An Approach to Lithium-Ion Battery System Design

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What's the appeal?

- Higher power and energy density
  - In terms of both weight and volume
- Near-constant voltage over usable range
- Very little drop in cell voltage under heavy load
- No significant Peukert effects
- High charge and discharge rates
- No hazardous gases to vent
- Possibly lower life-cycle costs than lead acid

Objectives
(for my own system)

- Relocate batteries, inverter, charger from storage bay near generator to dead space at rear
  - Want to reduce total space occupied by system while increasing capacity
- Want to be able to charge at rate close to generator's capacity to minimize fuel consumption
  - Influences cell type and configuration to some degree, though any Li system will be an improvement over FLA or AGM.
  - Full charge with lead acid batteries requires long period of time at low charge rate (~few hundred watts) while basically idling 12kW generator
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- Significantly increase usable capacity
  - Starting with 6 T105s that are several years old. 3*(200Ah)*(12V)*(50% usable for reasonable life)*(they're old)=<3kWh
- No transfer switching
  - Even the short time it takes for a transfer switch to operate can affect some electronics.
  - Want to be able to feed power to batteries and run house at same time—even if shore power is limited.
- Need to be able to charge chassis batteries from house, charge house batteries from alternator, and start generator from either source
- Enough power to run air conditioning for ~1 hour.
- Keep it simple to operate and maintain
- No fires, explosions, leaks, or funny smells

Considering Higher (48V) DC Voltage

Pros:

- Smaller copper wire ($$), less lossy
- Greater selection, cheaper inverter options
  - Inverter prices generally scale with DC current ratings, not total power
- Packaging and battery management simplified

Cons:

- Need to convert back to 12V for some loads
  - Easy for small loads, not so easy for high-amperage loads like leveling jacks
- More complicated management with 2 DC voltages

Why 48V?

- Inverter selection. 48V is pretty common for home off-grid systems
- High enough to be efficient and cost effective, without introducing HV safety concerns/costs.
- Pre-configured battery modules

Main Components

- Batteries
- Charger
- MPPT controller
- Solar panels
- 48V-to-12V buck converter
- 12V-to-48V boost converter
- Inverter

Batteries

- Before we talk about specific batteries, let's take care of some terminology.
- Forget about ratings in Amp-hours.
  - It's only relevant in comparing batteries of the same type and design.
  - Cell voltages are considerably different between FLA and lithium-ion batteries, and even quite different between different lithium chemistries.
  - When combining batteries in series-parallel configurations (e.g. 6V batteries in 12V system), you have to keep track of configuration when adding capacities.
  - Instead, we care about the amount of stored energy (measured in kWh), and the maximum charge and discharge rates (in kW)

How do I figure out what I have now?

- 6V x 225Ah = 1350 Wh = 1.35kWh
- However, as a general rule, for reasonable battery life, it's necessary to limit the depth of discharge to 50% for a lead acid battery.
  - This means that each T105 stores 0.675kWh of usable energy, drawn over 20 hours
  - Thanks to Peukert effect, faster consumption reduces this number further.
- 6 T105s would then be no more than 4.05 kWh of usable energy (when new), weighing 372 lbs. (10.9Wh/lb)

What about for lithium-ion batteries?

- Different chemistries operate at different cell voltages, but also have ratings in Amp-hours
- Calculate the capacity in kWh for a particular cell, and use 80% depth of discharge:
  - 100Ah CALB 3.2V $LiFePO_4$ cell would store 0.256 kWh, and weigh 7.5lbs (34.1Wh/lb)
  - Roughly 16 cells (120lbs) would be equivalent to 6 T105 batteries

8.62 x 5.59 x 2.63 inches

Common Lithium Battery Form Factors

- Pre-assembled batteries
  - Ready to install, many incorporate battery management systems.
  - Usually made up of LiFePO4 prismatic cells
- Prismatic cells
  - Easiest form factor to work with.
  - Threaded holes for terminal connections, many designed around a system of bus bars to make series and parallel interconnections easy.
- Pouches
  - Usually best capacity/cost ratio, harder to package. Highest specific power.
  - Must understand thermal control when packing tightly together.

