The Energy Fair
clean energy & sustainable living

Lithium Ion batteries for off-grid Renewable Energy (PV9)

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Randy Richmond, Manager
RightHand Engineering, LLC

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 PV9 Goal

Lithium-Ion batteries are increasingly being used for off-grid RE applications including telecom, homes and RVs. Come hear about real-life installations and the advantages of Li-Ion over lead acid batteries.

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

Outline

- Different types of Li-Ion Batteries
- Li-Ion Safety Issues
- My experience of using Li-Ion in my EV
- How Li-Ion compares to Lead-Acid (PbA)
- Li-Ion Battery Management Systems (BMS)
- Li-Ion Solutions for off-grid RE
- Two Li-Ion RE case studies

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Different types of Li-Ion Formats

- Cylindrical

- Pouch

- Prismatic

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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 (LFP)**

Many new types are being developed.

Li-Ion Safety Issues

Boeing 787 Battery Fire

- 2 events Jan 2013. $LiCoO_2$ batteries.
- NTSB Factual Report published 5/7/13
- Analysis Report due Fall 2014

Tesla Fire

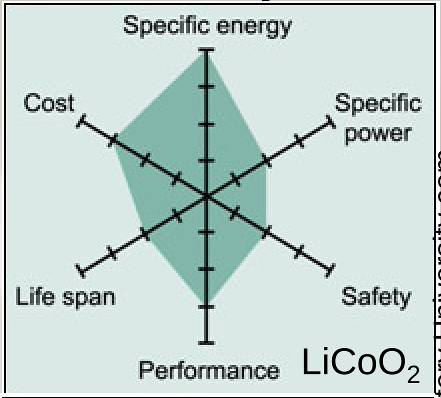
- 2 events Fall 2013. $LiCoO_2$ batteries.
- Caused by cell penetration from under vehicle
- Solved by improved armor plating and increased ride height.

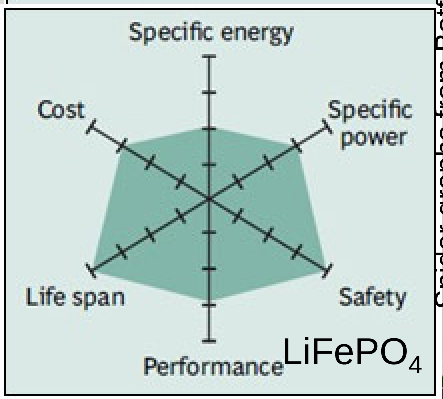
Li-Ion Safety Issues

- Cause of fires – short circuits leading to thermal runaway, fueled by volatile electrolyte
- Both incidents were $LiCoO_2$ cells:

"At elevated temperatures, $LiCoO_2$ liberates oxygen, which can react with organic cell components. ... In contrast, $LiFePO_4$ stands up especially well to thermal abuse due to the strength of phosphorus-oxygen bonds, Khalil Amine (Argonne National Lab) says. But the operating voltage and energy density on a volume basis are lower than those of $LiCoO_2$."

Assessing The Safety Of Li-Ion Batteries, Mitch Jacoby, Feb 11 2013, Chemical & Engineering News.





Spider graphs from Battery University.com

Li-Ion Safety Issues

Putting the Tesla fires in perspective:

- There is an average of 150,000 car fires annual – 1 in 20,000,000 miles.
- Tesla fires average 1 in 100,000,000 miles.
- Teslas are 5x less likely to burn that ICE cars.
- Which is more dangerous and likely? A gasoline tank rupture/fire, or a battery rupture/fire?

Li-Ion Safety Issues

What about $LiFePO_4$ (LFP) vs. PbA?

- LFP packs more energy per volume/weight than PbA, so there is more energy (heat) created when damaged.
- Which is worse: volatile electrolyte (LFP), or caustic acid and health-hazardous lead?
- They both have their hazards.

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 $LiFePO_4$
- I also design Li-Ion off-grid power systems

My Experience

Home Power 153

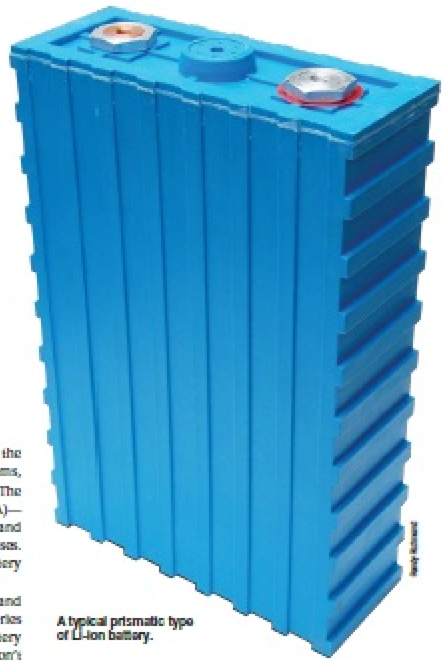
Lithium-Ion Batteries

for Off-Grid Systems

Is lithium-ion technology a good match for off-grid RE systems?

