WHITE PAPER

MARINE ELECTRONICS

Lithium Battery bank, building your own.

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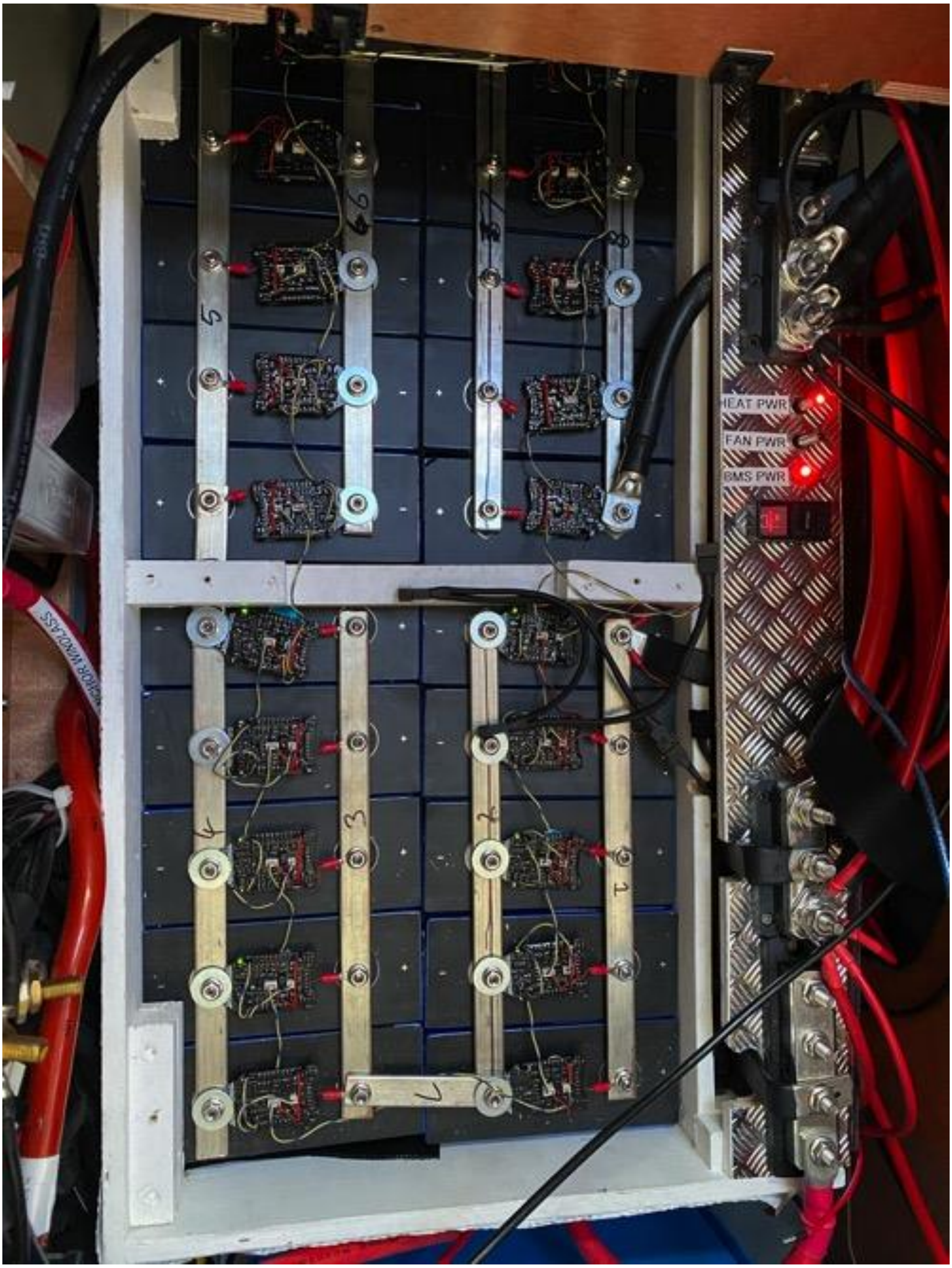

HEAT PWR
FAN PWR
BMS PWR

INTRODUCTION

NOTE: *Lithium batteries come in many different forms and it's important to start off by saying we are talking about LifePo4 chemistry here. It's safe and long lasting and appropriate for a boats house bank needs.*

Good quality LifePo4 batteries are now available easily, so why build your own?

To be honest the cost savings are reducing and although they are still a considerable factor, there are other reasons to build your own.

The biggest one in my book is building a battery as a system - a system that you understand and that is suitable for your exact requirements. Boats are different to other environments, and this will affect your choices when you build your own battery system.

More importantly, living on a boat you know EVERTHING breaks sooner or later, and you need to be able to fix it. A battery system that is off the shelf, sealed and warrantied is great for a local cruiser who is working out of a port, but if you intend to venture further afield, you might need to understand how to fix it yourself.

So as a cruiser, the question is "***Why build your own battery bank?***"

The answer is simple ***"To save money, whilst creating a battery bank that is specific to your needs and maintainable by you."***

If you are a weekend cruiser and never venturing further than a weekend away from your home port, you might consider buying one of the many good commercially available Lithium batteries. The extra money will be worth it for the warranty and support you can get locally.

This whitepaper is NOT a know everything you need to know.

It is designed to walk you through building a lithium battery bank, using my own practical experience as an example of the choices and components you need to successfully build a lithium battery bank.

As this is based on my own personal experience, it is NOT a comprehensive examination of everything LifePo4. It is rather specific to my own build and requirements and passing on those lessons for your benefit.

UNDERSTAND YOUR NEEDS

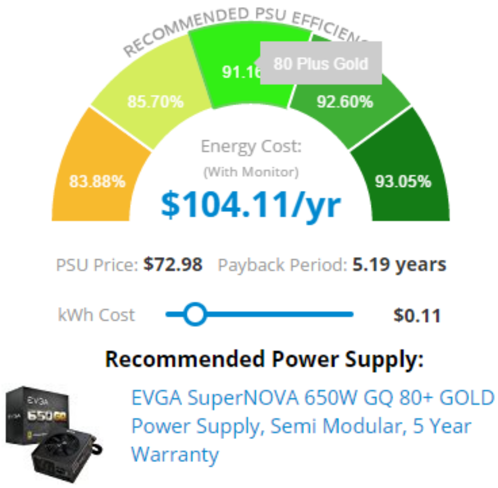


Figure 1 - Calculations and Recommendation of PSU

The first thing you need to understand is - what are your needs going to be from a battery bank? How big does it need to be? How are you intending to charge it, etc?

Most people on boats approach building a lithium battery bank with a focus on what they can afford or the minimum amount of power generation they need to survive.

I would strongly recommend that you do not approach this from a minimum viable product point of view but from a maximum desirable point of view and then scale according to the limitation you might have. Space, budget, charging ability etc. Lithium is NOT prohibitively expensive anymore, and if you do it, do it right. Leave any compromise you might have to accept to be challenged strongly, and only then accepted.

With this view and the fact my wife has never lived on a boat or been a sailor before and certain comforts of home are going to be required, I decided to monitor my power usage at my apartment in town and decide based on that, what a reasonable power requirement for our build needs might be.

Tracking my power usage for a few weeks I found I average about 16Kwh a day when both of us were present in the home. 16Kwh is a lot of energy, that equates to about 1230AH on a 12V system. (The math for this BTW is a 12V system works nominally at 13V for most of its life so 16000(Kilo is a 1000 watts)/13 = 1230AH).

This of course also included a lot of power consumption that I would not see on the boat, but there would also be power consumption on the boat that I would not see in the apartment, such as a water maker for instance.

I decided to use with this as a working figure and see what compromises I would need to make. A battery bank that would support 16Kwh a day would be nice.

Your own requirements might be less. You might not have a full household washing machine, 4 fridges/freezers, TV, NAS, water maker, etc. You might be much simpler and have less demand to generate your own power. But reduce with prejudice because it's great having more power than you need… but it's definitely not so great the other way around.

Understand how you are going to charge it

A battery bank is not going to last long if you can't charge it as fast as you use it. The battery bank is about storing enough power to get you to the next point where you can charge it again.

If that means solar, then you need enough solar to charge the battery bank WHILST you are supporting your day loads, or you will still be drawing from your battery.

In my case this mean I needed 16Kwh of power generation per day. As I wanted to be almost, if not totally solar for my power generation, then I need to be able to generate 16Kwh a day from my solar arrays.

Here is the first compromise I needed to make. I looked at designing a new solar arch and putting the maximum amount of solar onto it that would be safe to carry around the world.

This mean 5 X 415W solar panels. Or a maximum capacity of 2075W. To generate 16Kwh from this I would need to get 100% capacity for about 8 hours!! Every day.

Obviously, this was not going to happen because you soon realise that a good solar array will produce about 75% of its capacity a day or in my case 12Kwh a day at best. In truth I am more likely to average less than this.

After some calculations I based my best-case generation ability with this solar array at circa 10Kwh per day. Some of which would be needed for fulfilling household loads whilst I was charging the battery during the day.

Understand how much reserve you need

Of course, just because you live on a boat doesn't mean every day is full of sunshine and if you are living aboard in winter, you will generate a lot less power than during summer. How many days of cloud and rain will your system tolerate?

The answer for me was 3 days of cloudy weather with minimal generation. Winter was going to be either on shore power or using the generator, but during autumn and spring I wanted to be able to cope fully solar with some reserve. Combined with my generation capacity I now knew I, ideally, needed circa 30Kwh battery pack for the boat.