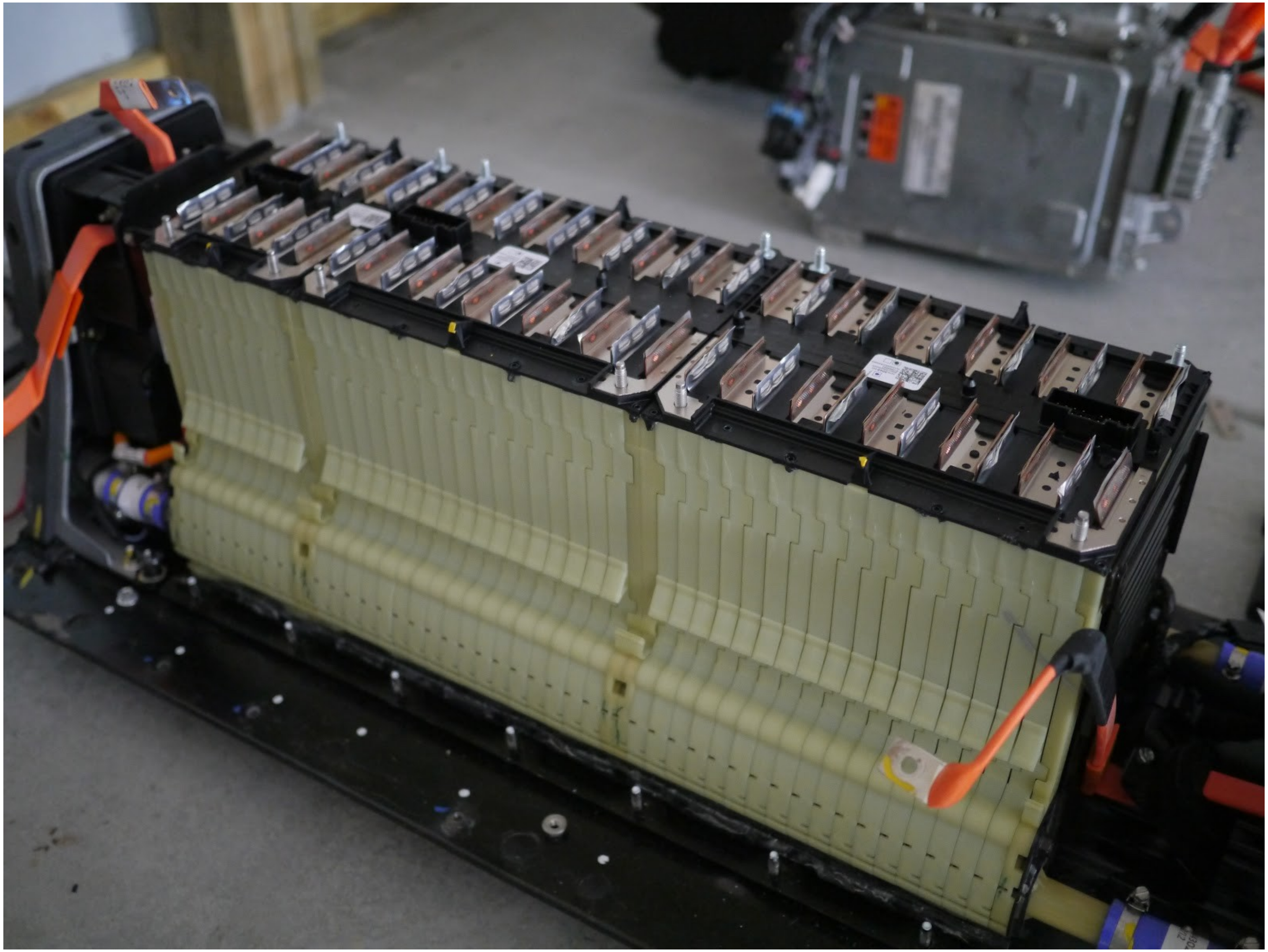
All three form factors shown here are lithium iron phosphate batteries (LiFePO4, or LFP)

Common Chemistries

- Lithium iron phosphate (LiFePO4, LFP)
  - Available in prismatic cells, easy configuration, probably most robust of any commercially available cells.
  - Easily sourced in cell sizes from 40-200Ah
  - Generally 3.2-3.5V/cell
- Other chemistries are not readily adaptable to RV use (cost, safety, availability concerns)