Comment & Discuss this article @ homepower.com/153.86

by Randy Richmond



A typical prismatic type of Li-ion battery.

For decades, lead-acid battery technology has been the mainstay of battery-based renewable energy systems, providing reliable storage and ample energy capacity. The most common battery used—flooded lead-acid (FLA)—requires regular watering to maintain electrolyte levels and venting to avoid the buildup of hydrogen and sulfuric gases. Additionally, FLAs are large and heavy, making battery replacement a challenging task for some systems.

With all of the recent action in the electric vehicle and personal electronics industries, lithium-ion (Li-ion) batteries have gained much attention. Here, we examine Li-ion battery pros and cons, and discover why most system owners won't be swapping out their FLA batteries anytime soon.

What's Behind Li-Ion?

"Lithium-ion" refers to a variety of lithium-based battery chemistries. Each chemistry has its strong and weak points, which means certain types of chemistries are better-suited for particular applications. There continues to be new lithium-based chemistries being developed (such as lithium-air), but it is too early to tell which will become commercially viable. See the "Lithium Battery Technologies" table for details on a few of the more common types of Li-ion chemistries.

Lithium Battery Technologies

Chemical Name	Material	Abbreviation	Applications
Lithium cobalt oxide	$LiCoO_2$	LCO	Cell phones, laptops, cameras
Lithium manganese oxide	$LiMn_2O_4$	LMO	Power tools, EVs, medical, hobbyist
Lithium iron phosphate	$LiFePO_4$	LFP	Power tools, EVs, medical, hobbyist
Lithium nickel manganese cobalt oxide	$LiNiMnCoO_2$	NMC	Power tools, EVs, medical, hobbyist
Lithium nickel cobalt aluminum oxide	$LiNiCoAlO_2$	NCA	EVs, grid storage
Lithium titanate	$Li_4Ti_5O_{12}$	LTO	EVs, grid storage

Source: batteryuniversity.com

Home Power 154

Lithium-Ion Batteries

for Electric Vehicles

Story & photos by Randy Richmond

Comment & Discuss this article @ homepower.com/154.76

In 2007, I converted a GMC Sonoma from its original gasoline propulsion to pure electric, using flooded lead-acid (FLA) batteries (see "Born to be Wired" in *HP122*). The type of FLA batteries most commonly used for EV conversions, golf cart batteries, have three 2 V cells and a capacity ranging from about 200 to 260 amp-hours (Ah). Moving the truck's 3,200 pounds required a higher voltage than the 96 or 120 volts commonly used for lighter-weight vehicles, so I used 24 batteries for 144 V and an energy capacity (at 100% discharge) of about 37 kilowatt-hours (kWh).

However, the battery weight (approximately 1,800 pounds) brought the vehicle very close to its maximum gross weight of 5,000 pounds. I expected my batteries to have a five-year life, but in the third year, they started to show signs of failure.

Eighteen of the original FLA batteries in a custom-built box in the truck bed. The six other batteries were housed under the truck's hood.

The short life boiled down to maintenance. I knew that the best practice for FLA batteries is to re-water them monthly if they are being cycled frequently (as they usually are in an EV). The charging process causes evaporation through electrolysis. I was usually good at watering the batteries, but on a few occasions, I postponed it, only to find that enough of the electrolyte had evaporated to expose the top of the lead plates to air. Exposed lead oxidizes, making it harder for the plates to interact with electrolyte and, thus, reduces their capacity.

This undoubtedly contributed to a shorter life, but the nail in their coffin occurred when I was unexpectedly called away for several weeks during the summer. In my original design, a daily timer was set on the battery charger to ensure the batteries were fully charged before I left on my morning commute. Without daily driving, the charger was excessively charging the batteries. This boiled off a significant portion of the electrolyte and overheated the batteries, causing them to swell.

