The Endless Search For Power

One of the most frustrating things on a cruising yacht has to be the collection and storage of enough power to support one's chosen lifestyle. And the amount of power required seems to directly impact the level of frustration in a linear progression.

Most cruisers have solar panels to help supply their power requirement when not running the engine. The more energy you need the more space on your vessel will be clobbered up with these big flat panels, causing more windage and line grabbers. In addition, high output alternators and wind generators are often added to the mix in order to climb the "slippery slope" of keeping the batteries charged.

I say "slippery slope" because most cruisers today are trying to charge lead acid batteries, which slowly refuse to absorb charge current the closer they get to being full. This diminishing charge acceptance rate of lead acid batteries is a real problem for all charging sources. Solar panels are at best only 17% efficient at converting solar energy to DC current. However, if the batteries are 75% full, most of that DC current from the solar panels is being turned away by the batteries. The same is true with alternators. We use a Balmar 165 amp alternator, but most of the time it is charging between 5 and 25 amps due to the lead acid batteries turning away the available charge current. Consequently, the engine has to run much longer to achieve a full charge. This situation becomes even worse as the batteries age.

However, it is important to keep on attempting to fully charge the batteries. Lead acid batteries do not like to be kept at a level of charge below full. Doing so will shorten their life.

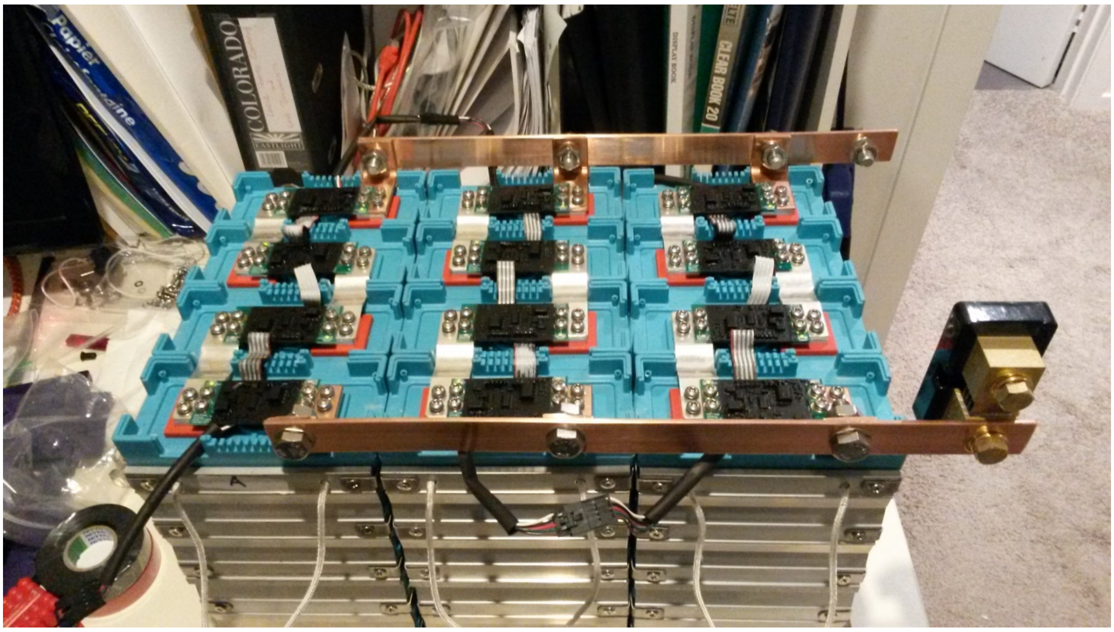
But there is more. In addition to being difficult to fully charge, they only give you back about 40 – 50% of their rated capacity (amp hours) between charges. This means that if you require 300 amp hours of useable energy for your electrical needs, you will need a battery bank rated at 600 amp hours or more. That battery bank will weigh over 175 kilos and will require a lot of space.

We have owned our boat, Mai Tai, for 28 years and consequently I have repeatedly removed the old, heavy batteries and installed new ones. The average life has been around six years. That is five sets of very expensive, large lead blocks. Cruisers are typically pretty goodat managing life's little disappointmentsif there is no better alternative. However, I am getting very tired of living with the inefficiency, weight and expense of lead acid batteries.