How much space and weight capacity do you have?

Next thing was how BIG and heavy would that be as a battery bank and did I have the space to fit it in. I am on a 45' catamaran ("condo-maran") so I had a lot of space but still this was not endless and I needed to fit in things like MPPT chargers, inverter, controllers, fuses etc.

This was my second compromise moment. I soon worked out that I could not fit 30Kwh of batteries into the boat without making major alterations and compromises in other areas. I would have to reduce the amount of power I would ideally like to have.

CHOOSING YOUR BATTERIES

Physical size, features, cost, reliability

Batteries are not just a power source; they are a system that controls one of the most important resources on your boat. You may want/need more features to look after, or control other systems based on your batteries health or state of charge.

My personal features list was:

- BMS that protected the battery cells from harm. Not just over charge or overdraw but temperature, parameter etc. I wanted to be able to control charging rates intelligently and not just disconnect my battery if the charge rate got too high etc. I really needed a smart BMS that could “talk” with other components in the system like the chargers and inverters etc.
- Cell level monitoring so that I could “see” each cell and know my battery was in good order, proactively avoiding any issues that might be caused due to balance issues etc.
- I wanted a BMS that could actively balance the cells, not just protect them when they got out of balance.
- I wanted cells that would be high quality and last the distance. I didn’t want to build an expensive battery bank only to have it last just a couple of years.
- I wanted to automatically be able to turn on cooling for the batteries and heating as needed.

- The BMS also needed to be robust which meant Chinese pass through BMS's were off the list. The BMS needed to support Connector or Remote Battery Switches (RBS) to control the large amp draw that would be possible with my battery bank.

This ruled out every "drop in" battery on the market. They had no active balancing. They could not heat or cool the battery if needed. They work in isolation with separate BMS in each, so even the better ones were not part of a system, a fault in a single battery would shut down the entire system. They could not control charging sources or inverters etc.

The battery "systems" that could meet my requirements were Victron's smart batteries, combined with their smart BMS system and the CanBus control for the Victron Inverter and Chargers. Or at least meet most of my needs. But not all.

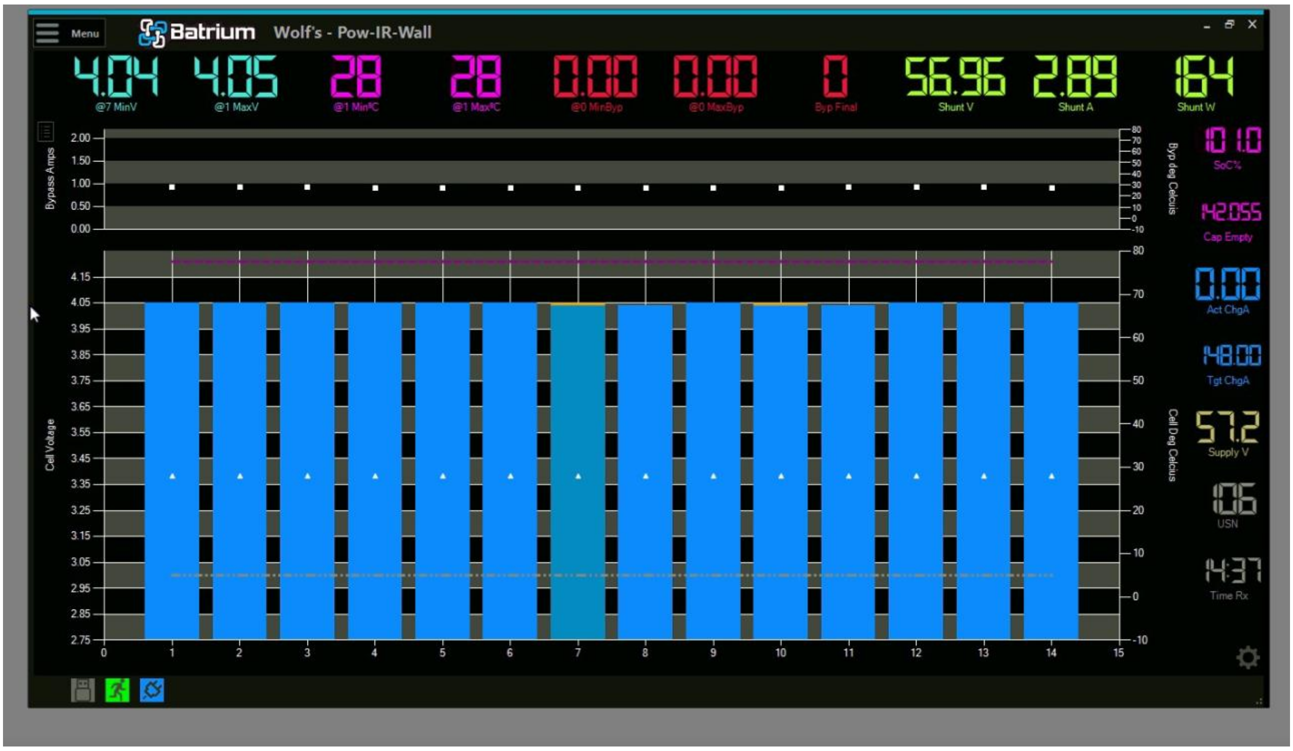
The problem here was that the cost of the Victron Smart Batteries were prohibitive and although very well thought out and made, not within my budget.

Continuing my research, I found out that I could do EVERYTHING I wanted using one of two very smart BMS's and building my own battery out of individual cells.

The Two BMS's were REC.bms and Batrium BMS.

Choosing cells and BMS's

I chose the Batrium BMS system because I was very impressed with their software and control mechanisms. REC.bms were also more expensive but perhaps more marine, as they already came in a waterproof box and didn't require a container to be made for them.



When it came to cells, I found that I could purchase Prismatic Lithium cells from China that would allow me to build a solid battery bank with only a few dozen cells and the reliability of the cells seemed to have a good history.

There were a few options but the one I choose were EVE 280AH prismatic cells. I have no experience with other brands and there is much discussion about the differences between each.

The cells I chose have proved very reliable and the experience has been very positive from the cost, to the balance they arrived with, and the state and build quality I received.

I would say, be careful to buy directly from the manufacturer and make sure you buy grade A cells. Seconds are sold through other sources much cheaper, but they are seconds for a reason.

The cost of the BMS, cells, busbars et al was 10% of the cost of an equivalent Victron Smart battery system.

CREATING A BATTERY PACK – FIRST STEPS

The first steps you need to understand are the configurations you are going to need to accomplish to create your battery.

NOTE: *if you are buying drops or some other system, this might still be worth a read because it will give you a good understanding of what's happening inside those drop-in batteries.*

The difference between "Cells" and Batteries

There is a difference between a cell and a battery. It seems simple but you probably need to understand this. Each comes with some industry standard features.

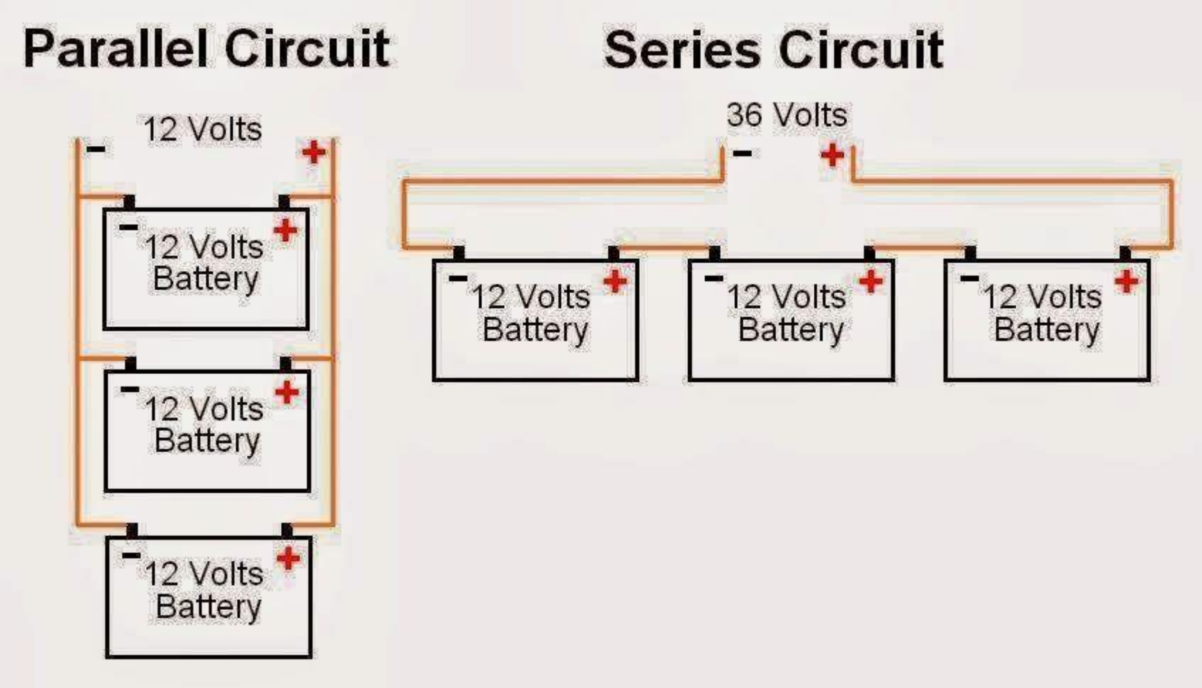
- A cell is a single unit of battery that cannot be broken down. It contains a single vessel with the chemistry of the cell inside.
    - LifePo4 Cells come in different configurations
    - The first of these were cylindrical cells like the torch batteries we are used to. These come in standard sizes 18650 (18mm X 65mm long), 21700, etc.
    - You also get Prizmatic Cells, which are larger rectangular cells and pack more Amp hours into each cell… BUT not more voltage. Prizmatic cells are cheaper to produce and fit the requirements of space better than cylindrical cells.
    - Pouch Cells, which are MOSTLY used for development and testing, although because they tend to be more flexible are also used for situations where cells need to be "moulded" into their locations.
- ALL LifePo4 Cells will have a nominal voltage of 3.2V.
    - To get a 12V or higher battery they will need to be combined in Series of 4 or more.

