WHAT IS THE BEST RECHARGEABLE BATTERY?

- **LOW CAPACITY BATTERIES – PORTABLE DEVICES**
- **HIGH CAPACITY BATTERIES –VEHICLE & SYSTEMS/UPS**

IMPORTANCE OF BATTERIES

Backup power and portable operation of systems/devices

Consider battery system design to accommodate mains power loss w/sufficient capacity

Batteries are considered one of the most frustrating elements of a system causing concern

Batteries are the most expensive and least reliable component of a portable device/system

One needs to understand the personality of the battery

- Characteristics/temperature
- Load control/discharging
- Maintenance/charging

LOW CAPACITY RECHARGEABLE BATTERY TYPES – FEATURES

Nickel Cadmium (Ni-Cd)

- Longest Cycle Life
- Memory effect
- High current output
- Not Bio-degradable

Nickel Metal Hydride (NiMH)

- Longer duty cycle with minimum memory effect
- Environmentally friendly
- Sensitive to low temperature
- High self-discharge rate and shorter cycle rate than Ni-Cd

NICKEL CADMIUM (NiCd) BATTERIES
>> NOT ENVIRONMENTALLY FRIENDLY<<

- **Charge voltage: 1.3-1.42 vdc per cell**
- **Fixed low current charges such as 0.1C w/limit of 10-20 hours maximum**
- **Battery does not perform well in continuous duty applications with no full discharges**
- **Automatic chargers must detect and react to battery temperature to turn on/off charge**
- **Output voltage is 1.25V cell with medium internal resistance**
- **Memory effect occurs when complete discharges do not occur (not all chemistry is used)**
- **Self discharges ~10% in first 24 hours then stable discharge based on load**
- **Performs well in low temperature applications**
- **Long life with proper battery exercising and high discharge rates are possible**

NICKEL METAL HYDRIDE (NiMH) BATTERIES
>> GENERALLY REPLACES NiCd <<

- **Charge voltage: 1.4-1.6 vdc per cell**
- **Fixed low current charges such as 0.1C w/limit of 10-20 hours maximum**
- **In continuous duty applications, pulse of higher current when battery drops below 1.3V**
- **Automatic chargers detect slight voltage drop when nearly full or use battery temperature to turn on/off charge**
- **Battery output voltage is 1.25V cell with a very low internal resistance**
- **Almost no memory effect**
- **Best used with low current draw loads**
- **Has replaced NiCad batteries except in low temperature applications**

TEMPERATURE/CAPACITY & CYCLES
>Ni-Cd wins low temperature for portable batteries<

Temperature	Ni-Cd	Ni-MH	Li-ion
115° F	90%	85%	85%
100° F	95%	85%	105%
70° F	100%	100%	100%
32° F	80%	85%	80%
0° F	65%	10%	15%
Cycles/Life – 80% Capacity	500-700	300-500	300-700

BATTERY CHARGING
NiCd & NiMH

- Slow recharge is always better than a fast charger, helping to redistribute the chemicals
- Fast recharge can be used for first 70% and then taper with a slow recharge
- Smart chargers can burp the battery during the first 70%, allowing gases to recombine
- Charging a battery above 113 degrees F is detrimental and can cause early failure
- Trickle charge of 0.05C can be used to overcome battery self-discharge
- Utilize a "smart battery" for longest life
- NiMH charger can be used for NiCd batteries also

EXTENDING BATTERY LIFE
NiCd & NiMH

- Never allow a nickel-based battery in a charger more than 24 hours after full charge
- Monthly, discharge a nickel-based battery fully so chemistry remains fully active
- Do not do a discharge each battery before every charge
- US Navy found they could extend battery life by 40% following a normal discharge/recharge cycle, i.e., using the battery until it was exhausted before recharge
- Avoid elevated temperature, especially during recharging
- Many NiCd batteries can be recovered, upwards of 50% - 70% & NiMH about 40%