I didn't realize this until I tried to drive my vehicle and heard a "bang" in the battery box, and the vehicle lost power. Several of the batteries in the middle of the pack (those that got the hottest) had swollen—one had swollen enough to cause an internal short circuit, which ignited the gasses at the top of the battery. I replaced the worst of the batteries, hoping that the remaining ones still had some life. But after testing, I found that all of the remaining batteries had a significant reduction in capacity—the only solution was to replace them all.

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 $LiFePO_4$
- FluxPower 200 Ahr $LiFePO_4$

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

Characteristics	PbA (Lead Acid)	Li-Ion ($LiFePO_4$ Lithium Ion)	
Reference Battery	Trojan T105	Large Prismatic	
Energy Capacity (Whr)	1350	608	
Recommended Max Discharge Depth	50%	70%	
Usable Energy Capcity (Whr)	675	426	
Volume (cm^3)/Whr	9.8	7.2	73%
Volume (cm^3)/Usable Whr	19.5	10.2	52%
Weight (kg)/kWhr	20.7	10.6	51%
Weight (kg)/Usable kWhr	41.5	15.2	37%

The Li-Ion data is based on an average of several different makes

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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	Large Prismatic	
Recommended Discharge Depth	50%	70%	80%
Cycle life	750	3000	2000
Recommended Discharge Current (A)	0.2C (45A)	0.3C (57A)	
Max Continuous Discharge Current (A)	2.2C (500A)*	2C to 3C (380A-570A)	
Peak 10 Second Discharge Current (A)	not specified	5C (950A)	
Min Discharge Voltage/cell	1.75	2.5-2.8	
Impedance (mΩ)/3.2V	2.2	0.5	
Usable Temp Range, Discharge	-20˚C to 45˚C	-20˚C to 55˚+C	
Temperature Effect	50% @ -18C. 100% @ 27C	92% @ -20C. 100% @ 25C	
Self Discharge (per month)	5-15%	1-3%	

The Li-Ion data is based on an average of several different makes

How Li-Ion compares to PbA Charging

Characteristics	PbA (Lead Acid)	Li-Ion ($LiFePO_4$ Lithium Ion)
Reference Battery	Trojan T105	Large Prismatic
Recommended Charge Current (A)	0.1C (23A)	0.3C (57A)
Max Charge Current (A)	0.5C (110A)*	1C to 2C (190A to 380A)
Max Charge Voltage	2.2/cell Float 2.45/cell Charge 2.58/cell EQ 2.70/cell MAX	3.65-4.0
Usable Temperature Range, Charge	-4˚C to 52˚C	0˚C to 45˚+C

The Li-Ion data is based on an average of several different makes

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	Large Prismatic	
Price	$145	$255	
Price/Ahr	$0.64	$1.34	
Price/Whr	0.11	0.42	
Recommended Discharge Depth	50%	70%	80%
Cycle life	750	3000	2000
Usable Energy Capacity (Whr)	675	426	486
Lifetime kWhrs	506	1277	973
Battery Management System $/Cell	0	$35	
Lifetime Price/kWhr	$0.29	$0.23	$0.30
Longevity	5-7 years	10+ years	

The Li-Ion data is based on an average of several different makes

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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
- Efficiency & Charge Time
- Self Discharge
- 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)

BMS Side-bar

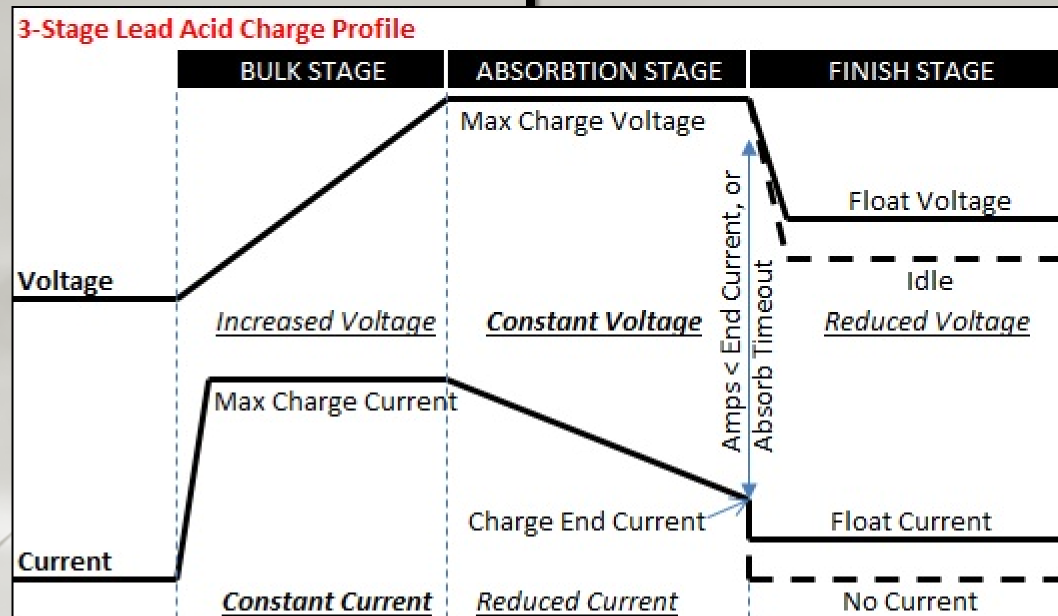
What is a BMS?

