Explanation for Beginners of Top and Bottom Balance

This document is intended to give the user a basic understanding of what top and bottom balancing cells is all about and when you would do top vs bottom balance.

This document is *not* intended to be a tutorial on how to top or bottom balance.

For this document I will be using a LiFePO4, four cell, 12V battery as an example. However, the concepts are the same regardless of the cell configuration.

See Also: (@ https://diysolarforum.com/resources/)

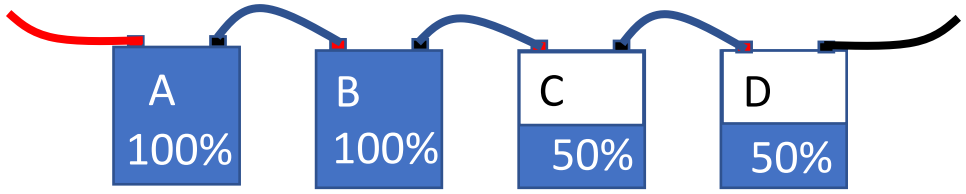
Beginners Summary of BMS Types, Functions and Features

Cell Configurations for 12V 24V and 48V LiFePo4 Batteries

Top Balancing LiFePo4 Cells using a low cost benchtop power supply.

What do we mean by ‘balanced’ cells?

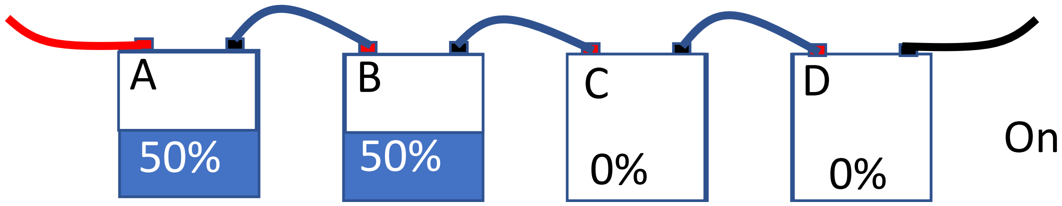
Balanced cells are cells that have been charged to a ‘fully charged’ state (Top Balanced) or discharged to a ‘fully discharged state’ (Bottom Balanced). To understand why we do this, let's look at a battery that is built out of two 100Ah cells that are fully charged and two 100Ah cells that are half charged. (This would be considered drastically out of balance.)



100Ah cells

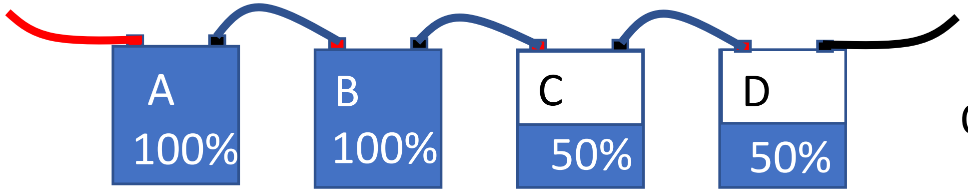
Since cell A & B are fully charged, you can not charge this bank any further without damaging cells A & B. The BMS must stop charging as soon as one of the cell voltage indicates 100% charge for that cell, even though the total battery voltage will be low.

You can discharge this battery, but since C & D are only half charged, you can only get 50Ah out of it. Any further discharge would damage cells C & D (The BMS must disconnect as soon as one of the cells hit a voltage that indicates that cell is completely discharged.)



Only 50Ah of discharge before discharge must stop.

You can charge the bank back up, but since A & B are still half charged, you can only get back to the original state.

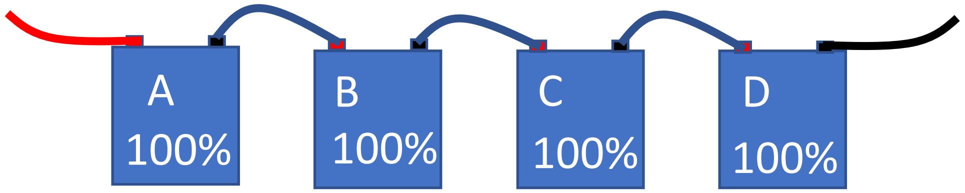


Only 50Ah of charge before charge must stop.

In this extreme example, the battery bank has an effective capacity of only 50Ah even though 100Ah cells were used.

