How to perform initial LiFePo4 battery pack balancing using MiniBMS

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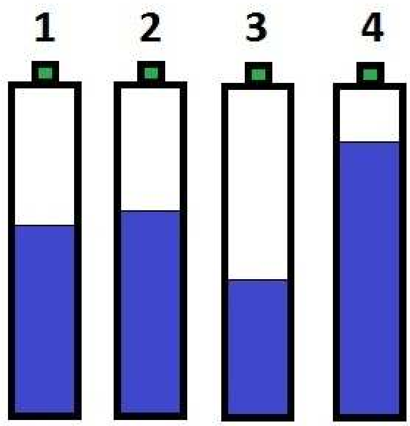
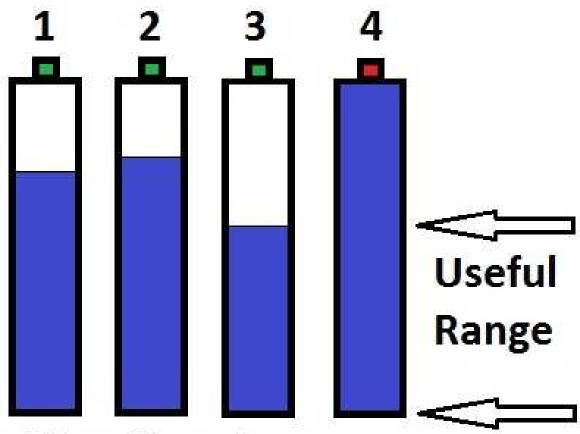
Disclaimer: **This paper describes a process referred to as "Top Balancing". This is not the only way to balance the pack, there is also "Bottom Balancing" and possibly some other methodologies. When the pack is used with shunting type BMS such as MiniBMS, Top Balancing is the only correct way to balance the pack. This paper is focusing on the balancing procedure when used only with MiniBMS system. The procedure may be different when using other BMS systems or not using BMS at all. CleanPowerAuto LLC is not responsible for any damage to any property or any person resulted by following this paper. Do your homework and ask questions if you aren't sure you understand what you are doing. When working with batteries, pay utmost attention to safety, batteries can be very dangerous when misused and can release lethal amounts of energy and power.**

When assembling a new LiFePo4 battery pack it's very important to perform initial pack balancing, because new cells could be from different manufacturing batches, have slightly different capacity and possibly significantly different initial state of charge due to variations in their shelf life. In order to get most energy out of the pack, you must have some kind of initial reference point, which we call "initial balancing". The useful capacity of a pack made from series connected string of cells will always be limited to the smallest or least charged cell in a string, because battery current equally flows thru all cells in a string and once the smallest cell is empty, the pack is considered empty. If you continue to draw current from the pack where one or more cells are empty, you will cause reversal of those cells, which will permanently destroy them and might even cause physical damage to adjacent cells due to overheating and deformation of damaged cells. This is one of the reasons people use cell level BMS, to prevent individual cells from reaching 0% SoC.

The picture below shows an example of initial state of charge of 4 cells in a battery pack. Cell number 4 has highest SOC and cell number 3 has lowest SOC. Once connected in series and used as a single pack, all cells in the pack will always charge and discharge at equal rates, so during first charge cell number 4 will reach shunting phase much sooner than other cells. Since the charger can't sense individual cell's voltage it will continue to push current thru the pack and it will quickly overrun BMS shunting capacity because the charger is likely to be in CC phase at maximum current at that time. Cell number 4 will quickly rise voltage and this will cause BMS to trip HVC alert and shut down the charger, to protect cell number 4 from overcharge.



Initial battery state



After first charge

However, as a result of early charge termination to save cell number 4 from overcharge damage, we end up with severely undercharged cell number 3, and also potentially undercharged other cells in the pack. Due to flat charge\discharge curve of Lithium cells we can't accurately know the state of charge of all cells based on their voltage, unless we observe them reaching the shunting level, indicated by red LEDs. If we start using the pack in this state, our useful range will be limited to amount of energy in cell number 3. This is why it's important to perform initial pack balancing, to bring all cells to equal SOC and get maximum useful range from the pack.