I'll be the first to say that I tend to bea bit hesitant to make a giant leap of faith to a new and un-proven product, especially whenit will be used in a yacht for offshore cruising. I'm the only guy left in the marina who still uses hank on sails. And as John wisely says, don't be a pioneer! It can be expensive and dangerous to experiment with new alternatives.

So here is the question: How long should we wait before new technology should be adopted? In my case, I am tired of waiting - the time is now! I don't want to put another set of lead acid batteries on Mai Tai and we really need new batteries NOW. The thought of living with lead acid batteries for another six years is unacceptable to me. Come what may, it’s time to be a pioneer!

With that decision made I began researching everything written about Lifepo4 batteries and have discussed the questions I had with several qualified professionals. What I found was interesting and far more simple than I had expected, based on all the scary stuff that has been written about lithium battery packs. Some of the following points are known to most of you. However, I thought I would make quick mention of them as a reminder.



Lithium Iron Phosphate Batteries (Lifepo4)

Lifepo4 batteries are very different from lead acid batteries. Here is how:

- They will take a charge current equal to their amp hour rating, (1 C), right up to their fully charged state. So theoretically, you could charge a fully discharged 300 amp hour bank of lithium batteries in an hour if you had a 300ah charger.
- They don’t care if they are fully charged or only half charged. In fact, when they are stored for long periods, they preferbe half full and they will lose less than 2% of their charge per month. So over a six month period your battery level may drop by 12%.
- Lifepo4 batteries will give back roughly80% of their rated amp hours and not be seriously discharged. If you need 250ah of useable power, a 300ah Lifepo4 bank will probably be plenty.
- Even as Lifepo4 batteries are discharged they maintain a very steady voltage level. This is good for your boat’s loads like electronics but it does have one disadvantage;it makes it very difficult to measure the state of charge (SOC) of your bank using voltagereadings alone.
- Lifepo4 batteries, when compared with a lead acid bank with similar useable energy, are generally a third the weight and less than a third the volume.

So what is the problem with Lifepo4?

The problem is not with the Lifepo4 batteries but with the existing infrastructure on our boats.The chargers, alternators, solar regulators and wind generators all form the support infrastructure for the batteries. For decades all the equipment surrounding our batteries has been developed to suit lead acid batteries and much of this equipmentis not suitable for a Lifepo4 system. Any battery system will fail if it is not treated properly. Here are some interesting points you need to know if you are considering Lifepo4 batteries:

- The lead acid charging regime usually has three steps; bulk, absorb and float. Whereas the Lifepo4 charging regime uses two steps; bulk and off. There is no need for the absorption phase and continuous float charging a Lifepo4 battery will shorten its life.
- Alternators use regulators designed to charge lead acid batteries, and this charging regime doesn't suit Lifepo4 batteries. However, some companies have now developed regulators for Lifepo4 batteries. Balmar is one of these companies with their new MC614 regulator.
- Solar panels use a solar controller to charge batteries and these need to be adjustable to suit Lifepo4. There are now several solar controllers on the market suitable for Lifepo4. This market has developed quickly due to the explosion of off-grid solar powered homes and RVs.
- The wind generator must also be regulated properly so it fits in with a Lifepo4 system. It must automatically shut down before the Lifepo4 batteries are over charged.
- Even the AC chargers we use when plugged in to the marina are intended to charge lead acid batteries, many touting their five-step charge regime.
- Lifepo4 batteries do not just get sick if they are over charged, they will die.
- If they are discharged below a certain level, they will also die.
- They do not like it hot or freezing. Do not charge Lifepo4 batteries if it is below 0C in the battery compartment and do not keep the batteries near a hot engine.

That about covers the infrastructure problems in our existing setup! Now all we have to do is create anew battery infrastructure, which aligns with these requirements. This shouldn't be too much trouble, right? We're cruisers so we should be able to figure out just about anything.

The point is, if we are willing to make some minor adjustments toour battery infrastructure, we can take a huge step forward in power and cost efficiency. Unfortunately, the first time we install Lifepo4 batteries it will cost more because we have to change the battery infrastructure. But didn't we go through that when GEL batteries first came out. Then we did it again when AGM batteries hit the market. Each step forward in battery technology has brought with it the cost of change. No surprise there!

I want to share with you what I have done to create a new Lifepo4 friendly environment on Mai Tai. As time passes and I gather more information about the success or failure of this system, I will share that as well. This is not intended to be the only solution available or a lecture on how to do it. Rather, I would like to start you thinking about the practical side of this changeover because you will all need new batteries within the next few years. You might as well have some practical information about the installation of Lifepo4 batteries.

