General Basic guidelines for assembling LiFePO4, lithium iron phosphate (LFP) battery.

Typical Prismatic LiFePO4 (LFP) cell.

This document is a basic guideline regarding Lithium Iron Phosphate cells being used to assemble batteries. This is not a fully comprehensive guide, nor does it cover all the various options and possibilities. There are additional resource references at the end of the document to assist you with further information. Always refer to the Manufacturer Specifications and data-sheets for correct voltages, torque tightening measurements and other important information.

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Precautions

- Exercise caution when working with all electrical equipment, wear safety glasses, gloves etc when appropriate. Sparks & Flashes can damage your eyes.
- Ensure cells are within operating temperature range prior to use.
- Do Not Use if cells are punctured, damaged or leaking.
- Provide adequate protection to cells during assembly & use thereafter.
- Dispose of properly to recycling or similar facility.
- Do Not submerge in water.
- Do Not allow to come in contact with direct heat, extreme temperatures or fire.
- Prevent harsh impacts or extreme vibrations which can cause immediate or cumulative damage.

Batteries in a Battery Bank

Batteries in Series add Voltage but not Capacity in AH. 12V+12V=24V

Batteries in Parallel add Capacity in AH but not Voltage. 100AH+100AH=200AH

Batteries in Series and Parallel add both Voltage and Capacity.

Example (2S2P): 2Series= 2x12V/100AH (24V/100AH), 2Parallel= 2x2S. Total 24V/200AH

* Not all BMS support Series or Parallel configurations.

Careful consideration for design & layout of a battery bank is essential to obtain balanced charge/discharge performance and to maximize fault tolerance. This is an extended discussion beyond the scope of this document.

See the General References: General sub-section.

BMS requirements

The use of a BMS is Very Strongly Recommended. A battery management system is essentially the "brain" of a battery pack; it measures and reports crucial information for the operation of the battery and also also protects the battery from damage in a wide range of operating conditions. These include but are not limited to:

- Main power voltage.
- Battery or cell voltage and health.
- Charging and discharge rates.
- Temperatures of the batteries or cells.

Due to the varied nature of usage and applications, this topic is beyond the scope of this document. It is however essential, that when choosing a BMS, you select one that supports the specific Battery Chemistry. The various Lithium Based Batteries have different voltage, charge & discharge specifications and requirements. They are not interchangeable. Some BMS' do have the ability to support different types of chemistries.

There are links within the Reference Section which address other extended subjects beyond the scope of this document.

Battery Cell Preparation

Often referred to as Top Balancing, Top Charging. When purchasing new LiFePO4 cells to assemble into batteries, it is essential to prepare them for use and to get the most you can from them. Cells are shipped at "Storage Voltages" near 3.200V +/-. This can be an extended discussion which is beyond the scope of this document, therefore, presented below is a very good, simply explained set of methods to use to prepare your cells.

Source: *Pre-Balancing Cells | Orion Li-Ion Battery Management System (orionbms.com)*

Method 1: Charge all cells individually. Before assembling the cells into a pack, each individual cell may be charged independently by using a battery charger designed for a single lithium ion cell. It is essential that if this method is used, the charger MUST be configured so that it does not overcharge the cell. Never leave a cell charging without an automatic method for shutting of the charger.

Method 2: Put all cells in parallel and fully charge together. Before assembling the pack, cells can be connected in parallel and charged together. This method may not work with some types of cells or if the cells are significantly out of balance, as significant currents may flow from one cell to another. Current flow can be calculated by taking the difference in voltage from the lowest to highest cell and dividing by the internal resistance. If you are unsure if current will flow or if you are using a chemistry other than iron phosphate, use one of the other methods. The charger must be setup with a maximum voltage no higher than the maximum cell voltage specified by the cell manufacturer. In order for this method to work, cells must have a charge applied while in parallel (simply connecting in parallel will not allow enough current to flow to balance the pack.)

