

VERSTAT POWER

LiFePO₄ DIY: A Practical Guide

From cells in a box to working backup power

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About This Guide

You ordered LiFePO₄ cells and a BMS. They arrived. And this is where it gets unpleasant: there's no manual in the box, and online every other source contradicts the one before it. Some say charge to 3.65 V, others warn that this will kill the cells. Some assemble without balancing, others hold the cells on a lab power supply for weeks.

This guide was written to remove that uncertainty. It's built on the experience of hundreds of client builds: the ones that have run for years, and the ones that burned or lost half their capacity in the first month. The second category taught more than the first, so every chapter contains not just "how to do it" but also "what happens if you do it differently" and "how to tell that something has already gone wrong."

Who this is for. Someone who can handle a tool, understands what voltage and current are, but isn't a professional electrician and hasn't built a battery pack before. You're being careful, and that's the right instinct: a 280 Ah LiFePO₄ cell isn't a AA battery, it's an energy source that can melt a wrench in a second.

How to use it. Read chapters 1-3 before you pick up your first cell. Chapters 4-7 will be useful during the build, keep them handy. Chapter 8 covers winter, chapter 9 covers common mistakes (read it twice), chapter 10 is a one-page checklist: print it out and check off items in pencil before the first startup.

Units and notation. Cell voltage is always given as V/cell. Current in amperes (A), capacity in amp-hours (Ah), energy in watt-hours (Wh). C-rate is current expressed as a fraction of capacity: for a 280 Ah cell, 0.5C = 140 A, 0.2C = 56 A. Torque in newton-meters (Nm).

Disclaimer. Working with large battery packs carries a risk of burns, fire, and electric shock. This guide provides field-tested guidance, but responsibility for your specific build is yours. Always cross-check against the documentation for your cells, your BMS, and your inverter: the values given here are typical ranges for common equipment, not a substitute for the manufacturer's datasheet.

Important: Liability

Working with lithium battery systems carries real risk: fire, electric shock, injury, property damage.

This guide is informational. It reflects a methodology proven on hundreds of client builds, but every build belongs to the person who makes it. You assemble and operate your system at your own risk, and you alone are responsible for verifying your component choices, the quality of your assembly, and compliance with local electrical codes and regulations. If you're unsure at any step, bring in a qualified electrician.

The seller has no knowledge of, and no way to verify, which components you actually use, how you assemble them, or in what conditions your system operates. For that reason all responsibility for the build and for any consequences of using the information in this guide rests with the buyer alone.

1. Safety

This chapter is short on purpose. It contains what you need to know before the first time you touch a cell, and nothing extra.

1.1 Why this isn't like a lead-acid battery

The main difference between LiFePO₄ and a familiar automotive battery isn't the chemistry, it's the internal resistance. A 280 Ah cell has an internal resistance of about 0.2-0.3 mOhm. Stack sixteen of them in series and you get a 51.2 V pack with a combined resistance of roughly 4-5 mOhm including the connectors.

Work out the short-circuit current: 51.2 V divided by 0.005 Ohm is over 10,000 A. In reality the current will be lower because of the resistance of the short itself and the contacts, but the order of magnitude is exactly that: thousands of amps. A lead-acid battery will give far less and will "sag" within seconds; LiFePO₄ will sustain that kind of current long enough for metal to vaporize.

Practical consequence: a wrench that falls across two terminals doesn't "spark," it explodes. Molten metal flies sideways, not down. This is exactly why the points below aren't overcaution.

1.2 Tools

- **Insulate every tool that will touch the terminals.** Heat-shrink over 2/3 of the wrench's length, or a dedicated dielectric tool. A single layer of electrical tape isn't enough: it slides.
- **Work with one hand** whenever possible. Keep the other hand in your pocket or behind your back. That way current doesn't have a path through your chest.
- **One terminal at a time.** Never hold a tool in a way that lets it reach both plus and minus at once.
- **A torque wrench is mandatory.** Not "by feel." The reason is in chapter 6.
- **A multimeter with 0.001 V resolution.** A cheap meter that shows 3.2 V instead of 3.284 V is unfit for this work: all balancing is measured in millivolts.

1.3 Jewelry, clothing, workspace

Remove rings, watches, bracelets, chains. A gold ring on a finger that bridges the terminals heats to the melting point of tissue faster than you can pull your hand away, and it can't be removed afterward. This is the most common serious injury in this line of work, and it's entirely prevented by one action before you start.

Wear natural-fiber clothing: cotton smolders, synthetics melt and stick to skin. Safety glasses are mandatory while torquing terminals and doing any busbar work. Rubber-soled shoes.

Work surface: wood, or covered with a rubber mat. Not metal. Don't keep anything metal on the table except what's currently in your hands. The most common accident scenario goes like this: someone sets a wrench on top of the cells "for a second," then moves the housing, and the wrench falls onto the terminals.

1.4 Fire

LiFePO₄ is significantly safer than NMC: it isn't prone to thermal runaway under normal conditions and doesn't ignite from puncture the way lithium-cobalt chemistries do. But under severe mechanical damage, reverse charging, or heavy overheating, a cell vents gas (mostly CO and hydrocarbons) that can ignite.

Gas from the vent is toxic. Besides carbon monoxide (CO), it contains hydrogen fluoride (HF), formed from the electrolyte and lithium salts. Don't breathe this smoke, even for a few breaths: HF damages the respiratory tract, and the effects show up with a delay. So the first action when gas or smoke is present is to get people out of the room and open it from outside, not to fight the fire from inside.

Distinguish two different scenarios:

- **Something near the pack is burning** (wiring, inverter housing, items in the closet), and the cells themselves are intact. This is an ordinary fire: cut power, extinguish with an ABC dry-powder extinguisher.
- **The pack itself is burning** (the vent has opened, the cell is throwing flame and gas). An extinguisher won't stop that cell: it generates its own oxidizer internally. Get people out, call the fire department, let the pack burn out. If it's safe to do so, cool what's nearby (neighboring cells, walls, belongings) with water from a distance so the fire doesn't spread further, but don't approach the pack and don't breathe the smoke.
- Keep an ABC-class dry-powder extinguisher nearby. Never apply water directly to an energized pack.
- Don't assemble or charge the pack in a room where you sleep. A closet, hallway, or a separate ventilated cabinet.
- Ventilation isn't needed because of "hydrogen off-gassing" (that's a lead-acid story), but so that in case of a fault, gas doesn't accumulate in an enclosed space. Natural room ventilation and a cabinet that isn't airtight (just not sealed) are enough.
- The inverter heats up on its own and needs clearance around its heatsink: at least 10 cm on the sides, 20 cm on top, with the fan never obstructed.

1.5 What to do if

A cell has swollen. Don't charge it, don't discharge it under heavy load, take it out of the room, let it cool. A swollen cell is either the result of overcharge, a factory defect, or the absence of compression. It doesn't go back into the pack.

A sharp, sweetish smell (electrolyte). A leak. Cut power immediately, ventilate the room, dispose of the cell.

A spark when connecting the inverter. This is normal: the inverter has large input capacitors, and the first connection produces a brief current surge. It's not normal when the spark continues: that's a short circuit. See chapter 7 for pre-charging the capacitors.

You shorted the terminals and nothing burned. Check every element the current passed through: terminals for scorch marks, connectors, the BMS. Micro-welding at the contact point damages the terminal's threads and plating. Don't treat this as "got lucky, all good."

2. Receiving the Cells

The most expensive mistake in this project isn't made with a soldering iron, but through inaction: cells get accepted "on faith," the pack gets assembled, and a month later it turns out one of the sixteen has 240 Ah instead of 280. It can no longer be returned, and the pack is now limited by its weakest cell forever.