HIGH CAPACITY RECHARGEABLE BATTERY TYPES - FEATURES

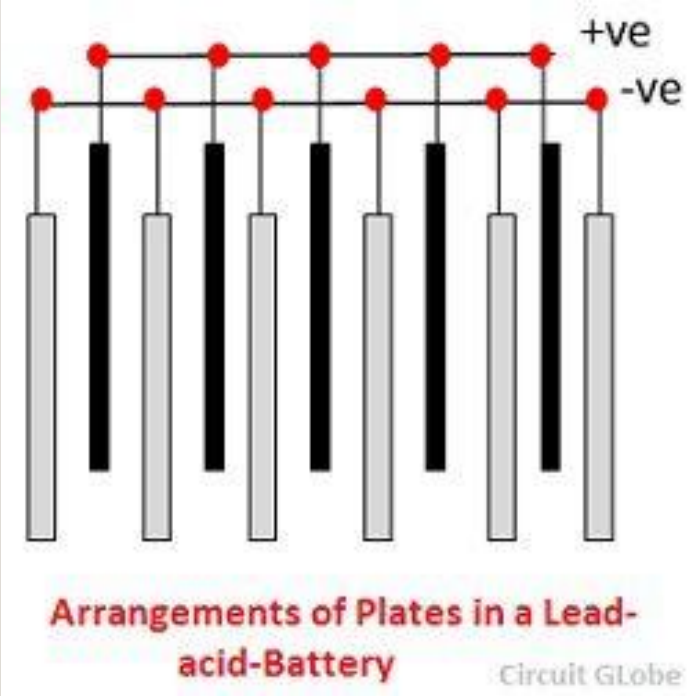
- **Lead Acid – Wet (Flooded), Deep Discharge, Sealed (SLA) and Absorbed Glass Matt (AGM)**
  - **Lowest initial cost** — **However – Highest long-term cost**
  - **Greatest weight (lead)** — **However – Very recyclable**
  - **Somewhat forgiving**
- **Lithium-ion Phosphate**
  - **Light-weight** — **However – Very low tolerance to heat**
  - **Long talk/standby time** — **However – Highest cost**
  - **Very high energy density**
  - **Longest duty cycle** — **Note: Overcharge/discharge protection REQUIRED**
  - **No memory effect**
  - **Environmentally friendly**

THE BASICS
CHARGING & DISCHARGING

- **Amp-hour (AH) ratings:**
  - **Lead Acid, 105AH, provides roughly 50% or 50AH with voltage dropping to 12.3V**
  - **105 AH means about 10 amps for 10 hours discharged to 10.5V => BATTERY KILLED**
- **What is the C/10, C/20, etc. rating? This has to do with charging the battery**
  - **C/10 is ten hours at 10 amps while C/20 is 20 hours at 5 amps**
  - **Manufacturer states max. rate for charge – DO NOT EXCEED**
  - **A fast charger can easily kill a battery in 20 minutes if battery is dead**
- **~30% loss of capacity when below 32 degrees F (0.1% per 10 degree drop)**
- **>> NEVER STORE A LEAD ACID BATTERY in an UNCHARGED STATE <<**

FLOODED LEAD ACID

- **Suspended plates immersed in liquid electrolyte (adding water when needed)**
- **Requires plates to be immersed completely**
- **Spillable thus operable upright only**
- **Sulfates easily when partially discharged**
- **Deepest discharge possible for recovery**
- **Always fully recharge immediately after use**
- **Cheap and have a long cyclic life**
- **Car batteries**



SEALED LEAD ACID – SLA (GEL BATTERY)

- **Positive Plates – Lead dioxide**
- **Negative Plates – Sponge lead**
- **Electrolyte – Sulphuric acid and gelling agent, no water**
- **During Discharge – Lead and lead oxide convert chemically to lead sulphate and water**
- **Recharging – The above action is reversed with the sponge allowing re-combining**
- **Undercharging – Allows some of the lead sulphate to not re-combine, thus crystalize and lowering of capacity**
- **Self-discharge Rate – About 5% per month, thus recharge at 70% of total charged battery**
- **Max battery charge voltage is 14.1 volts with float at 13.65 volts**

ABSORBED GLASS MATT - AGM

- **Longest lasting lead acid battery but needs careful attention to charge/discharge**
- **Dense fiber between the plates, thus much more rugged than SLA/GEL**
- **Sealed – cannot add water**
- **Very sensitive to overcharge thus battery temperature must be limited**
- **Max battery charge voltage is 14.38 volts with float at 13.6 – 13.8volts (13.65 best)**
- **Requires an AGM voltage regulated charger or early failure will occur**
- **Most expensive of the lead acid batteries**

LEAD ACID
TYPICAL NO-LOAD VOLTAGES

Wet (Flooded) and Deep Discharge, Sealed (SLA) and Absorbed Glass Matt (AGM)

Voltage	Description
≥12.6 VDC	Fully charged resting voltage
	Attempt to not get below 12.5 VDC
12.3 VDC	About 50% of useful capacity exists – Recharge needed!
<12 VDC	Battery is dead and likely not recoverable

Note: Ensure battery has stabilized about 2-3 hours before measuring after charging.