Method 3: Measure voltages of each cell and manually adjust using a charger or load. This is the most difficult method, but it may be significantly faster than the others if only a small number of cells are significantly out of balance while the rest of the pack is well balanced already. This is an especially useful technique after a cell in a pack has been replaced. Use an isolated load or isolated charger to manually adjust the state of charge of the particular cell requiring adjustment to bring it into balance with the rest of the pack. Careful attention must be given to ensure that a cell is not over charged or over-discharged with this method. This method can be used to balance a cell after it has been assembled into a series pack, but it is absolutely essential to ensure that the load or charger is isolated so that a short circuit is not created within the pack.

Method 4: Have the manufacturer “bin” the cells. While this is not usually an option for small scale systems, in production environments, cell manufacturers can “bin” the cells and match them based on current state of charge, internal resistance characteristics, and cell capacity. Building a pack using cells which are all approximately the same not only eliminates the need to pre-balance, but also keeps the pack in the best health long term since all cells are likely to age similarly.

Basic battery assembly tips

Tools

Screw drivers, wrenches or socket driver as required. If these are non-insulated tools, it is suggested that you tape or insulate exposed metal on wrenches etc to prevent accidental shorts.

"Bicycle" Torque Wrenches or Adjustable Torque Drivers are typically capable of 2 to 24 Nm force are perfect for the torque range for screws/bolts being attached to the cells. *The aluminum terminals are soft and not difficult to strip accidentally.*

Digital Multi meter to check connections, voltages, continuity of wires as needed.

Fine sandpaper 240 grit or finer, or brass brush.

Acetone or 90%+ Rubbing alcohol, cloth or paper towel for cleaning off components

Required components

Bus Bars, Stainless or Brass Screws or Bolts & Nuts (Grub Screws).

Lock Washer or Serrated Washers are suggested.

Strapping / Binding components.

A BMS is Very Highly recommended.

<u>Each battery should be appropriately fused.</u>

Preparation of components

- Bus bars often have ridges or edges, filing or sanding them smooth is important for full contact with cell terminal face.

- If making your own bus bars, chamfering the holes is recommended, slot one hole slightly to allow for adjustment between cells, ensure that the bus bar covers entire surface of cell terminal. This will greatly reduce incidents of external resistance issues causing problems.

- Prepare BMS wire harness and attach your Ring Terminals. Ensure the ring terminals match the screw/bolt size, oversized can lead to errors. DO NOT CONNECT BMS harness until after everything is properly assembled and double checked. It is recommended to verify each ring terminal connection lead for continuity using a Multi-meter.

- Align & Bind/Compress your cells per Manufacturer Specifications/Recommendations.

- Clean cell terminals & bus bars with fine sandpaper or brass brush, then wipe with acetone/ alcohol. To ensure a clean contact. There are often machining oils & wax residues which can interfere.

- You can use Noalox/Oxguard, (anti-oxidizing compound) on cell terminals ONLY, do not apply to screw/bolt threads. Only a very slight amount if required, just a very thin wiped on coating. Tinned/Nickle plated bus bars do not require it.

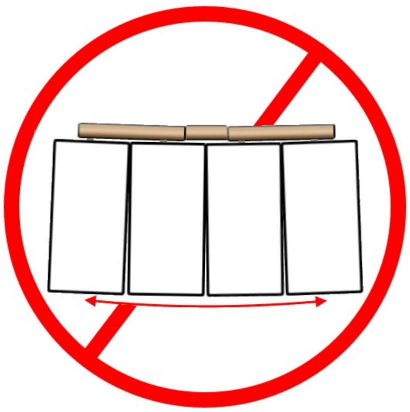
Be cautious about Screw/Bolt Length. Avoid "bottoming" the screw as this can damage the cell if it breaks through. If using "Grub Screws" go down to the bottom and back out screw at least 1 full turn to 1.5 turns.

CAUTION ! Some aluminum cell casings are not "neutral" or isolated as electrical leakage may be present. Verify by using a Multi-meter with the (-) on the (-) terminal & (+) probe on the metal casing. (you can gently lift the plastic top covering from the edge). Cover any damage such as tears or openings in the wrapping with electrical tape or recover cell.

