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clean energy & sustainable living

The use of Lithium Ion batteries for off-grid Renewable Energy applications. (WS131)

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About RightHand Engineering

Services:

- Off-grid RE power system design
- Contract engineering of specialty circuits for DC power systems & RE monitoring

Products:

- *WinVerter™* series solutions for monitoring residential and community RE systems.

House Keeping

- Please silence noise makers (cell phones, etc.)
- Please take time to fill out the workshop evaluation after the session – it helps MREA and me to improve.
- Some of you may know things about Li-Ion that I may not know. If it can help me or others in the audience, please speak up.
- Try to hold questions to the end so that we don't encroach on the next presenter's time.

Workshop #131 Goal

Lithium Ion batteries have revolutionized the Electric Vehicle industry, and the price of Li-Ion is coming down. Come see how Li-Ion batteries can also improve **off-grid Renewable Energy applications**.

Advanced Level (you'll need to know the meaning of volts, amps, amp-hours, watts/power, watt-hours/energy, impedance)

Outline

- History of Li-Ion Development
- Different types of Li-Ion Batteries
- Uses of Li-Ion in Industry
- The Bad Press about Li-Ion
- My experience of using Li-Ion in my EV
- How Li-Ion compares to Lead-Acid (PbA)
- How Li-Ion can improve off-grid residential energy storage
- Sources of Li-Ion batteries

History of Li-Ion Development

- Late 1970's thru 1980's– research on Lithium-based batteries
- 1991 – Sony commercializes Li-Ion battery – used in cell phones & laptops.
- 1996 – Bellcore commercializes Li-Poly battery.
- 1999 – First Li-Phosphate batteries commercialized.
- 2006 – Lessons learned from laptop fires. (Chemistry matters)
- 2007 – Large format Li-Ion batteries become available to consumers. Primarily used for EVs

Different types of Li-Ion Chemistries

"Lithium Ion" refers to a range of Lithium-based battery chemistry. Examples:

- $LiCoO_2$ lithium cobalt oxide
- $LiMn_2O_4$ lithium manganese oxide
- $LiNiO_2$ lithium nickel oxide
- LiPo lithium polymer
- **$LiFePO_4$ lithium iron phosphate**

Many new types are being developed.

Different types of Li-Ion Formats

- Cylindrical

- Pouch

- Prismatic

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Uses of Li-Ion in the Industry

- Personal electronics (cell phones, laptops, tablets, etc.)
- Portable tools (drills, saws, etc.)
- Electric Vehicles
- Telecom (on-grid backup, and off-grid)

What's missing?

- Residential Renewable Energy (primarily off-grid)

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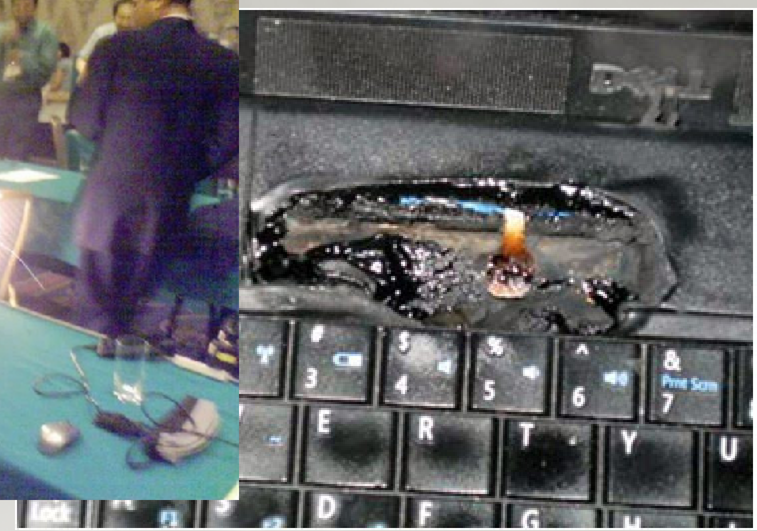
Li-Ion's Bad Press

- 2006-2007 Sony/Sanyo Laptop Battery Recall.