DEFINING BATTERY INTERNAL RESISTANCE

- Internal resistance is a term used but it is really impedance
- A battery as a power source represents Ohmic Resistance (R) in series with a parallel circuit consisting of Induction (L) and Capacitance (C)
- Most designs only talk about Internal Resistance (R)
- Computing internal resistance
  - Measure the no-load E
  - Load the battery and measure the battery voltage (E) and current flow (I)
  - Result: R = (no-load E – loaded E) / I
  - R is then considered to be series with the actual load thus reducing voltage to the load

LEAD ACID
TYPICAL INTERNAL RESISTANCE vs. LOAD

Flooded, Deep Cycle, SLA & AGM

Type	Description
Flooded	Lowest internal resistance, provides greatest short-term high energy – starting engines
Deep Cycle	Higher current applications capable of withstanding voltage drop over time such as trolling motors. Higher internal resistance than Flooded.
SLA	Reasonably low internal resistance thus used for long term low current applications (alarm systems and small UPS)
AGM	Same as SLA but can hold a lower internal resistance during load. Used for high end UPS systems and can be designed for high short currents.

TYPICAL CHARGING METHODS – LEAD ACID SLIDE 1

- **Constant-current** – Preset current is applied over a set period of time, typically 0.1C and generally requires 12 hours or more. This method is not widely used for lead acid.
- **Constant-voltage** – The method creates a high initial charge current, possibly exceeding battery maximum. Thus, like constant-current, is not generally used for lead acid. Though it is used as a maintenance charge (TRICKLE) for stand-by applications.
- **Modified constant-voltage** – In this method a set constant-current (BULK) is applied until a preset voltage is obtained, then constant-voltage (ABSORPTION) slightly below gassing voltage. Once this known voltage is reached, the charge voltage drops to the FLOAT level (13.6V) and continues.

CHARGING – LEAD ACID BATTERIES SLIDE 2

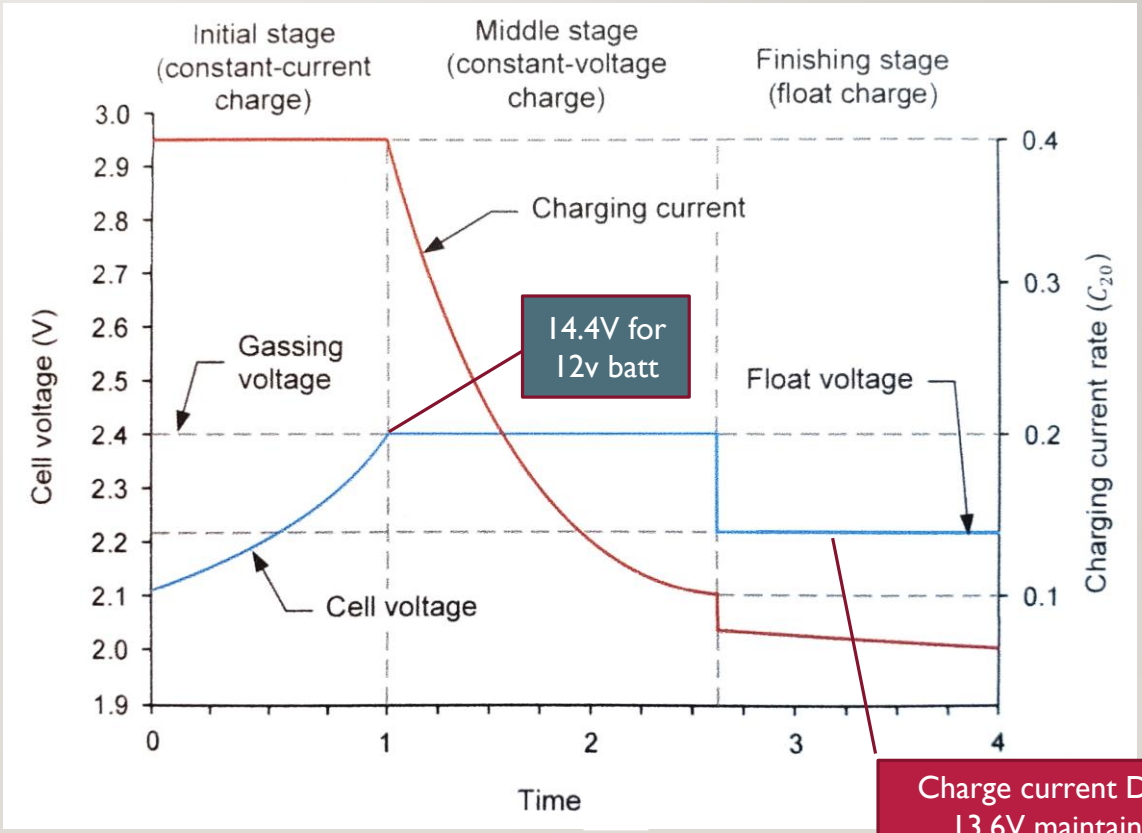
- **3-4 Stages**
  1. **Bulk (Boost) – Constant current and increasing voltage which stops based on terminal voltage**
  2. **Absorption – Charging voltage drops and is held for a controlled period of time**
  3. **Float – Battery at full charge but current is allow to trickle into the terminals to hold voltage**
  4. **Equalization – This state comes on about every 7 days to reduce acid sulfate stratification**