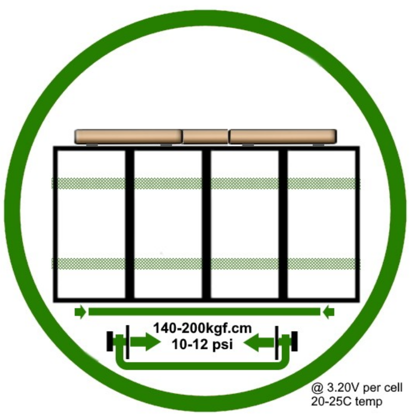
When using any electrically conductive enclosure, always line it with a non-metallic non-conductive material, to prevent accidental shorts.. ABS or fibreglass sheeting is commonly used for such applications.

Binding/Compressing Cells

This is often referred to as "fixture" in Manufacturer documentation due to the translation. Mild compression is recommended to maximize life cycles. As cells charge or discharge they will expand or contract slightly and depending on temperatures & C-Rate this will vary.



With mild compression applied, it helps prevent stress being applied to the terminals, or changes to the internal structure of the cells, which over time can result in decreased capacity and performance. This is especially important in any mobile application or one which will see vibrations. Friction may also wear the protective wrapping and casing over time.



A "basic general" rule is to use approximately 10-14 lb.ft / 140-200kgf.cm pressure / compression applied when the cells are at 50% SOC (3.200V) @ 25°C/77°F. *Always refer to manufacturer specifications data sheet.*

This can be done by using fibre-tape, strapping or other flexible binding materials. Protect cell corners from crushing. Alternatively, a frame with end plates pulled together with threaded rods & nuts. Custom cases are another common option used.

TIP: When assembling your "pack" of cells, take into account the placement of any temperature sensor probes for your BMS.

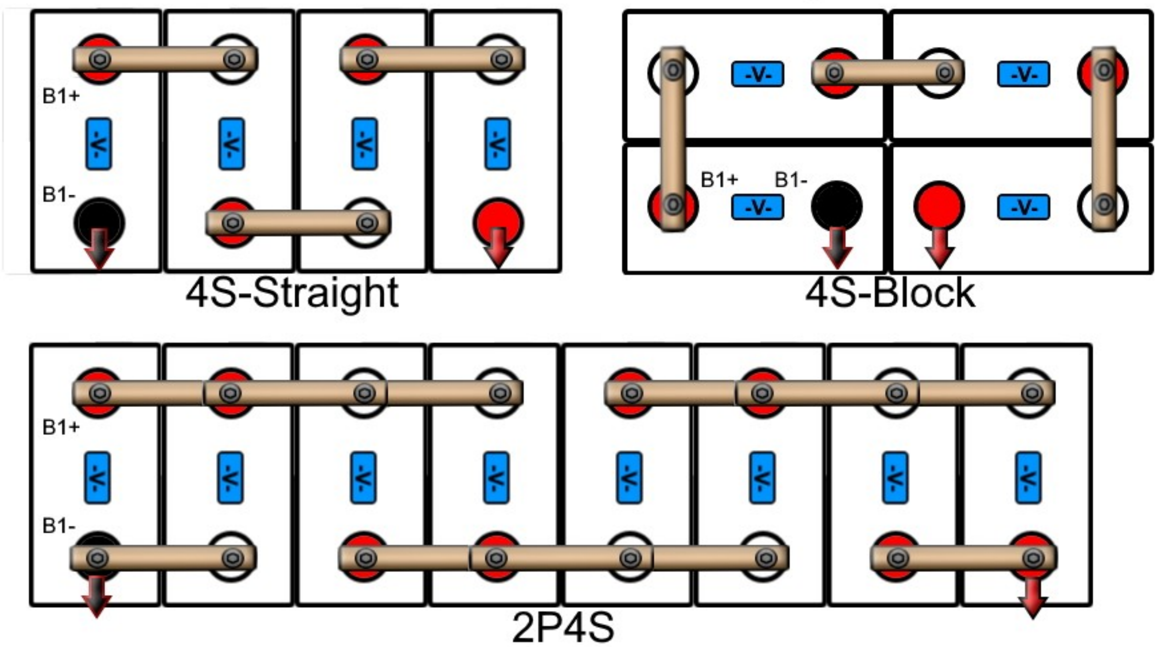
This is an extended subject beyond the scope of this document.