So, all LifePo4 Cells will conform to one of these formats and will be 3.2V nominal with varying capacities of AH storage for each cell.

With this is mind Prizmatic Cells are the cell of choice for building your own battery.

A battery on the other hand conforms to the requirements of different standards and are created by combining cells in different ways to create the battery you want for your situation.

Understanding Parallel and Series combinations of Cells



When combined together (wired together) cells will either combine their AH and remain at the same voltage or combine their voltage and remain at the same AH.

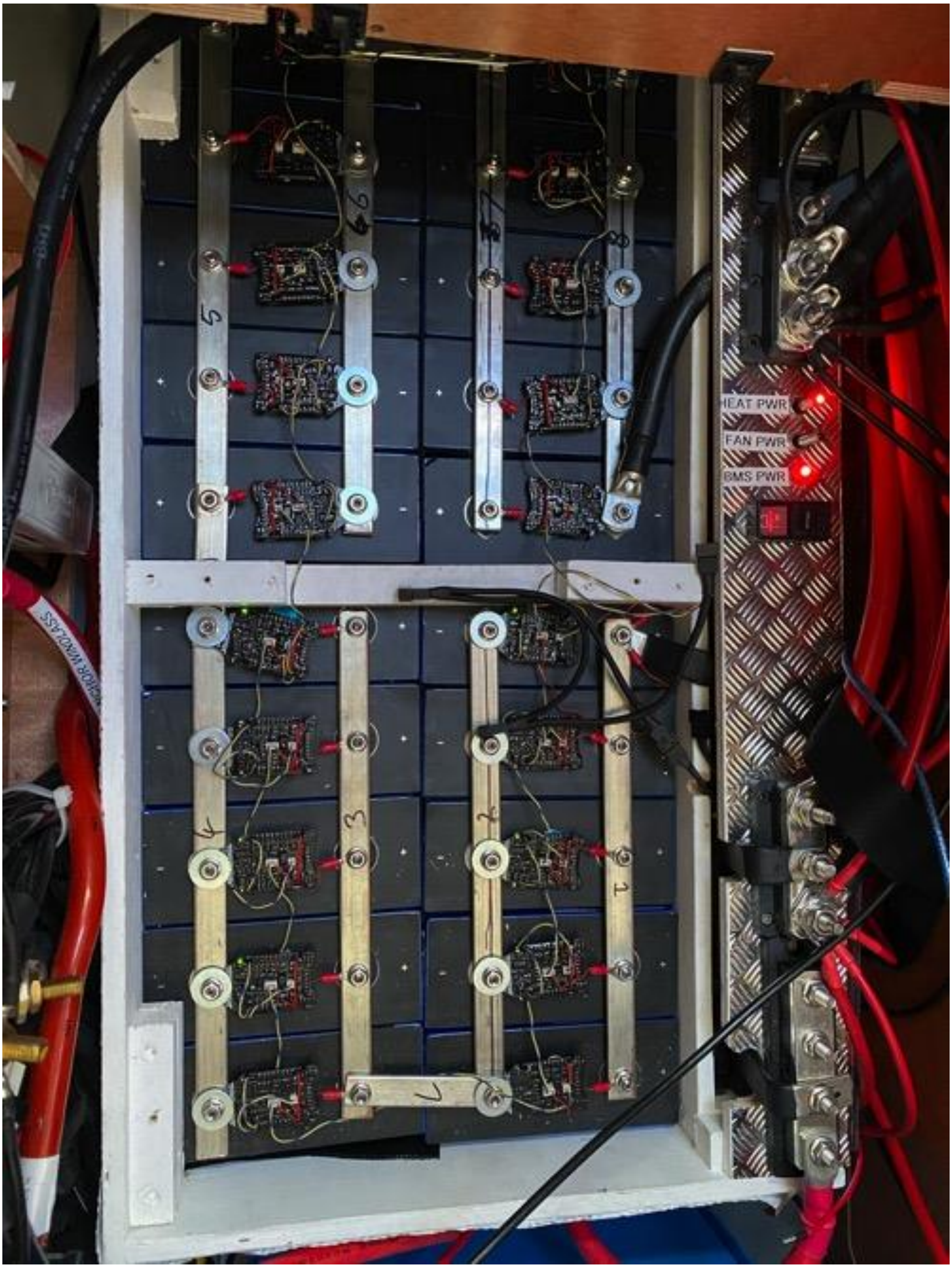
- Parallel means to wire cells positive to positive and negative to negative terminal.
  - This combines the AH of the cells, but the voltage remains the same.
- Series means to wires cells positive to negative
  - This combines the voltage of the cells but the AH remains the same.

We describe a battery by the combination of cells and how they are combined.
4 X cells in series would create a 12.8V nominal battery (4 X 3.2V) with the same AH as the individual cells. We call this a 4S configuration. An 8S would produce a 25.6V (8 X 3.2).

If we combine “packs” of weries together in parallel, we can thing achieve the AH and voltages we want.

For my own battery, I wanted about 1400AH (this was the compromise I ended up on based on space, charging capability and needs) at 12V nominal. This would mean I would want a 4S5P battery pack or 5 blocks of 4 cells wired in series then wired in parallel.

It would look like this:



Each cell here is 280AH so 5 X 280 = 1400 (the 5P part) and each cell would be 3.2V so 4 X 3.2 = 12.8V.

Cell health, balance and safety

The next thing we need to understand is how to keep our battery healthy and make sure it stays within safe operation.

Firstly, let's talk about protection actions.

There are two ways to protect your cells in your battery.

- Disconnection when things are not right
- Active control of the parameters so that they never are not right.

You are building a battery to power something and disconnecting that battery because something is not correct will shut down whatever it is that you are powering. If this is your boat… then you'll shutdown your boat!!

Obviously, this is NOT desirable, but this is the way drop in batteries work. Their BMS logic is about protecting the battery NOT about working with a system to make sure everything is always all right.

In truth you want both: you want to be able to disconnect the battery if all else fails, but primarily in normal operation you want to be able to have the battery control the sources of draw and charge.

Let's talk about what we are protecting

We are not protecting the battery in its entirety. What we are protecting is individual cells.

Once we understand this then being able to monitor individual cells and act accordingly for an individual cell becomes much more important. Most BMS's monitor each cell but DO NOT ACT at a cell level - they act at a battery level and mostly by DISCONNECTING.

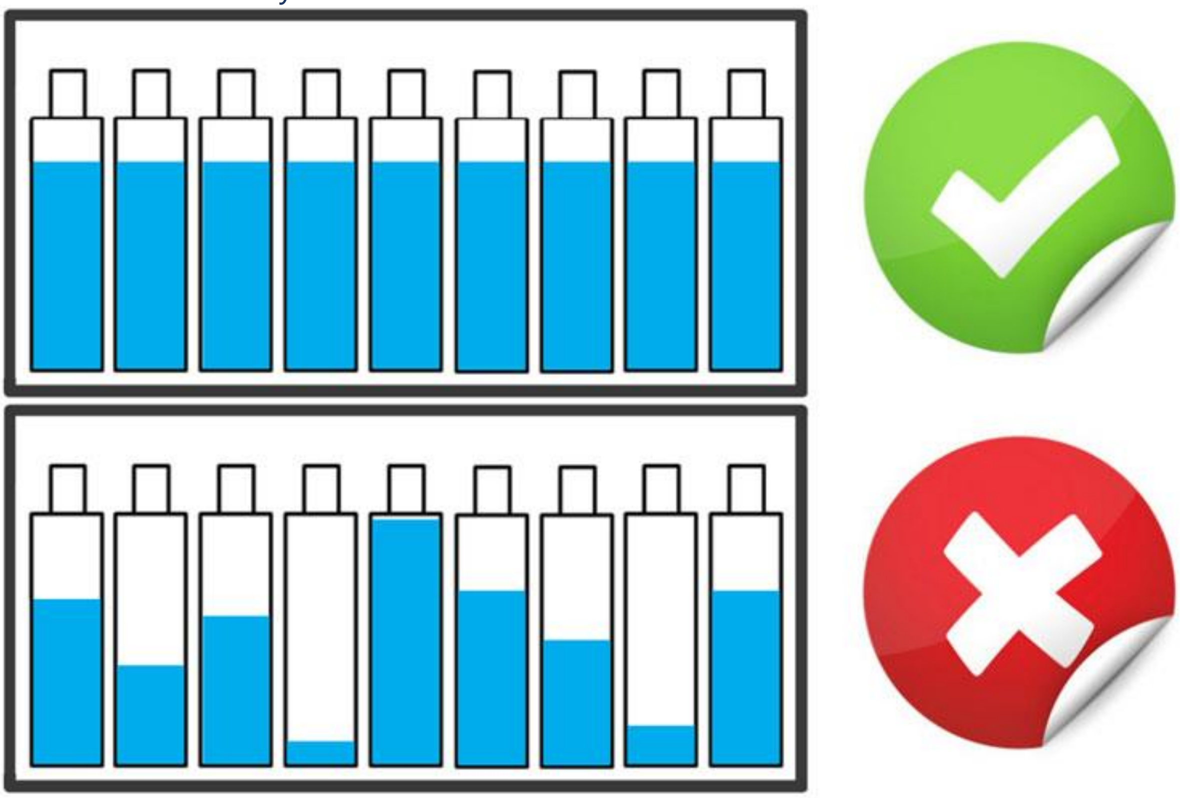
What are we protecting against?