Voltages	**Flooded**	**SLA/GEL**	**AGM**
Bulk:	**14.8V**	**14.1V**	**14.4V**
Absorption:	**14.2V**	**13.65V**	**NA**
Float:	**13.6V**	**13.6V**	**13.6V**

Notes:
1. Equalization stage only with flooded batteries
2. Overcharging is quickest way to kill battery

LEAD ACID BATTERY CHARGING TECHNIQUES SLIDE 3

- Modified constant-current – both constant initial current and constant finishing charge with a just under gassing voltage until current drops below 0.1C, then a float voltage.
- Initial charge is bulk and gets battery to 80% max capacity.
- Absorption, 2nd phase, takes a long-long time (10-12 hours).
- Float, fixed voltage charge then maintains.



CHARGING – SLA/GEL AND AGM BATTERIES SUMMARY

SLIDE 4

- **Charging Methods:**
  - **Constant voltage – most common but difficult to create the right amount of current**
  - **Constant current – solution only good for a single 2V cell, not a battery with multiple cells**
  - **Taper current – not recommended for SLA but sometimes used due to low cost**
  - **Two stage constant voltage – the most recommended solution for fast and float charge**
- **Other Factors to Maintain the Best Charge and AH Capacity**
  - **Battery temperature must be accounted for during charging with the 2-stage solution**
  - **68-77 degrees F maximum**
  - **Battery looses about 5% charge per month due to its internal resistance**
  - **A bad cell can alter performance and even reverse its polarity**

MAINTENANCE – LEAD ACID BATTERIES

- Leading Cause of Failure – Sulfating, Excess Gassing and Undercharging
  - Sulfating is when lead crystals form on charging plates thus making charging difficult
  - Undercharging exacerbates sulfating and leads to early battery failure
  - Long term storage when undercharged is quickest way to early failure
- Proper 3-Stage Charging is the Answer [Bulk (Boost) > Absorption > Float]
- Excessive Heat Causes Early Failure
- **If the battery rises from discharged (<12V) to fully charged (13.6V) quickly, the battery is very likely bad**
- **If the battery is recharged and left to sit 24 hours with no load and voltage is <12V, it is very likely dead**
- **If the battery is under charge and the terminal voltage quickly rises to say 14 volts in 4-5 minutes, its likely dead**

TEMPERATURE EFFECTS LEAD ACID BATTERIES

- % Loss of Capacity per day
  - 0 degrees – 0.025%
  - 60 degrees – 0.123%
  - 100 degrees – 0.5%
  - 140 degrees – 1.5%
  - 180 degrees – 5.0%

- **Batteries used in vehicles in Texas and Florida have a much shorter life than in the cold of the Midwest and Canada.**
- **For every 15 degree increase above 77 degrees => battery life is cut in half.**
- **For every 10 degree drop => battery voltage drops 0.10 volts.**

- High temperatures also cause the positive battery grid to deteriorate faster

DEEP CYCLING LOAD OF LEAD ACID BATTERIES

- **Deep discharge cycle below 50% of battery capacity causes damage**
- **Only 50 AH should ever be used from a 100 AH battery before recharge**
- **Remember a 100 AH battery really provides only 80 AH (80% of manufacturer rating)**
- **Doing the numbers, a 105AH AGM battery will provide only 84 AH and half of its full capacity is 42 AH**
- **Battery at 50%: Terminal voltage of 12.35 volts – cutoff circuit to save battery**
- **Typical no-load resting voltage of fully charged lead acid battery is 12.6 volts**

WHICH LEAD ACID BATTERY IS BEST FOR LONG TERM USE? IT DEPENDS ON INTENDED USE!