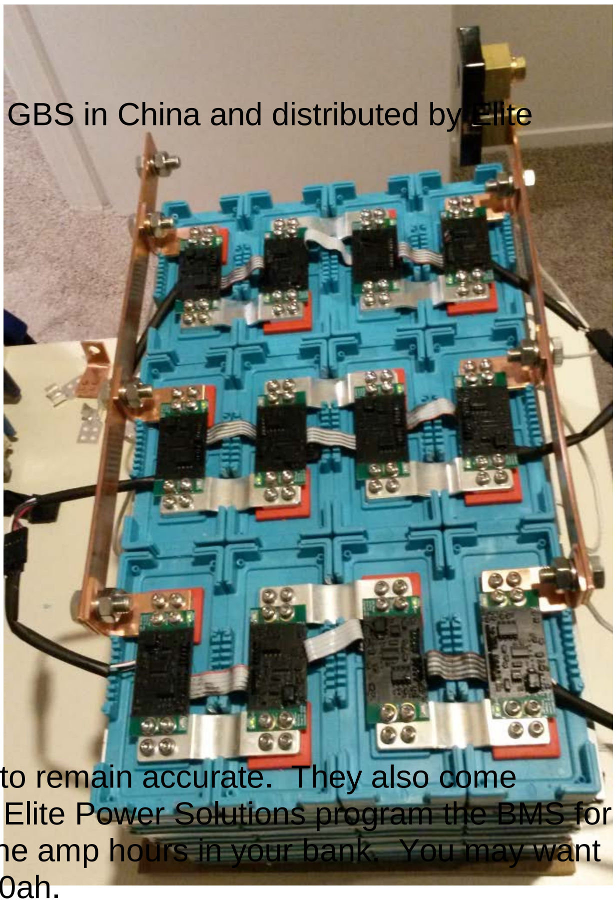
Step One: Research

As I mentioned before, I read everything I could find and I have listed links to a few of my favourite articles at the bottom. I won't bore you with theory as I'm not really qualified to do that. But through my research I was able to determine a likely path toward a very practical basic system brief:

- Move the battery bank inside the cabin or to an area that is insulated from the engine room heat and the outside cold (especially in high latitudes).
- Create three bus bars, one for all charge current going into the battery (Charge Bus), one for all current leaving the battery (Load Bus) and a common ground bus (Ground Bus). By doing this you can stop current from entering the battery when it is fully chargedby switching off the Charge Bus and stop current leaving by switching off the Load Bus when the battery is nearly empty. Each of these two bus bars are connected to a separate switch which is controlled by the "battery monitoring system" (BMS). The BMS constantly monitors the lithium cells and tells the switches to close when set levels are reached.
- Several systems I looked at had simplified this by having both the charge bus and the load bus on one switch. The problem I discovered with this system is that if the battery is over charged and the switch is turned off, the load bus is also turned off and you can't use the battery. While this keeps the cost down it prevents the battery from being used and brought back within an acceptable charge range. Having two bus bars and two switches allows the battery to be kept within its charge limits without removing the battery from the system completely.
- One of the issues with any lithium system using relays to stop the flow of current is what happens if the charge relay opens when you are charging the bank? For instance, if the alternator is grinding out 100 amps of current and suddenly the switch is thrown? The alternator no longer knows what the charge level of the battery is because it has been disconnected. This may cause wild spikes in voltage levels throughout the system and although unlikely, could cause some damage. Although the alternator is protected with diodes, this mayalso cause damage to the alternator. To solve this problem we put a sealed lead acid (SLA) starting battery alongside the lithium system. All it does is start the engine. However, we designed the charge bus relayso that it connects with the SLA battery before it switches off from the lithium bank. So ifthe charge bus switch is opened, the alternator immediately sees the lead acid battery in the system and adjusts its charging according to the new battery. The lithium battery is removed from the charging bus but is still running the loads through the load bus. As the charge level falls back to within the programmed range the relay brings the charge bus back on line and the SLA battery is disconnected.
- Keep in mind that the two relaysconnected to the charge and load bus are for "system failure" incidents (perhaps the wind generator fails to shut down when it should). Each of the charging sources should be programmed to keep the lithium pack within its limits without throwing the relay. **In the best possible design we want the whole system to operate without ever throwing one of these relays**.
- A few systems I looked at also use an SLA battery in the system and use a battery isolating relay to keep the batteries separate while allowing the charge bus to keep both batteries charged. When using this system it is difficult to sense the battery voltage because the isolator blocks the voltage from travelling back through the isolator to the post where it can be detected. This system has the advantage of allowing both batteries to be charged by the charging bus but they cause a lot of difficulty when trying to acquire an accurate battery voltage for the alternator. For this reason we haven't used a battery isolating relay. Instead, we worked with the good people at Perfect Switch to develop a "make-before-break" single pole double throw (SPDT) Mosfet solid state relay that will comfortably handle 250 amps at 12 volts continuous. This won't allow us to simultaneously charge the lead acid battery through the charge bus.