Inspection takes anywhere from three days to two weeks (mostly waiting, not work). It's the best investment of time in the entire project.

2.1 Unboxing and visual inspection

Unpack on the floor or a low table: a 280 Ah cell weighs 5.4-5.6 kg, a 314 Ah cell about 6 kg, and the lower the drop height, the less damage from an accidental fall.

Check every cell against this list:

What to look at	Normal	Concerning
Case	Flat faces, straight edges	Bulging sides, "barrel" shape
Insulation wrap	Intact, no cuts	Cuts down to the aluminum, scorch marks
Terminals	Clean threads, not stripped	Damaged threads, dents, oxidation
Vent (on top)	Flat, no marks	Bulged, signs of leakage
Labeling	Same batch on all cells	Different dates, different labels, altered QR codes
Barcodes	Sequential numbers	Random numbers from different batches

Bulging. Lay the cell on its side on a flat surface. A new cell should be flat. A slight bulge (up to 1 mm) is acceptable in new cells with a high SoC; a noticeable "barrel" shape is not.

Different batches. Cells from different batches have different internal resistance and different real capacity, even if the same number is printed on them. This isn't a reason to reject them, but it is a reason to measure each one (section 2.3) and be ready for a wider spread.

Case under voltage. Measure the voltage between the negative terminal and the aluminum case (wherever the wrap doesn't cover it). It should be close to zero, or a few tenths of a volt. A significant voltage means the wrap is punctured somewhere and the case is in contact with an internal element. A case like that can't go into a metal enclosure without additional insulation.

2.2 Voltage on Arrival

Measure every cell right after unboxing and record it in a table. This is your baseline, the one you'll come back to for the whole life of the system.

Normal values for new cells shipped from a warehouse:

State	Voltage per cell	What it means
Normal storage	3.28-3.32 V	About 50% charge, the way warehouses store cells
Reduced	3.10-3.28 V	Long storage or self-discharge, still acceptable
Low	2.90-3.10 V	Suspected self-discharge, monitor separately
Deeply discharged	2.50-2.90 V	Charge separately at 0.1C, under supervision, then keep monitoring it
Dangerous	2.00-2.50 V	Deep discharge, likely degradation, recovery only under supervision
Defective	below 2.00 V	Do not recover, dispose of it
Elevated	above 3.40 V	Not from a "fresh" warehouse batch, already used

The spread between cells matters more than the absolute value. A set where all sixteen cells read 3.286-3.294 V is a good set. A set with one cell at 3.31 V and another at 3.14 V will need longer balancing, and one of those two will almost certainly turn out weak in the capacity test.

There is a floor below which a cell isn't recovered. When voltage drops below roughly 2.0 V, the anode's copper current collector starts dissolving into the electrolyte, and on the next charge that copper plates back out wherever it ends up, including straight through the separator. Internal bridges form, and the cell can heat up and vent right during the "recovery" charge, while you're standing next to it. So the rule is firm: **below 2.0 V, a cell is not recovered, it's scrap, dispose of it.** No "let's try, maybe it'll come back": the cost of being wrong here isn't the price of the cell.

A cell that arrives in the 2.0-2.5 V range is revived with a very small current (0.02-0.05C, i.e., 6-14 A for 280 Ah) up to 3.0 V, and only then charged normally. Do this in a fire-safe location (concrete, metal, away from living spaces), under supervision, with a thermometer: the cell shouldn't warm more than a few degrees. If after this recovery it runs hotter than its neighbors or loses voltage quickly, it doesn't go into the pack.

2.3 Capacity Test: Procedure

This is the step most often skipped, and it's exactly the one that pays off. Goal: find out the real capacity of each cell and confirm that none of them is a clear outlier.

What you need: an adjustable power supply (lab PSU) rated 3.65 V and at least 10-20 A, an electronic load or a resistive load with a wattmeter, a coulomb counter (a wattmeter with Ah tallying, e.g. one of the "energy meter" type devices), a thermometer.

Procedure for a single cell:

1. **Charge.** Set the PSU to 3.65 V with a current limit of 0.2-0.5C (56-140 A for 280 Ah; in practice most builders are limited by what their PSU can deliver and use 10-20 A, which is also fine, just slower). Charge until voltage reaches 3.65 V and current drops to 0.05C (about 14 A for 280 Ah) or lower, and stops dropping.
2. **Rest.** 30-60 minutes with no load. Voltage will settle to about 3.40-3.45 V: this is normal, it's relaxation.
3. **Discharge with measurement.** Discharge at 0.5C (140 A for 280 Ah) or less, down to 2.50 V at the terminals under load. The coulomb counter will show how many Ah you pulled out. That's the real capacity.
4. **Record.** Log in the table: cell number, Ah removed, temperature at the end of discharge, time.
5. **Return to the working range.** Charge the cell back up to at least 3.30 V right away: leaving it at 2.5 V for a long time is harmful.

Reading the result. A healthy cell rated 280 Ah should deliver 275-290 Ah (manufacturers often build in a small margin). 260-275 Ah is acceptable, but already the lower edge. Below 250 Ah is grounds for a claim.

The key criterion is the spread, not the absolute number. If all sixteen cells delivered 281-287 Ah, you have an excellent set. If fifteen delivered around 285 and one delivered 258, that one will define the capacity of the whole pack: series-connected cells are always limited by the weakest one. Replace it, don't hope it will "even out."

Simplified version, when you don't have equipment for a full test: charge all the cells in parallel to 3.65 V (see chapter 3), then assemble the pack and run one full discharge cycle through the inverter with a coulomb counter. You won't learn each cell's individual capacity, but you'll see which one sags to the low threshold first under load. That's the weak link.

2.4 Internal Resistance

Internal resistance (IR) is the second health indicator of a cell, and it catches problems the capacity test misses.

Approximate values for new cells:

Cell capacity	Typical IR	Cause for concern
100-105 Ah	0.5-0.8 mOhm	above 1.2 mOhm
280 Ah	0.20-0.35 mOhm	above 0.5 mOhm
304-314 Ah	0.18-0.30 mOhm	above 0.45 mOhm

The values in the table are for the standard **1 kHz AC measurement** (AC-IR): that's how manufacturers state them and how a dedicated tester measures them. If you don't have a tester, there's a practical DC method (DC-IR): apply a known load to the cell (e.g. 50 A), measure the voltage with no load and under load after 10 seconds. Resistance = voltage difference divided by current. A sag of 0.015 V at 50 A means 0.3 mOhm, and the fact that this number falls inside the AC table's range above is pure coincidence: you still can't compare them.

These two numbers can't be compared to each other. The DC method includes not just the ohmic component but also electrode polarization, so it reads 2-4 times higher than the 1 kHz datasheet value. A cell that a tester would show as 0.25 mOhm will read 0.6-1.0 mOhm under load, and that's not a defect. So: **compare a DC measurement only between cells of the same set**, measured with the same method, the same current, and the same temperature. Don't check it against the ranges in the table above, or you'll "fail" a healthy set.

What to do with this. A cell with IR twice that of its neighbors heats up twice as much under the same current and will sag first under load. Even if its capacity is normal, in a high-current pack it becomes the weak link. For backup power with moderate currents (up to 0.3C), a small IR spread isn't critical.

Important: measure IR at the same temperature across all cells and at a similar SoC. A cold cell shows higher resistance, that's not a defect.

2.5 Compression

Prismatic LiFePO4 cells are designed to operate under compression. They expand during charge and contract during discharge, and without external restraint this "breathing" gradually damages the internal structure: electrode layers delaminate, and capacity drops faster than it should.