- Chevy Volt fire

My experience using Li-Ion

Featured in Home Power #122, Pg 41-50

- In 2006 I converted a GMC Sonoma mini pickup to electric using Trojan T145 PbA batteries.
- In 2011 I replaced the batteries with 200 Ahr $LiFePO_4$

My experience using Li-Ion

	Before (while using PbA)	After (while using LiIon)
Cost	PbA - $3300 (24 Trojan T-145s) (LiIon - $75,000, 2007 price)	LiIon (w/ BMS) - $15,000 (PbA - $5000, 2011 price)
Usable energy storage	50% of 37 KWhrs = 18 KWhrs	80% of 28 KWhrs = 23 KWhrs
Battery space required	12.3 ft^2	9.5 ft^2
Vehicle weight	5000 lb (1730 lb batteries)	4200 lb (960 lb batteries)
Driving range	30-40 miles*	75 miles
Acceleration	Poor (0-60 MPH in 35 sec)	Good (0-60 MPH in 21 sec)
AC Watt-hrs per mile	Approx 750 whr/mi	Approx 400 whr/mi

- More stable power through nearly the entire discharge curve
- Discharge much more deeply without any significant reduction in longevity
- Capacity isn't affected by sitting idle for several days
- Capacity is affected less by cold temperatures

Lead-Acid (PbA) vs. Lithium Ion (Li-Ion) Comparison

- The “Standard” Golf-Cart Battery (225 Ahr, 6V wet lead acid)

-VS-

- CALB 180 Ahr $LiFePO_4$
- Sinopoly 200 Ahr $LiFePO_4$
- PowerFlux 200 Ahr $LiFePO_4$

Except as noted (*) the following tables contain data from manufacturer’s spec sheets.

How Li-Ion compares to PbA
Size & Weight vs Energy

Characteristics	PbA (Lead Acid)	Li-Ion (LiFePO$_4$ Lithium Ion)					
Reference Battery	Trojan T105	CALB SE180AHA		Sinopoloy LPF200AHA		PowerFlux BATVXLFP200AH	
Cell Voltage – Nominal (V)	2	3.2		3.2		3.2	
Capacity – 20 hr rate (Ahr)	225	180		200		200	
Energy Capacity (Whr)	1350	576		640		640	
Recommended Max Discharge Depth	50%	70%		70%		70%	
Usable Energy Capcity (Whr)	675	403		448		448	
Volume (cm^3)	13188	3605		3605		5048	
Volume (cm^3)/Whr	9.8	6.3	64%	5.6	58%	7.9	81%
Volume (cm^3)/Usable Whr	19.5	8.9	46%	8.0	41%	11.3	58%
Weight (kg)	28	5.6		5.6		6.3	
Weight (kg)/kWhr	20.7	9.7	47%	8.8	42%	9.8	47%
Weight (kg)/Usable kWhr	41.5	13.9	33%	12.5	30%	14.1	34%

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How Li-Ion compares to PbA Discharging

Characteristics	PbA (Lead Acid)	Li-Ion ($LiFePO_4$ Lithium Ion)		
Reference Battery	Trojan T105	CALB SE180AHA	Sinopoloy LPF200AHA	PowerFlux BATVXLFP200AH
Cell Voltage – Nominal (V)	2	3.2		
Capacity – 20 hr rate (Ahr) [C]	225	180	200	200
Recommended Discharge Current	0.2C (45A)	0.3C (54A)	0.3C (60A)	?
Max Discharge Current (A)	500A* (2.2C)	1000A (5.5C <10 sec)	600A (1000A) 3C (5C 10 sec)	600A (1000A) 3C (5C 10 sec)
Min Discharge Voltage/cell	1.75V	2.5V	2.8V	2.5V
Usable Temp Range, Discharge	-20˚C to 45˚C	-20˚C to 55˚C	-20˚C to +70˚C	-45˚C? to 85˚C
Self Discharge	5-15%/month	<3%/month		
Impedance (mΩ)/3.2V	0.2*	0.1*	0.1*	?
Temperature Effect	50% @ -18C. 100% @ 27C	?	92% @ -20C. 100% @ 25C	90% @ -25C. 100% @ 25C