TIGHTENING TORQUES / Compression			
100 kgf.cm (7.23 lbf.ft)	70 kgf.cm (5.0 lbf.ft)	35 kgf.cm (2.5 lbf.ft)	7 to 12 kgf.cm (0.5 to 0.9 lbf.ft)

* Bicycle Torque Wrenches are most suitable for this application.

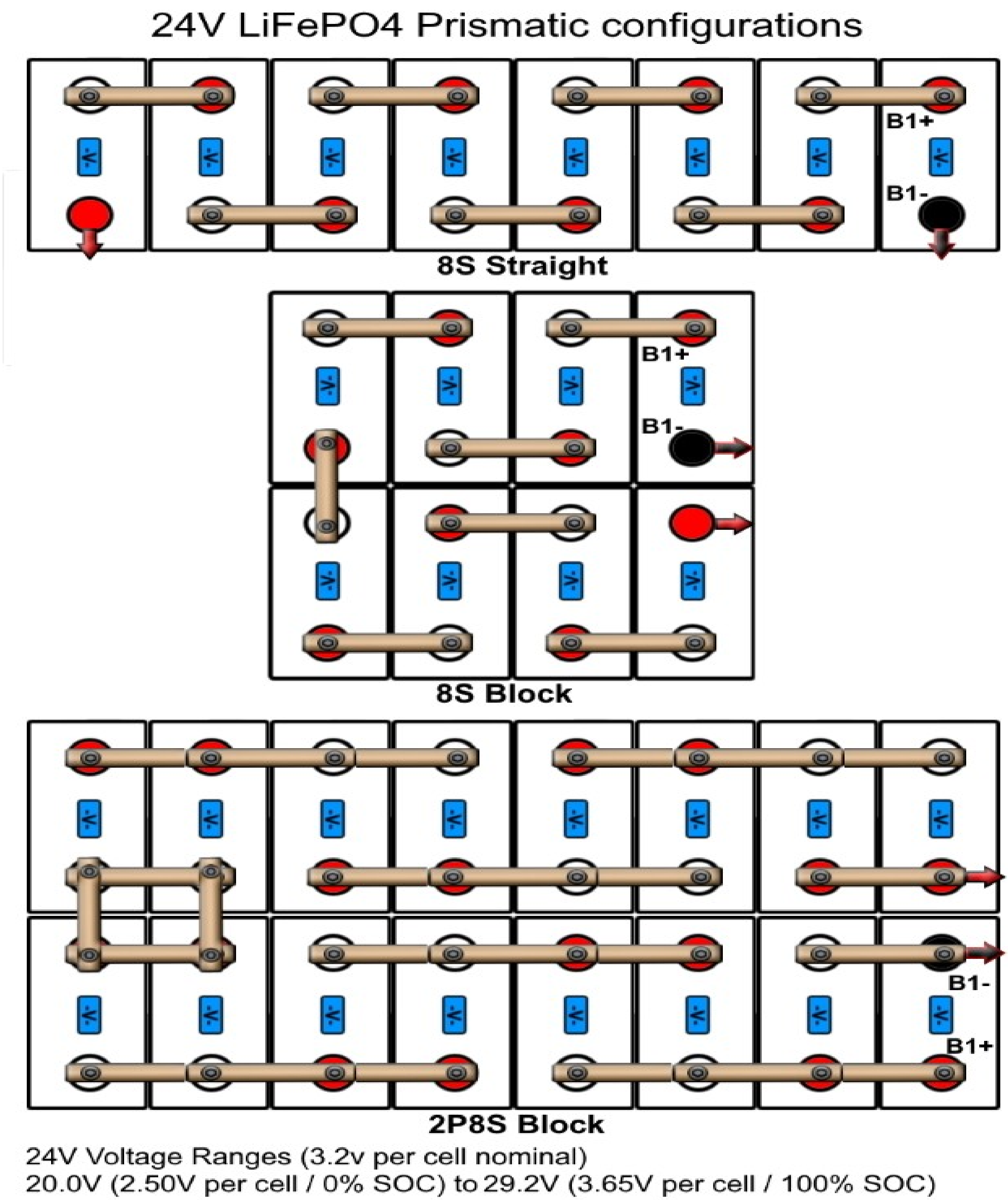
