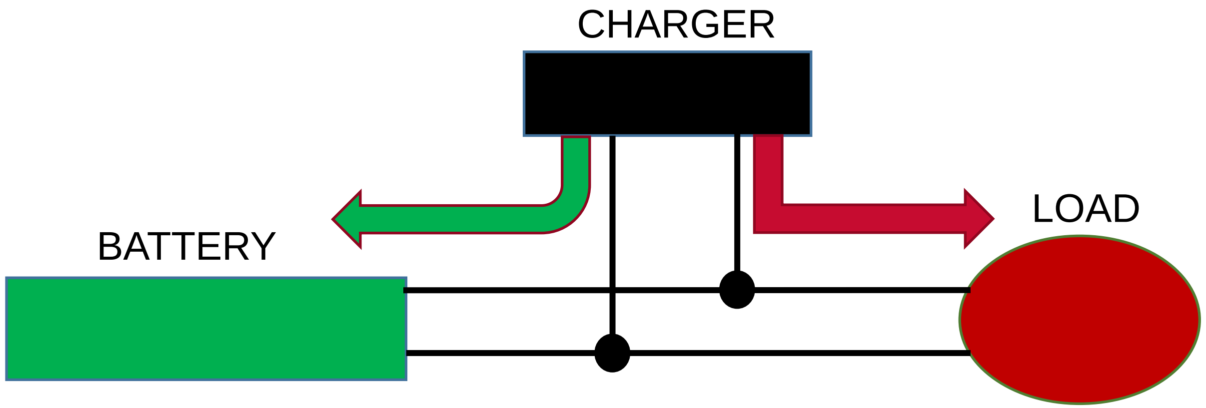
Utility & Substation Battery Trends

- In standby float applications, growing desire from customers for **longer life battery products for lower TCO**, via longer battery replacement intervals
  - 20-year design life product
  - Suited for the Industrial Power / Utilities market segment where trend is to replace traditional VLA batteries with advanced VRLA batteries due to the following benefits:
    - Lower maintenance
    - Lower ventilation
    - Space savings (ideal where installation space is limited)
    - Lighter weight than VLA batteries - Easier/simpler transportation and installation
    - Greater energy density
    - Reliable & Longer service life

Why do we need batteries?

During normal operation

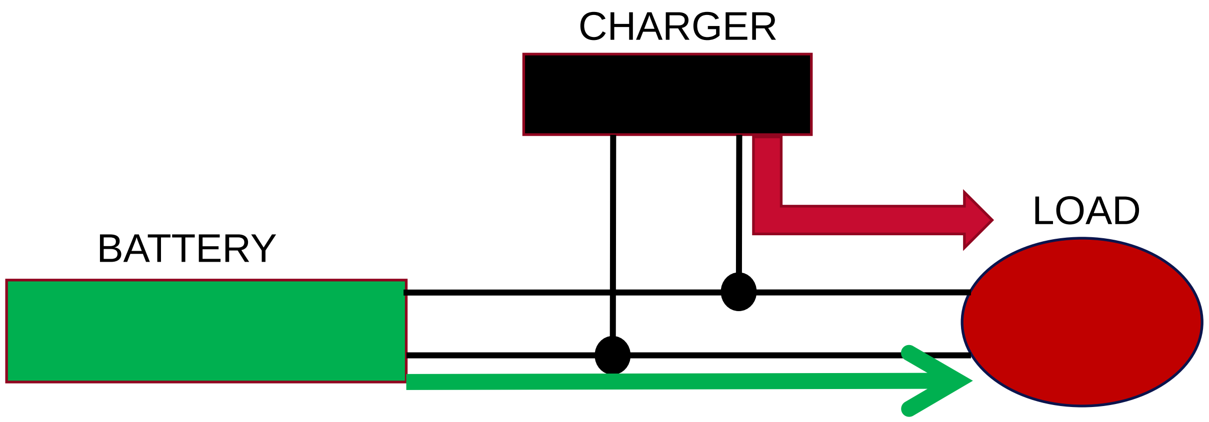
- The substation batteries for the DC system must be in operation 24/7 – 365 – NOT just for backup power, but also to provide the current needed for day-to-day switching operations
- Charger provides current for the load **&** a float current to charge the battery
- Charger alone **DO NOT** provide enough current if the load exceeds the charger output



Why do we need batteries?

During switching operation

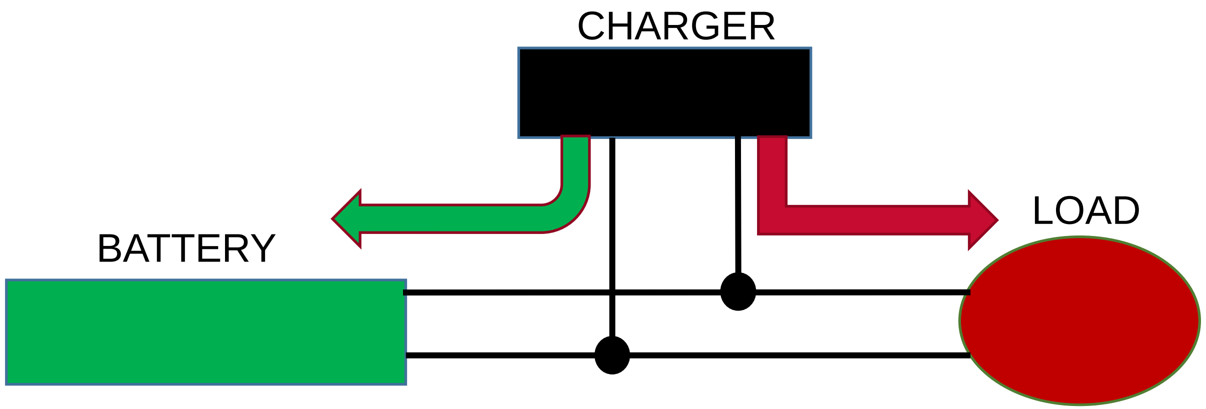
- Battery provides additional current to the load, which is beyond the charger's limited capacity



Why do we need batteries?