NOTE: When referring to a "cell" in this paper, we refer to either single cell or a group of cells connected in parallel to gain higher AH pack capacity. For example, if your pack is configured as 50S2P, it means you have 100 cells, all cells are grouped in pairs, each pair is connected in parallel, and then all 50 groups connected in series. In this case we refer to a paired group as a single "cell", and each BMS module is managing a "cell", so there would be 50 BMS cell modules in this pack.

When you finished assembling your pack and installing BMS you would need to do a first charge. The charger is connected to a pack as a whole and should be configured for correct pack voltage, based on cell count and cell HVC (High Voltage Cutoff) , which might be slightly different for different cell brands, for example 3.6V per cell for HiPower and CALB and 3.8V per cell for Thundersky. These are not max cell voltages, these are typically used voltage levels which are safely below max voltage, yet indicate a state of charge that we assume as "full" or 100%SOC. Theoretically you could push a little more energy into each cell to get it up to max voltage based on manufacturer's data sheet, but the difference is so negligible that we choose to give it up for safety reasons and to prolong the battery life. Think of it as a "safety margin".

So, in the example of a 50 cell pack, charger should be configured for 180V (3.6V * 50) for HiPower and CALB cells or 190V (3.8V * 50) for Thundersky cells.

Make sure MiniBMS is wired to shutoff the charger when BMS produces HVC signal, you can test it by interrupting signaling loop while charging and observe that charger gets shut off. If this does not work, refer back to user guide or get support. DO NOT proceed with initial full charge if BMS is unable to control the charger shutoff.

Once you are sure that MiniBMS can shut off the charger, proceed with initial full charge. This can take some time, depending on your charger size, pack size and initial SoC of the pack. At some point you will see red LEDs coming up on various cells; this indicates you are getting close to the end of charge. But the real work of initial pack balancing just begins.

Assuming worst case scenario, your cells came in from the dealer or the factory with widely different cell SoC levels. It means that one cell, which has highest SoC will finish charging first, while other cells are still at various SoC levels. This cell with highest initial SoC will likely trigger HVC event and cause BMS to shut off the charger while other cells are still not completely charged.

Observe all BMS modules at the end of initial charge; look for red LEDs being lit up. If you missed the time when charger was shutoff, you have to start it again to observe the end of charge. If BMS shut the charger, you must cycle Ignition key to reset the BMS back to normal and start the charger again.

NOTE: Red LED indicates the shunting phase, not HVC level. HVC is reached when Green LED on the BMS module turns off, which produces BMS alert. You have to watch closely since Green LED will quickly bounce back once charger is stopped. The cell which turns off Green LED is the cell which stops the charger and it's the cell which has the highest SoC. You may have many cells with red LEDs indicating shunting phase, but only one of them will reach HVC first and trip the charger. Make a note of this cell.

Observing the end of initial charge is critical, because BMS continues to shunt after the charge is done and resting voltage of all cells will gradually drop below shunting levels, so you will not see red LEDs unless you look at them at the very end of charge cycle.

Make a note of which cells had red LEDs lit up and which did not. If you are lucky, most or at least majority of red LEDs will be lit, which means the pack is not far off from balance. Those cells which did not have red LEDs lit up aren't full and must be charged further.

At this point you have to make a decision how to proceed. You have 2 choices:

1. Charge remaining cells with a single cell charger or in groups of 4 cells with 12V automotive smart charger. 12V charger only works if remaining cells are in adjacent groups of 4 cells. This process can take a long time if you have many cells which did not get to red LED phase. The idea is to charge remaining cells until every one of them gets to shunting phase (red LED indicates shunting in progress). Once you are finished charging cells individually or in groups of 4, give the last cell or a group time to rest, so their voltage settles below shunting level.