12 Volt Battery basic configurations

12V LiFePO4 Prismatic configurations



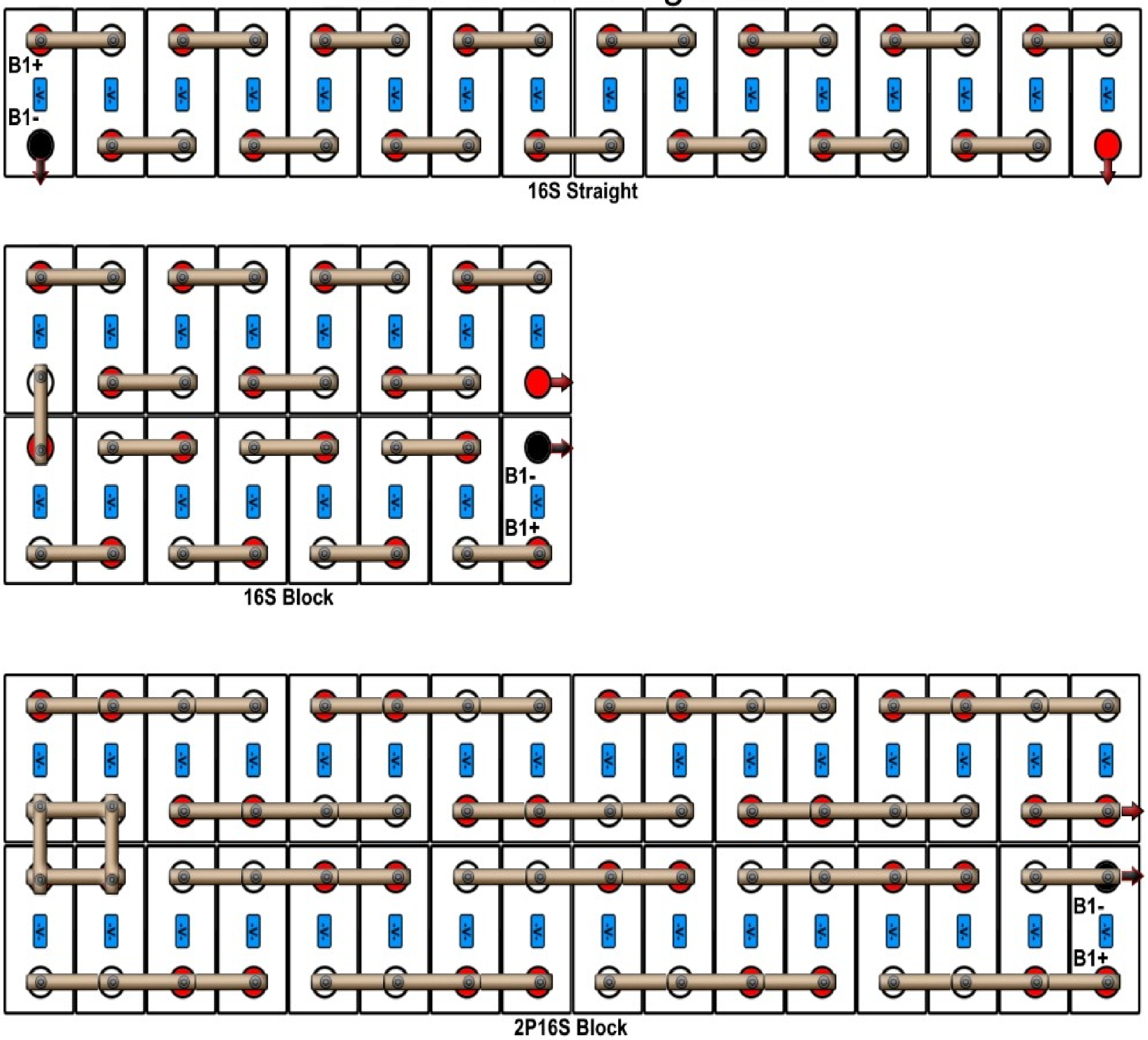
12V Voltage Ranges (3.2V nominal)
10.0V (2.50V per cell / 0% SOC) to 14.6V (3.65V per cell / 100% SOC)