However, we have a solar charge regulator, which will put a small charge to the lead acid battery independent from the charge bus. This should keep it well charged as the current draw on this battery will be quite low. In addition, we have placed a manual override switch in the system, which will allow us to bring the SLA battery on to the charge bus if it ever requires a quick top-up.

Step Two: Lifepo4 Battery Systemfor Mai Tai



The Batteries:

The lithium batteries we chose to use are made by GBS in China and distributed by Elite Power Solutions in the USA. What I like about these batteries is that they come with their own BMS solution, where each lithium cell is individually monitored by a network of small computer chips (as seen in the photo). These are constantly sending voltage and temperature information to the main BMS unit, while also performing cell balancing on the individual cells. The BMS unit also counts the number of amps in and amps out so it can give an accurate state of charge (SOC) for the bank without relying on the voltage reading. The information is sent by video link to an LCD display. Every time the bank is fully charged the BMS resets its amp count and by doing this it continues to remain accurate. They also come strapped together in 100 ah packs and the guys at Elite Power Solutions program the BMS for you before it is shipped, taking into consideration the amp hours in your bank. You may want 400ah or 600ah. We feel very comfortable with 300ah.

There are output pins on the BMS unit for powering under voltage (UV) and over voltage (OV) switches and alarms as well as the video output.

More on the Relays:

As I mentioned,we wanted a make-before-break relay for the Charge Bus, which would allow the charge bus to sense the SLA battery before losing contact with the lithium bank. This will protect the system from the charge bus throwing out stray current with nowhere to go. We also wanted the relay to have its own set of criteria for switching off in case the BMS unit lost power or in some way failed. (Never to many backup systems!)

Perfect Switch in Southern California helped me out. They have developed some pretty amazing solid state relays and were keen to have a look. They put together a Slave and Master unit for the make-before-break relay. You can see in the attached diagram that the Slave unit is connected to the lithium bank and is normally “on”, which means it is closed. The

Master unit is connected to the SLA battery and is normally “off” or open. They are both connecteddirectly to the Charge Bus. When there is an “event” where the BMS over voltage pin (OV) sends out a shut off signal, the Master unit closes just before the Slave unit opens, thereby providing a path to the SLA battery for any charge current coming in. Since the Master and Slave units are both bi-directional the alternator is always able to get an accurate voltage reading of the battery being charged. Anyway, without getting too technical, this arrangement solves several difficulties and at the same time gives an additional layer of safety. These relays are able to be programmed to switch off at a certain voltage so I have set them up to shut off at just a bit higher voltage than what the BMS is set for. If the BMS fails, the relays should shut off the charge bus before any damage is done to the batteries.

The Load Bus is pretty straight forward. It uses one relay, which switches off the loads when the BMS sends a message that the voltage level in the lithium bank is too low (UV). I should mention here that the BMS is programmed by the engineers at Elite Power Solutions and they are very experienced in setting the parametersh for cruising boats. We ended up using 90% charged for FULL and 20% charged for Empty. This gives us useable amperage of roughly 70% of 300 amps or 210 amps of useable power while keeping the Lifepo4 batteries well within their best operating mode.

Obviously, it is very important to have all loads from the boat connected to the Load Bus and all charging systems connected to the Charge Bus in order for this system to work properly.

Step Three: Adjusting the Existing Infrastructure

We needed to check each part of our charging systems in order to make sure that none of the charging units would try to kill our lithium batteries.

Solar:
The first one I attacked was the solar panels. Mine were old (eleven years) and newer, more efficient ones were available for less than I paid for the old ones. I upgraded both panels to 160 watt panels and settled on a Votronic MPP 350 Duo Digital solar regulator, which has switchable settings for charging lithium batteries. I also set up a switch on the panel, which allows me to shut off the solar panels completely so they won’t try to trickle charge the batteries to death when we are not onboard. No problem there!