- Two rigid end plates (3-5 mm steel, 12-15 mm plywood, or aluminum extrusion) and 4 M6-M8 rods through the corners.
- Thin spacers between cells (1-2 mm foam or fiberglass laminate), so they don't rub against each other and have some room to expand.
- Target compression around 300 kgf across the pack, roughly 12 psi over the side-face area. A practical reference without a torque gauge: compress until the cells no longer shift by hand, but without visible deformation of the wrap or any "bowing" of the end plates.
- Don't use the busbars as the structural element holding the pack together. A busbar carries current, it doesn't compress the assembly.

A cell that has run for a year without compression usually already has a mild "barrel" shape and 5-15% less capacity. This is permanent.

3. The First Charge, Step by Step

This chapter covers the single most important procedure in the whole build: top balancing. It's done once, before the cells go into a series string, and it determines whether your pack delivers its rated capacity or 70% of it.

3.1 Why Top Balancing Specifically

Cells connected in series receive the same current but fill up differently, because they have slightly different capacities. Picture sixteen buckets connected by one hose: they're filled equally, but one bucket is smaller and overflows first.

The BMS stops charging as soon as **any** cell reaches the overcharge threshold (3.65 V). If the cells started out filled to different levels, the fullest one will hit the ceiling while the rest are still far from full, and the pack "runs out" at 80%, or even 60%.

Top balancing evens the cells out precisely at the top point: they all reach 3.65 V at the same time. The bottom points will diverge (the weaker cell discharges first), and that's the right tradeoff: better to fall short at the bottom, where voltage drops gently, than at the top, where the curve rises sharply and the BMS reacts instantly.

Bottom balancing is used in specific scenarios without a BMS. For a home backup system with a BMS, the right answer is top balancing.

3.2 Preparation: Parallel Connection

Cells are balanced in **parallel**: all positives together, all negatives together. That way they naturally settle at the same voltage, and the external power supply fills them to the same level.

Watch out for voltage difference. If one cell is at 3.32 V and another at 3.10 V, connecting them will drive a large current between them: a 0.22 V difference across a combined resistance of 0.5 mOhm is over 400 A. That's dangerous and harmful to both cells.

The correct sequence:

1. Sort the cells by voltage.
2. First connect in parallel those that differ by no more than 0.05 V. They'll even out within minutes.
3. Bring outlying cells up to the group's level separately, with a power supply (charging) or a small load (discharging), and only then add them to the parallel bank.
4. Alternative: connect each next cell through a smaller-gauge wire (e.g. 2.5 mm²) or through a resistor of a few ohms for the first few minutes, so the equalizing current is limited, then switch to a normal busbar.

Busbars for the parallel bank. Current in a parallel connection splits between cells during charging, but the entire PSU current passes through the end cells. A 16 mm² wire handles up to 80 A, which is more than enough for a typical 20-60 A PSU. Torque the terminals to the normal spec (chapter 6): a loosely torqued terminal on a parallel bank means not just heat, but also a distorted balancing result.

PSU wiring layout. Positive from the power supply to the end cell on one side, negative to the end cell on the opposite side. This way the charging current passes through the whole chain more evenly than if both leads were clamped to the same cell.

3.3 Balancing Procedure

1. **Set the PSU to 3.65 V** and a current limit at whatever it can pull (0.2C or less across the total: typically 20-50 A for the whole parallel bank). Don't set 3.70 V "to go faster": no cell should ever see more than 3.65 V.
2. **Connect and leave it.** At first the PSU runs in current-limit mode and voltage climbs gradually. This is the bulk phase.
3. **Watch for the transition into absorption.** When the voltage across the bank reaches 3.65 V, the PSU switches to voltage-regulation mode and current starts to fall. This is where the longest part begins.
4. **Wait until the current drops to 2-4 A across the whole bank** and stops falling. In practice it drops nearly to zero. The usual single-cell end-of-charge criterion of 0.02-0.05C doesn't apply here: for a bank of sixteen 280 Ah cells (4480 Ah combined) that would be ninety to over two hundred amps, and would stop the process long before the cells even out. On the balancing bank, the reference is absolute, in amps: a few amps for the whole assembly.
5. **Hold for another 6-12 hours after the current stops falling.** This is exactly when the last few percent fill in, and exactly where the cells even out. Total procedure time: 12-48 hours depending on the starting state and PSU power. This is normal. There's no point shortening this step, it's the whole point of the exercise.
6. **Check.** Disconnect the PSU, wait 2 hours, break the parallel connection, and measure each cell individually. After correct balancing, the spread should be within 0.005-0.010 V.

Sign of a problem: one cell drops to 3.35 V after disconnection, while the others hold 3.45 V. That's self-discharge or a defect. Flag it and test it separately: charge it to 3.65 V, leave it for 72 hours with no load, and compare how much it sagged relative to its neighbors.

3.4 Assembling into a Series String and the Pack's First Charge

1. **Break the parallel connection.** All cells are now at the same voltage, roughly 3.40-3.45 V at rest.
2. **Assemble the series string** according to your configuration (4s = 12.8 V, 8s = 25.6 V, 16s = 51.2 V), following the torque specs from chapter 6.
3. **Before connecting the BMS, verify polarity.** Measure the pack's total voltage: for 16s it should be about $16 \times 3.42 = 54.7$ V. If the number is lower than expected by roughly double a single cell's voltage, one cell is installed backward somewhere. A reverse-connected cell will destroy both itself and the BMS.
4. **Connect the BMS balance leads strictly in order**, from the pack's minus (B-) upward, one at a time. This is the single most common place for a mistake with catastrophic consequences: swapped balance leads burn out the BMS's input circuitry.
5. **Check the BMS readings** before connecting any load: all cells should be at the same voltage, the total voltage should match what the multimeter reads, and the temperature sensors should show room temperature.

First charge of the pack with a charger. Set the charger's final voltage based on 3.50-3.55 V per cell (not 3.65). For 16s that's 56.0-56.8 V, for 8s 28.0-28.4 V, for 4s 14.0-14.2 V.

Configuration	Nominal	Charge (3.50 V/cell)	Charge (3.55 V/cell)	Absolute limit (3.65 V/cell)
4s	12.8 V	14.0 V	14.2 V	14.6 V
8s	25.6 V	28.0 V	28.4 V	29.2 V
16s	51.2 V	56.0 V	56.8 V	58.4 V

Why 3.50-3.55 V and not 3.65 V. The top of the LiFePO₄ curve is very steep: less than 3% of capacity is packed between 3.45 V and 3.65 V, yet that's exactly where the cell ages fastest and where the BMS keeps tripping on overcharge. Charging to 3.50-3.55 V per cell costs you a few percent of capacity and buys a significant extension of cycle life and calm operation without constant trips. The loss is actually even smaller than it looks: a charge that finishes at 3.55 V with a taper down to low current captures roughly 99% of the cell's real capacity. The difference between charging "to 3.55 V" and "to 3.65 V" isn't tens of percent of runtime, it's one or two percent.

3.65 V is needed during balancing (to reliably hit the ceiling on every cell at once) and as the BMS's emergency limit. In day-to-day operation, there's no reason to go there.

Charge current. Stay within 0.2-0.5C. For 280 Ah that's 56-140 A. Less is always fine, just slower. More than 0.5C shortens cycle life and overloads the BMS.

3.5 What to Watch During the First Charge

Stay by the pack for its first charge, don't leave it unattended. Watch:

- **Cell voltage spread (delta).** 0.005-0.015 V at the start of charge is normal. If delta grows to 0.05 V or more by the end of charge, balancing was insufficient or there's a weak cell.
- **The highest cell.** It shouldn't reach 3.65 V ahead of the rest. If it does, stop the charge and repeat top balancing.
- **Temperature.** Cells charging at 0.2-0.5C warm up 3-8 degrees above ambient. Localized heating of one cell or terminal means poor contact or a problem cell.
- **Terminal and connector temperature.** By hand (back of the hand, carefully). A warm terminal means an undertightened terminal or insufficient wire gauge.
- **Current.** It should match what's set on the charger. If current is lower than expected, there's high resistance somewhere in the circuit.