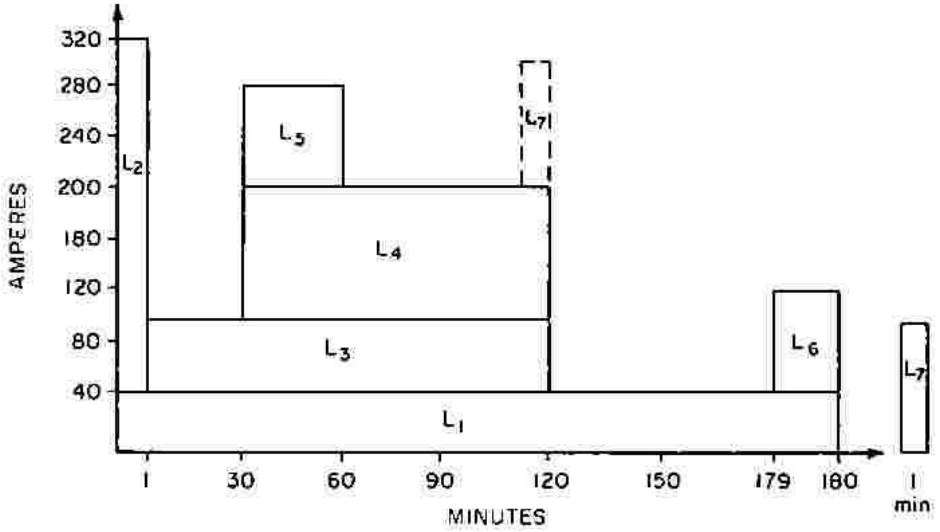
After the switching operations

- Charger provides current for the load **AND** a float current to recharge the battery
- Batteries are designed to provide power to the relay protection circuits & motor operated switches
- Batteries are sized large enough to handle an 8 hour power outage, with a worst case switching event at beginning & the end of that period



Switchgear & Control application

- Switchgear Requirements
  - Duty cycle
    - Combination of continuous and noncontinuous loads
    - Initial and last loads are the most important
    - Example:
      - Initial high rates-1 minute (Sheds loads)
      - Long duration, sustaining rate
      - Concluding high rate-1 minute (turn off battery)
  - Installation issues
    - Unmanned sub-stations
    - Remote sites
    - Environmental conditions vary (A/C & Heat)



Switchgear & Control application

- A typical system is 120 volts DC nominal
  - Other voltages also exist
  - 24V, 48V, and 250V
- Provides a multi-step duty cycle consisting of a continuous load (normally carried by the charger), non-continuous loads and momentary loads (normally provided by batteries)
- The batteries may be called upon to supply back-up for total of 8 hours or longer
- Site conditions vary!

Site conditions

Substation Lead acid battery:

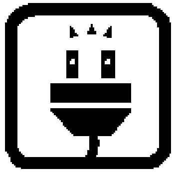
Common battery types

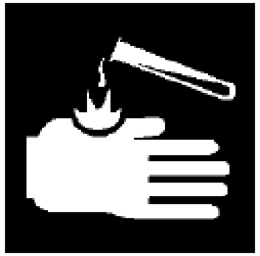
Common battery types in substations

- Lead acid
  - VLA
    - Flat plate
    - Tubular plate
  - VRLA
- Nickel Cadmium
- Others

Basic lead acid battery chemistry

- 2 volts per cell
- Fully rechargeable
- Self discharge
- Sulfuric acid
- Electric shock hazard
- 98%+ recycled in North America





Types of Standby Lead Acid Battery

VLA *(Vented Lead Acid)* Battery

- Also called Flooded or Wet
- Common types are Lead-Calcium, Lead-Antimony, Low lead-antimony (lead-selenium), and Pure Lead

VRLA *(Valve Regulated Lead Acid)* Battery

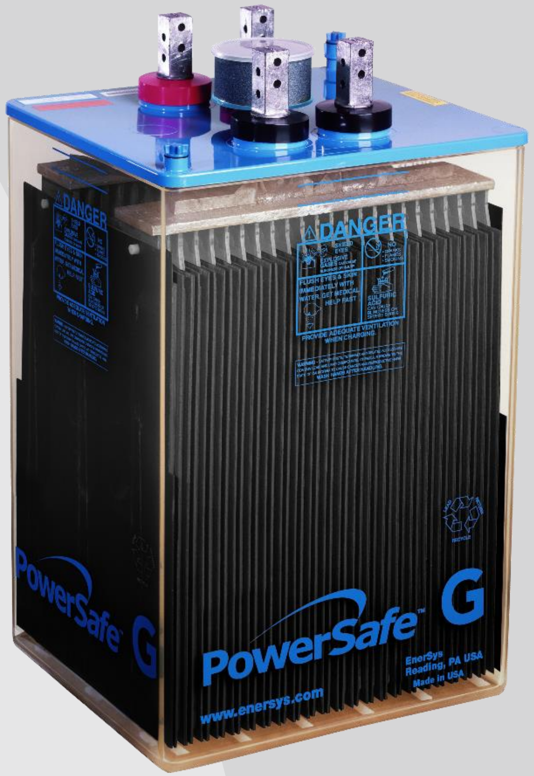
- Also called Sealed or Maintenance-Free
- AGM (Absorbent Glass Mat), Gel or hybrid
- Not sealed
- Not maintenance-free

Benefits of AGM VRLA

- Space savings
- No water addition or monitoring of electrolyte
- Higher energy & power densities
- Low hydrogen venting (gassing) due to 98-99% recombination rate
- Better cycling capabilities (no sediment)
- No free acid - "Non-spillable"

Benefits of VLA (Flooded)

- Typically a longer float life
- Easier to recover from abuse
  - Overcharging still results in gassing & water loss
  - In VRLA, water cannot be added back. Once water is gassed, it is gone for good
- Better indication of battery's health via visual inspections
- Less power consumption (lower float current)
- No dependence on pressure vents
- Typically built larger (more Ah – up to 4000 Ahrs) than VRLA
- Less sensitive to heat issues
  - electrolyte acts as "heat sink"
  - space between cells helps with heat dissipation