- 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).

Charge Profile Comparison

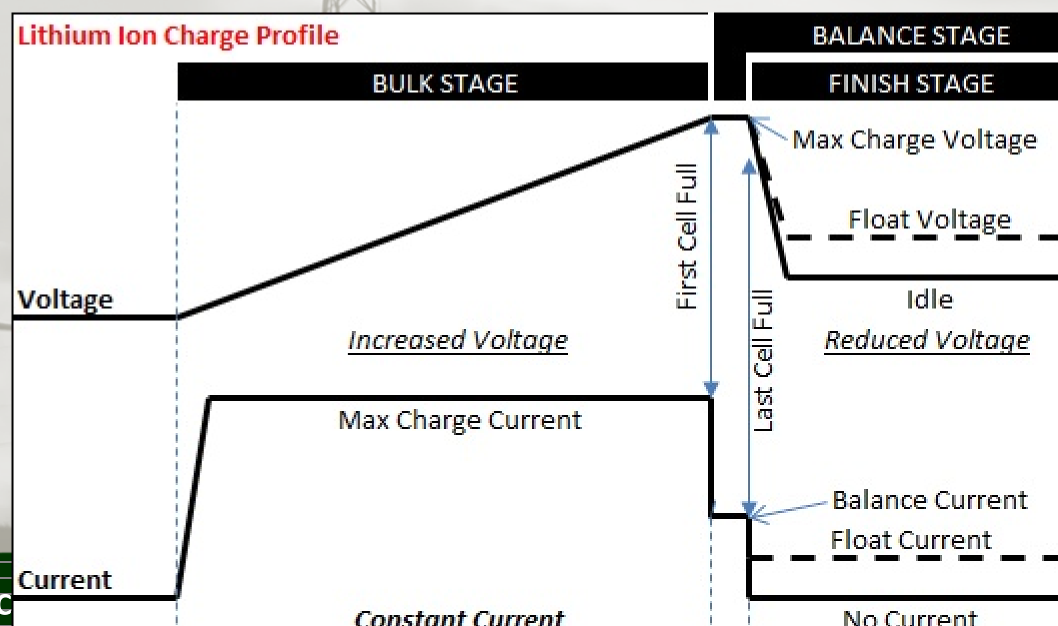
Lead Acid Cell/Battery Charge Profile.

Absorbtion Stage typically lasts 2 hours finishing the final 20% of charge.



Ideal Lithium Ion Battery (pack) Charge Profile

Balancing Stage typically lasts 10 minutes finishing the final 1% of charge.



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BMS/Charger Interface

For **ideal** Li-Ion BMS **integration**, the charger should know:

1. When the first cell is full (or hot) – so that it can reduce charge current.
2. When the last cell is full (or any cell is too hot) – so that it can terminate the charge.

Both of these cannot be known by measuring only the charger output. A BMS Interface is needed.

BMS/Charger Interface

There are no defined standards for interfacing BMS signals to chargers. Various methods employed include:

- Binary on/off signals; first full, all full.
- Binary pulse width modulation (PWM) to rapidly turn the charger output on/off.
- Using the charger's communications protocol to control (e.g. CAN-bus, Mod-bus, SunSpec).

Solutions for Legacy Chargers

External contactor:

- isolates battery from charger when any cell gets too high/hot.
- Isolates battery from load when any cell gets too low.
- Plus high-amp diodes if charge source and load are on the same bus.

End of BMS Side-bar

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)
- Store them at 40-60% SOC.
- Avoid the combination of high volts, high temp, and time. This reduces cycle life. Best to charge rapidly when temp is high.
- The industry is still learning the optimum way to treat $LiFePO_4$ batteries. (e.g. some say charging to 80% max will greatly increase cycle life, some say greatly limit charging below 0 ˚C).

