Lithium vs. Lead

A comparative analysis of Lithium Iron Phosphate and Lead-Acid (flooded, gel and AGM) battery technology for marine applications

Bruce Schwab
Bruce Schwab Marine Systems
Representative for Genasun Lithium Batteries

Overview

- Lead-Acid batteries – A refresher on characteristics, charging, & useable capacity
- Lithium battery technology – an overview
- Lithium advantages
- Typical boat installation: Lead-Acid vs. Lithium
- Comparison of weight, charging, costs
- Care and protection of Lithium systems

Lead-Acid Battery Technology

A refresher …

Lead-Acid Characteristics

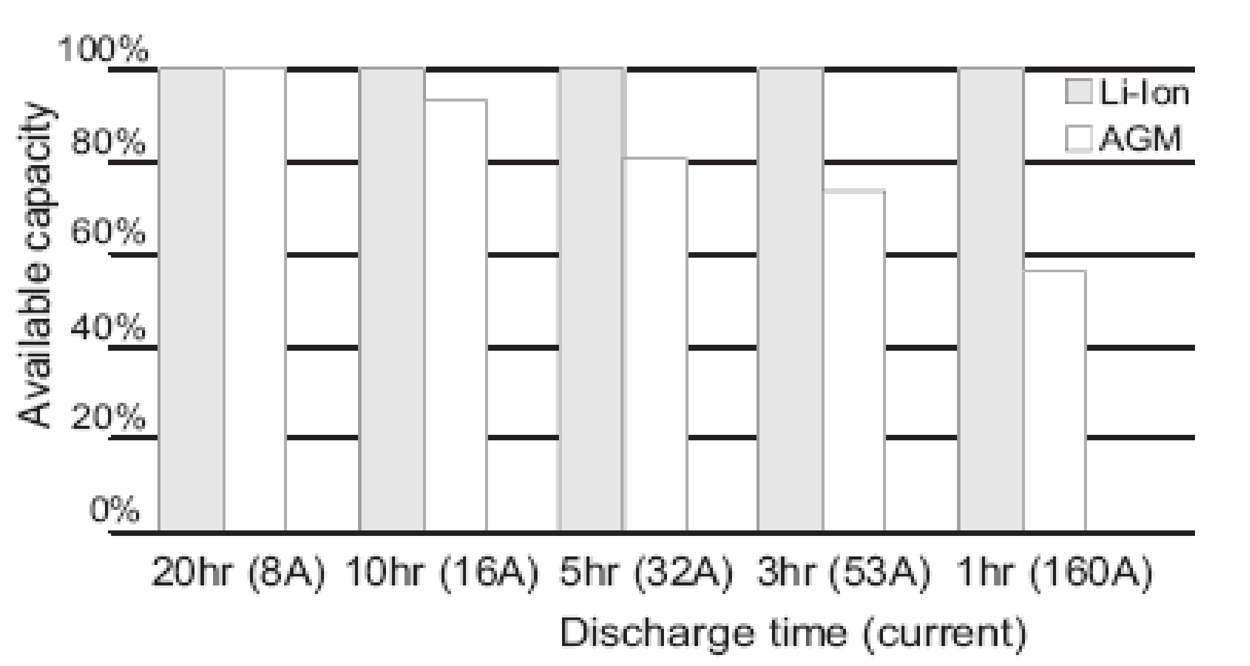
- Lead-Acid includes flooded, gelled & AGM
- Limited "useable" capacity
  - Typically 30-50%
- Limited cycle life
  - Typically 400-500 cycles
- High maintenance
  - Especially flooded cells
- They are really, really heavy

Charging Lead-Acid Batteries

- Smart, three-stage charging is required
  - Poor charge regulation can ruin batteries quickly
- Charging is time (and fuel) consuming
  - Fast charging range is only ~30% of total capacity
  - Final ~20% of total capacity has increasingly slow charge acceptance rate (CAR)
- Yet, full charging is required to prevent sulfation and cell imbalances can greatly shorten life
  - Slow charging sources (e.g. solar & shore power) are needed for topping off (vs. fuel)
- ~15% of amps in are lost due to inherent charging inefficiency