- Lithium manganese spinel
  - Most extensive application is Chevrolet Volt
    - 16kWh total capacity, 288 cells
  - Including used packs, by far cheapest acquisition cost

Another Reason for 48V



Charging a Lithium-Ion Battery Bank

- Will an existing charger “work” on a 13.2V lithium-ion battery pack?
  - Maybe. On a 3-stage charger, bulk charging will be current limited by the charger, float stage may not be high enough to reach full charge.
  - It's also possible to overcharge a lithium-ion bank. The voltage rise nearing 100% SOC can be very quick, and many 3-stage chargers do not switch to float mode fast enough.
  - More importantly, an existing 3-stage charger can be expected to charge much more slowly than what the battery bank can handle.
    - This means longer time running the generator!

Do I need a battery management system (BMS)?

- A battery management system connects to individual cells to monitor cell voltages. Many also control a shunt, so that individual cells can be taken out of the charging circuit when fully charged.
- If individual cells are properly connected and at the same state of charge when connected, detailed monitoring is not really needed any more than with lead acid systems.
- State of charge cannot be effectively estimated with voltage, so some sort of monitor keeping track of net power in/out of battery is necessary.
- Lithium-ion batteries can be severely damaged, if not rendered unusable, with as little as one discharge too far. A low-voltage disconnect is a must to protect the batteries.
- A battery management system does provide health information about individual cells that allows you to know more about what's going on, and can make re-balancing cells easier (but that shouldn't be needed).

How complicated is the charging process?

- Simpler than lead acid.
- Provided voltages are properly set, a single “bulk” charging stage is adequate.
  - Remember, generally we want to operate between 10% and 90% state-of-charge, which is mostly the flat-voltage region. The key requirement is the ability to set the charge voltage correctly.
- Depending on the capability of the charger and batteries, thermal management and current limits may be necessary.
  - Since these cells can be damaged by charging at elevated temperatures, a temperature cutoff for the charger is recommended. This also prevents overheating when charging at a high rate.

Are there good chargers already available?

- The best (but pricey) charger option is offered by eMotorWerks.
- Open-source hardware and software, available fully assembled or as a parts kit
- 12kW charge rate, 97% efficiency, power-factor corrected.
  - Even at this rate, a Volt battery pack is being charged at only a small fraction of what it can handle!
- Any input voltage or frequency from 85VAC (120VDC) to 400VAC
  - No more worries about low voltage at the pedestal!
- Software-selectable voltages, and programmable current limits
  - In other words, it can be set to charge at <15A on a 15A outlet, or 50A 220V when that's available.

Are there good chargers already available?

- Morningstar's MPPT controllers can accept power from a DC power supply, and have configurable charging stage voltages.
- Some 48V inverter-chargers already have charge profiles for some lithium-ion chemistries.

48V Inverters

- Lots to choose from
- Many offer split-phase 220V output
- Have to watch for 220V only inverters
  - Though a center-tap isolation transformer could make this workable
- Must be at least able to configure for 60Hz operation (remember, most of the rest of the world operates on 50Hz)
- Many have charge controllers built-in
  - Some even have dedicated wind/solar inputs with MPPT algorithms
- Surge capacities are typically very high—often 5x steady-state rating
- Cost per kW AC power out is generally much lower than an equivalent 12V inverter

Charging from Truck Alternator

- Not all that much power can be expected
  - Typical 160A (peak) alternator outputs <2kW, and still has to run truck systems
- Need to step up to 48V battery voltage
- Need to limit current drawn from 12V system
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50A at 12V input, $30

Supplying 12V Loads

- What's left after AC loads?
  - Leveling jacks
  - Water pump
  - Lighting
  - 12V outlets
  - Radios
  - Antenna amplifiers
  - Refrigerator, water heater, and furnace controls
  - Air conditioning thermostats
- All except leveling jacks easily serviced by buck converter located at DC load center.
- Unlike when operating a normal battery system, buck converter will provide a much more stable DC voltage
  - Lights won't dim when the water pump is on!

System Layout