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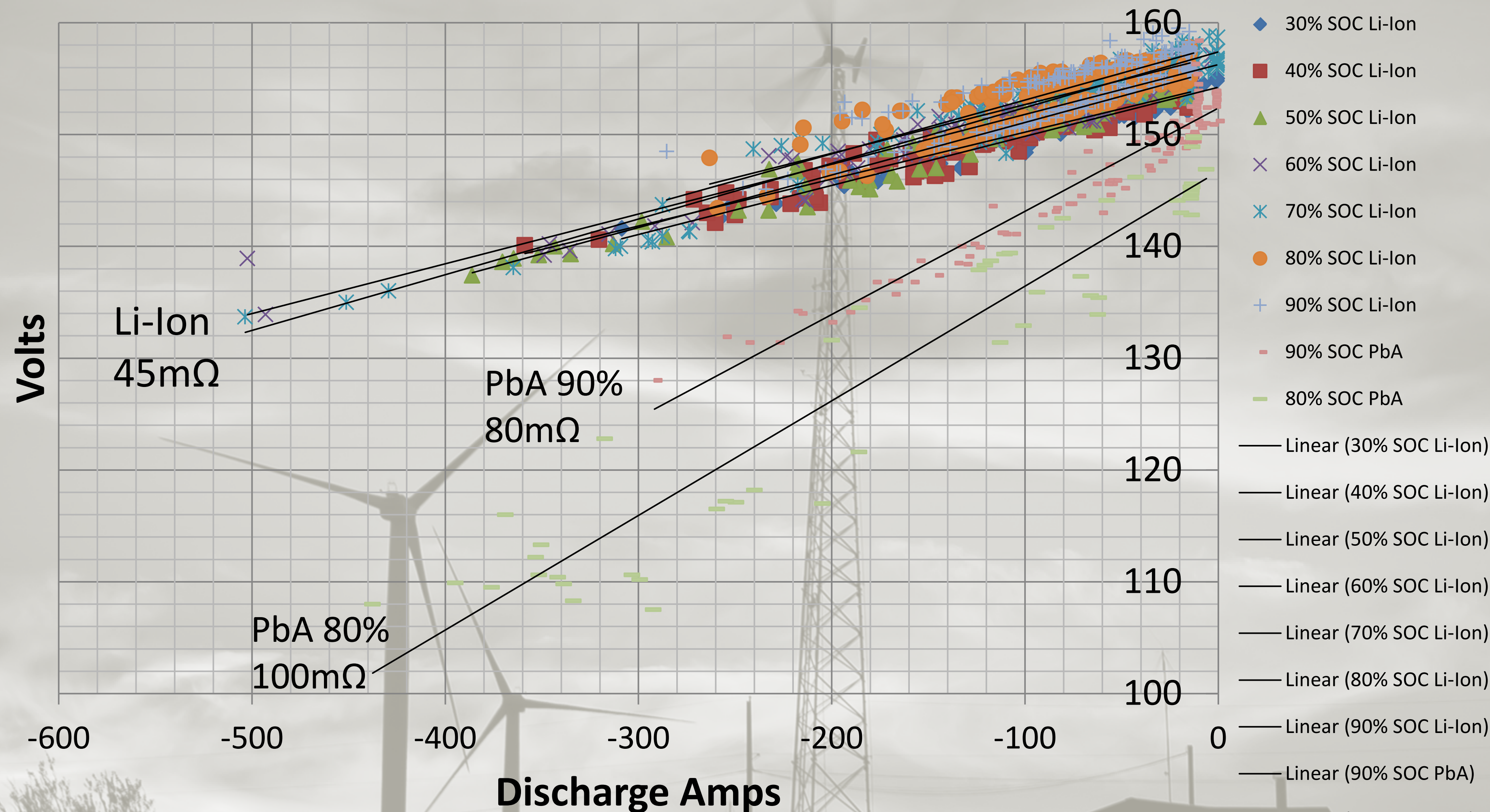
Li-Ion vs PbA Battery Impedance



Data obtained from my EV conversion

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How Li-Ion compares to PbA Charging

Characteristics	PbA (Lead Acid)	Li-Ion ($LiFePO_4$ Lithium Ion)		
Reference Battery	Trojan T105	CALB SE180AHA	Sinopoloy LPF200AHA	PowerFlux BATVXLFP200AH
Cell Voltage – Nominal (V)	2	3.2		
Capacity – 20 hr rate (Ahr) [C]	225	180	200	200
Recommended Charge Current	0.1C (23A)	0.3C (54A)	0.3C (60A)	?
Max Charge Current (A)		?	3C (600A)	?
Max Charge Voltage	2.2/cell Float 2.45/cell Charge 2.58/cell EQ 2.70/cell MAX	3.6V	3.8V	3.9V
Usable Temperature Range, Charge	-4˚C to 52˚C	0˚C to 45˚C	0˚C to 70˚C	-45˚C? to 85˚C