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Is Li-Ion ready for off-grid RE?

Good RE applications

- Mobile (RV, Marine) where weight & space are precious.
- Stationary Off-Grid where cycle life & depth-of-discharge are important.
- On-grid peak shaving (high cycle)
- Any situation where minimal maintenance is required.

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RE LiIon Solutions Available Today

For New Installations:

- **Integrated** (Cells + BMS + Charger).

For Existing PbA-based Installations:

- **Drop-in Replacement** Batteries/Packs (Cells with integral BMS).
- **Add-on BMS** (Cells with separate BMS – DIY).

Some are marketed for residential off-grid RE

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Integrated Solution

Corvus Energy

Pure-Energy Hybrid

Uses RE equipment but typically not sold for residential RE applications.

Price ?

www.corvus-energy.com

Integrated Solution (future)

Tesla Energy, **Power Wall**

7kW of Lithium Cobalt cells.

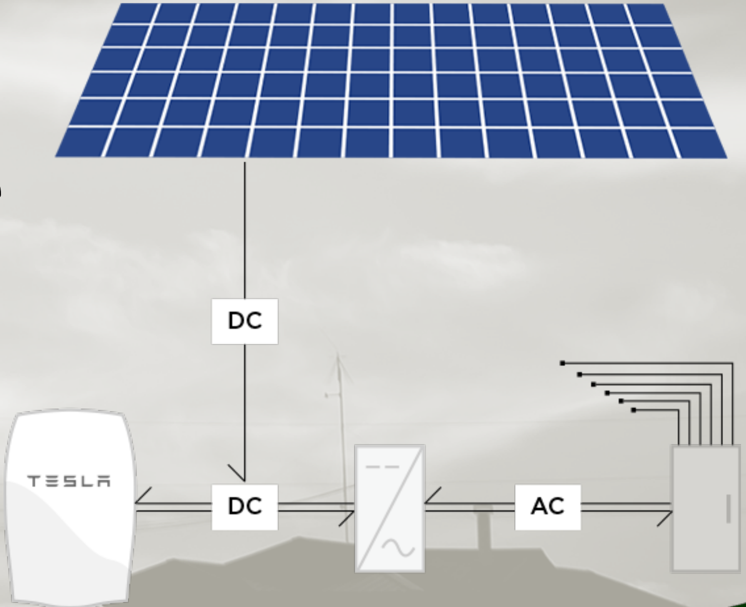
350-450V, 3.3kW peak power.

Available "early 2016".

Compatible inverter available "soon".

Price $3000 ($428/kWhr)

Teslamotors.com/powerwall



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Drop-in PbA Replacement Battery

Smart Battery

Contains LFP cells + internal BMS & disconnect switch. Available in 12V only from 7 to 300 Ahr.

Self-protecting.

$1300 12V, 100Ahr ($1K/kWhr)

www.smartbattery.com

POWERED BY... SMART™ BATTERY ...LITHIUM

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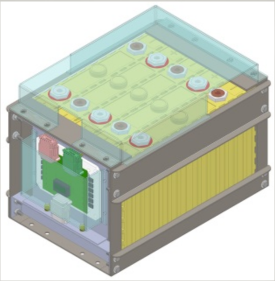
Drop-in PbA Replacement Packs

Cased cells + BMS & protective contactor

Polar Power POLAR POWER INC



72, 100, 180, 400, 700 & 1000 Ahr.
~$450/kWhr. For telecom sites.

Balqon balqon Corporation

24 & 48V, open or enclosed.

$450-$600/kWhr. 160 to 2100 Ahr.

Iron Edison IRON EDISON

12, 24 & 48V, open or enclosed.