- **AGM is unable to take on a high current spike, plates can break down**
- **AGM batteries do not leak & can be installed in almost any position**
- **AGM costs about 40% more than flooded, however they are sealed**
- **AGM have low self-discharge rate thus excellent shelf life**
- **AGM is better than deep discharge battery in cold weather**
- **AGM has about the same life as a flooded or deep discharge lead acid used in the same**

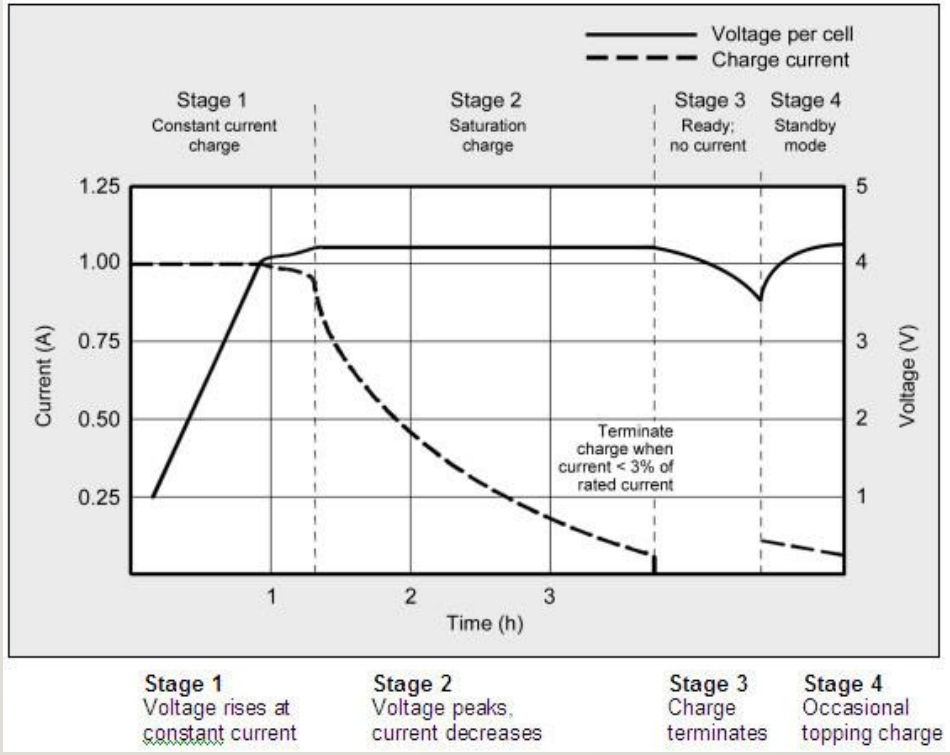
Assuming battery use is not for vehicle starting, rather long-term power draw.

LITHIUM ION PHOSPHATE ($LiFePO_4$)

- Produces 12.8 vdc (four 3.2 volt cells in series) – almost no drop in voltage with use
- 85% - 90% usable energy, easy to charge and half the time of lead acid
- Charge max 3.65 volt/cell (can be charged series or parallel)
- Extremely long life compared to other choices
- Half weight of same physical size lead acid battery
- Requires battery management system (BMS)
  - Each cell needs to be separately managed (charge and discharge)
  - Low temperature (below freezing) charging is not acceptable
  - Cell equalization for greater AH output
- **Low cut off is 10.0 volts vs. ~12.3 volts for lead acid**