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How Li-Ion compares to PbA Maintenance

- Wet lead-acid requires re-watering 1-3 months.
- Wet lead-acid requires Equalization charging every 1-3 months.
- Lead-acid requires cleaning periodically (acid seeps through porous lead terminals)

(sealed lead-acid has a higher price and lower cycle life than wet lead acid)

- Lithium Ion has no periodic maintenance (except perhaps checking bolt tightness)

How Li-Ion compares to PbA Cost

Characteristics	PbA (Lead Acid)	Li-Ion (LiFePO$_4$ Lithium Ion)					
Reference Battery	Trojan T105 (6V)	CALB SE180AHA		Sinopoloy LPF200AHA		PowerFlux BATVXLFP200AH	
Price*	$145	$261		$290		$260	
Price/Ahr*	$0.64	$1.45		$1.45		$1.30	
Price/Whr*	0.11	0.45		0.45		0.41	
Energy Capacity (Whr)	1350	576		640		640	
Recommended Discharge Depth	50%	70%	80%	70%	80%	70%	80%
Cycle life	750	3000+	2000+	3000+	2000+	5000?	3000?
Usable Energy Capacity (Whr)	675	403	461	448	512	448	512
Lifetime kWhrs*	506	1210	922	1344	1024	2240	1536
Price/Lifetime kWhr*	0.29	0.22	0.28	0.22	0.28	0.12?	0.17?
Longevity	5-7 years	10+ years		10+ years		10+ years	

How Li-Ion compares to PbA Summary

Compared to PbA, Li-Ion has better:

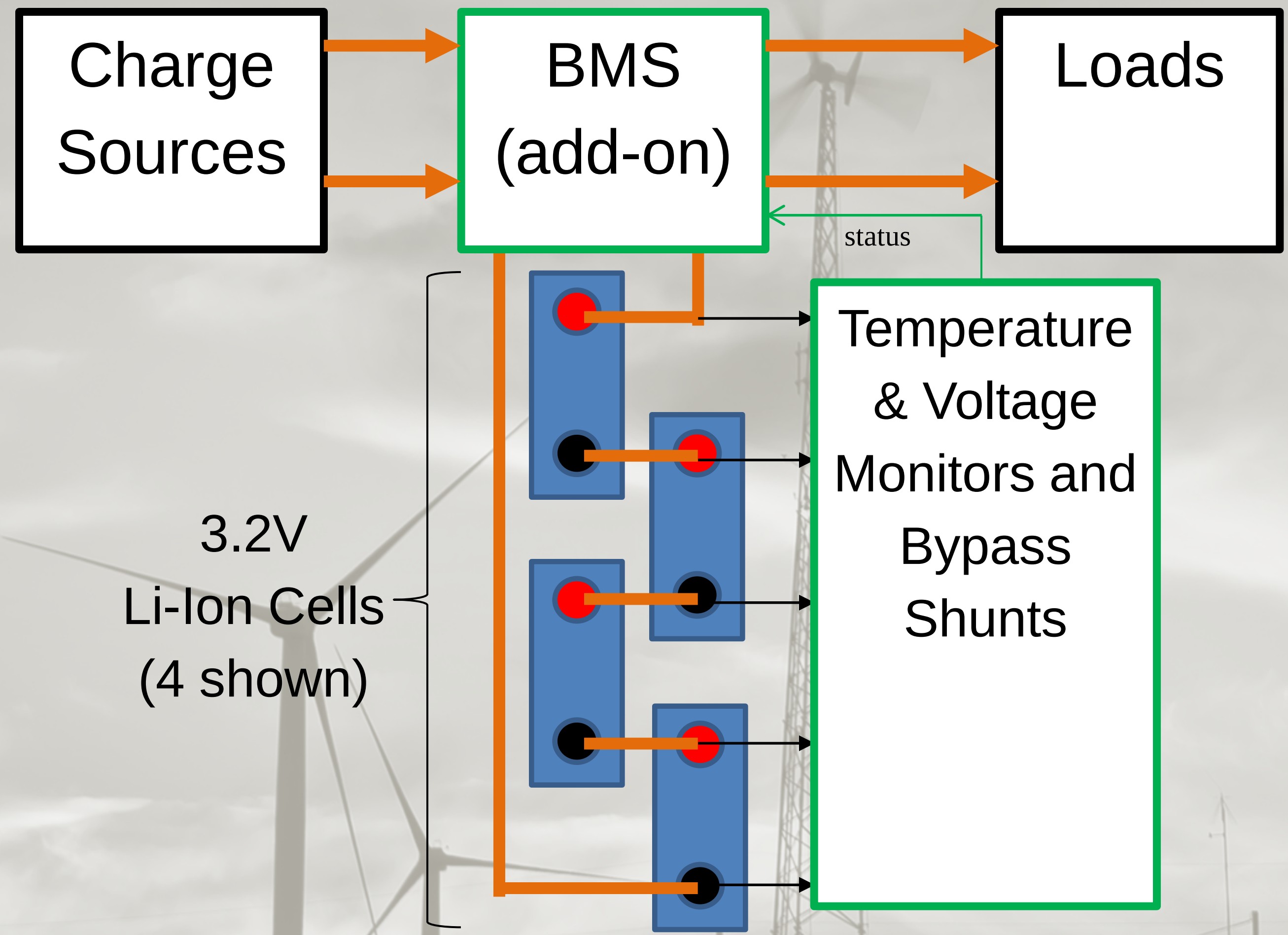
- Weight (1/3 of PbA)
- Space (1/2 of PbA)
- Depth of Discharge (70-80%)
- Low Temperature Capacity
- Discharge & Charge Power
- Self Discharge
- Idle Memory
- Impedance
- Maintenance (none)
- Cycle Life (3000 vs 750)
- Longevity (10 vs 5-7 yrs)
- Lifetime Energy (kWhrs)
- Price/Lifetime kWhr

