Introduction

Before I designed my BMS and installed LFP batteries in my boat I spent quite some time reading blogs and scientific reports in order to not do anything stupid that easily could have been avoided by using existing knowledge. Here is a summary of what I think is the most important stuff I learned.

LiFePo4, LFP

A battery technology based on lithium ions. Hard to get into a thermal rush = safe, long lifetime and reasonable priced, and therefore the best lithium battery technology to be used in a boat today. It has a few differences compared to lead batteries: It dies directly if completely discharged, dies slowly when being overcharged or charged at too low temperature, or with too high current. Each LFP cell has a nominal voltage of 3.2 V, so four cells are enough to build a nominal 12 V battery (compared to lead that need six). These differences make it unfortunately not possible to get a simple “drop-in upgrade to LFP”. These only exist in marketing.

LFP lifetime

Even if you keep the LFP battery within the boundaries given by the manufacturer, they will anyway lose capacity over time. There are many reasons for this, and most of them are very complicated so I will not even try to describe them, mainly since I do not really understand them myself. But the main one’s users in a boat can influence are: how to store, discharge and charge them.

The one that seem easiest to understand is discharge and charge. It shall be done symmetrically around 50 % SoC (State of Charge, i.e how much the battery is charged) to achieve maximum life length. Best lifetime wise is cycling between 49 % and 51 % SoC, worst is between 0 % and 100 % SoC. I’ve seen many reports showing how expected life length decreases significantly when increasing the cycling depth. Many of these estimates do not specify exactly what lithium-technology they are based on, so many are probably based (or influenced) on other lithium technologies then LFP. A recent article in Journal of the Electrochemical Society indicates that the difference is not that significant for different cycling depths for LFP, as for NCA and NMC. So, if managed correctly, lifetime might be a lot longer than 2000 cycles, even if it is cycled between 100 % and 0 % SoC. Time will tell.

Storage also seems to benefit from being symmetrical around 50 %. There are however reports that indicates that there is a “knee” at 95 % SoC, above which degeneration increases more rapidly. So, with a monthly self-discharge of 3 % (which many vendors claim), it is just to do the math. If stored for two month, charge to 53 % and disconnect the battery. When returning SoC shall be 47 %.

To store at temperatures above 35 degrees Celsius is definitely not good. But also, storage at low temperatures is not good either. I have seen a report indicating that 15 degrees Celsius is best storage temperature, but that was also the lowest temperature tested. But since I leave my batteries in the boat over winter and cannot influence the storage temperature, I have not spent much time to try to find out more details either.

And lastly, the lower current you charge and discharge with, the more it will extend the lifetime of LFP. This is especially important when charging at low temperatures. Charging below 0 degrees Celsius is really bad.

Using LFP

To prevent that the LFP dies from over-discharge there should be an undervoltage protection the switches off all loads before this happens. The minimum voltage is 2.5 V for many of the common vendors cells. If the protection voltage is set a bit higher (e.g. 3 V) then there is enough power left to e.g. start an engine. In a perfectly balanced battery, the undervoltage supervision can be done on aggregated level (12 V). But the slightest unbalance can then bring one cell outside of the allowed voltages if the limits are set to max. Therefore, it is much safer to base the supervision on individual cell voltage, i.e. let the BMS control it.

It is also important that the skipper get some warning before the power is switched off, so the BMS must be able to handle this.