By the end of the charge, the BMS should show all cells within 3.50-3.55 V with a spread under 0.010 V, and SoC around 100%. If that's the case, the hardest part is behind you.

4. Balancing in Operation

Top balancing (chapter 3) is done once, by hand, before assembly. After that, the BMS watches over cell equality. This chapter covers exactly how it does that and why balancing "doesn't work" in so many builds.

4.1 Passive and Active Balancing

Passive balancing is a resistor and transistor on every cell. When a cell is higher than the rest, the BMS switches on the resistor and bleeds the excess off as heat. Typical balancing current is 30-200 mA, up to 300 mA on beefier boards.

Consequences:

- Balancing only works "downward": excess energy is drained from the highest cell, there's no way to top up the lowest one.
- So passive balancing only makes sense **during charging**, when the pack approaches the top and the difference becomes visible. Balancing at rest or during discharge is just wasted energy.
- Speed is very low. A 100 mA current takes 50 hours of continuous balancing time to close a 5 Ah gap, and balancing only runs for a few minutes at the end of each charge. Hence the main takeaway: **passive balancing doesn't fix a bad start**, it only maintains a pack that's already balanced.

Active balancing pumps charge from a higher cell to a lower one through a capacitor or transformer, at 80-90% efficiency. Current on consumer boards is 0.6 A, 1 A, 2 A, up to 5 A on stronger units. This is an order of magnitude faster and works in both directions.

Popular JK BMS boards have a built-in active balancer (which is part of why they're popular). But even a 2 A active balancer doesn't replace top balancing: to even out cells that have drifted apart by 20 Ah, it needs 10-12 hours of continuous operation (20 Ah at 2 A), and it typically only works within a defined voltage range and only for a few minutes at the end of charge.

4.2 Balancing Threshold Settings

Three parameters determine when the balancer switches on.

Balance trigger voltage. The balancer only switches on once the highest cell's voltage crosses this threshold. Typical value **3.40 V**, sensible range 3.38-3.45 V.

Why there: below 3.40 V the LiFePO₄ curve is practically flat, and a voltage difference doesn't correspond to a difference in charge. A cell at 3.28 V and a cell at 3.30 V can have the same SoC, and a balancer turned on in that region would be "correcting" an imaginary imbalance while creating a real one. Above 3.40 V the curve is already rising, and voltage becomes a reliable indicator of fullness.

Balance delta / trigger difference. The minimum spread between the highest and lowest cell at which it's worth doing anything. Typical value **0.010 V (10 mV)**, sensible range 5-30 mV.

Too small (3 mV) makes the balancer run constantly and heat the board off measurement noise. Too large (50 mV) means the imbalance has time to become noticeable before work even starts.

Balance current. For active JK-type boards, 0.6-2 A depending on the model; often adjustable. Set the maximum the board allows, but watch the balancer's temperature: it runs warm, and that's normal as long as the heating stays moderate.

Balance only during charging. Most boards have a separate switch that limits balancing to when charge current is flowing. For passive balancers, this should be on. For an active balancer, balancing at all times is acceptable, and even beneficial, since an active balancer doesn't waste energy as heat, it shifts it to the neighboring cell. **Check your BMS's manual:** this parameter is named differently and behaves differently across brands.

4.3 How to Tell Balancing Is Working

Watch delta (the difference between the highest and lowest cell) at three points in the cycle:

Point in cycle	Healthy pack	Needs attention
At rest, mid-SoC	0.002-0.010 V	above 0.020 V
End of charge	0.005-0.020 V	above 0.050 V
End of discharge	0.010-0.040 V	above 0.100 V

Delta at the end of discharge is always larger than at the end of charge: the bottom of the curve is steep too, and the weaker cell falls off faster. This is normal and not, on its own, a diagnosis.

Delta growing across cycles (it was 0.010 V, now it's 0.030 V three months later): this is either natural drift the balancer can't keep up with, or one cell has elevated self-discharge. Watch which specific cell keeps "running off." If it's always the same one, and always downward, it's self-discharge.

Delta jumping sharply within a single cycle: check the contact, not the cell. A bad terminal or an oxidized connector creates a voltage drop that the BMS reads as a cell sagging.

4.4 When to Repeat Manual Top Balancing

On a schedule, once a year, or on these signs:

- Delta at the end of charge consistently exceeds 0.050 V.
- The BMS cuts off charging on one cell's overvoltage while SoC is still below 95%.
- The pack delivers noticeably fewer Ah than a year ago, even though the cells themselves are healthy.

The procedure is the same as in chapter 3: break the series string, connect in parallel, charge to 3.65 V, hold. It's a few hours of work once a year, and it restores the pack to its rated capacity.

5. BMS Configuration

A BMS isn't "a smart device that handles everything on its own." It's a set of thresholds, and by default they're set by the manufacturer to generic values, sometimes simply wrong for your configuration. This chapter covers exactly what to set and why.

The values below are typical ranges for common JK-series boards. **Check your BMS's manual:** parameter names, and even their underlying logic, differ across brands and firmware.

5.1 What a BMS Does and Doesn't Do

Does: monitors each cell's voltage, total current, and temperature; opens the power switches when limits are exceeded; balances cells; calculates SoC.

Doesn't do: it isn't a daily on/off switch (chapter 9, mistake 6), it doesn't replace a fuse (opening the MOSFETs isn't galvanic isolation, and under a short they can fail closed), it doesn't save you from wiring mistakes, it doesn't compensate for skipping top balancing.

5.2 Threshold Table (Typical Profile, 16s, 280 Ah Cells)

Parameter	Typical value	Sensible range	Comment
Cell overvoltage (Cell OVP)	3.65 V	3.60-3.65 V	Absolute limit, not a working point
Overvoltage release	3.55 V	3.45-3.55 V	Hysteresis, so it doesn't "chatter"
OVP delay	1-2 s	1-5 s	
Cell undervoltage (Cell UVP)	2.80 V	2.70-2.90 V	Below 2.5 V the cell degrades
Undervoltage release	3.00 V	2.95-3.10 V	
UVP delay	2-5 s	2-10 s	A longer delay rides through inrush currents
Pack overvoltage	58.4 V (16s)	3.65 x N	Mirrors the cell threshold
Pack undervoltage	44.8 V (16s)	2.80 x N	
Charge current limit (Charge OCP)	100 A	1.2 x charger's max current	And never above 0.5C of pack capacity or the board's own rating
Charge OCP delay	5-10 s		
Discharge current limit (Discharge OCP)	150-200 A	per calculation, section 5.3	
Discharge OCP delay	5-10 s	3-30 s	Must survive inverter startup

Parameter	Typical value	Sensible range	Comment
Second-stage discharge (OCP2)	250-300 A	1.5-2 x OCP1	Delay 0.1-1 s
Short circuit (SCP)	factory-set		Trips within microseconds
Charge, upper temperature limit	50-55 C	45-55 C	
Charge, lower temperature limit	5 C	3-5 C, absolute minimum 0 C	Critical, section 5.4
Low-temp charge lockout release	10 C	8-12 C	
Discharge, lower temperature limit	-20 C	-20...-10 C	
Discharge, upper temperature limit	60 C	55-65 C	
MOSFET temperature cutoff	80-90 C		Factory-set, don't raise
Balance start voltage	3.40 V	3.38-3.45 V	Chapter 4
Balance start delta	0.010 V	0.005-0.030 V	
Balance current	0.6-2 A	per board model	
Cell voltage for SoC 100%	3.55 V	3.50-3.60 V	Should match the charger's profile
Cell voltage for SoC 0%	2.80 V	2.75-2.90 V	Should match UVP
Pack capacity (Capacity)	280 Ah	as measured in the test	SoC is calculated from this

For 8s and 4s, pack-level thresholds scale by multiplying by the number of cells; cell-level thresholds don't change.