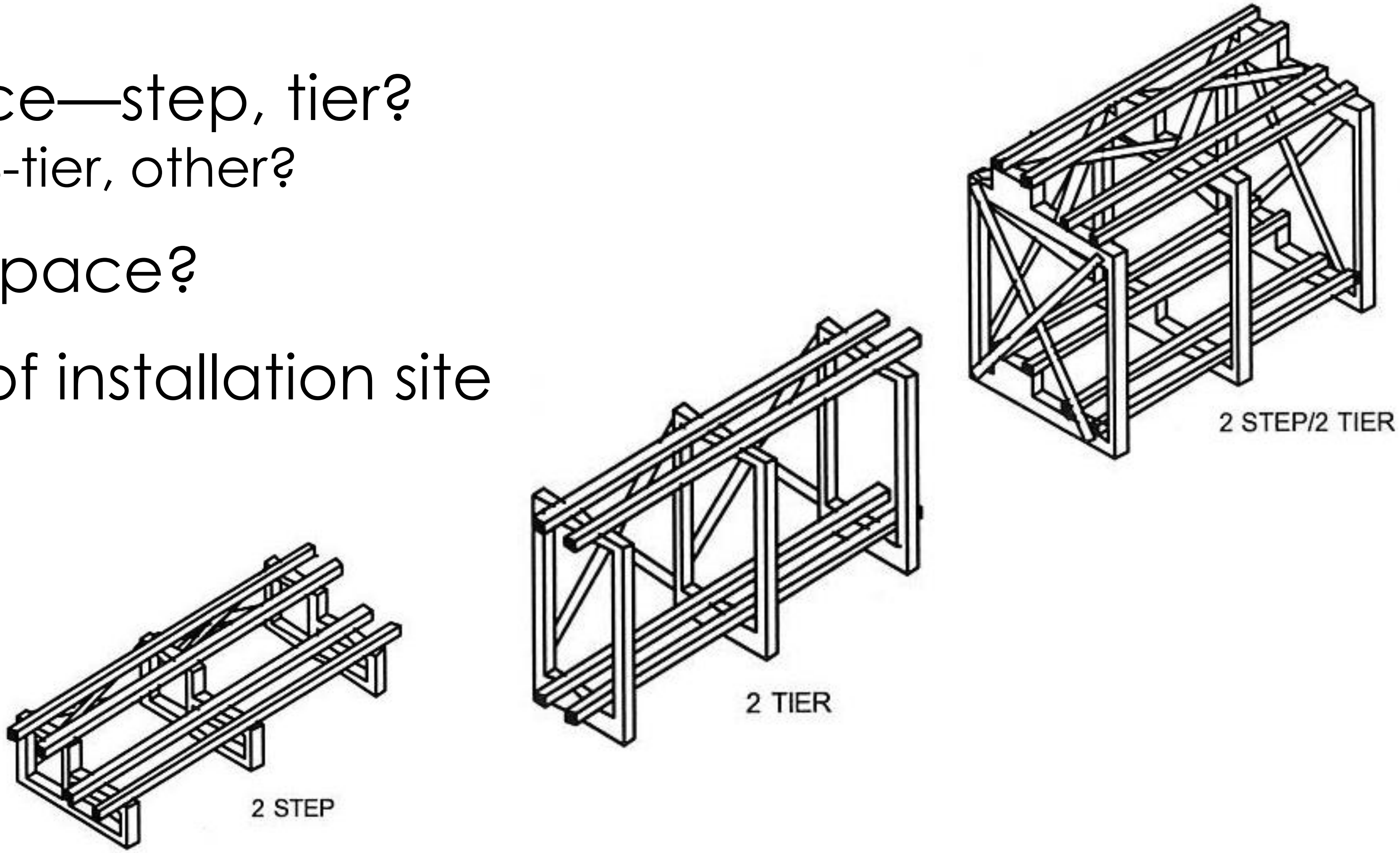
Battery technology comparison: Lead acid battery: VLA vs. VRLA

VLA (flooded)	VRLA
• Free electrolyte	• Absorbed electrolyte
• Larger footprint	• Smaller footprint
• High hydrogen gassing	• Very low hydrogen gassing
• Need ventilation	• Need ventilation
• Robust to hostile conditions	• Sensitive to environment (temp)
• Visual internal inspections possible	• Cannot visually inspect internal condition
• More maintenance requirement	• Less maintenance requirement

Components of battery systems

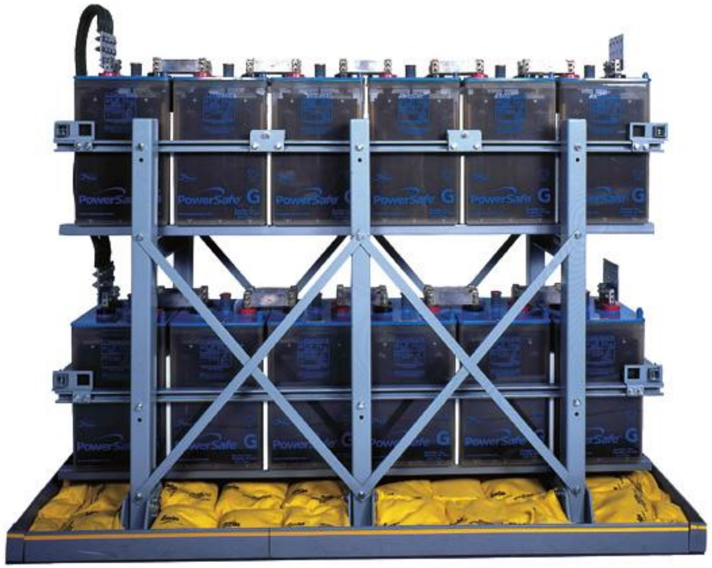
- **VLA (flooded) racks**

- Rack preference—step, tier?
  - 2-step, 2-tier, 3-tier, other?
- How critical is space?
- Seismic rating of installation site
  - UBC
  - IBC
  - IEEE 693
  - NEBS



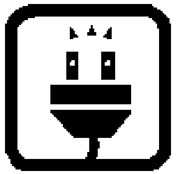
Components of battery systems

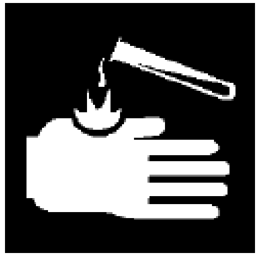
- **Spill containment**
  - Is the spill containment required by codes?
  - Check with local inspector & fire marshals
  - Contains acid spills



Basic Nickel Cadmium battery chemistry

- 1.2 volts per cell (nominal)
- Fully rechargeable
- Self discharges
- KOH electrolyte
- Electric shock hazard
- Limited recycling facilities