$500-$675/kWhr. 160 to 2100 Ahr

Marketing to off-grid RE scenarios

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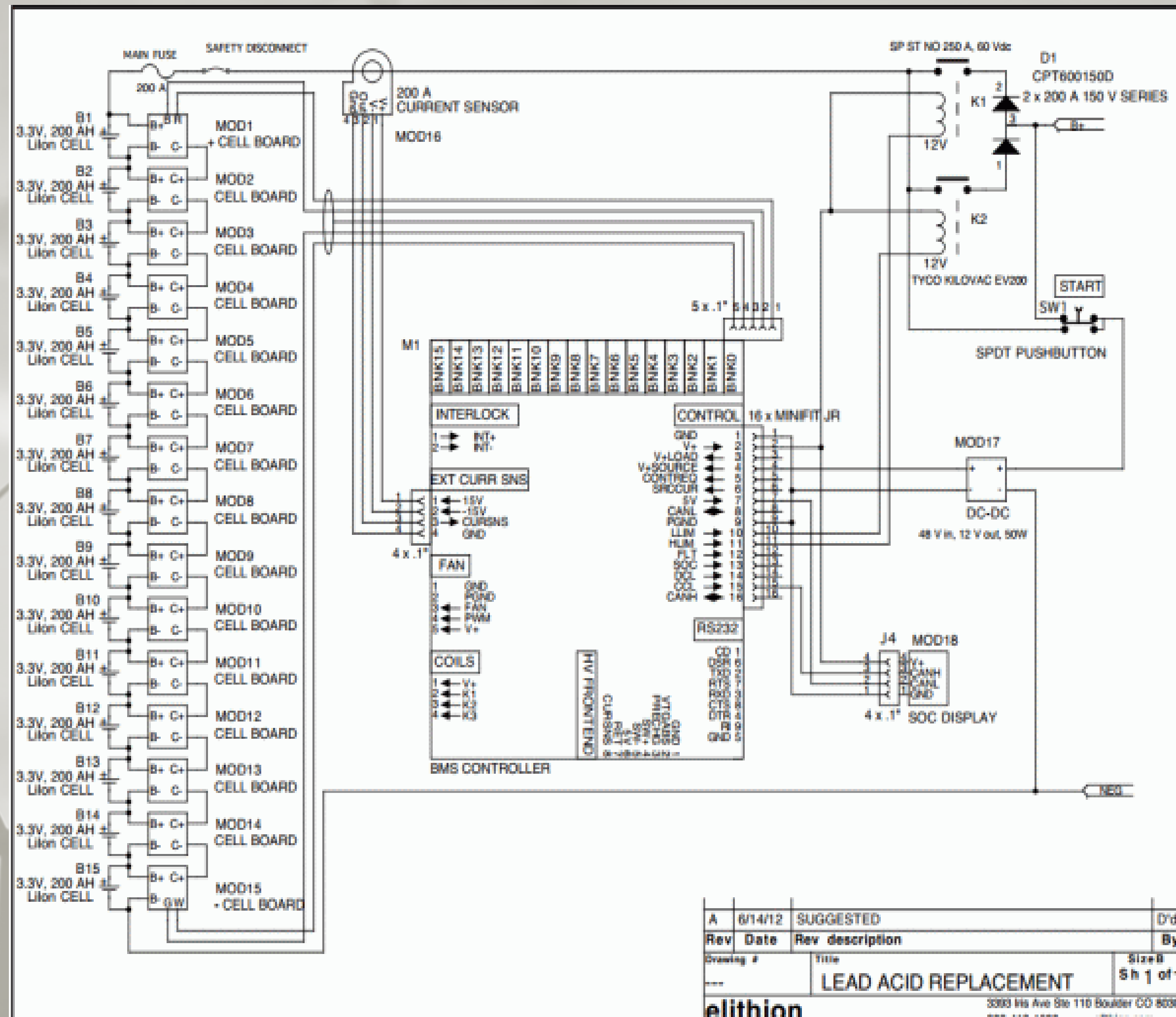
Add-on BMS Solution (DYI)

Elithion

Lithiumate

Uses any LiIon cells. Add a mini board for each cell, master controller & a pair of contactors & diodes.