5.3 Calculating Current Thresholds

Current thresholds are derived from load power, not pulled out of thin air.

Step 1. Continuous power (contW). The sum of the power of everything running at the same time: $\text{contW} = \text{sum}(\text{power}_i \times \text{count}_i)$.

Step 2. Peak power (peakW). The largest single startup surge on top of continuous power: $\text{peakW} = \text{contW} + \text{max}(\text{startup}_i - \text{rated}_i)$. A fridge rated at 150 W with a 900 W startup surge adds 750 W to continuous power, not 900.

Step 3. BMS current. $\text{BMS current} \geq \text{peakW} / V \times 1.25$, where V is the pack's nominal voltage (12.8, 25.6, or 51.2 V), and 1.25 is a mandatory 25% margin.

Example: a 25.6 V pack, contW 800 W, the largest startup increment 750 W, so $\text{peakW} = 1550 \text{ W}$. $1550 / 25.6 \times 1.25 = 75.7 \text{ A}$. Round up to a 100 A BMS.

Why 1.25 specifically. The 25% margin covers: pack voltage sag under load (at 20% SoC a 25.6 V pack runs closer to 24 V, so current climbs), the BMS's own measurement error, and real startup surges deviating from datasheet values. Without this margin, the BMS would trip on every compressor start.

An honest note on efficiency. The formula calculates current from load power, but the actual current drawn from the pack is higher: the inverter absorbs losses, and at 0.88 efficiency it draws roughly 14% more than it delivers ($W / 0.88 / V$). The 1.25 margin doesn't replace this difference, it stacks on top of it: as long as the inverter isn't running flat out, its rated power is usually well above the actual load, and that's exactly what the simplified $\text{peakW} / V \times 1.25$ calculation relies on. But if you plan to run the inverter continuously at its full rated power, calculate the real current with efficiency accounted for first: $I = W / 0.88 / V$, then, as always, apply the same 25% margin: size wire and fuse from $I \times 1.25$, not directly from I . For a 3000 W inverter at 25.6 V: $I = 3000 / 0.88 / 25.6 = 133 \text{ A}$, with the 1.25 margin that's 166 A, so a 200 A fuse and 50 mm² wire, instead of the 150 A and 35 mm² that a calculation off the nominal current without the efficiency correction would give.

Delay matters more than the threshold. A motor's startup lasts 0.1-2 seconds. If the threshold, even with the 1.25 margin, still gets exceeded at startup, the right fix is to increase the first-stage trip delay to 5-10 seconds and rely on the second stage (OCP2) with a shorter delay for real faults. Don't raise the threshold above the board's own rating.

5.4 Temperature Thresholds: The Most Important Parameter

Charging cells below 0 C is forbidden. This isn't a recommendation or "preferred." During charging in cold conditions, lithium doesn't intercalate into the anode's structure, it plates onto its surface as metallic dendrites (lithium plating). Consequences:

- Capacity is lost irreversibly, a few percent per episode.
- Internal resistance rises.
- Dendrites can, over time, puncture the separator and cause an internal short circuit.
- **There are no external signs.** The cell looks normal, voltage looks normal, and you find out about the problem six months later, when the pack holds half of what it used to.

So set it up like this:

1. **The temperature sensor must be on a cell**, not on the BMS board and not in the air. Beyond that, which specific cell matters, because two different protections look in opposite directions.

Low-temperature charge lockout should be based on the coldest cell. The lockout trips on what the sensor sees, and lithium plating happens in whichever cell is actually cold. If the sensor sits on the center (warmest) cell, it will read +6 C while the end cell against the enclosure wall is at 0 C, and the BMS will allow a charge that destroys that end cell. So **the primary charge sensor goes on the end cell against the outer wall or the floor** (where the cold comes from), at the coldest point in the pack.

The high-temperature cutoff, by contrast, should be based on the hottest cell, which is the center one: it's surrounded by neighbors, heats from them, and sheds heat slowest. A second sensor goes on the side face of the center cell, and that one governs the overtemperature cutoff for both charge and discharge.

If the board only has one sensor input, put it on the cold end cell: in winter, an error toward the cold side costs more, and overheating in a household backup system with moderate currents happens far less often.

2. **Lower charge limit 5 C, lockout release at 10 C.** The absolute physical minimum is 0 C, but the threshold is set with margin: the sensor has its own error (a typical NTC is $\pm 1-2$ C), and there's always a gradient of a few degrees between the measurement point and the coldest part of the cell. The 5-degree gap between lockout and release is also there to keep the system from cycling on and off right at the boundary.
3. **Don't rely on the charger.** Most chargers don't know the pack's temperature. The protection has to live in the BMS.
4. **Discharging in the cold is allowed** down to -20 C, but capacity at -10 C drops by roughly 20-30%, and that's normal: it comes back once the pack warms up.

5.5 Setup and Verification Sequence

1. Connect the BMS to its app (Bluetooth) or a PC before wiring up the power leads.
 2. Set the cell count (S count) and chemistry (LiFePO4/LFP). A mistake here makes everything else meaningless.
 3. Set the pack capacity from your chapter 2 test results (e.g., not 280, but the measured 275 Ah).
 4. Enter the cell-level thresholds from table 5.2.
 5. Enter the current thresholds from the 5.3 calculation.
 6. Enter the temperature thresholds from 5.4.
 7. Enter the balancing parameters from chapter 4.
 8. **Verify with a real trip.** Temporarily lower the undervoltage threshold to just above the current cell voltage and confirm the BMS actually disconnects the load. Then restore the working value. A protection that's never been tested is an assumption, not a protection.
 9. Save the settings and **write them down on paper** or take a screenshot. After a board replacement or a reset, you'll be glad you did.
-

6. Wiring

Most builds that burn don't burn because of the cells, they burn because of the connections. A cell spreads heat across its whole case; a bad terminal concentrates it into a spot the size of a coin.

6.1 Wire Gauge

The table below gives working values for stranded copper wire over a short run (up to 2-3 meters) inside an enclosure or cabinet, at ambient temperatures up to 40 C. They're deliberately conservative: in backup power systems, margin is cheaper than a repair.

Cross-section, mm ² (approx. AWG)	Continuous current	Typical application (calculated as $\text{peakW} / \text{V} \times 1.25$)
6 (approx. 9 AWG)	30 A	Small loads, branches up to 30 A, chargers up to 30 A
10 (approx. 7 AWG)	50 A	Medium-power 12/24 V lines, a branch with a 40 A fuse
16 (approx. 5 AWG)	80 A	600 W at 12 V, 1200 W at 24 V, 2400 W at 51.2 V (about 59 A in all three cases, 60 A fuse)
25 (approx. 3 AWG)	100 A	1000 W at 12 V, 2000 W at 24 V, 4000 W at 51.2 V (about 98 A, 100 A fuse)
35 (approx. 2 AWG)	150 A	1500 W at 12 V, 3000 W at 24 V, 6000 W at 51.2 V (about 147 A, 150 A fuse)
50 (approx. 1/0 AWG)	200 A	2000 W at 12 V, 4000 W at 24 V (about 195 A, 200 A fuse)

How to choose. The order is:

1. Calculate current the same way as for the BMS: $\text{current} = \text{peakW} / \text{V} \times 1.25$.
2. Round it **up** to the nearest fuse rating in the series 40 / 60 / 100 / 125 / 150 / 200 / 250 A (section 7.1). This ladder is sized for main and inverter circuits; protect small branch circuits up to 30 A (e.g. a 12 V line for small loads) with automotive blade fuses rated 5-30 A, sized by the same rule: current x 1.25, rounded up within the blade-fuse range, but never above what the wire itself can carry.
3. Take the table row whose continuous current rating is at least the fuse rating, not the calculated number.