Battery technology comparison: Nickel Cadmium

- Advantages
  - Very good high power rating
  - Reduced loss of capacity at low temperature
    - The NiCd system looses only half of the capacity compared to Lead-Acid system
  - No freezing at temperatures below 32°F (0°C)
  - Robust against deep discharges & Long shelf life
  - No passivation in case of prolonged storage in partial discharge conditions
  - Robust against abusive environment & optimized for harsh operating conditions
  - No electrolyte stratification

Battery technology comparison: Nickel Cadmium

- Disadvantages
  - Contains cadmium
  - Cost (initial as well as at disposal)
  - More cells needed to reach operating voltage
  - Possible memory effect
  - Faster self discharge
  - Must have proper commissioning charge

Lead acid – NiCd comparison

Characteristics	Lead Acid (VRLA)	Lead Acid (VLA)	Nickel Cadmium (Ni-Cd)
Footprint Req'd	Lowest	Middle	Highest
Ventilation	Regular room air exchange may be sufficent	Regular room air exchange is NOT sufficent	Regular room air exchange is NOT sufficent
Spill Containment	Typically not required	Typically required	Typically required
Charge and Discharge Rate	Greater than 10 hours	Greater than 10 hours	Within 8 hours
Recharge Cycle Life	Better	Good	Best
Self Discharge per Month	3% to 4%	3% to 4%	20%
Temperature Tolerance	Good	Better	Best
Initial Cost	Lowest	Middle	Highest
Maintenance cost	Middle	Highest	Middle
Life Cycle Cost	Highest	Middle	Middle
Useful Life	10 to 12 years	15 to 20 years	20 to 25 years
Cell Voltage thru Discharge	Drops away	Drops away	Dimishes gradually
Reliabilty	Good	Better	Better
Maintenance watering	None	Check elecrolyte level during normal maintenance	Regular checks for flooded type, Little to None for valve regulated type
Electrolyte	Sulfuric Acid (H_2SO_4)	Sulfuric Acid (H_2SO_4)	Potassium Hydroxide (KOH)
Hazardous Metal	Lead (Recycleable)	Lead (Recycleable)	Cadmium (Hazardous)
Disposal	Readily recycled	Readily recycled	Costly to dispose

Applicable Codes & Documents

Sizing & Selection

- IEEE Std 485: IEEE Recommended Practice for Sizing Lead-Acid Batteries for Stationary Applications
- IEEE Std 1184: IEEE Guide for Batteries for Uninterruptible Power Supply Systems
- IEEE Std 1189: IEEE Guide for Selection of Valve Regulated Lead Acid (VRLA) Batteries for Stationary Applications
- IEEE Std 535: IEEE Standard for Qualification of Class 1E Vented Lead Acid Storage Batteries for Nuclear…Stations
- NEBS (Network Equipment-Building System) GR-63, GR-1089: the most common sets of safety, spatial and environmental design guidelines applied to telecommunications equipment in the United States
- OSHPD, ASHRAE, NFPA, and more…

Applicable Codes, Regulations, & Documents

Installation & Maintenance

- IEEE Std 450: IEEE Recommended Practice for Maintenance, Testing and Replacement of Vented Lead-Acid Batteries for Stationary Applications
- IEEE Std 484: IEEE Recommended Practice for Installation Design and Installation of Vented Lead-Acid Batteries for Stationary Applications
- IEEE Std 1187: IEEE Recommended Practice for Installation Design and Installation of Valve-Regulated Lead-Acid Storage Batteries for Stationary Applications
- IEEE Std 1188: IEEE Recommended Practice for Maintenance, Testing and Replacement of Valve-Regulated Lead-Acid Batteries for Stationary Applications
- NERC PRC-005-06: North American Electric Reliability Corp (NERC) Protection and Control (PRC) standards – under FERC
- And more…

What the FERC is NERC?

Federal **E**nergy **R**egulatory **C**ommission (**FERC**)

- Independent government (DOE) agency that regulates interstate transmission of ENERGY
  - Electricity, natural gas, and oil
  - Protect the public and energy customers, ensuring that regulated energy companies are acting within the law

North American **E**lectric **R**eliability **C**orp (**NERC**)

- Subsidiary of FERC
- Agency that develops and enforces reliability standards for the national electric power grid
  - Maintenance and Testing direction
  - Load forecasting
  - Monitoring the bulk power system

PRC-005-6

• Table 1-4 (a)	VLA
• Table 1-4 (b)	VRLA
• Table 1-4 (c)	NiCd

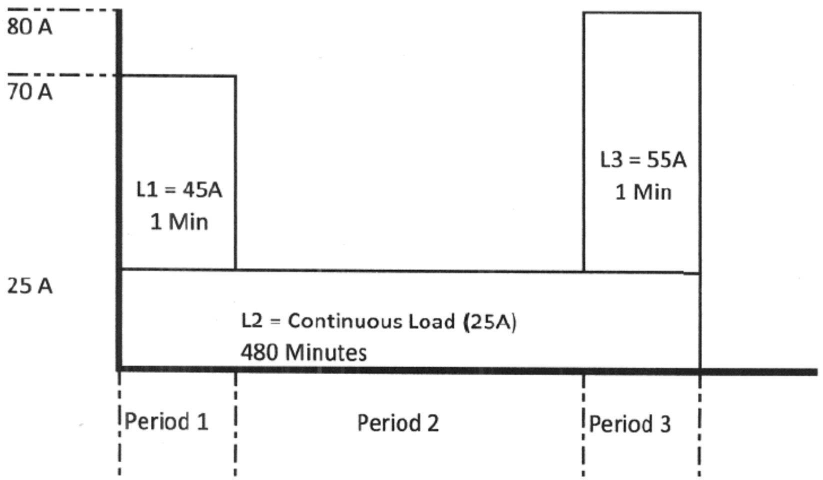
- Table 1-4 (a) and Table 1-4 (b) mentions “ohmic testing”
- It is important to know that ohmic testing does not get you out of verifying battery’s performance!