$15/cell,
$400 controller,
$430 other
+$450/kWhr cells



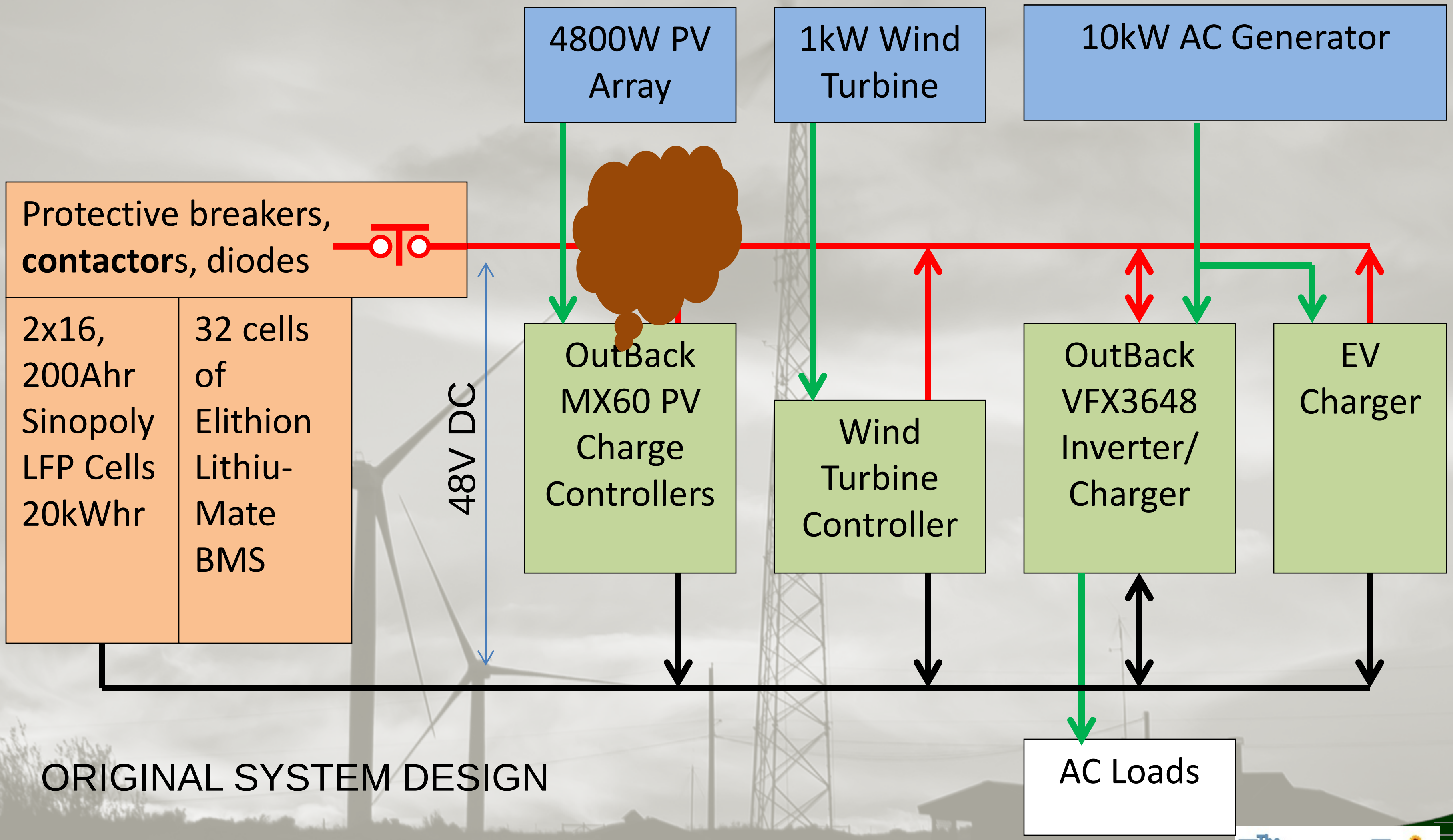
Elithion.com

Case Study #1, Off-Grid Residence

- Off-grid home in Idaho.
- DIY owners.
- Wanted zero maintenance & long cycle life.