Step 3 is easy to skip, and that's exactly where the most dangerous mistake happens. The calculation gives 73 A, you pick 16 mm² (80 A) and fit the nearest fuse from the series, which is 100 A. Now the wire handles 80 A while the protection trips at 100 A: the run burns, not the fuse. Wire is always sized from the fuse rating.

Example: a 3000 W inverter on a 51.2 V pack. $3000 / 51.2 \times 1.25 = 73 \text{ A}$, nearest fuse up is 100 A, so 25 mm² wire (100 A). The same inverter on a 25.6 V pack gives $3000 / 25.6 \times 1.25 = 146 \text{ A}$, a 150 A fuse, 35 mm² wire. This is why a higher pack voltage cuts wiring cost so noticeably.

Inverter efficiency correction. The calculation above starts from load power and assumes the inverter's rated power is a peak, not a continuous rating. If the inverter will run continuously at its full rated power, first calculate the real current with its efficiency factored in: $\text{W} / 0.88 / \text{V}$, then, as always, apply the 1.25 margin and pick the gauge from the table above using that number (section 5.3).

Two corrections.

- **Length.** For runs over 3 meters, account for voltage drop as well as heating. Rule of thumb: the drop over the whole run, out and back, shouldn't exceed 2-3% of nominal voltage (0.3 V for 12.8 V, 1.2 V for 51.2 V). For longer runs, go up a gauge.
- **Bundling and temperature.** Several power cables in one conduit or an enclosed hot box heat each other up. Derate the allowable current by 20-30%, or go up a gauge.

Copper only, stranded only, quality insulation only. Don't use aluminum in a DIY build: it flows under terminal pressure, and a connection torqued correctly yesterday is loose tomorrow. Insulation should be rated for 90 C or higher; welding cable (fine-stranded, "KG" class) bends easily and works great. Don't use automotive "audio" cable of unknown gauge with copper-clad aluminum (CCA): the actual copper cross-section there is a fraction of what's marked.

6.2 Lugs and Crimping

Soldering power connections is not acceptable. Three reasons: solder wicks into the strand by capillary action and stiffens it, creating a failure point; in a fault, solder is the first thing to melt, so the joint comes apart exactly when you need it least; and a soldered joint's resistance is unstable.

Correct: crimp with a hydraulic press and a hexagonal die. Not "a hammer and chisel," not pliers.

Sequence:

1. Strip the insulation exactly to the depth of the lug's barrel, no more. Bare copper beyond the lug oxidizes.
2. Don't twist the strand by hand, don't tin it.
3. Select the lug by cross-section (marking "25-8" means 25 mm² for an M8 bolt) and the die by cross-section.
4. Crimp in two passes along the barrel's length, rotating the lug 90 degrees between presses if the die calls for it.
5. Verify: pull firmly. The lug shouldn't move at all. A wire that spins inside the barrel is a bad crimp.
6. Adhesive-lined heat-shrink, 20-25 mm over the insulation/lug transition. This isn't cosmetic: it locks the transition down and keeps moisture out of the strand.
7. Color coding: red shrink on positive, black or blue on negative. A year from now, you won't remember.

6.3 Torque Specs

The terminals on prismatic LiFePO₄ cells are made of aluminum (positive) and copper or steel (negative). Aluminum threads strip easily and permanently.

Terminal thread	Torque	Note
M6	4-6 Nm	Typical for 100-105 Ah cells
M8	8-12 Nm	Typical for 280-314 Ah cells

Always cross-check against your cells' datasheet: a specific manufacturer may specify a narrower range, and their value takes precedence over this one.

Rules that save terminals:

- **A torque wrench is mandatory.** An untrained hand can put anywhere from 3 to 25 Nm on an M8, and the second figure strips the threads.
- **Check the bolt length.** A bolt longer than the terminal's threaded depth bottoms out and gives a false sense of tightness, while the busbar is actually clamped loosely. Worse: on some cells an overly long bolt reaches the internal element. Rule: the threaded portion of the bolt should engage the terminal 6-8 mm and no deeper.
- **Washer order:** busbar, then flat washer, then spring (lock) washer, then bolt. A spring washer directly against the busbar gouges it and ruins the contact.
- **Don't use toothed (star) lock washers** on an aluminum terminal: they cut through the plating, and oxidation starts right at the cut.
- **No graphite-based grease, ever.** A thin layer of dedicated conductive paste for aluminum contacts is fine; ordinary grease creates an insulating film.
- **Retorque after the first cycle.** After a week of operation (a few charge/discharge cycles and a few thermal expansions), go over everything with the torque wrench again. After that, every six months.

6.4 Busbars

- **Busbar cross-section should match the pack's current**, per the same table 6.1. A 20x3 mm copper busbar has an area of 60 mm² and comfortably covers 200 A with margin. The thin decorative busbars that come with cheap cell kits are often rated for only 100-150 A, and in a high-power build they'll become the hottest point.
- **Flexible braided busbars are better than rigid ones** when the cells can shift slightly: a cell "breathes" over a cycle, and a rigid busbar transfers that motion to the terminal.
- **The busbar doesn't hold the pack together.** The compression plates handle the mechanics, the busbar only carries current.
- **Coated copper (tinned or nickel-plated).** Bare copper on an aluminum terminal forms a galvanic couple and oxidizes at the contact point, gradually increasing resistance.
- **Wipe contact surfaces before assembly** with alcohol, not sandpaper: scratches reduce the actual contact area.

6.5 Balance Leads

- Cross-section 0.5-1.0 mm², a separate harness, routed nowhere near the power cabling.
 - **Every balance lead needs its own fuse**, 1-2 A (fuse holders or resettable PPTC fuses). This is standard practice that's often skipped: if a balance lead chafes against the case and shorts to a neighboring potential, without a fuse the BMS burns, and sometimes the harness too.
 - Connect strictly in order starting from B- upward. Check the voltage between adjacent connector pins with a multimeter before plugging it in: it should read one cell's voltage (about 3.3 V), not double, and not zero.
 - Secure the connector so it can't vibrate loose or pop out. Lose one balance line, and the BMS sees that cell as zero or as double, with the corresponding trips.
-

7. Fuses and Switching

A BMS is electronics, and electronics can fail. A fuse is physics, and it trips even when nothing else works. A pack without a main fuse is not a finished installation, no matter how many smart functions its BMS has.

7.1 Sizing the Fuse

The same multiplier as for the BMS and the wire:

`fuse rating >= peakW / V x 1.25`, then round **up** to the nearest standard rating.

Standard series to choose from: **40, 60, 100, 125, 150, 200, 250 A**.

Examples:

Pack	Inverter	Calculation	Fuse	Minimum wire
12.8 V	600 W	$600 / 12.8 \times 1.25 = 58.6 \text{ A}$	60 A	16 mm ²
12.8 V	1000 W	$1000 / 12.8 \times 1.25 = 97.7 \text{ A}$	100 A	25 mm ²
25.6 V	1500 W	$1500 / 25.6 \times 1.25 = 73.2 \text{ A}$	100 A	25 mm ²
25.6 V	2000 W	$2000 / 25.6 \times 1.25 = 97.7 \text{ A}$	100 A	25 mm ²
25.6 V	3000 W	$3000 / 25.6 \times 1.25 = 146.5 \text{ A}$	150 A	35 mm ²
51.2 V	3000 W	$3000 / 51.2 \times 1.25 = 73.2 \text{ A}$	100 A	25 mm ²
51.2 V	5000 W	$5000 / 51.2 \times 1.25 = 122.1 \text{ A}$	125 A	35 mm ²

Notice the wire column: it's not sized from the calculated current, it's sized from **the fuse rating after rounding up**. That's why 73.2 A doesn't get 16 mm², it gets 25 mm²: the fuse at that point is already 100 A.