Cells have a set of operating parameters that they should not operate outside of. In the case of LifePo4 these will not usually result in dangerous conditions but will damage your battery.

The things you are protecting against are:

- Overcharging - Charging an individual cell beyond 3.75V or above 1C (a C is a measure of current expressed as a ratio of the cells AH capacity 1C = the AH rating of the cell, 0.5C would = half etc.)
- Over discharging – Draining a cell below a specified voltage, normally with LifePo4 this would be 2.4 volts)
- Charging when the cell is too cold – 0C for LifePo4
- Charging when the cell is too hot – 54c for LifePo4
- Discharging when the cell is too hot – 54c for LifePo4
- Discharging at too high a C rating (depends on cell brand but usually 1C is safe)

Cell balance and why we care



Batteries are made up of individual cells. Individual cells will all differ slightly in internal resistance and therefore some will charge quicker and discharge quicker than others. This can result in cells that are not at the same voltages as each other in a battery pack.

Why do we care if each cell is within its safe operating limits? Well, if one cell were to get too low in cell voltage it might stop power being drawn from the battery before it was really empty because its voltage would drop too low whilst others would still be in a safe zone. Or the same could be said for charging but with a single cell voltage getting too high.

So, what is cell balancing? Static balancing is making sure that all the cells in your battery are at about the same top voltage when they are installed so that they will stay reasonably within limits of each other and prevent a single cell from stopping your battery prematurely.

This is the same reason we want all the cells to be about the same age in a battery, as internal resistance changes over the cell life.

Active vs Passive

But what about Active Cell balancing? Even with very good balancing before assembly cells will slowly get out of balance because of the internal resistance differences in their manufacture.

There are two ways to deal with this, once a year or so check each cells voltage and manually rebalance the cells again or use a BMS that does active balancing.

An active balancing BMS "moves" current from one cell to another via resistance in small increments to actively combat cells slowly creeping out of balance.

They can NOT deal with large differences, but with cell manufacturers making sure cells are reasonably close in tolerances they can keep your cells balanced across years of operation.

I definitely wanted an Active Balancing BMS as part of my system.

Management and Control

The next thing you want from your BMS is the ability to manage and control what it is doing; to see what is actually going on and possibly setup rules and change things according to conditions of your battery or the surroundings.

One of the reasons I went with the Batrium BMS was that it monitored each cell at a voltage, temperature, current etc. and actively balanced it. All of this information is presented to me via a web interface, with a built in a number of relays that I could program to open or close based on conditions.

It also supported communication via Canbus and rules that could be set here to control things like inverters, chargers etc.

The REC.bms also had all of this but lacked the relays and management UI that I could use to monitor it all and setup rules.

Control, Temperature, Charging and Discharging

Using the Batrium BMS relays, programming interface and a small amount of electrical knowledge I was able to hook up the following additional features that would mean I would not have my battery just shut off, but actively manage its conditions.

- Heating pads, under the cells that would be turned on if the cell temperature dropped below 5c.
- Fans to cool the battery pack if the operating temperature of any cell climbed above 35c
- Controlling signals in Victron format sent across the Canbus that would allow me to connect the BMS to the smart components of the Victron setup (MPPT's, Inverter and Cerbo GX) and control their output to ensure safety, and that the battery was able to manage its own requirements.
    - For instance, when my battery gets to a certain cell voltage (3.5v) it starts to actively balance current away from that cell. This is setup in the BMS software, and I can vary when it happens. But when a number of cells are all wanting to move current off to lower voltage cells, we don't want high charging currents being provided by the MPPT's or shore chargers (Inverter) so the BMS asks them to provide a limp charge mode and limit the current.

Using the above features, I am able to see actively what is happening but also setup rules and ensure that the WHOLE system works together to keep the batteries operating safely, balanced and not over stressed.

So far it works faultlessly.

Electrical Safety

The next part of building your own battery AND THIS APPLIES TO BUILDING YOUR OWN SYSTEM USING SOMEONE ELSES BATTERIES, is the electrical safety part of your design.

Current moving through batteries and connections create heat, the more current and resistance the more heat. If this is controlled that heat can cause fires and even explosions.

This is the job of several components of the system.

- Connections – The connections between cells, between battery and loads etc. must all be appropriately sized.
  - The larger the conductor used the lower the resistance to current flow.
  - The longer the conductor the higher the resistance to current flow
  - Connection MUST be appropriately sized and kept as short as possible.
  - NOTE: the busbars that come with many of the Prizmatic cells are designed and appropriate for 2-300A that the cells can provide, but when you start putting these cells into parallel configurations and the current goes up, THEY ARE NOT AND NEED TO BE REPLACED WITH LARGER DIMENSIONED BUSBARS.
- Fuses and Circuit breakers
  - Circuits (yes, your battery forms part of an electric circuit) are built to perform within predefined parameters. If for some reason these parameters are exceeded, you need to make sure your battery is disconnected from the circuit.
  - The BMS plays part of this role in a functional safety.
  - Fuses and circuit breakers are more about physical safety and making sure your connections and devices are not exposed to too much current and therefore produce too much heat and fire risk.
- Disconnection Current and Interrupt Current
  - Most people look at fuses and circuit breakers in relation to the amount of current they are designed to disconnect at. This is important and must be within a safe margin of your connection's capacity.
  - BUT a very big part of the measure of a fuse or circuit breaker is their interruption capacity. This refers to the amount of current that will be prevented from passing through the fuse or breaker once it has opened. i.e. if

you maximum possible current is higher than your specified interrupt current, your breaker or fuse will NEVER stop current flow.

- **VERY IMPORTANT**. **BREAKERS AND FUSES MUST BE FOR DC. AC CIRCUIT BREAKERS WILL NOT PERFORM PROPERLY ON DC.**

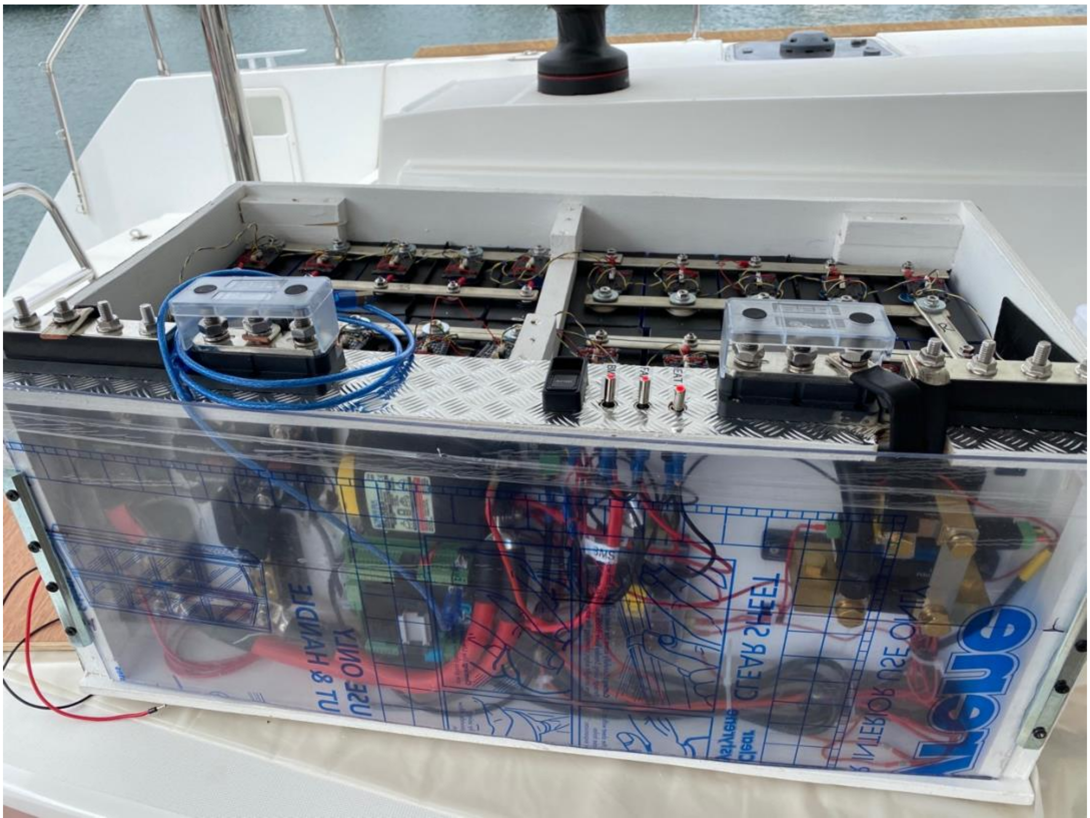
Circuit breakers have the wonderful feature of being able to be reset and therefore a temporary short can be fixed and the same circuit breaker just reset and continue to be used.