Useable Capacity of Lead-Acid

- Cycle life reduced if depth of discharge (DOD) exceeds 50%
- Top 20% of total capacity is very slow to accept charge
- For fast charging, useable capacity is ~30% of rated capacity
- Fast discharging greatly reduces capacity (Peukert's losses)



Lithium Battery Technology

An overview …

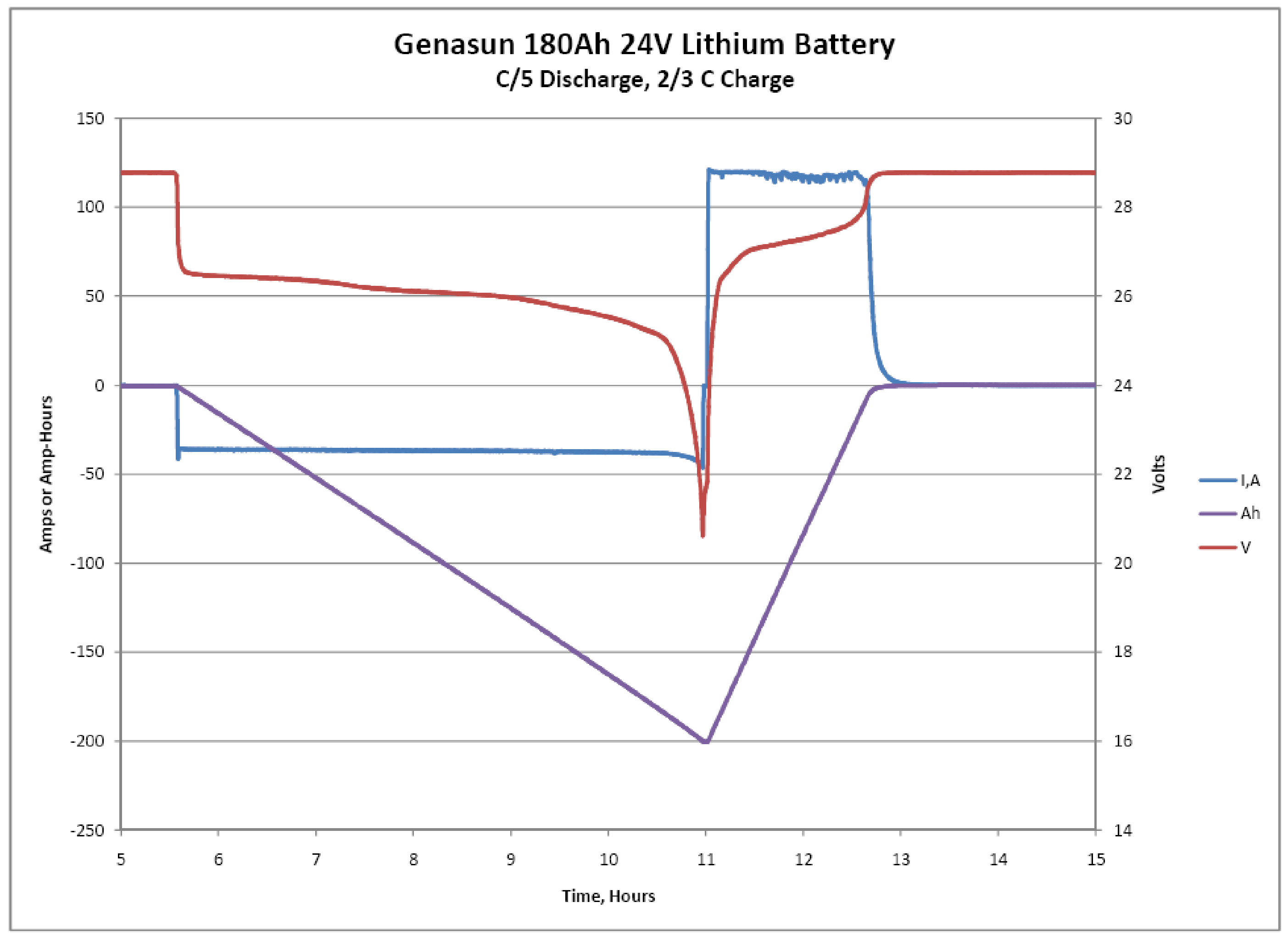
Lithium Ion Flavors - Chemistry & Characteristics