Three components, one current. Wire, BMS, and fuse are all sized with the same formula and the same 1.25 margin. The protection logic only works if the fuse trips before the wire has a chance to overheat. So the fuse should never be rated higher than what the wire it's connected to can carry: otherwise the run burns, not the fuse.

Cross-check against table 6.1: a 150 A fuse requires at least 35 mm² wire. If you have 25 mm² (100 A), either change the wire or fuse at 100 A.

7.2 Fuse Type: Why It Matters Specifically Here

The key spec for a lithium pack is **interrupt rating**: the maximum current the fuse can actually clear without turning into an arc. Recall the calculation from chapter 1: the pack can deliver over 10,000 A into a short circuit. A fuse with a 2000 A interrupt rating doesn't save you in that situation, it becomes a source of plasma arc inside the enclosure.

Type	Interrupt rating (DC)	Suitability
Class T	up to 20,000 A (at 125 VDC)	Best choice for LiFePO ₄ , the only one recommended for 51.2 V
MRBF (terminal-mount)	10,000 A at 14 VDC, about 5,000 A at 32 V, about 2,000 A at 58 V	12 V and 24 V systems only, up to 300 A
ANL / MIDI	2,000-6,000 A	Acceptable only for small 12 V packs
Automotive "knife" blade	1,000-2,000 A	Not for the main protection
AC household breaker	not DC-rated	Do not use on DC

Interrupt rating depends on voltage, and for MRBF it's decisive. The rated 10,000 A applies at 14 VDC. Already at 32 V it clears about 5,000 A, and at 58 V (i.e., a 51.2 V system at the top of charge) about 2,000 A. A 16s pack can deliver over 10,000 A, so in a 51.2 V system an MRBF fuse ends up in the same category as an ANL: it won't clear the fault current, it will arc instead. So the rule is simple:

- **12 V and 24 V:** MRBF is acceptable (convenient, mounts directly on the terminal), Class T is better.
- **51.2 V: Class T only.** No MRBF, ANL, or blade fuses as the main protection.

AC circuit breakers don't work as protection on DC. Direct current has no zero crossing, so the arc at the contacts doesn't self-extinguish. A breaker rated for 230 V AC may not clear the circuit at all at 51.2 V DC, and instead stay in a state of sustained arcing. If you need a breaker, get one explicitly marked for DC with a stated voltage (e.g. "48 VDC" or "125 VDC") and the required interrupt rating.

A fuse's voltage rating must not be lower than the pack's voltage. A fuse marked 32 VDC is unfit for a 51.2 V system, even if its amp rating looks correct.

7.3 Where Things Go

Order from pack to load:

```
[+] pack -> main fuse -> main switch -> distribution bus -> loads
[-] pack -> BMS (B-) -> negative bus -> loads
```

- **The main fuse goes on the positive lead, as close to the pack terminal as practical**, within 15-20 cm. The section of wire ahead of the fuse is unprotected, so it should be as short as possible and mechanically protected (conduit, an insulated holder).
- **The main switch** goes after the fuse. This is how you de-energize the system for service. It must be DC-rated and rated for the system's full current.
- **A separate fuse on each branch** after the distribution bus, sized to that branch's own current. The inverter, the charger, and a 12 V line for small loads are three different branches with three different ratings.
- **The charger gets its own fuse** sized to its own current, not to the inverter's.
- **The BMS sits in the negative circuit** (the typical layout on most boards): the power switches open the negative leg, so the entire negative-side current passes through the BMS's B-. Don't connect any load to the pack's

negative terminal bypassing the BMS: it will run unprotected, and the BMS won't see its current.

7.4 Pre-charge

An inverter's input capacitors are discharged when you connect it, and for that first instant they act like a short circuit. The current surge reaches hundreds of amps within milliseconds. Consequences: a strong spark, pitted switch contacts, welded contacts, and sometimes the BMS tripping on overcurrent.

The fix is simple: feed power through a resistor before closing the main switch.

- A 50-100 Ohm resistor rated 5-10 W, in series, for 2-5 seconds. The capacitors charge up, and there's no spark on the main connection. The value is chosen so the time constant $R \times C$ fits within those 2-5 seconds: for a typical inverter input capacitance of 10-20 mF, a 50 Ohm resistor gives a time constant of 0.5-1 s, so full charge in 2-5 s. A smaller resistance (10 Ohm) lets through too big a surge and becomes a spark source itself; a larger one (over 200 Ohm) charges the capacitors so slowly that someone gives up waiting and closes the switch prematurely.
- Implementation: a separate button with a resistor wired in parallel with the main switch, or simply touching a wire with a resistor in line before closing the switch.
- Ready-made switches with a pre-charge function also exist and are convenient.
- Sign that pre-charge is needed: a noticeable bright spark with a snap every time you connect the inverter. Sign of a problem, not a missing pre-charge: a spark that doesn't stop. That's a short circuit, and it needs to be tracked down, not suppressed with a resistor.

7.5 Grounding

- The metal cabinet or enclosure is bonded to the building's protective ground.
 - The pack's negative **isn't** bonded to the enclosure or to ground, unless the inverter's documentation explicitly requires it. A floating DC circuit is safer in a residential installation: a single fault to the case doesn't create a current path.
 - Ground the inverter strictly per its manual: on hybrid inverters with grid-switching, the neutral-to-ground bonding scheme matters for the protection to work correctly.
 - Don't use water pipes or rebar as a ground.
-

8. Winter

A Ukrainian winter is both the main reason this pack gets built and the main threat to it. This chapter covers how to get through it without losing capacity.

8.1 What Cold Actually Does

Charging below 0 C damages the cell. The mechanism is described in section 5.4: lithium plates onto the anode as a metal layer instead of intercalating into its structure. The damage accumulates, it's irreversible, and it's invisible from outside. This is the one absolute "don't" in all of winter operation. Zero is the physical limit, and the BMS threshold is set above it, at 5 C with release at 10 C: the sensor has error, and there's always a gradient of a few degrees inside the enclosure.

Discharging in the cold is allowed and safe, but:

Cell temperature	Available capacity	Charging
+25 C	100%	Allowed
+10 C	approximately 95%	Allowed
0 C	approximately 85%	Forbidden
-10 C	approximately 70-80%	Forbidden
-20 C	approximately 60-70%	Forbidden

Capacity loss in the cold is temporary: it fully returns once the pack warms up. Don't mistake reduced winter runtime for pack degradation.

Internal resistance roughly doubles in the cold at -10 C versus +25 C. Practical consequence: voltage sags harder under load, and the BMS may trip on undervoltage sooner than expected. This is another reason not to set the UVP threshold too high.

8.2 The Cheapest Fix: Put the Pack Somewhere Warm

Before buying heaters, consider the simple option: a 51.2 V, 280 Ah pack is about 100 kg and roughly 40-60 liters in volume. That's a hallway closet, a pantry, under the stairs, a heated basement.

- A room at +10 C or above removes the whole winter problem entirely.
- An unheated but insulated balcony sharing a wall with the apartment typically holds 0 to +5 C even in a hard freeze, and that's already enough with a little supplemental heat.
- A garage, an outdoor cabinet, an uninsulated shed: these are scenarios that need active heating.

The pack itself gives off heat while operating (internal-resistance losses), and its large thermal mass changes temperature slowly: 100 kg of cells cools by a few degrees over a day, not an hour. That works in your favor.