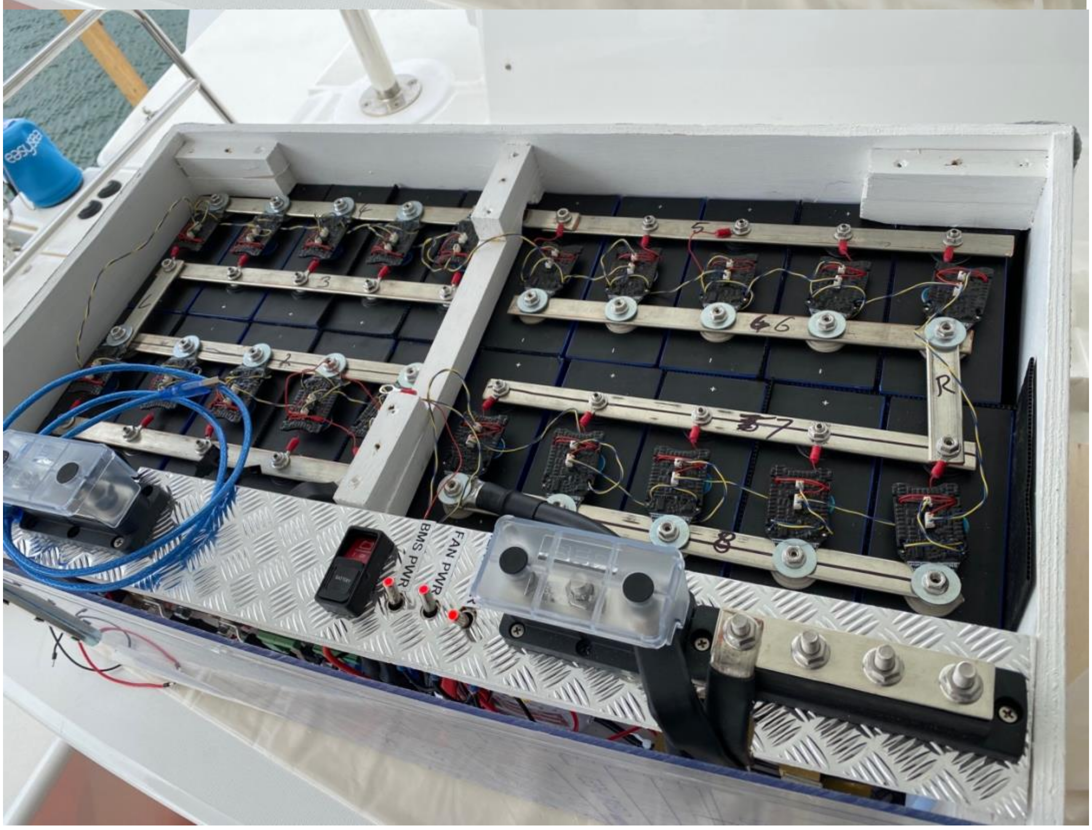
The problem, however, is that circuit breakers are also more complex and more expensive for high levels of interrupt capacity. They have a small but always present danger of an issue called contact welding, which occurs when a sudden surge of current “welds” the contacts together and even though the breaker has been triggered it does not disconnect.

For this reason, I am a fan of both fuses and circuit breakers in your design for your battery circuits safety. The breakers being at a lower current and therefore prone to earlier triggering than the fuses and the fuses at a higher but still safe level.

Fuses do not suffer from contact welding at and if the interrupt capacity is good enough. You should be safe from failures that leave power connected and therefore dangerous.

CREATING A BATTERY PACK – SECOND STEPS





Once you have spec'd out your battery and understand your requirements for the build the next thing is the physical build.

Containing Your Cells

Some prismatic cells really like to be compressed. There is much debate about how much they like being compressed, so let me just say that I contacted the manufacturer in China and asked the question. The answer was "They are fine uncompressed but will disform over time. Containing their dimension so that any swelling will create the pressure required to stop the swelling is sufficient."

In short you do not need to compress the cells, but you do need to build a box that will contain them with no room for expansion.

Building a box also makes for a good idea as you DO NOT want the busbars to be the single factor that is holding your batteries together.

There is a lot of debate about Eve cells vs Winston based on the shell, and that Winstone cells have a stronger plastic shell withstanding swelling better as a result. I personally don't think that there is enough in this to worry about, and the choice may well come down to availability or price.

Busbars and cells connectors – CAUTION

The Prizmatic cells I used are 280AH Eve cells and they came with Busbars that were designed to work for 280AH and are good quality.

BUT you must remember that if you are paralleling these cells to any degree you need to be mindful of two things:

1. **the manufacturers specs about how many parallel strings you can do and**
2. **the busbar size being appropriate.**

The thing that is missed here is that as you parallel the cells more current passes through each busbar and each terminal on the cells. The manufacturer will have set a design limit on this, but the busbars provided will be appropriate for very little more than a single series set.

I recommend you get bigger busbars and be sure to check how big you can go without exceeding the terminal current limits. If you do there will be excessive heat generated and you know what that means.

My own battery is 4S5P and that 5P is right at the limit described by Shenzhen for the Cell Parallel limits and therefore current limits.

I still find under high, prolonged loads I see creeping temperatures in the final cells for the battery pack and in hindsight would have paralleled them using busbars instead of direct cell busbars, which would have meant each cell would have run at a lower temperature.

Charge/Discharge Circuits?

I did not go for this design BUT it is a very valid design. That is where you have separate charge and discharge battery circuits, fuses, and contactors (RBS).

The main reason for this is to save money and separate faults. It is applicable where you expect the current load on your charging side to be very different from the load side.

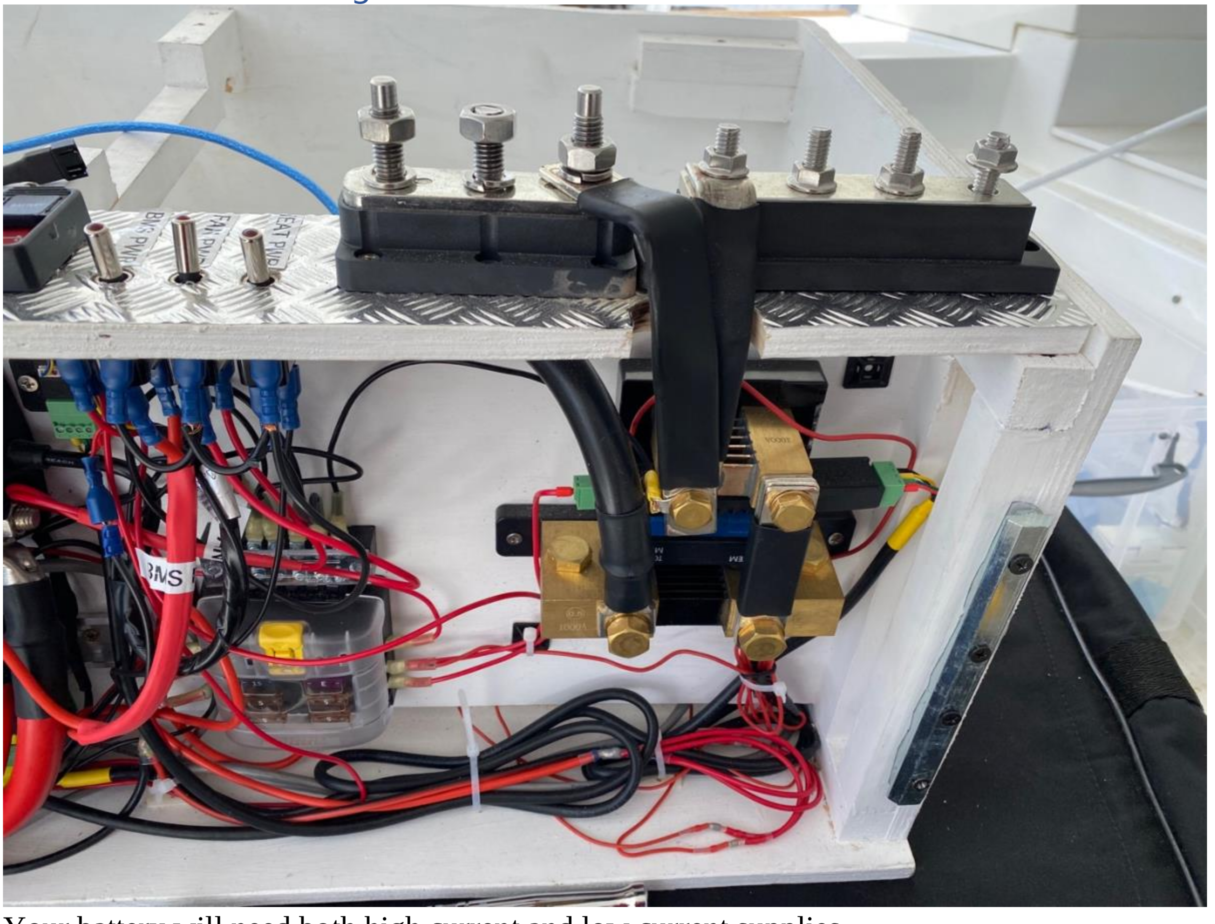
Usually this is because you have less space for solar/gen/etc. and expect you'll be charging at a much lower rate than you might have to draw for short periods for say cooking.

This can save money, smaller wires, busbars, fuses etc on one side and separates the Charge from Discharge side of the battery for maintenance and support purposes.