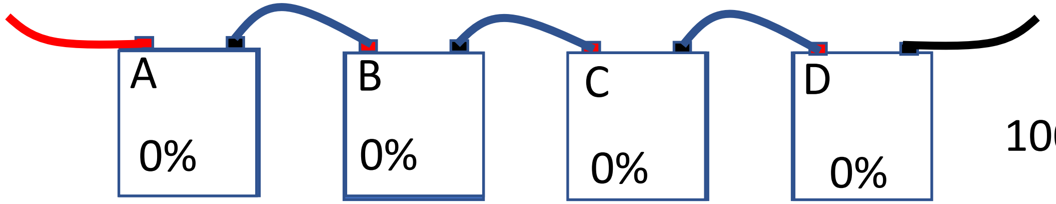
What do we mean by ‘balanced’ cells? (Continued)

By contrast, lets look at a battery built from 4 fully charged (Balanced) cells.



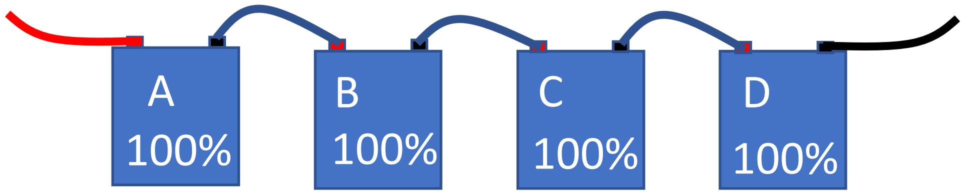
100Ah cells

With this as the initial condition, you can drain 100Ah from the battery before all of the cells are empty



100Ah of discharge before discharge must stop.

You can also charge the bank with 100Ah before all of the cells are fully charged.

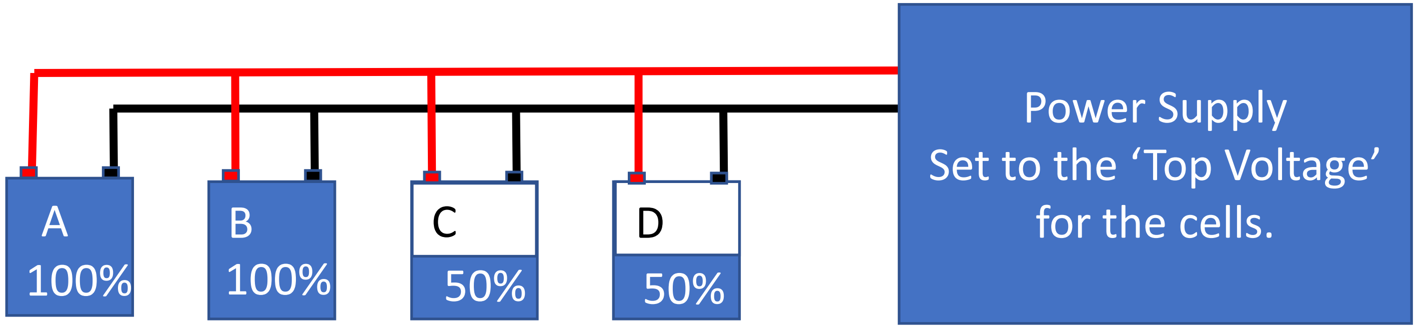


100Ah of charge before charge must stop.

You can see from this example that in order to get the full use of the cells, you need to start with cells that are all at the same state of charge (Balanced).

What is TOP Balancing

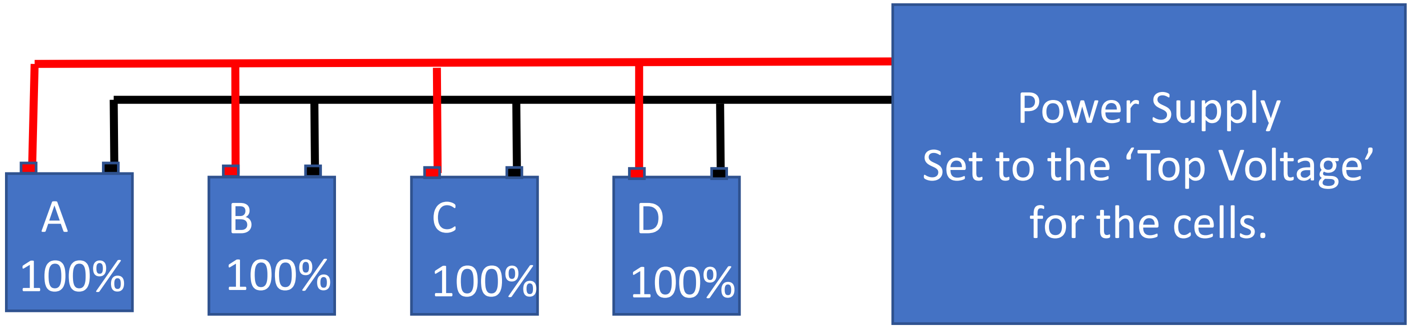
Top Balancing is a process of charging all the cells to 100%. This is accomplished by wiring all of the cells in parallel, charging them to their top voltage and holding it at that voltage till the current tapers to zero or near zero.