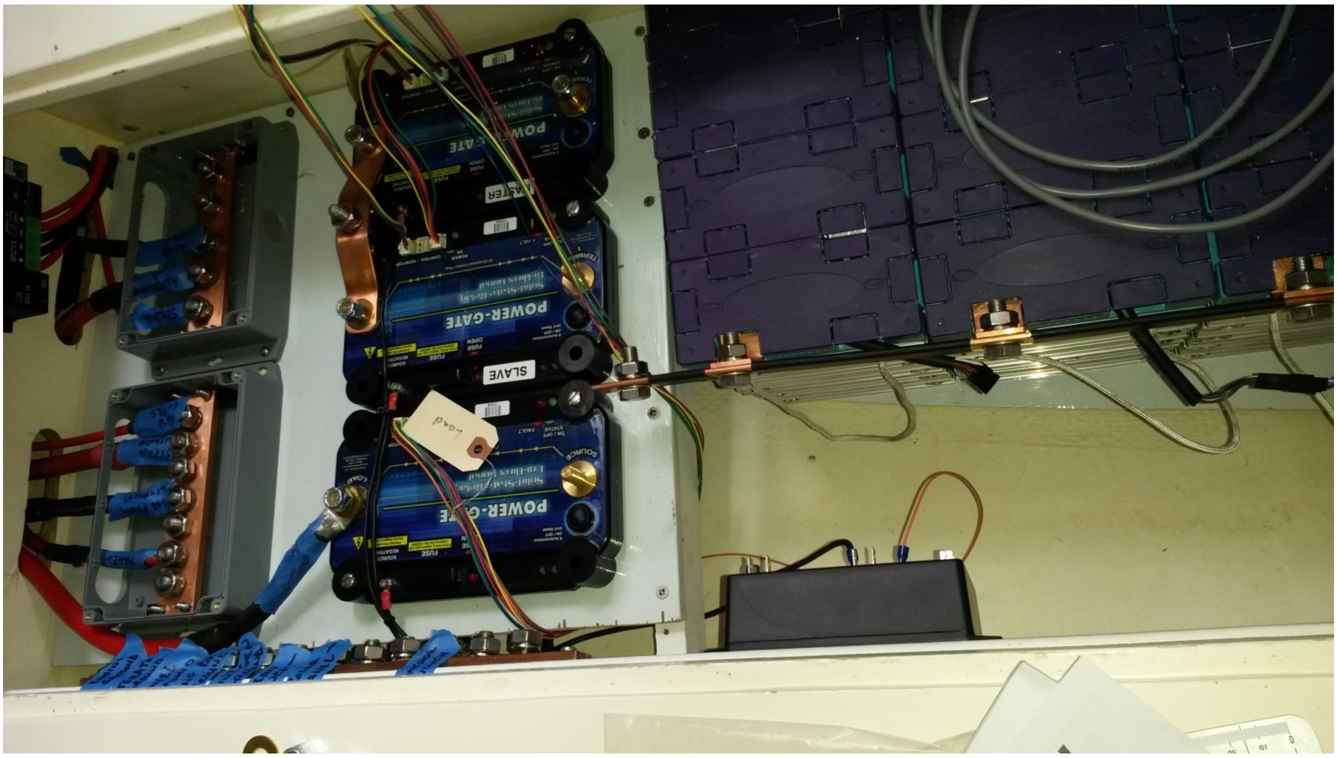
Wind:
Our wind generator is an Air-X-Marine unit with new Blue Blades, which, by the way, has made a huge difference in the noise. These units have an internal regulator, which would be very difficult to adjust. However, they do have an exterior “pot” screw on the body that can change the cut-out voltage on the unit. I adjusted the cut-out voltage to 14.0V as the BMS on the lithium bank will cut out at 14.4V. This should shut the unit down long before a critical voltage level is reached. However, I remain unsure about the accuracy of the units shut down settings and will have to monitor it closely when it is in use.