As I say, I did not go this way as I regularly charge at 200A and also draw quite higher but not a high enough difference to warrant it in my opinion. KISS principle applied.

This also meant that charging circuits like solar, were directly connected to things like the inverter so I could actually maintain the battery fully disconnected and run everything I needed on a sunny day with no power down time. Separate circuits won't work this way without a bypass mechanism.

Low current bus and high current bus



Your battery will need both high current and low current supplies.

The BMS for instance will need to be fused, so will the fans, heater etc if you use these. These will all run on 12V and at low current draws and therefore low amp fuses etc.

You'll want to fuse them separately for ease of maintenance and resiliency so plan for a low current circuit as part of your battery and a separate fuse block for this.

I personally used automotive style blade fuses for this purpose and appropriately fused and wired all the low current part of the battery, including the RBS control circuitry.

Heating and Cooling

I mentioned above, cooling and heating. This is of course optional, although I would argue that cooling is NOT. I suppose if I lived on the east coast of the US or Canada, I would argue even heating is not.

Cells like to live in a temperature zone and although that is quite wide it is easily exceeded, especially the high mark in hot climates with loads on the battery. Although LifePo4 doesn't produce much heat, connections will generate heat, and you need to manage this or your battery will disconnect.

Fans are quite adequate for cooling and can just be computer 12v fans for this purpose. Make sure you have good coverage across the cells and that there is adequate airflow between the cells. Heat sinks are not a good idea as generally they are metal, and you should try to keep conductors away from your battery unless they are wrapped in insulators. I accomplished this using plastic sheeting that was vented as crush cushioning between the cells and underneath.

This was another reason for replacing the busbars as the original's holes were not wide enough to accommodate this padding. The 12v fans, controlled via relay on the BMS, push air around and through this padding. This has proved very effective in maintaining a very stable temperature on the batteries.

For heating the same was accomplished using silicon heating pads (12V) that were placed under the cells and again managed by relays on the BMS. The heat was of course, heating the bottom of the cells but also hot air was rising through the corflute packing.

Airflow and compression

Compressing cells and airflow around cells are almost contradictory requirements.

The solution to this is some form of compression medium between the cells that will allow air flow. In my case I used corrugated corflute for its insulating properties and this has worked very well. I have also seen people use aluminium heat conducting sheet and other things.

Breakers and Fuses

I'm not an electrician so have been learning on the job. As such, I am happy to take advice if any of this is wrong or can be improved.

The general rule is that you fuse on the positive wire as close to the power source as possible. With a battery this means that you need to fuse somewhere on the positive lead before the positive terminal at an amperage that is the maximum your system is designed to operate at.

The example here would be my own system. I have all my connections designed to a level of 600A and the maximum I expect to draw is 400A or less. My breakers on the positive side are rated at 500A disconnect and have an interrupt well beyond the 1400A that is possible from the battery.

I also have fuses on the negative side that are physical destruction fuses, not resettable breakers and these are rated at 600A.

The RBS (Remote Battery Switch) that is controlled by the BMS is rated NOT designed to be a core safety measure and is designed to prevent damage to the battery not to the entire circuit IT IS NOT A CIRCUIT BREAKER OR FUSE. This is important as I have seen designs where it was thought this was sufficient.

BMS and Contactors

BMS's come in many different configurations and the Chinese passthrough BMS's often seem quite popular. This is because they are cheap not because they are appropriate.

Pass through BMS's do not have an external contactor switch or RBS unit but instead an internal breaker that is often circuitry based.

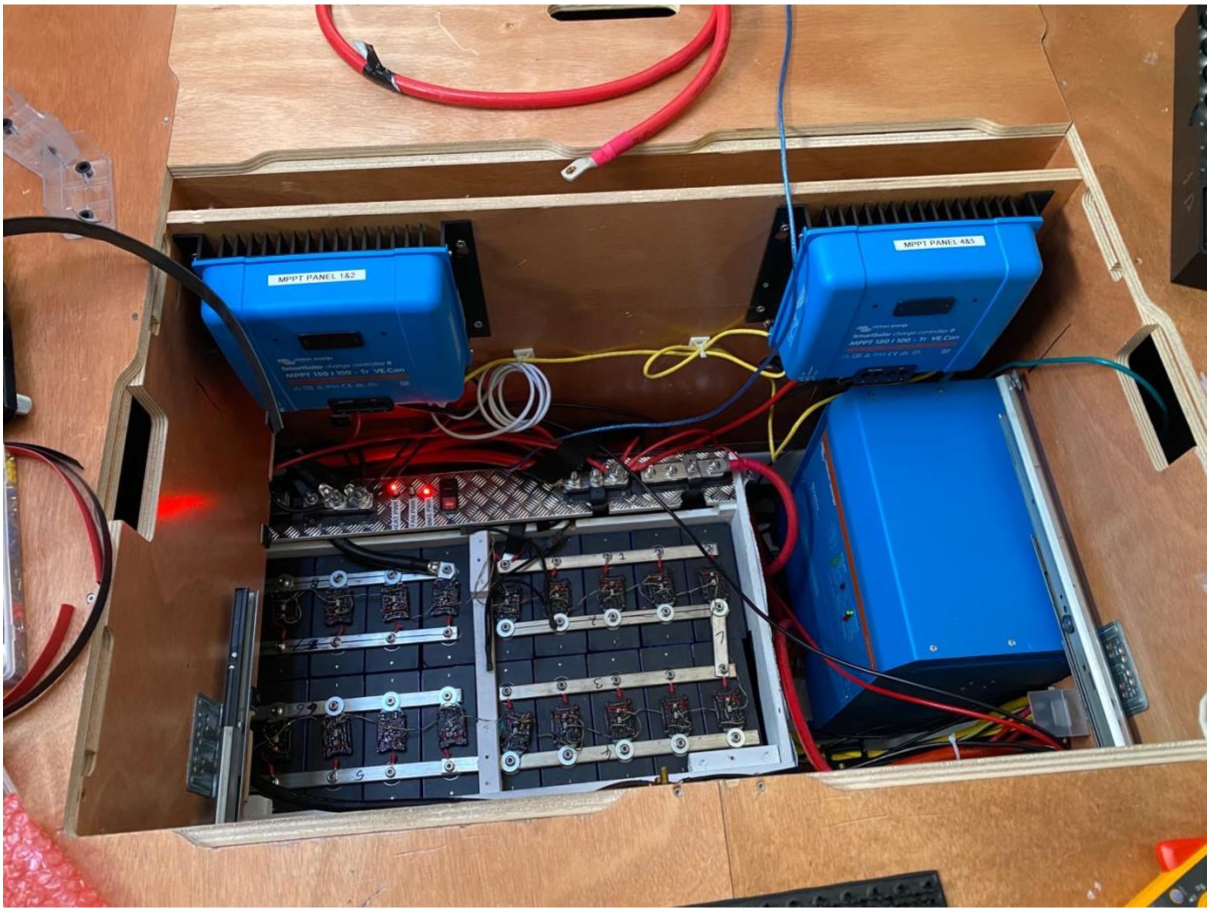
The problem here is that current creates heat, heat kills things and being integral with your BMS if your breaker breaks, so does your BMS.

BUT MORE IMPORTANTLY if you expect your battery to never draw more than 300A and buy a passthrough BMS that is designed to interrupt 300A and then connect it to a 1400A battery (for instance) the chances that your BMS will actually be able to reliably break that current is small.

IF YOU ARE BUILDING A SIGNIFICANTLY SIZED BATTERY DO NOT USE A PASSTHROUGH BMS.

Use instead, a BMS that is designed to control an external contactor or RBS that you can then spec to support the maximum load your battery is capable of delivering.

Access and maintenance



The last thing that I had not thought about during my original design was access for maintenance and what that maintenance would require access for.

Because I built a lovely compact and well sorted battery, I found once it was installed, I needed to physically lift it out to get access to all of it - and that wasn't practical.

I basically disassembled it and spread its components around the bay where I installed it. It wasn't so pretty and compact but it was a lot more accessible and maintainable.

Think about how you are going to access every connection bolt to annually tighten them when they loosen and cause heat, or how you are going to access the BMS when you need to wire in a new relay or change something because of an issue. Or space to get meters in to measure current when you have an issue and are trying to track where?

You get the idea. Pretty is nice, functionally accessible is better.

LITHIUM BATTERIES ARE AT LEAST 6 DIFFERENT CHEMISTRIES.

Not all Lithium batteries are the same. There are many varying chemical make ups and also very different charge rates and responses. There are also widely ranging safety criteria and responsibilities for each chemistry. So, the first thing we need to understand is "What are Lithium-Ion Batteries?"

Lithium Ion Cobalt ($LiCoO_2$):

You will often see these in laptops, cellphones etc. They have a high energy density, which is saying per kilo they can store a lot of energy. They have a cobalt oxide cathode and a graphite carbon Anode.

As far as chemistry goes, they are not particularly safe and can cause fires if overcharged and/or damaged physically. They also have a relatively short lifespan (500-1000 cycles) compared to some other chemistries.

Lithium Manganese Oxide ($LiMn_2O_4$):

You may find these in medical equipment and things that need a high temperature tolerance. They are a particularly safe chemistry and rather inexpensive.

Being rather new in chemistry terms, they are seen as an even safer replacement for LifePo4 batteries. Their lifespan is quite short though (300-700 cycles) so not entirely suitable for boat battery banks.