Top Voltage
The 'top voltage' you choose for top balancing can be anything in the range of 3.55V to 3.65V. However, you should top balance to a voltage at least as high as the max cell voltage you will set your BMS to allow. (I use 3.65V for top balancing. Another common voltage used for LiFePO4 top balancing is 3.6V)

Each cell will take current till it is fully charged and then stop taking current. When there is no more current flowing from the power supply, the cells are fully charged.

Note: With cells that are way out of balance, you may want to first equalize the cells with resistors before balancing. (See appendix A: Equalizing Cells)



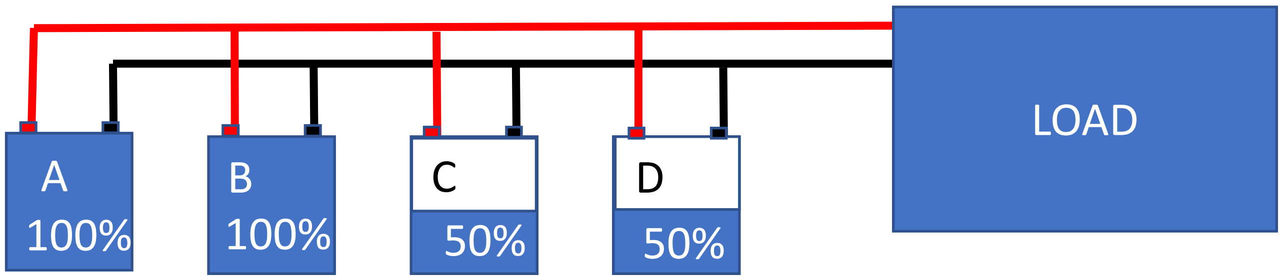
Note: After the top balance is complete and the power supply is disconnected, the cell voltage will drop a little bit to a resting voltage. This is normal.

At this point you can put the cells back into a series battery and they will discharge and charge together. Consequently, you will get the max storage out of your battery.

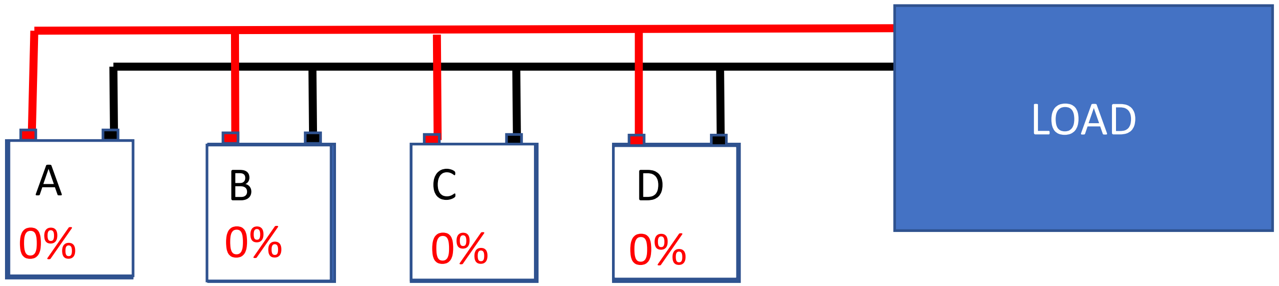
NOTE/Warning: The above description is for conceptual understanding and should not be used as a top balance tutorial

What is BOTTOM Balancing?

Bottom Balancing is a process of discharging all the cells to near 0% state of charge. This is accomplished by wiring all the cells in parallel and hooking them to a load to drain the energy till they reach the voltage indicating 0% state of charge.