- Lithium-Cobalt-Oxide ($LiCoO_2$)
  - Highest energy density
  - Popular for phones, PC's etc.
  - Risk of thermal runaway in larger systems
- Lithium-Manganese-Oxide ($LiMn_2O_4$)
  - Relatively safe
  - Lower energy density
  - Susceptible to heat decay
- Lithium-Nickel-Oxide ($LiNiO_2$)
  - Great energy density
  - Expensive
  - Environmentally risky
  - Short calendar life
- Lithium Iron Phosphate ($LiFePO_4$)
  - Most stable
  - Good density
  - Long life
  - Economical
  - Genasun, Mastervolt, etc.
- Lithium NMC $Li(LiaNixMnyCoz)O_2$
  - Very high density
  - Expensive
  - Very attractive for propulsion
- Nano-phosphate
  - Very high power density
  - Good for very small starting batteries, etc.

The Lithium Advantage

- Useable capacity is 80% or more of total capacity
- Light weight
  - ~33% of Lead-Acid, ~25% for same useable capacity
- Simple, fast charging
  - Charge acceptance rate up to 3x total capacity
    - Fully charge a 720Ah battery @ 2160A in 20 minutes !
  - Require no temperature regulation of charge voltage
  - Single charge phase. No voltage tapering or float phases necessary
- Extremely high cycle life, 2000-5000 cycles typical
- High efficiency charge and discharge cycles
  - Same amp-hours in as out
  - Greater efficiency for big loads such as inverters and propulsion
    - Less voltage sag in discharge cycle, virtually no Peukert's losses

Lithium Charge-Discharge efficiency



Charging Requirements

- Individual battery cells must be balanced
  - For maximum performance
- Cells and complete banks must be protected
  - From over charge and over discharge
  - From over heating during charge or discharge
- Use without a Battery Management System (BMS) is asking for trouble
  - True of any battery type – Lithium or Lead-Acid

Sizing Comparison…
Sizing Baseline:

- Example house loads
  - 15A @ 12V average consumption = 360Ah total daily use
- Typical house capacity: 720Ah

Typical Lead/Gel/AGM Sizing

- Capacity 720Ah
  - 4 ea 180Ah x 12V AGM
  - Weight ~528 lbs
- Provides ~360 useable Ah and ~500 cycles
- Roughly 30-40% of this useable capacity will be in the fast charging range, so at sea ~250Ah is useable
- Need to charge more than once per day
- Life often less than two years in real world

Typical Lithium Sizing

Same total capacity as Lead

- 720Ah system
- Weight 226 lbs
  - 42% of Lead-Acid
- Provides ~540 useable Ah and lasts >2000 cycles
  - 150% of Lead-Acid
- Charge twice in three days
  - One third as often
- Lasts 7-10 years or more of daily cycling

Same USEABLE capacity

- 360Ah system
- Weight 123 lbs
  - 23% of Lead-Acid
- Useable capacity ~288Ah
  - 15% more than Lead-Acid that's twice as large
- Charge twice per day
- Lasts 3-5 years of daily cycling

Weight Comparison – 12V Analysis

Lead Acid[1]			
Capacity	Useable	Type	Weight
420	220	Flooded	240
392	196	Gel	287
400	200	AGM	260
378	227	TPPL[2]	258

Lithium Iron Phosphate[3]		
Capacity	Useable	Weight
200	160	68
360	288	123
720	576[4]	227

[1]Lead-Acid weighs in at ~0.70 lbs per Ah when measured at the 20hr rate. All above have ~200Ah useable capacity, or ~1.3 lbs per useable Ah

[2]Odyssey TPPL has ~227Ah useable capacity or ~1.1 lbs per useable Ah

[3]LFP weights in at ~.33 lbs per Ah or ~0.42 lbs per useable AH

[4]For 90% of the weight you can have 2.5x capacity!