BUT – you do need a Battery Management System (BMS)

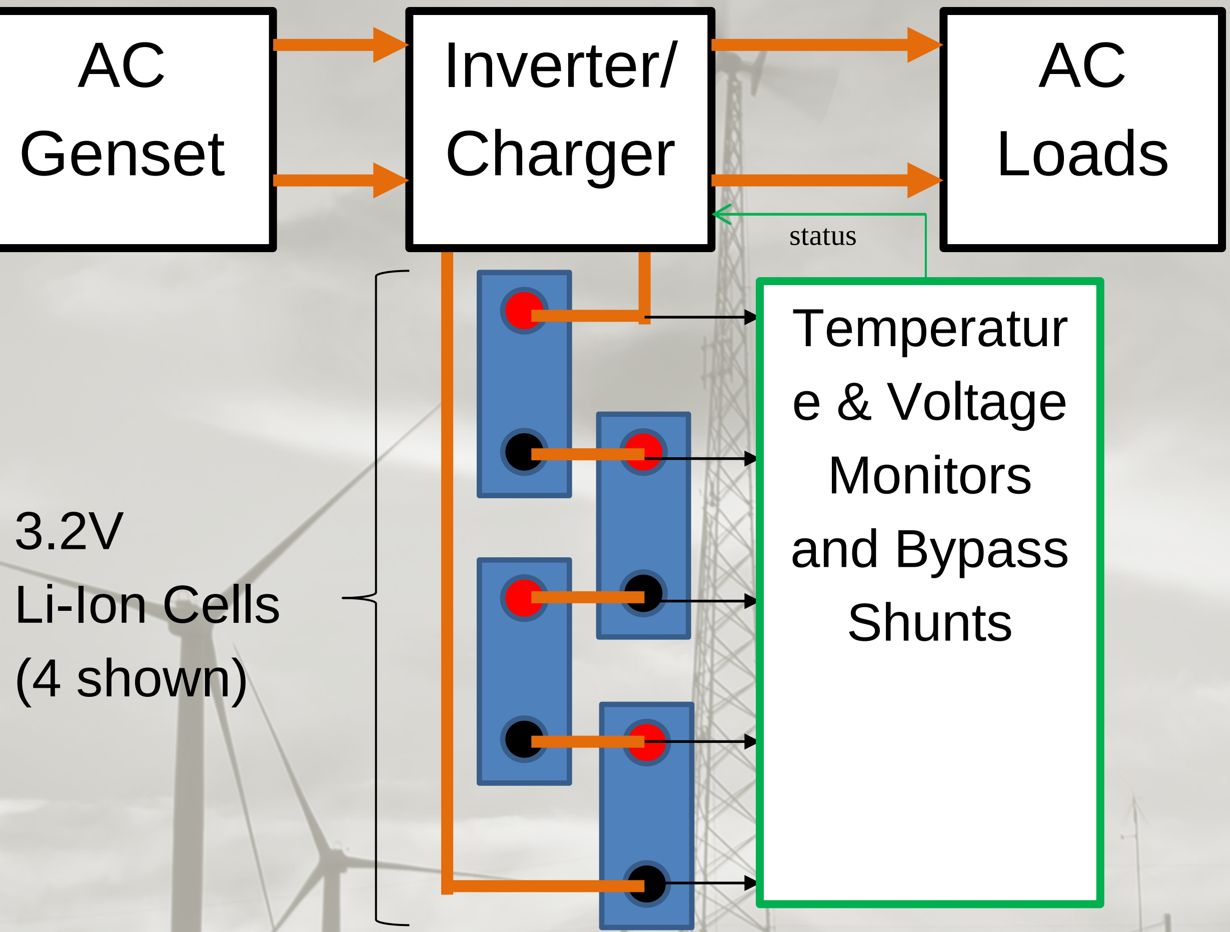
What is a BMS?