   NOTE: When using 12V charger on group of 4 adjacent cells it's possible that one of 4 cells will reach HVC and produce BMS alert. However, since your BMS is not controlling the 12V charger, this can cause overcharge of that cell if you are not around to hear BMS alarm. DO NOT leave 12V charger unattended when using this method and immediately turn it off when you hear BMS buzzer alarm. You may need to individually finish charging remaining 3 cells in this group.

   A good option for this method is to buy variable bench power supply, with ability to set both voltage and current, or at least voltage. Get the model with decent power rating, so you can charge in reasonable time, at least 3-5Amp or more. Mastech makes wide variety of DC bench power supplies; there are often good deals on Ebay for those. You can set the voltage between shunting level and HVC level, so when you charge individual cells you can safely walk away knowing that cell will not get overcharged. Make sure to set the voltage before connecting to the cell, since voltage will drop to whatever cell voltage is as soon as you connect the power supply to the cell. This will likely result in maximum current the power supply is capable of, so you may want to reduce it a little, so the power supply does not overheat. You may need active ventilation for the power supply if running at max rated current for a long time; they tend to get very hot. Shunting voltage is 0.1V below HVC voltage on MiniBMS modules, so if you have 3.6V BMS modules, set the power supply to 3.55V, or if you have 3.8V modules, set it to 3.75V.

2. If you have severe imbalance, where only one or a few cells get full, you have an option of draining energy from those cells and repeatedly cycle the main charger until all other cells catch up. You have to identify the cell with highest SoC, this is the cell which turns off Green LED at the very end of charge, which you marked earlier. You will need some way of loading this cell, like a low voltage lamp or high wattage low value resistor, something that can pass reasonable amount of current in reasonable time. You have to be careful not to overdo this process and not to drain too much; otherwise you'd have to charge these cells again. I recommend to start draining in fractions of one amp hour. For example, if your load takes 1 amp from the cell, run this load no more than 5-10

minutes, then remove the load and cycle main charger again. At some point you will notice that another cell has triggered charger shut off, so you have to move the drain load to that cell. The idea is to bring down fullest cell which trips the BMS until all other cells get to shunting phase. As you see more and more cells reaching shunting phase, you may want to reduce draining time, so you don't drain too much off the last cell.

NOTE: DO NOT leave your pack unattended when draining individual cells. Resistive loads can produce a lot of heat and can melt wire insulation. Pay attention to safety and do not touch any other cell terminals or BMS modules during this procedure.

At this point all cells had a chance to enter the shunting phase, which means the pack is balanced. Use the main charger one more time to see that all or almost all red LEDs come up before charger stops on its own. This indicates a well balanced pack. Its possible that despite all or most cells reaching shunting phase, one cell would still trigger HVC and shutoff the charger, probably due to charger voltage being a little too high for your pack. This is not a problem and there is no damage even if BMS stops the charger every time, as long as all cells reach the shunting phase, indicating well balanced pack. Measure the pack voltage at the end of charge and divide by number of cells in the pack to ensure you have correct voltage.

It's also possible that some of your cells have Internal Resistance (IR) level which may be considered within the specs, but be significantly different from other cells, perhaps if cells came from different manufacturing batches. In this case, despite perfect initial balance, those cells may not reach shunting phase every time, or may trigger HVC at the end of charge, depending on which direction their IR differs from other cells. As long as you know about this behavior and it does not affect your driving range, you may just ignore it. However, if those cells get worse over time, you'd want to consider replacing them.

Remember, there is always going to be one cell which marks pack's overall SoC, so perfect balance every time is not the goal in of itself. The goal of initial balancing is to get your pack to a starting reference point, so you know each cell had a chance to be fully charged at least once. Over time, if you notice decreased driving range and suspect that pack may be off balance, you can perform this procedure again and note which cells drift away. If same cells drift away and cause reduced range, consider replacing them.