Lithium Nickel Manganese Cobalt Oxide ($CoLiMnNiO^+$):

Having a relatively high specific density they are often found in automobile battery banks for electric vehicles. They are not as safe as some other chemistries but safer than LCO and have a longer life than LCO at cheaper cost.

Lithium Nickel Cobalt Aluminum Oxide ($LiNi_{0,84}Co_{0,12}Al_{0,04}O_2$.):

They have a high energy density and a long lifespan, but are not as safe as other chemistries and are rather expensive. You do see this chemistry being used in electric automobiles.

Lithium Titanate (Li_2TiO_3):

These batteries most benefit from very fast charging and a high safety. They might appear perfect for electric automobiles other than the range issues (weight vs power) brought about by the density. They have a long life also but are rather expensive.

Lithium Iron Phosphate (LifePo4):

LifePo4 (LFP) batteries are very robust and have a long life, being able to exceed 2000 cycles if well looked after. They are quite tolerant and very safe as a chemistry.They will hold a charge for long periods of time with very little loss.

They also have a nominal resting voltage of 3.2v per cell which means 4 in series is a perfect match for existing 12v (nominal) systems, such as our boats.

Thermal runaway threshold is extremely high, meaning you can put an axe through a fully charged battery and although you will cause a short and much heat will be developed the battery will most likely NOT ignite and cause a fire. This means they are very safe for overcharging and physical damage.

They have a reasonably energy density, but not as high as some other chemistries.

ARE LITHIUM BATTERIES SAFE

Reading from above, you will understand that Lithium batteries is a general term, and some are safe whilst other are more volatile. LifePo4 is used for boat battery banks because of its safety parameters putting it in very much the same ballpark as FLA (Flooded Lead Acid, your normal lead battery).

I WOULD NOT EVER PUT LITHIUM BATTERIES INTO MY BOAT THAT WERE NOT LIFEPO4 CHEMISTRY.

I make this statement because LifePo4 (Lithium (Li) Iron (fe) Phosphate) batteries are as safe if not safer than Lead Acid batteries.

But don't' take my word for it, a picture is worth a thousand words, look at https://www.youtube.com/watch?v=Qzt9RZ0FQyM .

From real world experience, I personally have woken in the middle of the night to the smell of smoke and found one of my starter batteries (Lead Acid) had developed an internal short and was heating up to the "could cause a fire" point. Even after a day of sitting on the dock it was still too hot to touch. A friend had his brand-new car catch fire whilst driving and the car burnt to the ground, fortunately after he and his family had exited. The cause, a faulty starter battery (FLA). Lesson: Lead Acid is not completely safe either.

But why might Lifepo4 batteries be safer than Lead Acid? The answer is 'C Rating'.

The Charge/Discharge rating of a battery is limited by the internal resistance of that battery and therefore the heat that is generated through charging/discharging. C ratings are given to batteries chemistries based on the safe heat generation that a given C rating creates.

Because LifePo4 batteries have a C rating 5X higher than a lead acid battery they produce far less heat and are much more within their safe parameters during use as a house battery where the loads can be high and lengthy.

NOTE: Lead acid starter batteries often have what is called a CCA which is very high (cold cranking amps), but this is a momentary delivery of discharge and reading the fine print will inform you that full CCA should never be maintained for more than a few seconds at a time. This is to allow the battery to dissipate the heat generated by that load.

BATTERY CHEMISTRY AND CHARGING

Different batteries require different charging strategies for the long-term health of the battery and, safety. This is NOT a negotiable fact. Please understand that lithium batteries require different charging than FLA.

Here are some strong statements I have heard, with my responses that I will back up:

Can you charge a Lithium (LFP) battery with a lead acid charger: **Yes**
Will it damage the battery: **Yes**
Will it blow up: **No**
Will it shorten the life: **Yes**
"Should" you charge an LFP battery with a FLA charger: **NO definitely NOT**.

Can connecting a Lithium battery to an engine alternator charge the battery: **Yes**
Can it damage the Alternator: **Yes**
Can it cause a fire: **Yes**
Will it always: **No**
Can I get away with it for a while: **Perhaps, perhaps not**.
"Should" I charge from an alternator without modifying/checking: **NO definitely NOT**.

FLA battery charging requirements:

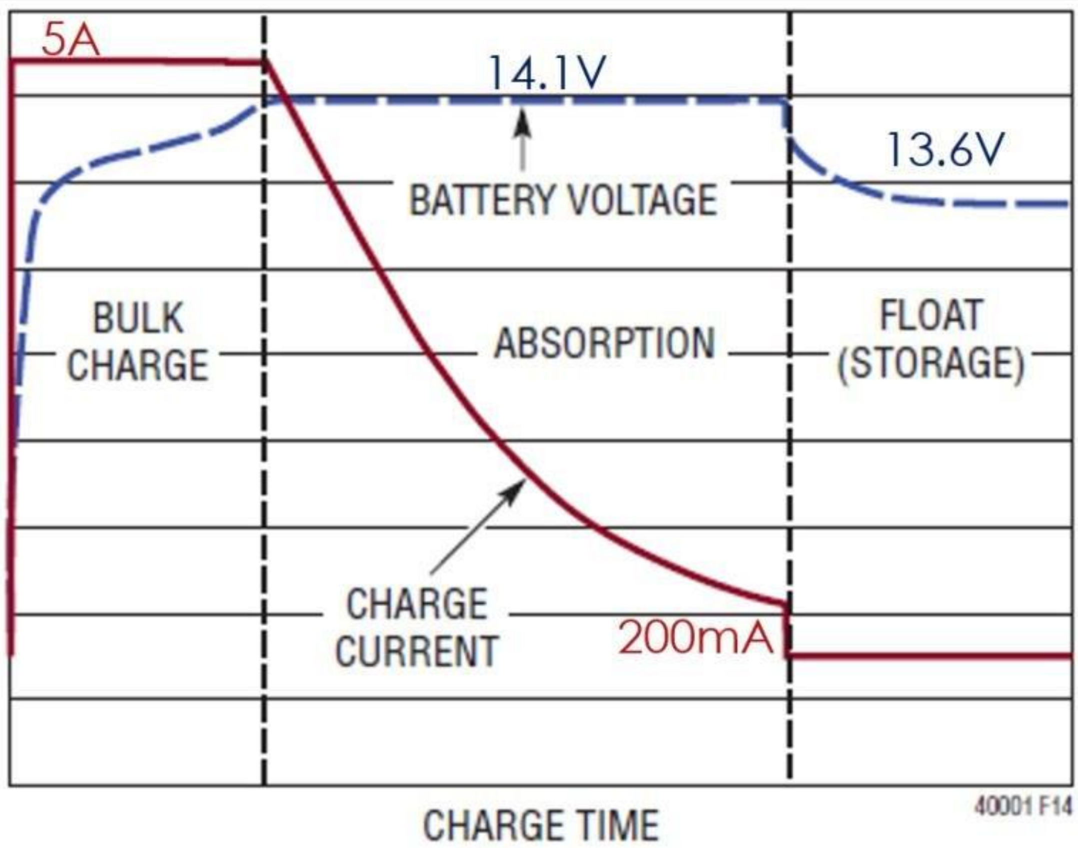
Let's start with the charging requirements for a Flooded Lead Acid battery. Because we tend to discuss Lithium as if it's something very strange and difficult, whereas if fact FLA is more difficult and strange, we are just used to it and our systems are designed for it.

FLA has a very high internal resistance and more importantly the resistance climbs quite quickly as the battery charges.

Overcharging, forcing too much voltage into a FLA battery will cause heat and rapidly shorten the life of the battery. It can cause a fire if really excessive.

For this reason, FLA batteries DO NOT LIKE TO BE RAPIDLY CHARGED TO FULL CAPACITY.

They prefer to be charged rapidly to less than 80% capacity and then slow charged after that point. An FLA charge curve looks like this below (the red line):



This means that FLA chargers are designed to charge at full amps and then drop down to an "absorption" phase and eventually to a "float" stage.

The "float" stage is because FLA batteries LIKE to be kept charged and keeping them "topped" off works well for their lifespan.

This makes them particularly suited for vehicle starter batteries where an alternator will constantly keep them charged and their off-charge use will be limited. FLA's like this very much and will live a long time.

They also do not like being discharged too deeply, i.e., beyond 50%.

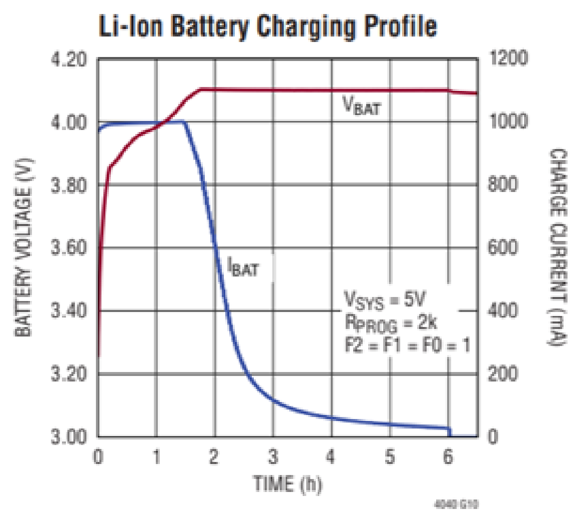
Lithium Battery Charging Requirements:

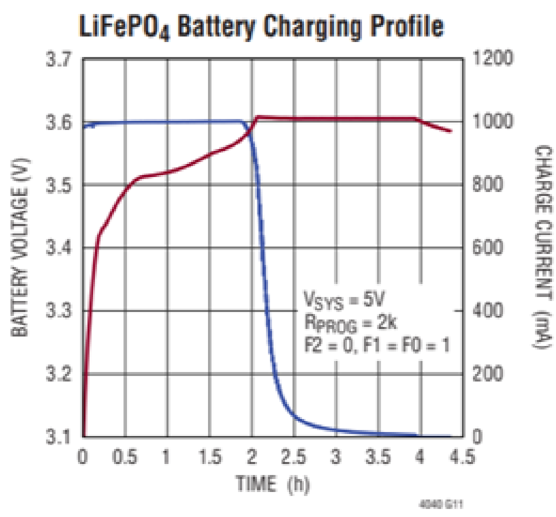
Lithium batteries have a very low internal resistance, and this does not change dramatically during their charging cycle.