- It is the responsibility of the Protection System owner to maintain a documented process that demonstrates the chosen parameter(s) and associated methodology to determine if the battery string can perform as manufactured

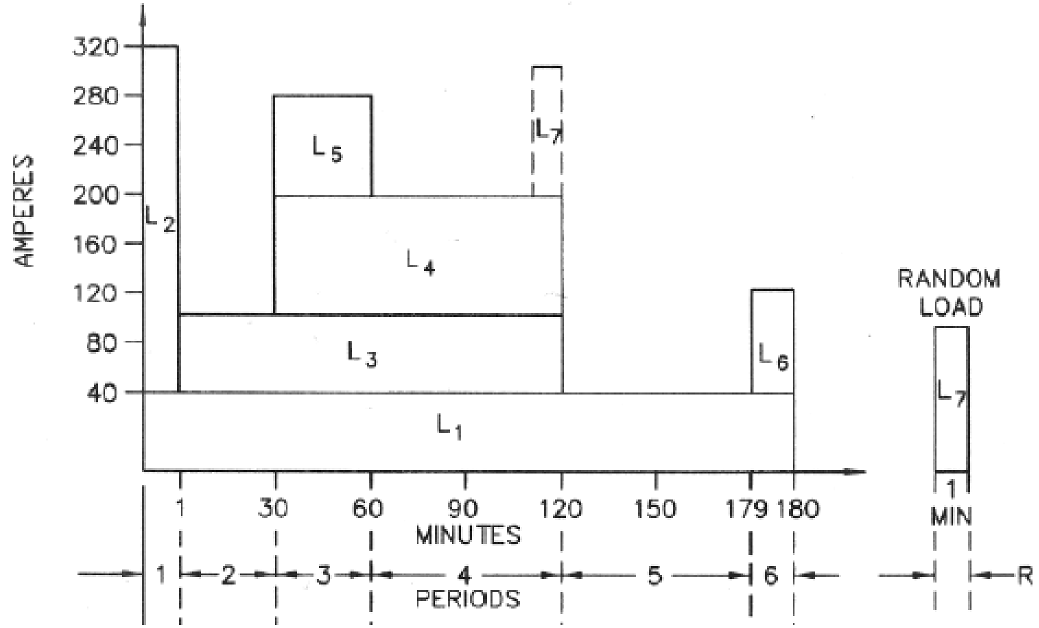
Substation Lead acid battery sizing:

Sizing matters!

Switchgear sizing



Minutes	Load (A)
1	70
478	25
1	80



What Information Do We Need to Size the Battery?

- **Voltage window of the equipment being operated?**
  - Determines number of cells in a battery system
    - Telecom: 42VDC to 56VDC (typically 24 Cells)*
    - Switchgear: 105VDC to 140VDC (typically 58 to 60 Cells)*
    - UPS Data Center: 400VDC to 580VDC (typically 240 Cells)*

- **End Cell Voltage**
  - Typically 1.75 for Telecom & Switchgear
  - UPS? 1.67VPC, 1.70VPC, 1.65VPC & ….

Calculation of Number of Cells & Minimum Cell Voltage

$$\frac{\textbf{Maximum Allowable System Voltage}}{\textbf{Cell Voltage Required for Charging}} = \textbf{Number of Cells}$$

$$\frac{140\ VDC}{2.35\ VPC} = 60\ Cells$$

$$\frac{\textbf{Minimum Battery Voltage}}{\textbf{Number of Cells}} = \textbf{Minimum Cell Voltage}$$

$$\frac{105\ VDC}{60\ Cells} = 1.75\ Volts\ per\ Cell$$

What Information Do We Need to Size the Battery?

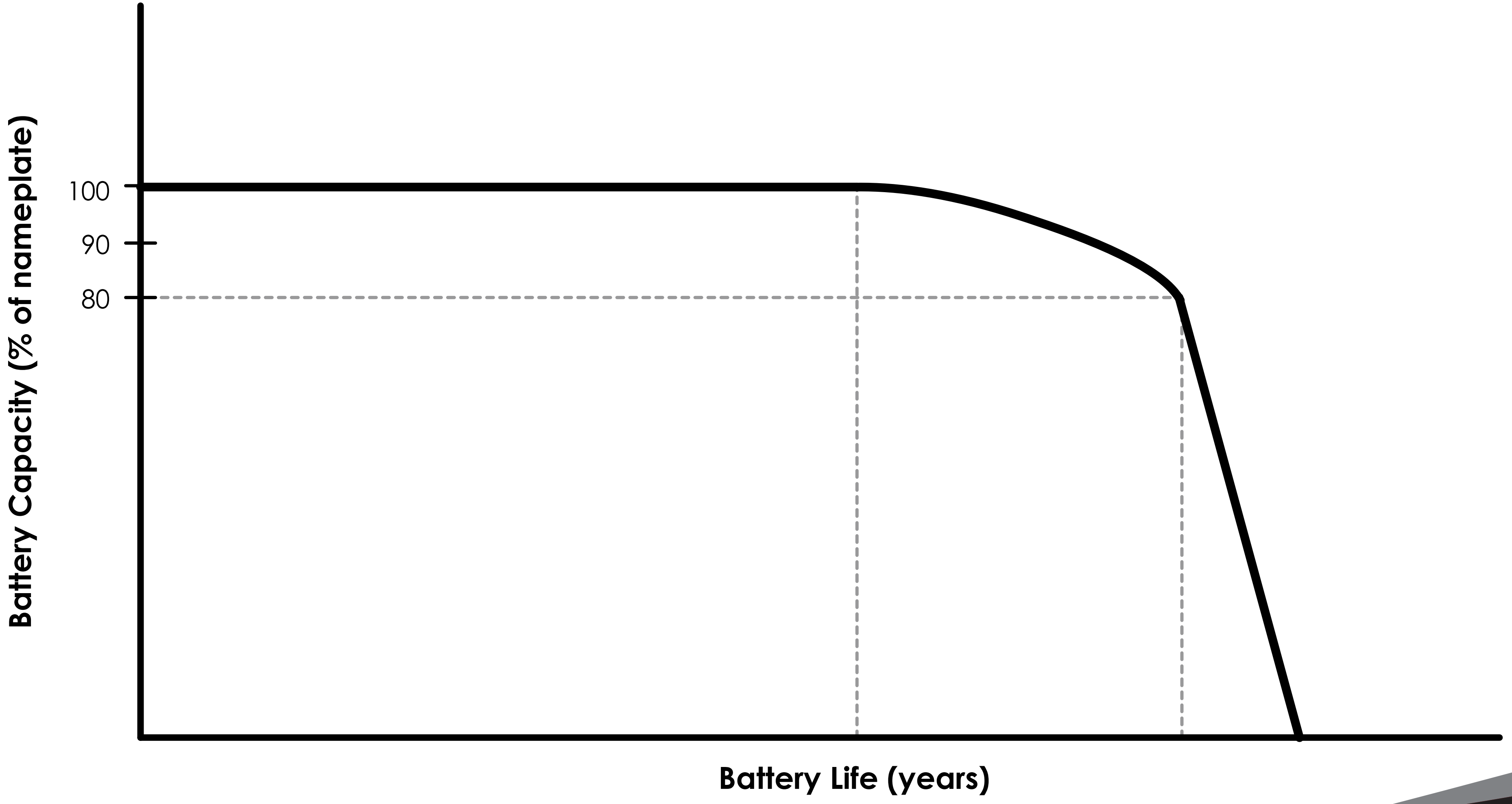
- **Minimum Operating Temperature**
  - "Rule of Thumb" – Use 77F or 25C unless the actual ambient temperature the batteries will encounter is LESS than 77F/25C. Use 77F/25C if temperatures will be above 77F/25C.
- **Design Margin**
- **Aging Factor**