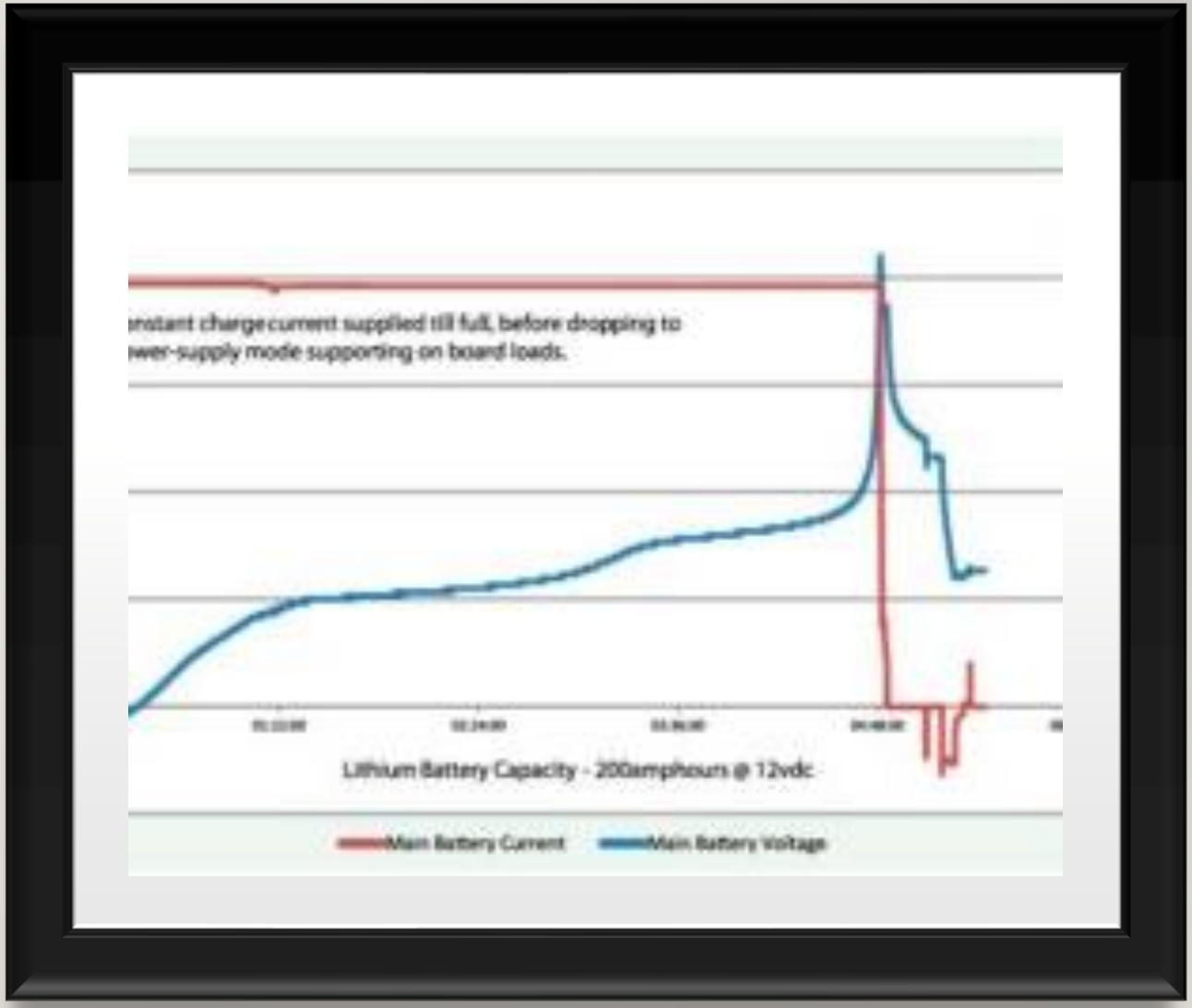
CHARGING LITHIUM ION CELLS SLIDE 1

- **Each cell has a battery management system (BMS) to ensure max voltage not exceeded**
- **Charging:**
  - **Requires higher voltage output that a lead acid battery charger**
  - **Constant voltage / constant current**
  - **Overheat thermal cutoff switch**
- **Battery likes less than full charge (85-90%)**
- **BMS cuts output with low battery level**