Cost Comparisons

Based on Q1 2011 Pricing

Cost Comparison (equal total capacity) - TPPL vs. Genasun

Supplier	TPPL	Genasun
Technology	AGM	$LiFePO_4$
Capacity kW-H (Ah x V)	9.072 (756Ah x 12V)	9.216 (720Ah x 12.8V)
Lifetime (cycles)	400 @ ~ 70% avg DOD	2000 @ 80% avg DOD
Lifetime capacity (kW-H)	2540 (x5 = 12,700)	14,746
Cost (USD)	$2,900 (x5 = $14,500)	$14,000
Cost ($/lifetime kW-H)	$1.14	$.95
Charge efficiency	85%	100%
True cost ($/kW-H)	$1.34	$.95
Weight (lbs/kg)	516 / 235	226 / 103

Notes:
Lead-Acid batteries <u>must</u> periodically be fully recharged to prevent sulfation.
Comparison does not include additional costs of replacing the AGM bank five times, increased engine/generator hours or fuel.

Cost Comparison (~equal total capacity) - Typical AGM vs. Genasun

Supplier	Typical AGM	Genasun
Technology	AGM	$LiFePO_4$
Capacity kW-H (Ah x V)	8.64 (720Ah x 12V)	9.216 (720Ah x 12.8V)
Lifetime (cycles)	500 @ 40% avg DOD	2000 @ 80% avg DOD
Lifetime capacity (kW-H)	1,728 (x8 = 13,825)	14,746
Cost (USD)	$1,890 (x4 = $15,120)	$14,000
Cost ($/lifetime kW-H)	$1.09	$.95
Charge efficiency	85%	100%
True cost ($/kW-H)	$1.26	$.95
Weight (lbs/kg)	486 / 240	226 / 103

Notes:

Lead-Acid batteries <u>must</u> periodically be fully recharged to prevent sulfation.

Comparison does not include additional costs of replacing the AGM bank four times, increased engine/generator hours or fuel.

Cost Comparison (~equal useable capacity) - Typical AGM vs. Genasun

Supplier	Typical AGM	Genasun
Technology	AGM	$LiFePO_4$
Capacity kW-H (Ah x V)	8.64 (720Ah @ 12V)	4.61 (360Ah @ 12.8V)
Lifetime (cycles)	500 @ 40% avg DOD	2000 @ 80% avg DOD
Lifetime capacity (kW-H)	1,728 (x4 = 6,912)	7,376
Cost (USD)	$1,890 (x4 = $7,560)	$7,700
Cost ($/lifetime kW-H)	$1.09	$1.04
Charge efficiency	85%	100%
True cost ($/kW-H)	$1.26	$1.04
Weight (lbs/kg)	486 / 240	123 / 56

Notes:

Lead-Acid batteries must periodically be fully recharged to prevent sulfation.

Comparison does not include additional costs of replacing the AGM bank four times, increased engine/generator hours or fuel.

Battery Management System

Requirements and Variations

BMS Requirements

- Cell balancing
  - Preferably full time
- Protect each cell from abuse
  - Over charge
  - Over discharge
- Monitor for over or under temperature
- Isolate battery if any of the above occur
- Alert if there's a problem

Cell Balancing Approaches

- Manual balancing
  - Monitor while charging
  - Bring up lower cells at the end of charge cycle
  - Rather painstaking and error prone
- Simple shunting
  - Circuit boards/diodes on each cell stop charge at pre-set voltage
  - Current must be low, so as not to overwhelm/overheat the boards/diodes
- BMS controlled simple shunting
  - BMS master tells boards/diodes to shunt energy at programmed voltage
  - Current must be low, so as not to overwhelm/overheat the boards/diodes
- Constant BMS balancing
  - BMS balances cell voltage whenever a voltage difference is detected between cells
  - Very accurate voltage monitoring required
- Current redirecting
  - BMS directs current from cells at high voltage to cells with lower voltage