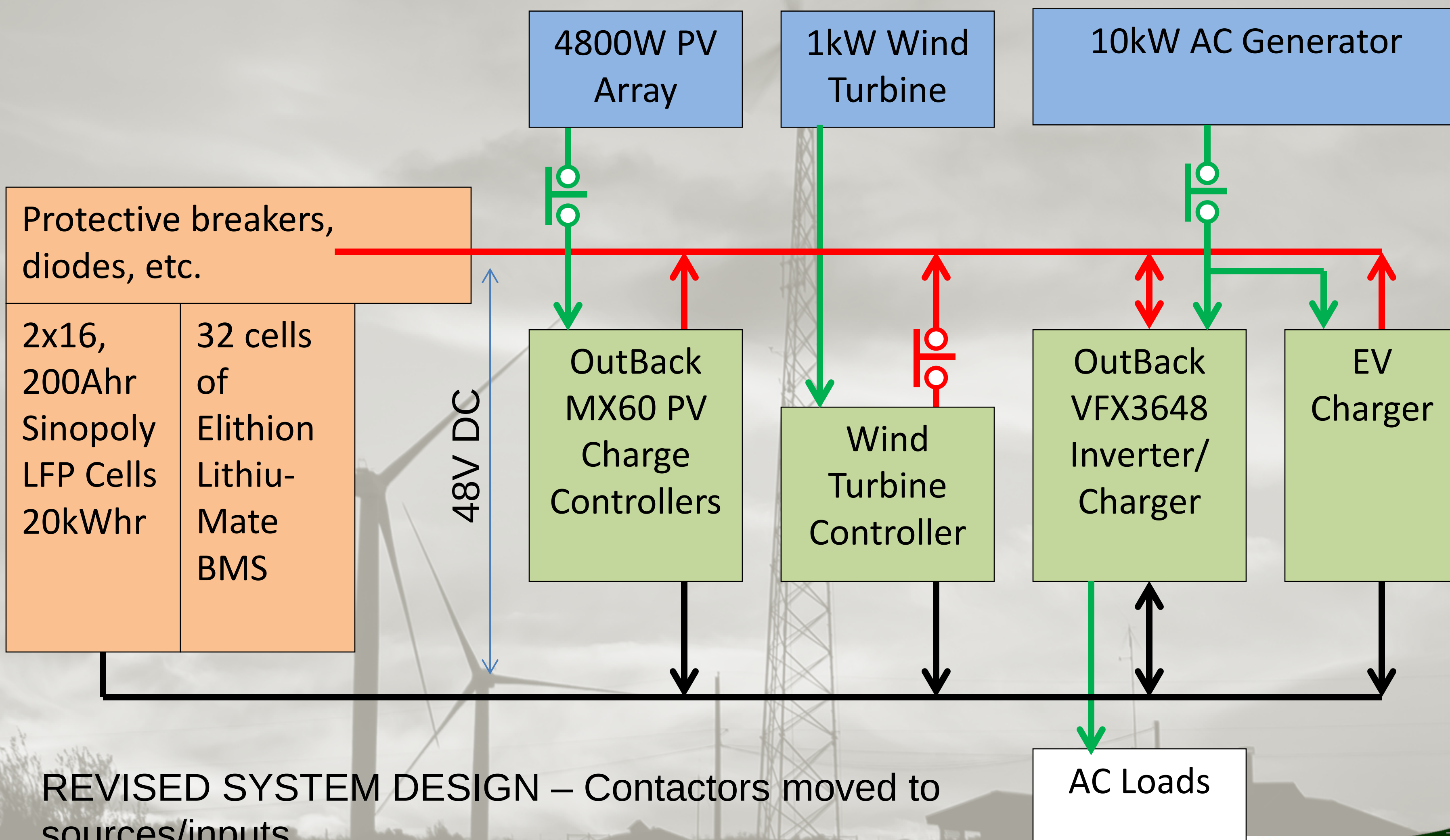
Description	**Cost**
System Engineering	$ 1,000.00
48V, 400Ahr (20kWhr) Sinopoly LFP Pack	$ 8,640.00
Elithion LithiuMate BMS	$ 2,467.84
Cables, Breakers, Diodes, DC-DC, etc.	$ 1,360.20
TOTAL	$ 13,468.04

Case Study #1, Off-Grid Residence



ORIGINAL SYSTEM DESIGN

Case Study #1, Off-Grid Residence



REVISED SYSTEM DESIGN – Contactors moved to sources/inputs.

Case Study #1, Off-Grid Residence, Lessons Learned

- Some power conversion equipment can't handle sudden loss of battery load.
- Equipment interaction can damage other equipment that normally can handle the loss of battery load.
- Design the system to avoid disconnecting the battery while under change.
- If disconnection is required, do it at the source/input rather than the charger output.

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Case Study #2, Off-Grid Telecom

- Cellular company in Alaska
- The site is inaccessible most of the year.
- Needs high reliability, zero maintenance, long cycle life, and good cold temp performance.

Copper Valley Telecom
The People You Know

- Purchased 3 each 700 Ahr (100kWhr), 48V **Polar Power** LFP systems. Also have Polar Power generator that is BMS-aware.
- Installing late this summer. $45K ($445/kWh).

QUESTIONS/COMMENTS?

Please fill out the evaluation questionnaire:

- Workshop PV9: Lithium Ion batteries for off-grid Renewable Energy.
- Presenter: Randy Richmond
- Time/Place: Sat 4 PM, Red Tent

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

RE manufacturer invitation!

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)

Workshop PV9, Li-Ion for RE

Randy Richmond, Manager
Randy@RightHandEng.com
www.RightHandEng.com

RHE
Experts in Renewable Energy Monitoring
www.RightHandEng.com

Makers of *WinVerter*™

Services:

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- Turn-key Solutions
- Monitoring System Design
- Consulting for Manufacturers, Resellers & End Users