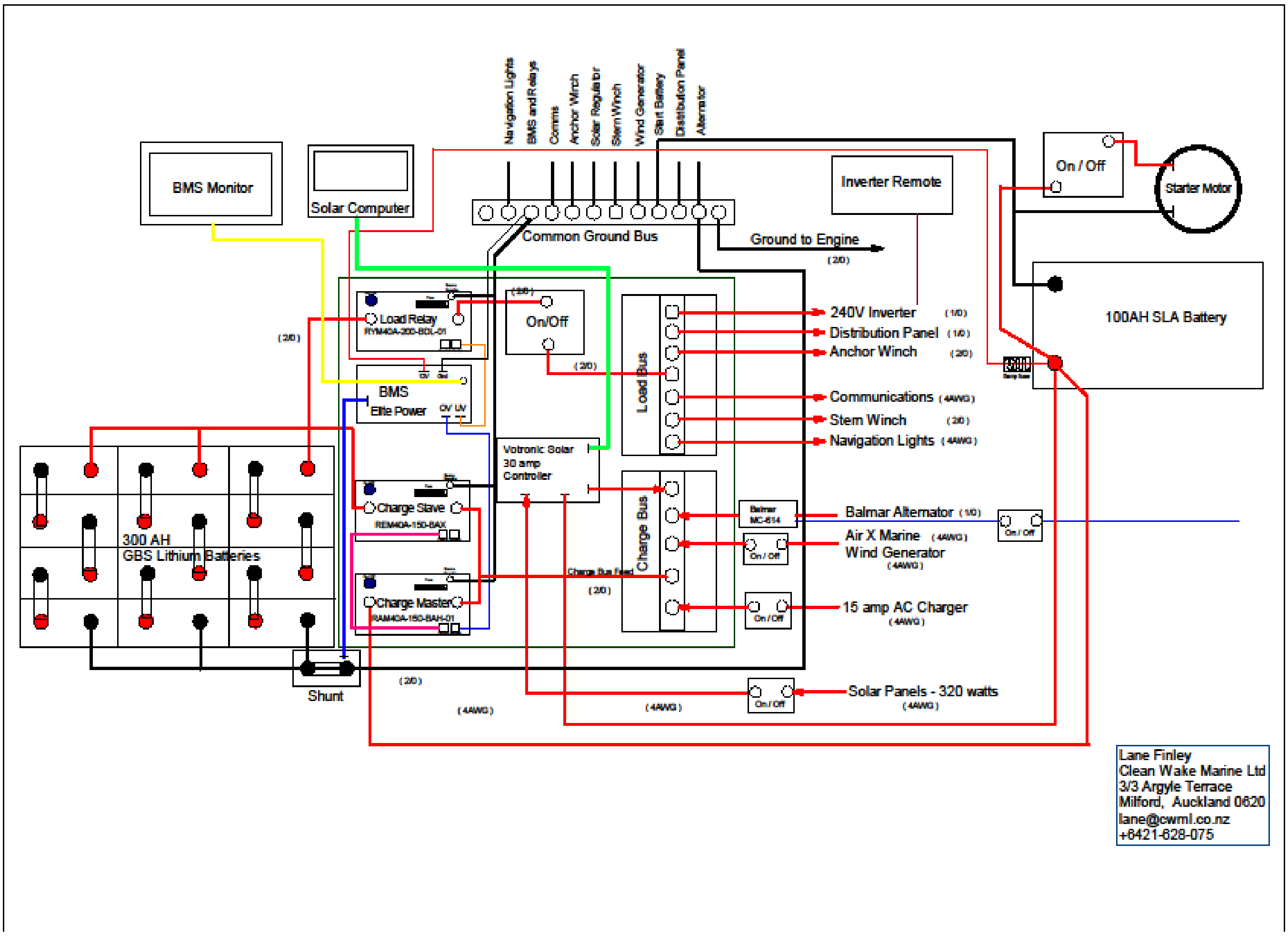
Alternator:
The alternator is a Balmar 165 with an external MC-612 regulator. I spoke with Balmar and they said they have developed a new regulator that has a lithium charging regime all set up as a battery charging option. However, they also said that my older model MC-612 was able to be programmed to suit lithium batteries. In December, 2017, Balmar issued a service bulletin, which explains how to re-program the MC-612 for lithium, which was very useful. Job done!

AC Charger:
When I ordered the GBS lithium batteries from Elite Power Solutions, they also offered a small AC charger, which has a control cable that plugs directly into the BMS unitand charges the batteries according to the BMS readings. It only puts out 15 amps, which is pretty much the maximum you can get from marinas outside the USA anyway. So this unit is aboard and connected, ready to use if we ever tie up to a marina berth that has power. Also, no problem!

Step Four: Testing the System

The next step





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