Over Charge Protection - HVC

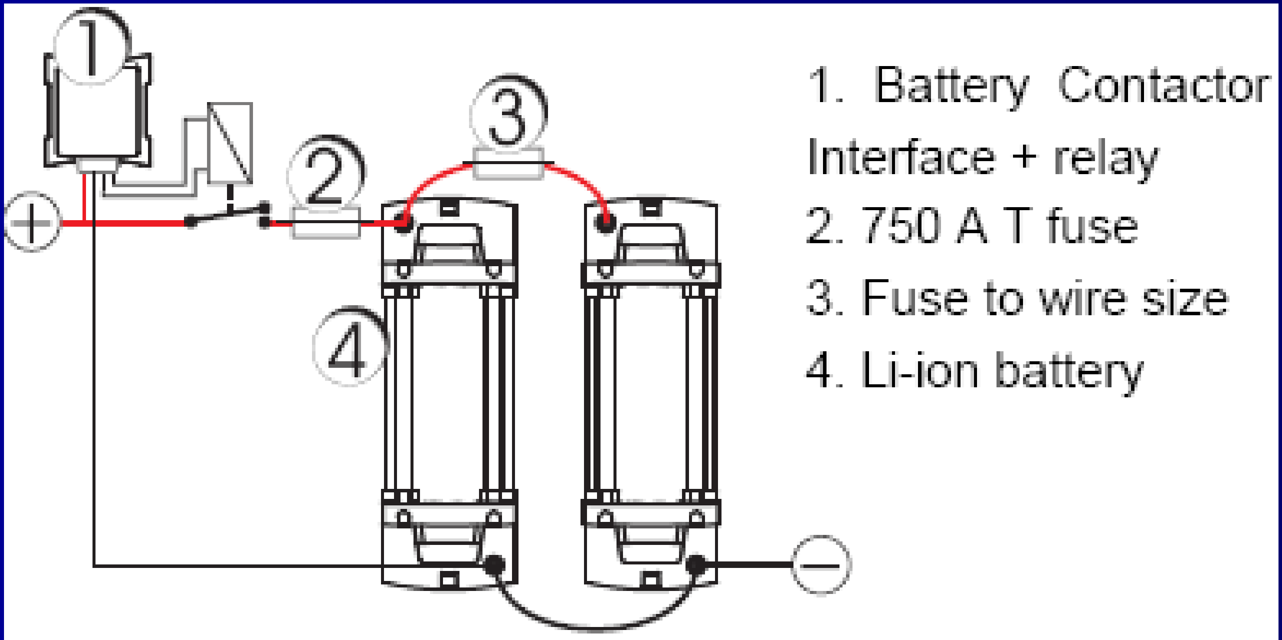
- All charging sources must be regulated
  - At or below the maximum specified system voltage
- BMS should be able to open relay(s) to isolate the battery from charge sources if any device regulation fails
  - Referred to as “High Voltage Cutoff” (HVC)
  - Some utilize one relay per charge source
  - Some utilize network communication to control each source
- Alternators must be turned off prior to opening relay to prevent damage
  - Not all BMSs have this ability
- Loads can be left connected when HVC occurs
  - But some BMSs turn off everything, effectively disabling the boat to save the battery

Over Discharge Protection - LVC

- In general – there should be a monitor/alarm system to track SOC (State Of Charge); with alarm to alert users in case of low SOC and/or low voltage
- BMS must be able to open relay(s) to isolate the battery from loads when low cell voltage is detected
  - Referred to as "Low Voltage Cutoff" (LVC)
  - Some BMSs leave charging sources on when cutting off loads, allowing system to recharge
  - Some BMSs do not have this ability