- A BMS monitors the voltage and temperature of each individual cell to protect them from excessive charging and discharging.
- When a cell becomes full (max voltage reached) it bypasses some current around the full cells until all cells are full.
- It isolates the battery from the charger and/or loads when things get dangerous (voltage or temp are too high or too low).

BMS As An Add-On



Charger/Inverter-Integrated BMS



Integrated solutions for Off-Grid RE are rare (so far)

Li-Ion Precautions

- NEVER over charge them! A BMS is essential.
- NEVER short them!
- Don't place them upside down (any other orientation is OK)
- When creating a pack, use cells of same make and model and of same age (same as PbA)
- Avoid putting cells in parallel (same as PbA)
- Avoid trickle or float charging – these work best when cycled.
- Store them at 40-60% SOC.
- The industry is still learning the optimum way to treat $LiFePO_4$ batteries. (e.g. some say charging to 80% will greatly increase cycle life).

Is Li-Ion ready for off-grid RE?

Yes, if…

- Your depth of cycle is often more than 30% of capacity (otherwise PbA cycle life may be more cost effective). OR
- You don’t have the space or can’t support the weight of PbA. OR
- You are concerned about frequent maintenance (LI has no watering, no cleaning, 2-3 times the replacement interval).

AND

- You cycle frequently (avoid prolonged float/trickle charge)
- Your charge system includes (or you add) a Battery Management System (BMS)

So Why Are There No COTS Solutions for Li-Ion in Off-Grid RE?

- ?Dealers & Manufacturers have a long history with PbA – change is hard?
- ?High up front cost?
- ?The high cost of making a battery-damaging mistake?
- Lack of fool-proof integrated BMS solutions

Sources of Large Li-Ion Batteries

- Lithium Storage (CALB, Sinopoly, RealForce)
- Manzanita Micro (CALB, Headway)
- EV America (PowerFlux)
- EVolve Electrics (CALB, GBS)
- EV Source (CALB)
- Clean Power Auto (HousePower BMS)

These same sources can provide EV-centric BMS systems too.

Purchase Suggestions

- Ask for a report of each cell's capacity and impedance (there can be significant differences between cells even of the same batch).
- Request that all the cells shipped to you are close together in capacity and impedance.
- Ask about the supplier's policy if a cell fails to meet mfg's specs or dies prematurely.

QUESTIONS/COMMENTS?

Please fill out the evaluation questionnaire:

- Workshop #131: The use of Lithium Ion batteries for off-grid Renewable Energy applications.
- Presenter: Randy Richmond
- Time/Place: Sat 11 AM, Brown Tent

For a copy of this presentation email Randy@RightHandEng.com

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Additional Resources

Helpful web sites:

- Cadex Battery University (batteryuniversity.com)
- Energy Efficiency & Technology Magazine (EETmag.com)
- Elithion web site (liionbms.com)
- EV Discussion List (evdl.org)

Note – there is no known resource for Li-Ion in Off-Grid RE applications (yet).

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Experts in Renewable Energy Monitoring

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