Battery sizing definitions

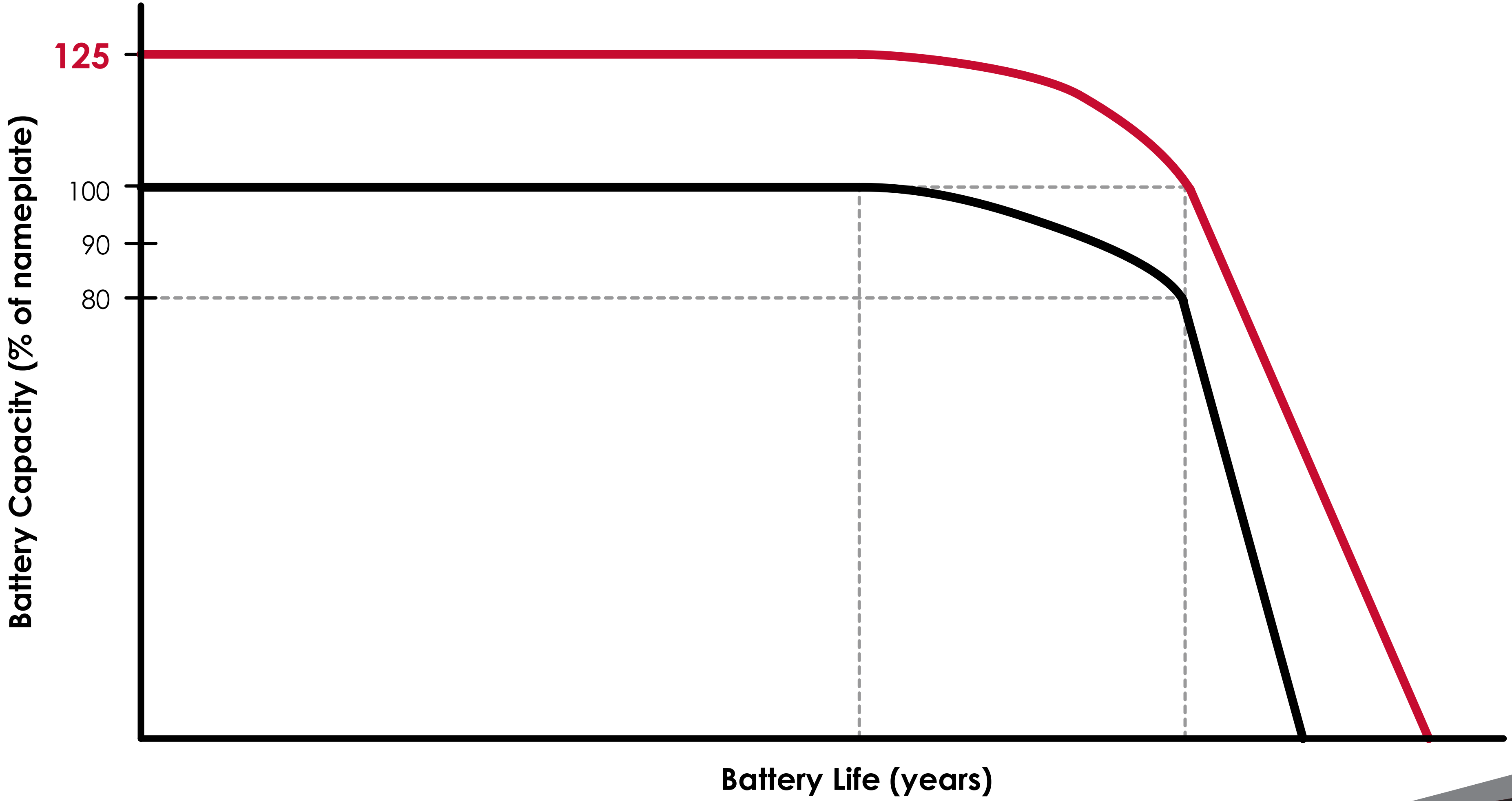
- **Design Margin:** A factor that adds capacity battery allowing for load additions to the DC system. Typically Design Margins are in 10% to 15% range (1.10 or 1.15)

- **Aging Factor (also called End of Life (EOL) capacity):** Used to insure 100% capacity at the end of life. Normally the accepted IEEE-450 end of life capacity is 80% (knee of curve) however some critical applications can not afford the reduction in capacity so aging factor is required (1.00 or 1.25)

Aging Factor



Aging Factor



Replacement battery sizing

- What is the actual load? (tells you if the same Ahr capacity battery will work)
- Did the operating temperature change? (helps you size the correct battery)
- Did the operating voltage range change? (helps you set the proper charger voltage)
- Do you require spill containment? (helps you meet the latest local codes)
- What are required design and aging margins? (helps you size the battery)

- In most cases, replacing like-for-like will work; however, above questions should be asked in order to get the reliable battery system