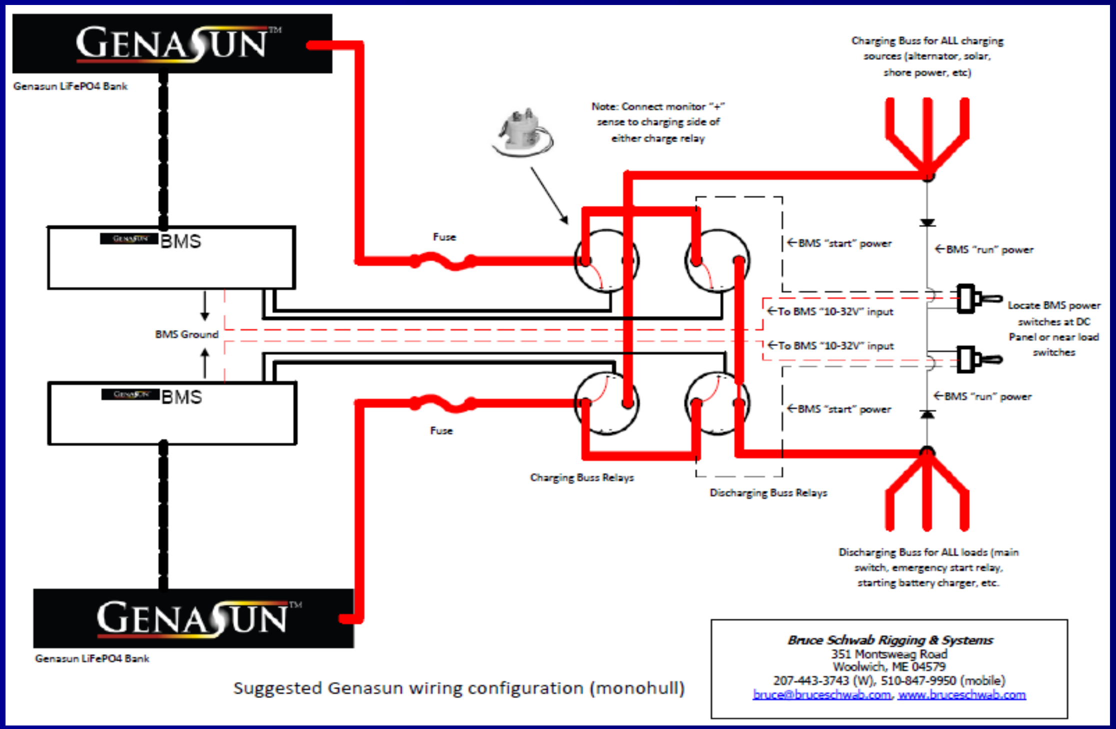
Single Buss BMS

- One positive bus for both loads and charge sources
  - One relay per battery, or one relay for batteries in parallel
- If battery needs to be isolated from charge sources, then loads are also cut off
  - And visa versa



Dual Buss BMS

- Two relays per battery (dual positive busses):
  - One for connection to charge sources
  - One for connection to loads
- Battery can be isolated from charging sources or from loads independently
  - Allows charging even if loads are cut, and loads to stay on if charging cut
  - Prevents charge sources from powering loads directly (without battery as buffer)



What the BMS should do - Summary

- Monitor cell voltages and balance as needed
- Cut off charging sources in over-charging situations
  – But leave load buss on (don’t shut off boat!)
- Cut off loads in over-discharging situations
  – But leave charge buss on so you can charge again
- Turn off alternator before cutting charging buss
  – To protect alternator from running with no load
- Completely isolate battery if it reaches minimum voltage and no charging sources have been activated
  – Note that the BMS itself can drain battery down and damage cells over enough time, so must turn itself off eventually

Thank You

Please contact Bruce Schwab Marine Systems or Genasun if you have any questions or comments

Bruce Schwab Marine Systems
351 Montsweag Rd Woolwich, ME 04579

Web: www.bruceschwab.com
Email: bruce@bruceschwab.com

207-443-3743 (ph/fx), 510-847-9950 (mbl)