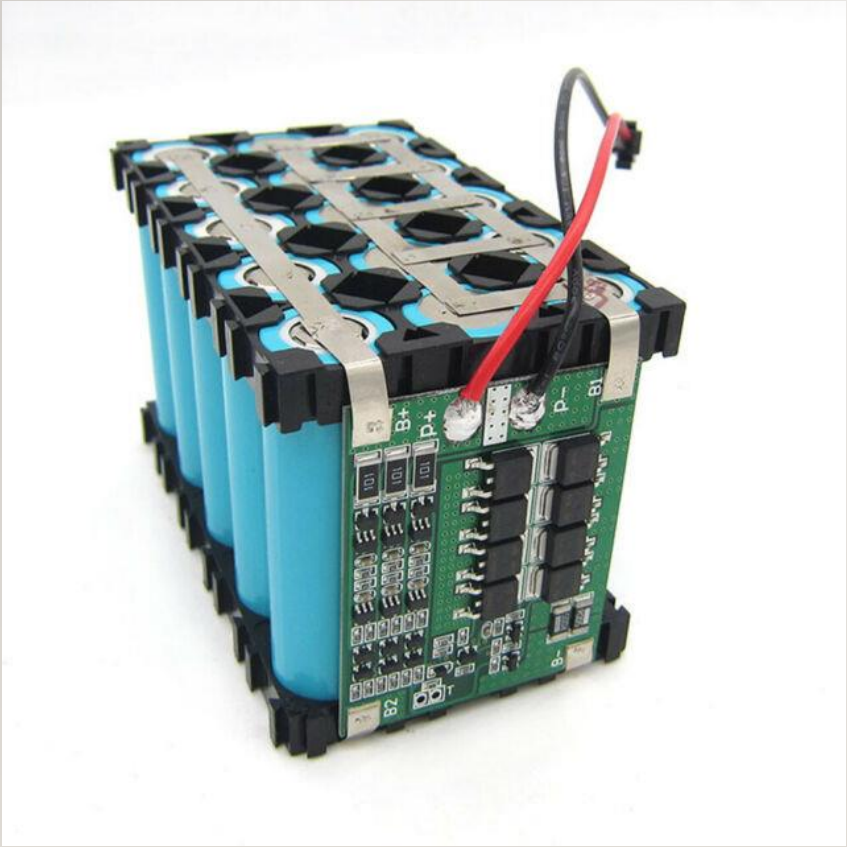


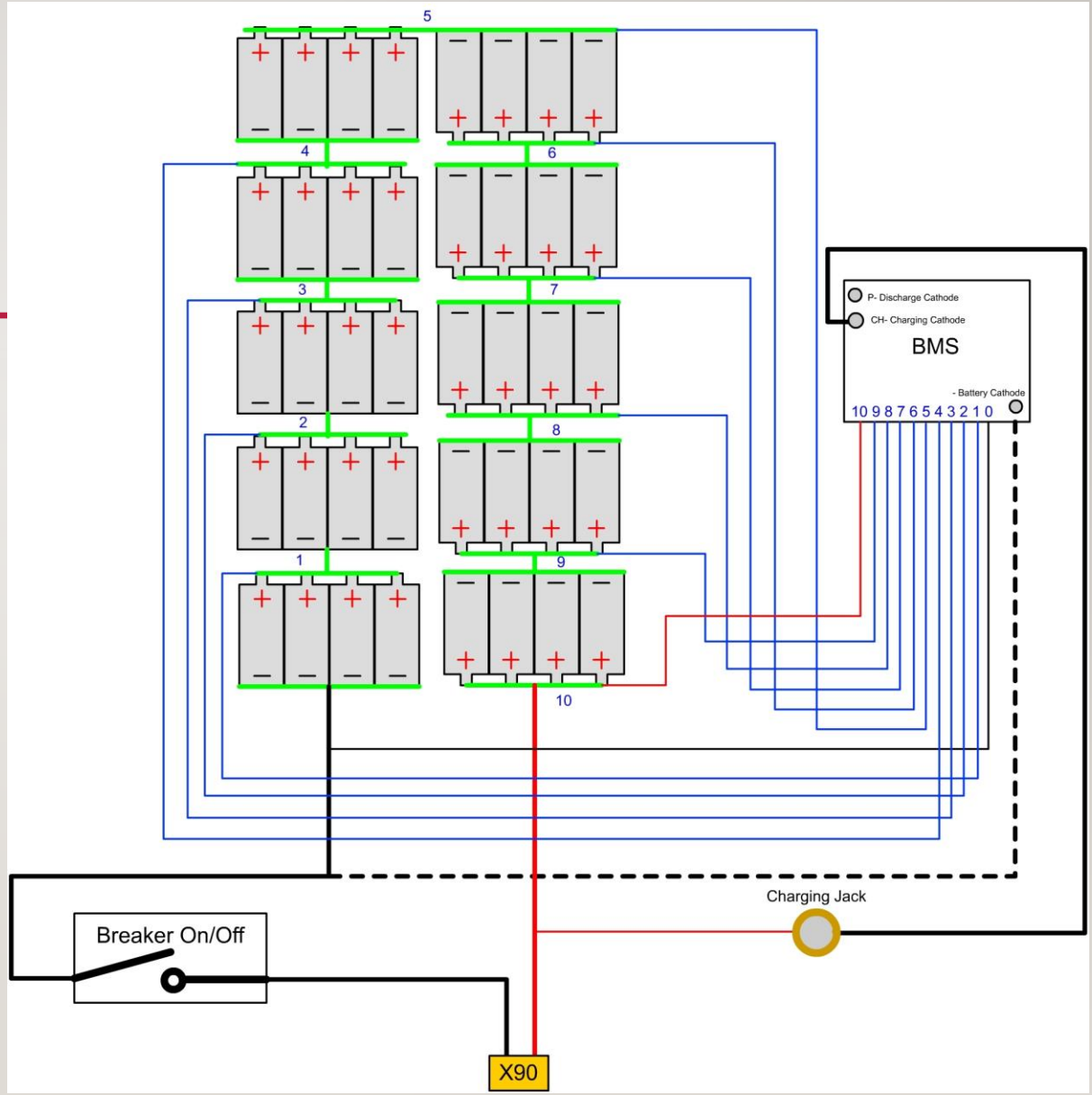
CHARGING A LIFEPO4 BATTERY

- **Lithium chargers use constant voltage/ constant current with careful control**
- **Lead acid chargers offer a 3-stage process – bulk – absorption – float**
- **A lead acid charger can be used only if it does not have an equalization 4th stage**
- **Once battery is charged, the lead acid charger must be disconnected**