Charging of LFP

Can be charged with high current (1 C) however this will shorten its lifetime (C is an expression of current in relation to a batteries capacity, 1 C for a 100Ah battery is 100 A). There is normally a recommended current from the manufacturer, often between 0.3-0.5 C. To use a lower current is even better (from a lifetime perspective). When charging it is important to not exceed the recommended maximum voltage, often 3.65 V. If the charging is done with e.g. 0.5 C, then the SoC will be above 90 % when the cell voltage reaches 3.6 V, so then there is really no need to continue with any absorption charging unless it is important to reach 100 % SoC. If 100% is important, the manufacturer states at what current charging shall be discontinued, often around 0,02–0.04 C. The problem with continued charging after that is that when there are not enough free lithium ions available, so the charging current will be used for lithium plating, which is a slow way of killing an LFP cell. This is also what happens if charging is done at a too low temperature, or with high current. So, when charging is finished, either stop charging completely, or decrease the voltage to below the LFP open cell voltage (often around 3.35 V). The supervision can be done at an aggregated level (12 V). But the slightest unbalance will then bring one cell outside of the allowed voltages if the limits are set to max. Therefore, it is much safer to base the charging control on individual cell voltage, i.e. let the BMS do it.

Temperature

If an LFP battery is used for heavy loads (> 1C) and/or rapid charging (>0.5C) it can become too hot for its own good, especially in areas with high ambient temperatures. Then the battery’s temperature also must be supervised, and charging and loads be disconnected before the temperature becomes too high (limit seem often to be around 45-60 degrees Celsius). High temperature is generally bad for the battery, especially when it is fully charged or fully discharged. So, these extremes should be avoided as much as possible when the battery’s temperature is high.

Alternator

Most alternators are not built to produce the stated current over any longer periods. And the built-in regulator is most of the time of a CV type (constant voltage, often set to target 14.2-14.4V). This means that it produces max current until it almost reaches the set voltage, and after that it produces enough current to maintain this voltage. A lead battery reaches this voltage much earlier than an LFP battery, so LFP technology can be a problem for the alternator. Some modern alternators contain a (fairly primitive) over temperature protection that decreases the current (often by decreasing the target voltage, which is not good enough for a large LFP bank) before the set voltage is reached. A simple test to see if your alternator is at risk is to touch it with a wet finger after it has been heavy loaded without reaching its target voltage for a while (>30 min). If it boils it is probably too hot, and you should look for a solution. If you don’t, the solution will soon be a new alternator (or in worst case, a new boat).

Another issue is if you install batteries that can disconnect themselves during charging (e.g. drop in batteries). If that happens, the energy produced at the disconnection moment have nowhere to go, so when the current drops down the voltage skyrockets. This can hurt both the alternator as well as connected electronic equipment. A common way to mitigate this is to have a lead battery connected in parallel that can take care of this power surge. (Someone compared this solution with bringing a horse in the car in case of the car breaking down). A better way is to let the BMS stop the alternator from producing power before the disconnection happens (but after that disconnection is really unnecessary).

Drop in batteries

A drop in battery is simply 4 LFP cells, a supervision circuit (BMS) and a power switch. A problem with the cheap and cheerful drop-in is often that the settings for when it disconnects is not set for optimal life length, but for disaster prevention. So, to use its BMS as the primary solution can be problematic unless you know the settings and adopt your installation to it. The exception to this is batteries from the larger suppliers like Victron. Their batteries have a communication channel between the batteries and the rest of the system, so they are a part of a complete system and do not act on their own.

Another problem is that drop-ins often use MOSFETs as switch, which limits the amount of current it then can handle. Around 100 A is a common limit, when the LFP limit often is in the range of 1000 A.

Yet another problem is that they do not give any warning before a disconnection happens.

System vendors solution

A good way to get a well working system is to buy it all (batteries, BMS, chargers, regulators, inverters…) from a recognized single vendor. Then you get a system where all parts communicate and handles all events in a predefined way. The only disadvantage by going down this path is the price-tag.

Custom built solution

Another way to handle the problems/cost is to build your own system. You need four LFP cells, a BMS and preferably a separate switch instead of a built-in MOSFET. Then you can choose a switch that can handle all the current you need, and configure the BMS to interact with all charging sources. This is not a lot more complicated than using drop-in batteries, but it makes it possible to solve many of the above described “problems” in a better way. And a bonus with to do it yourself is that you will understand your system better and the cost is much lower.

But you must have an understanding of the battery and charging system in the boat to do any of this. If you are uncertain, always ask for professional help.