24 Volt Battery basic configurations



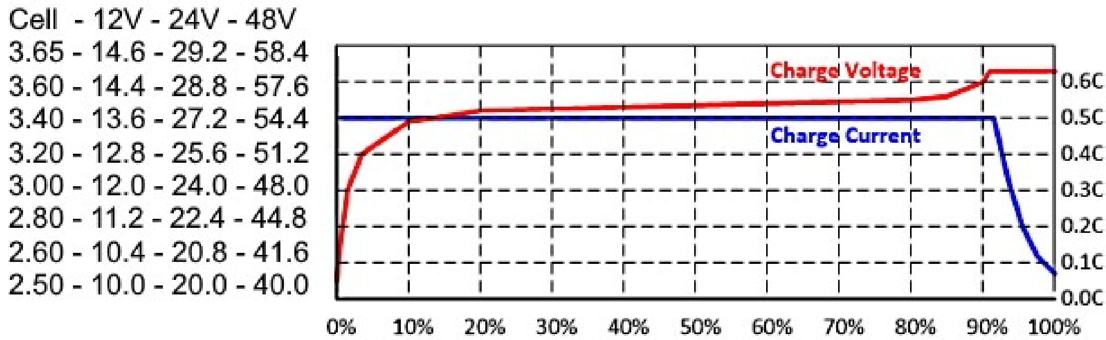
48 Volt Battery basic configurations

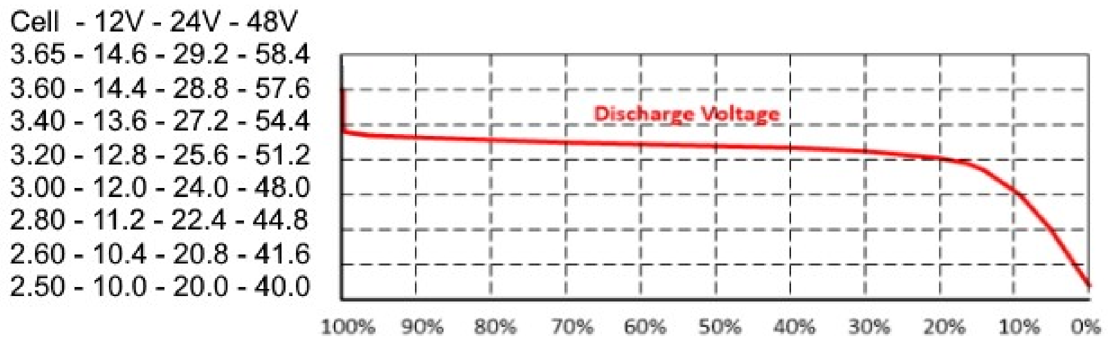
48V LiFePO4 configurations



48V Voltage Ranges (3.2V per cell nominal)
40.0V (2.50V per cell / 0% SOC) to 58.4V (3.65V per cell / 100% SOC)

Basic Voltage Charts & Information





SOC	Vpc	12v		24v		48v	
25°C temp	Volt per cell	rest	load	rest	load	rest	load
100%	3.50 | 3.40	14.0	13.6	28.0	27.2	56.0	54.4
99%	3.45 | 3.35	13.8	13.4	27.6	26.8	55.2	53.6
90%	3.35 | 3.32	13.4	13.3	26.8	26.6	53.6	53.2
70%	3.30	13.2	13.2	26.4	26.4	52.8	52.8
40%	3.30 | 3.27	13.2	13.1	26.4	26.2	52.8	52.4
30%	3.25	13.0	13.0	26.0	26.0	52.0	52.0
20%	3.22	12.9	12.9	25.8	25.8	51.6	51.6
17%	3.2	12.8	12.8	25.6	25.6	51.2	51.2
14%	3.15 | 3.12	12.6	12.5	25.2	25.0	50.4	50.0
9%	3.10 | 3.00	12.4	12.0	24.8	24.0	49.6	48.0
0%	2.60 | 2.50	10.4	10.0	20.8	20.0	41.6	40.0