New battery string sizing

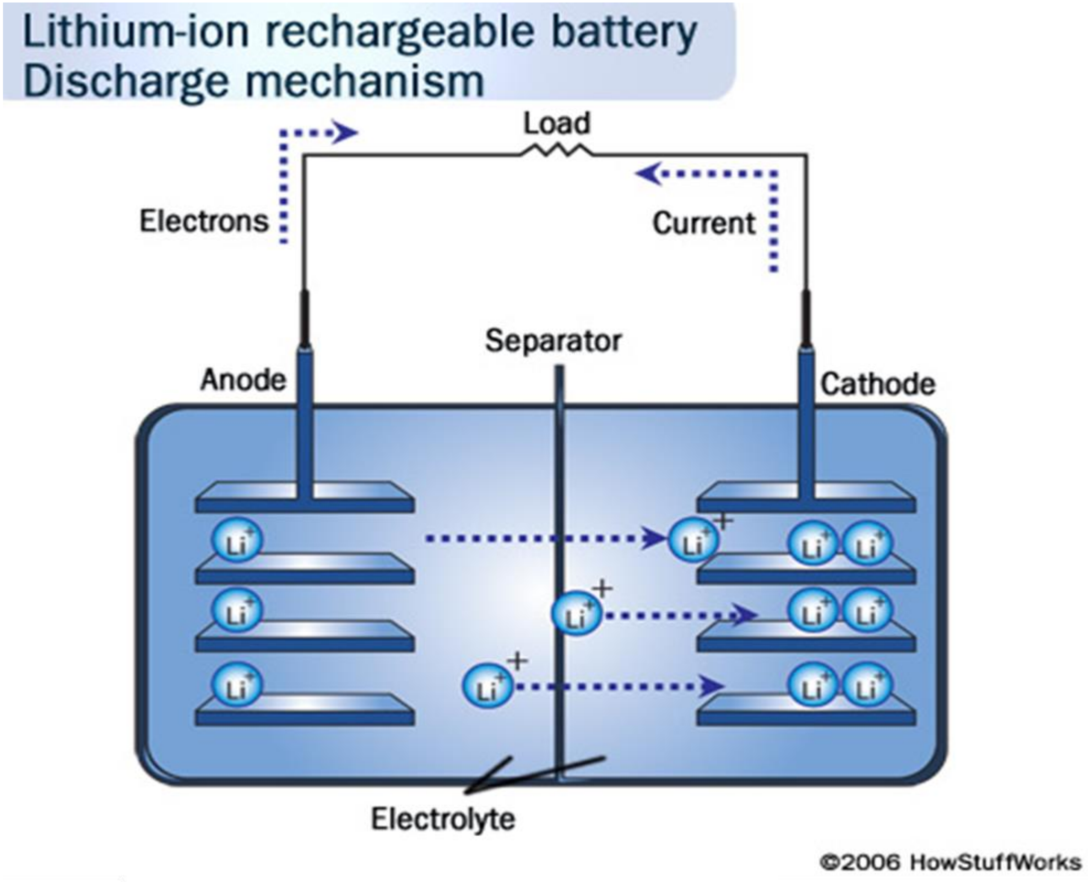
- What are you backing up? (tells you the type of application)
- Do you have a space constraint? (tells you if the flooded is applicable or if you need the multi-cell jars)
- What is the max / min voltage the system can handle? (helps you using the correct Amp or KW values)
- What is the load requirement? (tells you capacity required)
- What is the system voltage? (tells you the # of cells required)
- What is the operating temperature? (helps you size the correct battery)
- What are required design and aging margins? (helps you size the battery)
- What is the seismic zone? (helps you choose the correct rack)
- Do you require spill containment? (helps you meet the local codes)

Substation batteries:

Think outside the box!

Basic principles of Li-ion battery operation

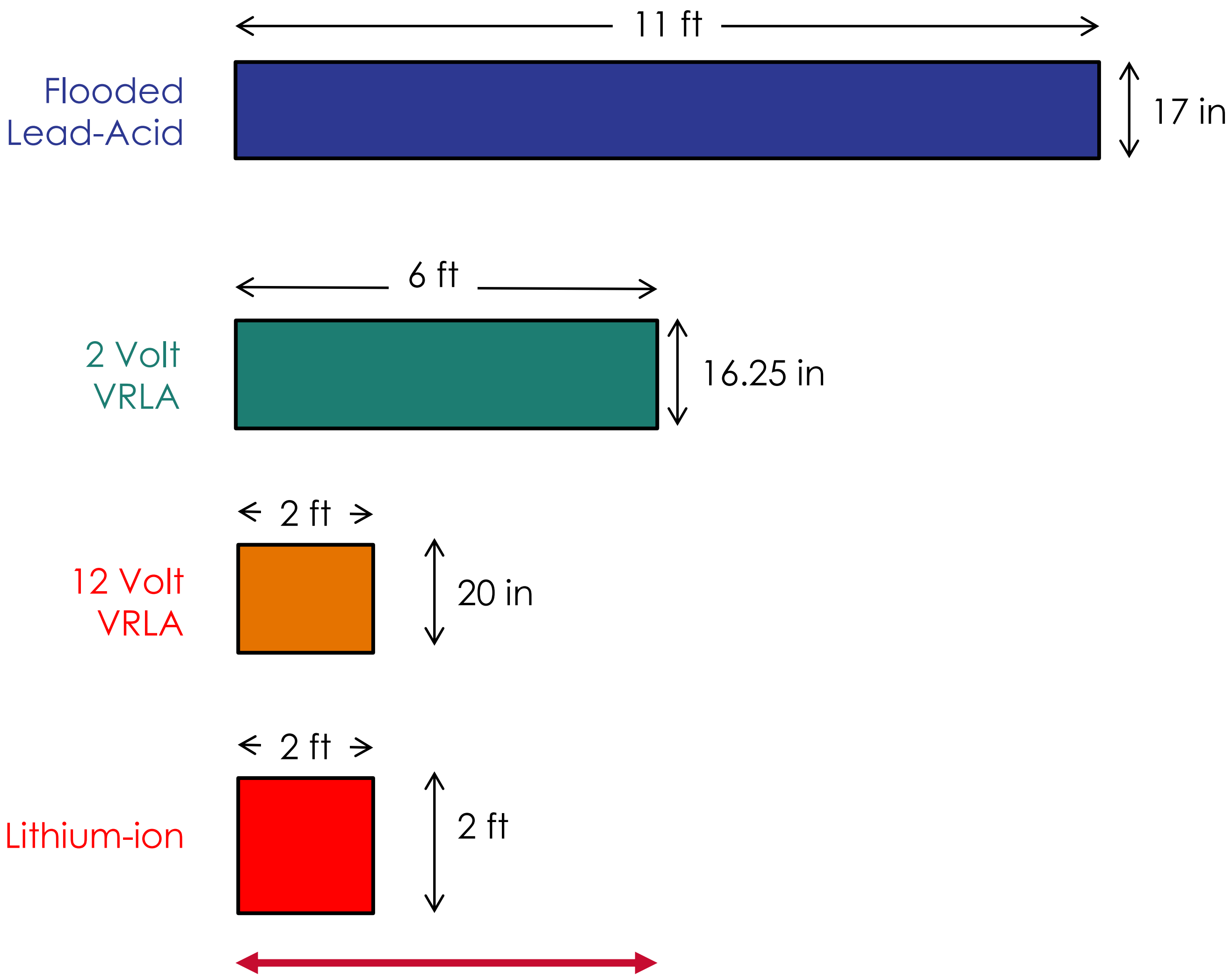
- There is no lithium-metal in a lithium-ion battery!
- A battery that uses lithium-ions as the species that is exchanged between electrode layers
- Lithium-ions are so small that they fit between the atoms of the anode and cathode materials
- Lithium-ions move between the anode and cathode through the separator
  - Lithium is in the anode when the battery is charged
  - It moves to the cathode as the battery discharges
  - Charging the battery drives the Lithium back into the anode