BATTERY & BMS SLIDE 3





BATTERY MANAGEMENT SYSTEM (BMS) SLIDE 4

The BMS manages a rechargeable battery (cell or battery pack) by monitoring its state, calculating secondary data, reporting that data, protecting the battery, controlling its environment, and/or balancing it.

A BMS may monitor the state of the battery as represented by various items, including total voltage and/or voltages of individual cells.

- **Temperature: average temperature, or temperatures of individual cells**
- **State of charge (SOC) or depth of discharge (DOD): to indicate the charge level of the battery**
- **State of health (SOH), a variously-defined measurement of the overall condition of the battery**
- **Current: Charge in or discharge out of the battery**

EXTENDING LITHIUM ION BATTERY LIFE SLIDE 5

- ✓ **Maintain battery at room temperature, never charge when hot**
- ✓ **Suggest a high-capacity vs. a spare as batteries age even when not in use**
- ✓ **Partial battery discharges are much better than complete discharge**
- ✓ **About every 30th charge use a full discharge to reduce memory effect**
- ✓ **Best to normally not completely discharge cells below 2.5 volts thus cells internal safety device kills the output at <2.5 volts/cell**
- ✓ **Extended storage of a lithium-ion battery, battery should be at about 40%**
- ✓ **Follow these guidelines and 1000+ charge/ discharge cycles are not unheard of**

BATTERY COST COMPARISON – SAME 100 AH

	Flooded Lead Acid	Absorbed Glass Matt	Lithium Ion
Maintenance	X Not sealed	✓ **Sealed**	✓ **Sealed**
Capacity (Usable Energy)	X 50% (12.3V)	X 50% (12.3V)	✓ **80% (Still at 12V)**
Longevity	X 7-10 Years X ~1000 Cycles	XX 6-8 Years XX ~700 Cycles	✓ **20+ Years** ✓ **~3000-5000 Cycles**
Cost	✓ **$150** X $0.23 / kWh	✓ **$300** XX $0.38 / kWh	XX $1,000 **$0.21 / kWh**

Per Duet Justis, Youtube video, Nov. 23, 2017

MAINTAINING GREATEST BATTERY LIFE - ALL

- **Maintain battery temperature: 20 – 25 degrees C (68 – 77 degrees F)**
- **Avoid deep discharge: 2.05 volts per cell for lead acid and 2.5 volts per cell for lead acid**
  - **Use a battery cut-off of load circuit to ensure cut-off happens to save battery**
- **Never store any rechargeable batteries in a discharged state**
- **Recharge with battery voltage drops:**
  - **12.3 volts for lead acid**
  - **10.0 volts for lithium ion**
- **NEVER OVERCHARGE!**

> Every battery gradually decreases its capacity.
> Battery is exhausted when capacity is at ~65%.

SUMMARY

- Over a 20-year period Lithium Ion Phosp… lowest cost
- Lithium ion phosphat… …60% of lead acid
- Lith… …intains its output terminal …its discharge period
- …ion Phosphate can be recharged faster than …d acid, >90X, due to used of BMS
- Lithium Ion Phosphate has a low temperature problem
- Lead acid batteries can discharge a higher current level than Lithium Ion Phosphate – STARTING!

>>>>>> QUESTIONS <<<<<<

A SHORT QUIZ:

1. What is the voltage of a fully charged 12 volt lead storage battery after 24 hours, with no load?
   - Good _____
   - Dead _____
2. What is the trickle charge of a 12 volt lead acid battery? _____
3. What is the best cut-off voltage for an AGM battery? _____
4. What is the nominal voltage of a:
   - Ni-Cd or Ni-Mh cell _____
   - Lithium Ion cell _____
5. What is the best operating temperature range of any battery? _____
6. What kind of storage battery offers the lowest overall cost?
7. What is the best kind of charger for a lead-acid battery?
8. Should a back up UPS battery be routinely exercised?
9. What happens if a rechargeable battery is stored in an uncharged state?