They like to be charged as fast as the chemistry will allow, but mostly 1C or better right up to full capacity and then for charging to stop. This stop can be quite sudden with LFP.
An absorption phase is very bad for a lithium battery because low current charging can encourage the formation of "tendrils" lithium formations on the cathodes that extend into the battery and cause an internal short. FLA batteries also suffer from this problem but mostly when overly discharged rather than the charging current.

For the same reason LFP batteries do not like "float" charging and "float" should not be allowed to happen whilst charging an LFP battery.

Below is a chart comparing Li-ion (lithium) to LifePo4 (LFP, Lithium). You can see they like to be getting full current right up to fully charged and then will sag to resting voltage. This graph is for a cell, rather than a 12v battery so the numbers (3.6) refers to volts for a cell. Multiply by 4 to get 12V battery equivalents (i.e., 3.6 = 14.4v). The sag to 13.6 is what is called resting voltage, i.e., charging has stopped at 14.1 or 14.2 and battery voltage will sag to rest at 13.6.





Battery voltage the full story:

When we talk about a 12V system we are describing the “nominal” voltage of that system. By agreement this means a system that will work somewhere between the boundaries of 10VDC and 13.7VDC.

This does not by the way, mean that everything will accept the lower end or higher end, but it does mean that a 12V DC battery may in fact be 13.7V fully charged or indeed in the case of LFP 13.6 resting and 14.2V at the fully charged point.

A 12V FLA battery is fully charged at 13.7VDC and will drop to resting of 12.5 approximately.

A 12V LFP battery is fully charged at 14.2VDC and will drop rapidly to 13.6 resting.

Immediately you can see there is a problem if you have a FLA charger because it will expect the battery to be fully charged and in “float” well below the full voltage required for a LFP battery. Despite, absorption phase and float it will never get to a high enough voltage to charge correctly.

WHAT DO I NEED TO KNOW ABOUT BATTERY CHARGING TO MOVE TO LITHIUM?

There are some things you need to understand. I should point out that the only reason you think you don’t need to know these for lead acid is that you already have a well-designed (one would hope) lead acid environment that you have not had to consider.

Moving to Lithium the rules change, you get bigger C ratings for a start, and they require a slightly different supporting environment to Lead Acid batteries.

Can I Just Buy "Drop in Lithium" Batteries and Be Done With It?

The answer is no, any more than you could if we were going in the other direction, from a lithium battery environment and adding lead acid. Batteries fit into a supporting environment, and it all needs to line up.

Unfortunately to move to lithium you need to understand how you must adjust your environment to fit the new batteries requirements or things can go wrong.

What Changes With Lithium Compared to Lead Acid?

The two most important changes are:

- Charge/Discharge rates i.e., internal resistance of the batteries
- Charge Profile (style if you like) of the different chemistries.

The second one is important because lead acid and lithium require slightly different charging techniques.

You might not be aware, but your battery chargers currently are charging your batteries according to a pattern that is best for your lead acid batteries. This is not good for your lithium batteries in the long term and will slow down their charging greatly in the short term.

So, either your chargers will be able to be re-programmed (presuming you are not keeping any lead acid batteries around) or you might need new chargers.

If you get this wrong, the whole thing won't blow up, it just won't last as long or take advantage of one of the benefits of lithium, which is fast charging.

Things Can Go *BANG* If You Don't Understand

The C rating (Charge/Discharge rate) is a much more important factor to consider.

Lead acid batteries have a much higher internal resistance, and therefore their charging rate is much lower.

Some of the components of your electrical system may well depend on this fact to protect them. Your alternators on your engines for instance; if they are not regulated and many perhaps most, are not, then they will attempt to provide as much current as the battery demands.

They can get away with this because they are designed to work with the maximum C rating of a lead acid battery, but if you suddenly put a lithium battery in there and it now demands 5 times the current from the alternator, if it doesn't have some external regulator, it will simply get too hot and burn out.

Again, a picture is worth a thousand words, so take a look at https://www.youtube.com/watch?v=jgoIocPgOug kindly provided by Victron to educate us.

This is the reason that putting "Drop in Lithium" batteries is not such a good idea.

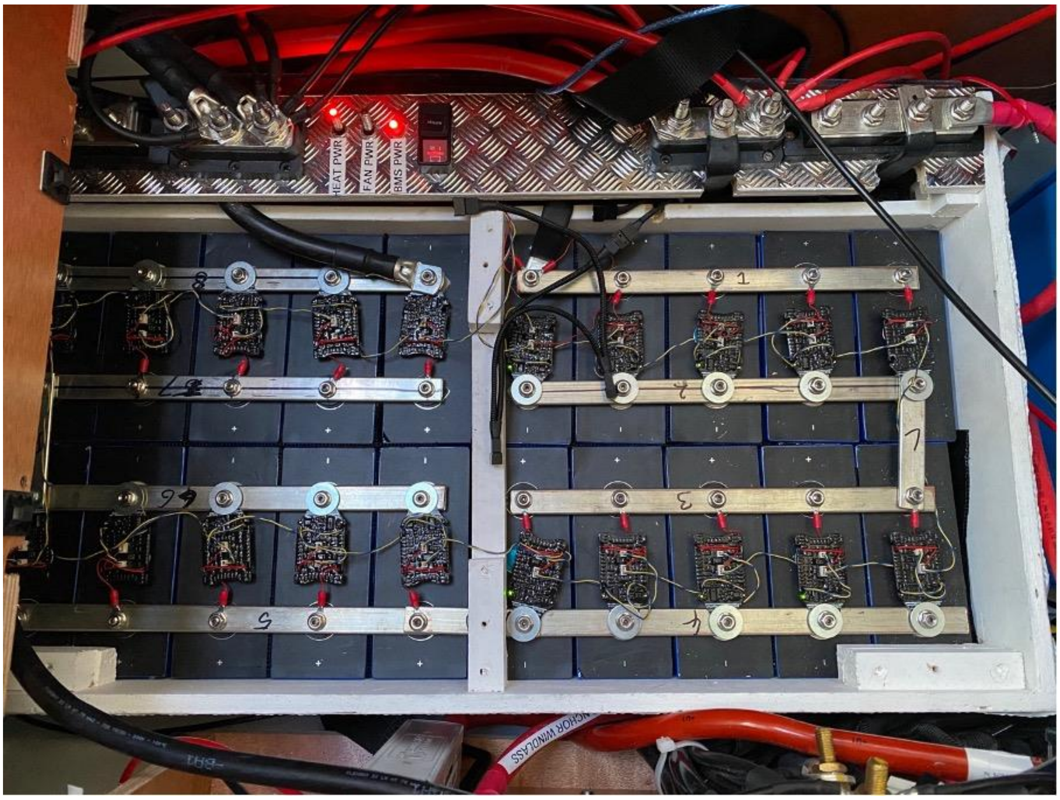
If you want to geek out, or learn a little bit, consider this….

> *A Lead Acid battery bank can only be charged at 0.2 C until it approaches 80% charged. Then the internal resistance will reduce the rate at which the batteries can be charged because of the increasing internal resistance.*
>
> *A 125Amp alternator would be at maximum capacity if the battery bank had 625AH of free space left before it got to 80%. This would mean that the battery bank because you should not discharge below 50% for lead acid, would have to be over 1500AH and almost fully drained to draw 125A from the alternator.*
>
> *But a lithium battery, which could accept 1C of charge right up to 100% would only need a battery of 125AH that was partially drained (just a little) to draw the same current. Imagine how much a slightly empty 600AH battery would try to draw from that 125A alternator (600A would be the answer).*

In Conclusion

You cannot "just drop in" a drop in lithium battery because you need to consider what impact your chargers might have on it and what impact it might have on components in your system, like your alternators.

KEY FINDINGS



- Building you own battery bank is not as difficult as you might think. It is doable by anyone willing to take the time and do some learning.
- Big battery banks have big potential power and need to be built with this in mind.
- The cost savings can be considerable, but the time spent is also considerable. There is more than just saving money at stake and being cheap is not a good motivator for building a potentially dangerous battery bank.
- You can end up with something that is not only cheaper but better than you could otherwise purchase.
- The biggest motivator should be to build an appropriate system. Drop in batteries are not suitable for this style of operation.

CONCLUSION

Lithium Iron Phosphate are excellent batteries and by putting in the time and effort you can end up with a much more intelligent, maintainable and robust battery system than you might be able to purchase.

It is not difficult, but it does take a degree of research, planning and learning to accomplish.

I would highly recommend that you investigate Lithium (LifePo4) for household battery requirements, where they really do shine.

CONTACT DETAILS:

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Good luck with your future boat projects and good power to you.