The cells are drained till they reach a voltage indicating 0% state of charge. This is typically done multiple times at different voltages in order to get them all to a target resting voltage.



At this point the cells can be put back into a series battery and they will charge and discharge together. Consequently, you will get the max storage out of your battery.

Bottom Voltage:
The 'bottom voltage' is usually in the 2.5 to 2.7V range. However, the bottom balance voltage should be at least as low as the minimum cell voltage the BMS will be set to allow.
Warning: Allowing cells to get too low will quickly damage them.

Note: With cells that are way out of balance, it may be desirable equalize the cells with resistors before balancing. (See appendix A: Equalizing Cells)

Note: In order to avoid damaging the cells by letting them discharge too far, it is best to have some kind of low-voltage disconnect device in the circuit during the bottom balance procedure.

NOTE/Warning: The above description is for conceptual understanding and should not be used as a bottom balance tutorial

The real world: Each cell will be slightly different.

In the real world, no two cells are identical.   A set of cells that are all rated at the same Ah capacity will each have slightly different capacities. This means that some cells will charge or discharge slightly faster than others. Consequently you choose top vs bottom balancing based on whether you want to optimize for high state of charge (Top Balance) or optimize for low state of charge (Bottom Balance)   With Top Balanced cells, they will all hit ‘fully charged’ at approximately the same time.   With bottom balancing they will all hit ‘fully discharged’ at approximately the same time.

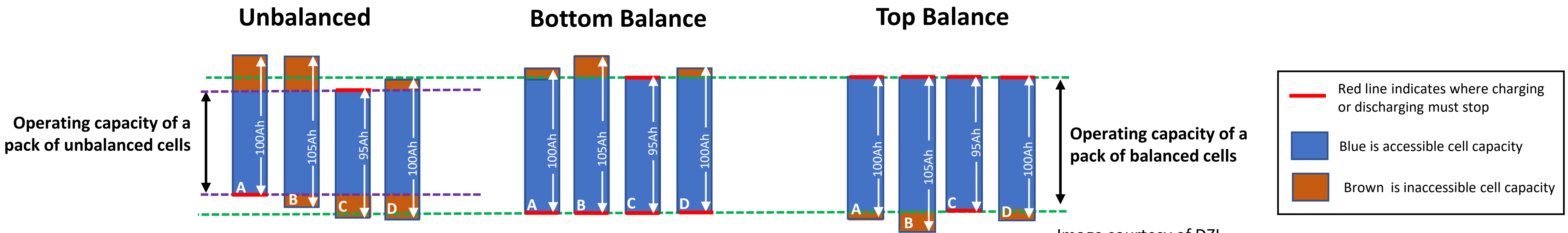


Image courtesy of DZL

Notice that in the unbalanced case above, the charging must stop when cell C hits its max charge even though A, B & D could still be charged more. Furthermore, discharging must be stopped when cell A hits it’s minimum charge even though cell B, C & D could be discharged further.

Also notice that when the cells are balanced, the Ah capacity of the battery is defined by the cell with the lowest Ah capacity.

The diagram above also points out another important point: In the real world it is impossible for a set of cells to be both top and bottom balanced at the same time, consequently **you never do both top and bottom balance.** .

When to Top Balance and when to Bottom Balance?

(Spoiler: You will almost always top balance)

When to Top Balance

- Almost all BMSs will top balance the cells as they are charging. Consequently if your BMS top balances, you should top balance your cells before you build them into a battery. (The BMS would mess up a bottom balanced set of cells)
- If your application will typically run the cells mostly charged, top balancing is best. (This is the case for the vast majority of solar systems using LiFePO4 cells.

When to Bottom Balance

- If your application will frequently drive the cells to a very low state of charge, you may want to bottom balance. This may be common with electric vehicles but is rare with home solar installations.
- Some people run their batteries without a BMS. (I do not recommend this). Since LiFePO4 is far more sensitive to undercharge than over-charge, it is probably better to bottom balance your cells if you will be running them without a BMS. (Note, I always use a BMS so I never bottom balance).