Li-ion battery - Advantages

- Compared to the latest generation lead-acid batteries, lithium has advantages in performance
  - Half the weight
  - Half the volume
  - Higher cycle life
  - Larger temperature window
  - Higher round trip efficiency

Footprint Comparison – 400AH, 8 Hrs



8 ft to meet NFPA 855*

120 volt / 60 cells
1 x 11 ft 2-tier rack

120 volt / 60 cells
10 wide x 6 high configuration

120 volt / 60 cells
4 wide x 3 high configuration

120 volt system with BMS

*NFPA 855 requires 3ft of clearance on all sides for lithium-ion

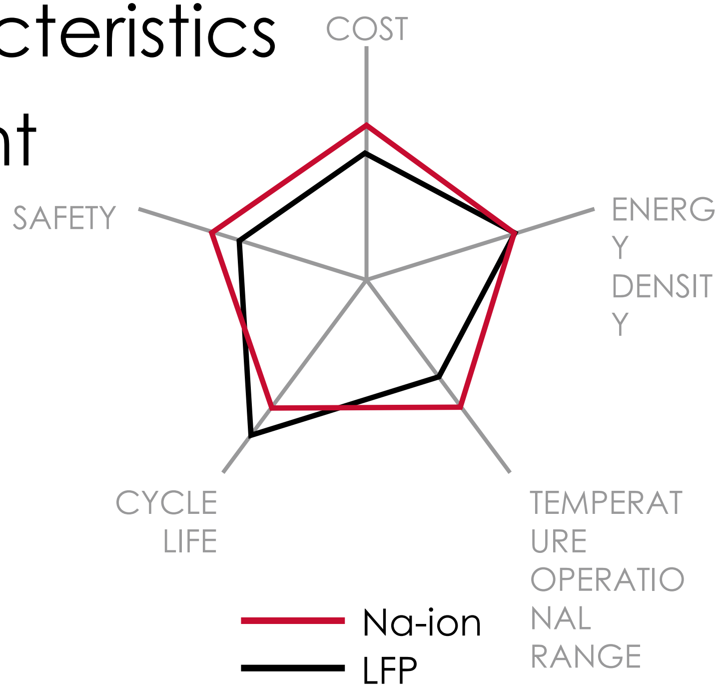
Li-ion battery - Disadvantages

- Operation windows are strict and inflexible
  - LVD is built in and can't be bypassed
  - High temp will disable battery
  - High rates cannot be accommodated

- Existing charger may not be compatible
- BMS introduces electronic failure modes
  - Single points of failure per module
- New Codes for deployment increase installation and site prep costs
- Most insurance carriers have increased coverage premiums

Alternative battery technologies: Sodium-ion

- Lithium Ion alternative
- Raw materials are abundant and free of cobalt
- Precursor materials are lower cost compared to lithium ion
- Improved safety, storage, and transport characteristics
- Manufactured on existing lithium ion equipment
- 18650 and pouch form factors
- Available voltage range: 0v - 4.3v
- Energy density:140 -155 Wh/kg
- Energy efficiency: 92%
- Temperature range: -20°C to +60°C



Advances in VRLA battery technology

- Multiple benefits of the **advanced TPPL technology**
- Same cell dimensions as OPzS and OPzV for **easy replacement on existing racks**
- **Alleviate lifting weight concerns**: 44 lbs for 320 Ahr & 53 lbs for 400 Ahr cells
- **Simple installation**, **safe** (classed as non-spillable battery) and **reliable** operation (field proven) as well as **ease of recycling**
- Cell installation in **horizontal and/or vertical orientation** for maximum installation flexibility
- High energy density: **more Ah capacity in given footprint or reduced installation space**
- Wider operating temperature range (-40F to 122F) & Flame retardant material

High Purity & High Grade Materials in TPPL VRLA batteries

Low rate of self-discharge
=
Shelf life typically 4x longer than conventional AGM battery

Low float charge current
=
Less energy consumption and reduced OPEX

Low rate of grid corrosion
=
Longer design life than standard AGM battery

Low gassing rate
=
Reduced water loss

The careful selection of high purity and high grade materials greatly contributes to the **longer shelf life**, **lower OPEX/TCO**, **longer service life**, and **more reliable performance** products

Eliminates the need for watering –
Reduces truck rolls –
Saves maintenance cost

Where is TPPL used in Utility?

48V Communications applications

48V & 120V switchgear applications

250V Industrial UPS applications

Summary

- Lead acid batteries dominate the switchgear & control applications
- VLA batteries are still very popular, but VRLA batteries are making inroad
- Alternative battery technologies are progressing, but not be ready for primetime yet
- Reliability and safety is paramount!

Thank you.

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