- Minimum Voltage 2.50, Maximum Voltage 3.65, Nominal Voltage 3.20 per cell.
- Batteries should be stored (more than 1 month) indoors, dry and clean environment between 0℃~35℃ / 32°F~95°F. Avoid contact with corrosive substances, fire and direct heat source. The battery should be charged and discharged every 6 months. The recommended storage SOC is between 30 ~ 50% .
- Operation Temps: Discharge Min -10°C, Max 50°C. Charge Min 2.0°C, Max 50°C.

**Refer to Manufacturer Specifications / data-sheet.*

Basic Inverter and Charge Controller Charge Settings

Below are the typical settings when using an inverter or charge controller with LiFePO4 batteries.

- LiFePO4 batteries do not require Equalizing / De-Sulphation.
- LiFePO4 batteries do not require Temperature Compensation for voltage.

CHARGE PARAMETERS	**12V**	**24V**	**48V**
Bulk Voltage	14.0 - 14.6	28.0 - 29.2	56.0 - 58.4
Absorption Voltage	14.0 - 14.6	28.0 - 29.2	56.0 - 58.4
Absorption Time	depends on charging profile being used		
Float Voltage	13.3 - 13.8	26.6 - 27.6	53.2 - 55.2
equalize(not used) set to lowest time	*13.3*	*26.6*	*53.2*
Low Voltage Cutoff	11.0 - 12.0	22.0 - 24.0	44.0 - 48.0
High Voltage Cutoff	14.6	29.2	58.4
Termination Current *	≤0.05C	≤0.05C	≤0.05C

Termination Current Example: 100AH charge max 0.5C/50A, termination current = 0.05C/5A
* when using multiple batteries in a battery bank, reading current from the bank as a whole is ineffective.

LiFePO4 can be safely charged with either of these modes:

1-stage profile (constant current (CC) aka Bulk Stage) profile will charge the battery ~95%. The 1-stage profile is sufficient, since LiFePO4 batteries do not need to be fully charged, they will settle to 95% after charging.

2-stage profile (constant current, constant voltage (CC-CV) profile aka Bulk and Absorption Stages). The 2-stage profile will charge the battery 100%. This may also have the effect of triggering a BMS HVD (High Voltage Disconnect), therefore take appropriate precautions by using conservative charge settings to begin with.

- Optimal Charging will occur at 0.5C charge rate per battery. The number of batteries multiplies the amps required to meet 0.5C charge rate.
- The ability for any single battery within a bank of batteries should be capable of handling the full charge & discharge potential of the system.

NB: Some BMS' (Battery Management Systems) can interact with Inverters, Chargers & Solar Controllers which can improve overall performance, reliability and longevity of the battery systems. These capabilities are dependent on the equipment being used.

* Equalize: Some Solar Charge Controllers / Chargers / 3-Stage chargers have this. Disable or Set to lowest time allowed and at float voltage equivalent. LFP does not require this.

General References

From Battery University

- Basic to Advanced Battery Information from Battery University
- BU-803a: Cell Matching and Balancing – Battery University
- How to Prolong Lithium-based Batteries - Battery University

From Orion BMS *(Technical documentation)*

- Pre-Balancing Cells | Orion Li-Ion Battery Management System
- High resistance cell | Orion Li-Ion Battery Management System

From Li-Ion BMS *(Technical documentation)*

- Li-Ion BMS - Tips for prismatic cells
- Li-Ion BMS - White Papers

BMS Resources

- How to best select Battery Management Systems (BMS) for High Voltage Li-Ion Batteries — ION Energy

General

- VICTRON Wiring-Unlimited-EN.pdf
- Electrical Design For a Marine Lithium Battery Bank | | Nordkyn Design
- LiFePO4 Batteries On Boats – Marine How To
- Electrical Property Conversion Calculators - Inch Calculator
- DIY Solar Power Forum