Don't Balance at all

Since the BMS will work to top balance the cells, some folks feel the whole top-balance process is unnecessary. There is some truth to this, particularly if your BMS has an aggressive balancing algorithm and high balancing current. However, it is likely to take the BMS an extremely long time to balance the cells… **if ever.**

If you choose not to balance your cells, you must set your charge voltage low enough to prevent the BMS disconnecting due to a cell voltage getting too high. Otherwise the BMS will cut out before the charger does. Likewise, your loads must disconnect at a high enough voltage to prevent the BMS from disconnecting due to a Cell undervoltage.

Also, if you are going to do a capacity test on the battery you just built with your new cells, balancing first will give you a more accurate result.

Appendix A: Stepwise Charge-and-Pause Top Balance.

There is a slightly more involved ‘stepwise’ top-balancing process where the cells are balance charged to a lower voltage, let rest and then driven to a slightly higher voltage. This continues till the target top voltage is reached.

There is nothing wrong with the stepwise approach and there is general agreement that both approaches achieve an acceptable result. The debate between the two approaches comes down small differences in the outcome.

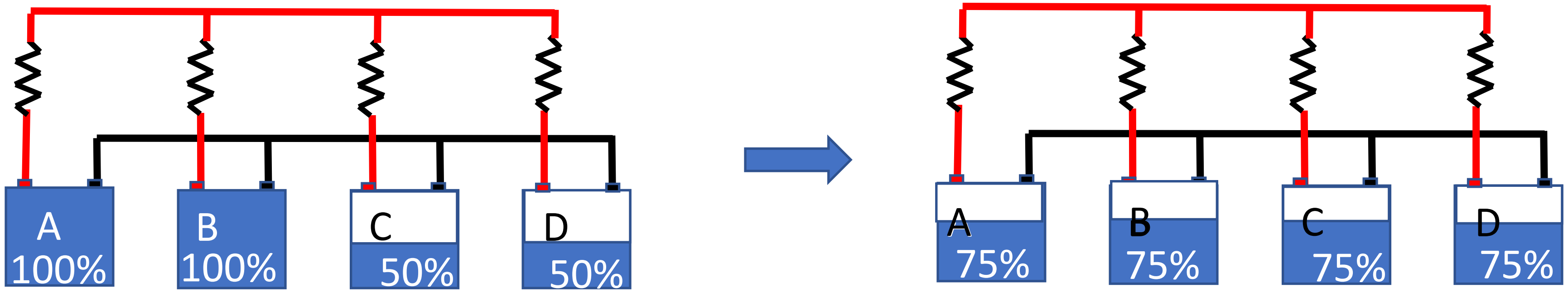
Regardless of whether the ‘stepwise’ or ‘single step’ method is used, the top balance concept and goal is the same: Get the cells all to the same state of charge and the same voltage.

I personally use the single step approach but have no issues with the multi-step approach either.

Appendix B: Equalizing Cells

This is a process of wiring all your cells in parallel and letting current flow between them till the voltage equalizes. (This is NOT balancing the cells). Usually, the cells are close enough in voltage that this is not necessary.

If the cells are radically out of balance, (> .2V difference) you can minimize the rush of current between the cells by using a small resistor (> 1 ohm max) as shown below:



Note: The voltage difference between a fully charged and full discharged battery is only ~0.5V. Consequently, with a 1 ohm resistor, the equalization process can take a very long time.

Another technique for getting cells close is to charge them individually to around 3.4 – 3.5 volts. With a lot of cells this could become tedious, but it would ensure they are all close to the same charge and voltage.

Note: Myself and other people believe that the voltage differences are small enough that even without resistors, the internal resistance of the cells and the resistance of the connections between them is sufficient to keep the current down to an acceptable level. Consequently, we don't equalize the cells before balancing.

Appendix C: Matched Cells vs Balanced Cells

Balancing Cells is sometimes confused with Matched Cells.

- **Balance cells are cells that have been charged or discharged together to have the same state of charge.**
  (The body of this document describes Balancing cells.)
- **Matched cells are selected to have very similar capacities and internal resistance.**

All cells are slightly different due to manufacturing variances. The two most important characteristics are capacity and internal resistance. If these two characteristics are nearly the same for a set of cells, they will all charge and discharge at a very similar rate. Matched cells allow you to set the system charge and discharge voltage more aggressively without one of the cells hitting the voltage extreme well before the others.

Matching cells is usually done by reputable cell suppliers at time of purchase. (They have large numbers of cells to select from). However, some people advocate purchasing extra cells so you can match them yourself.

Note: The process of measuring internal resistance and capacity of a cell is beyond the scope of this document.