8.3 Insulation

Insulation is cheaper and more reliable than heating: it doesn't consume energy and it can't fail.

- Extruded polystyrene (XPS), 20-30 mm, on every wall of the enclosure, including the floor and lid. The floor matters most: cold comes up from concrete.
- Don't set the pack directly on concrete. A wooden pallet or a layer of XPS underneath.
- Leave a gap in the insulation for the BMS, and especially for the inverter: the inverter runs hot and needs free airflow, don't insulate it along with the pack.
- Don't seal the enclosure airtight. Insulated but ventilated is the right combination.

8.4 Active Heating

When the pack has to sit in the cold:

Equipment. Silicone heating pads at 12 V or 24 V, 20-50 W per pad. A 16s pack typically needs 2-4 pads, 60-150 W total.

Placement. Pads under the pack and on the side faces of the end cells, not on top (heat rises on its own anyway). Through a thin layer of thermally conductive material, not directly against the cell's wrap, to avoid local hot spots.

Control. A thermostat with a sensor on a cell: switch on at +5 C, off at +12 C. That puts the pack a bit above the charge-lockout release threshold (10 C, section 5.4) so charging actually starts. This hysteresis keeps the system from clicking on and off every minute. Many BMS units have a heater control output; if yours does, that's the most convenient option, since the BMS already knows the cell temperature.

How the heater is powered is the real subtlety. Heating the pack from the pack itself in winter means discharging it in order to be allowed to charge. The correct scheme:

1. Grid power available: the heater runs from the grid (via a power supply), and the pack charges once it's warmed above 10 C.
2. No grid power: the heater is either off, or runs from the pack in a minimal mode (just enough to hold temperature above -10 C for discharge). There's nothing to charge from anyway, so maintaining +10 C serves no purpose.
3. Emergency low-SoC cutoff: if pack SoC falls below 20-30%, the heater shuts off completely. Better a cold pack than one discharged to zero.

Work through why that third point matters. A 100 W heater running for a full day with no grid draws $100 \times 24 = 2400 \text{ Wh}$. A 51.2 V, 280 Ah pack holds $51.2 \times 280 = 14,336 \text{ Wh}$, so the heater alone eats roughly 17% of the whole reserve per day, without powering anything useful. Two or three days of a blackout in a freeze, and the pack is discharged to zero by the heater alone. So in winter without grid power, the heater is either off or holding the bare minimum needed for discharge, not a comfortable +10 C.

Sequence when grid power returns after a winter blackout. Warm up first, then charge. If the BMS is configured correctly (section 5.4), it will do this on its own: it will block charging until the cells reach 10 C. If you skipped that setting, do it now, before the first freeze.

8.5 Winter Checklist

- Temperature sensors physically on the cells, readings verified.

- Lower charge limit of 5 C set and verified, lockout release at 10 C.
 - Insulation installed, floor isolated from concrete.
 - Heating (if fitted) verified with a real thermostat trip.
 - Heater power doesn't depend on the pack whenever grid power is available.
 - Terminals retorqued with the torque wrench (temperature swings loosen connections).
 - Pack charged to 100% before the season, delta checked.
-

9. Common Mistakes

Ten scenarios that repeat from build to build. For each: what people do, how it shows up, and what to do instead.

Mistake 1. Assembling Without Top Balancing

What people do. They receive cells reading 3.29-3.31 V, figure "they're already the same," assemble them in series, and charge.

Symptom. The pack charges to 60-85% and the BMS cuts off charging on one cell's overvoltage. That cell is at 3.65 V while the lowest is still at 3.30 V. Runtime is well below what was calculated.

Why. A 0.02 V difference on the flat part of the curve can mean up to 10% of capacity. "Same voltage" doesn't mean "same charge." Passive balancing (100 mA) can't close a gap like that in any reasonable time.

What to do. Break the series string, do a proper top balance per chapter 3. Once, and the problem is gone for years.

Mistake 2. Charging in the Cold

What people do. They put the pack in a garage or on a balcony without setting the BMS's low-temperature charge cutoff.

Symptom. None, at first. Everything works fine for the first few weeks. After one or two seasons, the pack holds noticeably less, internal resistance has climbed, and voltage sags harder under load.

Why. Lithium plating on the anode. Irreversible, accumulates with every episode.

What to do. Set the lower charge limit to 5 C (release at 10 C) in the BMS **before** the first freeze. Sensor on the coldest end cell, not in the air, not on the center cell. Ten minutes of work that saves the pack.

Mistake 3. Charging to 3.65 V Per Cell Every Day

What people do. They set the charger to 58.4 V for a 16s pack, "so it charges fully."

Symptom. The BMS cuts off charging at the end of nearly every cycle, sometimes several times. Delta between cells grows over the months. Capacity falls faster than it should.

Why. Less than 3% of capacity is packed between 3.45 and 3.65 V, yet that's exactly where the cell ages fastest. Living at the top all the time is the worst regime for cycle life.

What to do. Set 3.50-3.55 V per cell (56.0-56.8 V for 16s). A few percent of capacity lost, cycle life and trouble-free operation gained.

Mistake 4. Missing or Wrong Fuse

What people do. They rely on the BMS ("it protects against shorts anyway") or fit an automotive blade fuse or an AC household breaker.

Symptom. None until a fault. During the fault: the BMS's MOSFETs fail closed and won't open, or the fuse can't clear the arc, and instead of tripping you get sustained burning.

Why. The pack can deliver over 10,000 A. Protection needs a matching interrupt rating, and it has to be physical, not electronic.

What to do. Main fuse on the positive lead, within 15-20 cm of the pack terminal, sized by the 1.25 calculation, rounded up along the 40/60/100/125/150/200/250 A series. Type by system voltage: for 12 and 24 V, MRBF works (or Class T), **for 51.2 V, Class T only**. MRBF's interrupt rating drops with voltage: 10,000 A at 14 V, about 2,000 A at 58 V, meaning in a 16s system it no longer handles the pack's short-circuit current. Also verify the wire can handle the fuse's rating, not just the calculated current.

Mistake 5. Stripped Threads or an Oversized Bolt

What people do. They torque terminals "by feel" without a torque wrench, or grab bolts from an old parts bin without checking their length.

Symptom. Stripped threads: the terminal no longer holds torque, the joint runs hot, the cell is effectively unusable for a proper mount. Oversized bolt: the busbar looks tight, but the contact is actually weak, the terminal heats under load; in a bad case, the bolt reaches the internal element.

Why. The threads in an aluminum terminal don't forgive over-torquing. A bolt that's bottomed out gives the same "click" from a torque wrench as one properly seated.

What to do. Torque wrench, M6 = 4-6 Nm, M8 = 8-12 Nm, cross-checked against the cell's datasheet. The bolt's threaded section should engage the terminal 6-8 mm. Thread the bolt into the empty terminal (no busbar) first and confirm it doesn't bottom out.

Mistake 6. Using the BMS as a Switch

What people do. They power the system down through the BMS app, toggling charge or discharge, instead of using a physical switch.

Symptom. MOSFETs degrade from switching under load, resistance and heating in the switches climb over time. In the worst case, a switch welds shut, and the BMS loses its ability to protect.

Why. The BMS's power switches are built for rare emergency disconnects, not daily cycling. A protection component shouldn't double as a control.

What to do. A DC main switch rated for the required current, after the fuse. The BMS only disconnects on a fault.

Mistake 7. Wrong Wire Gauge or Soldered Lugs

What people do. They fit 16 mm² where 35 mm² is needed, or solder lugs instead of crimping. Often it's CCA cable (copper-clad aluminum) with an inflated marked cross-section.

Symptom. Wire and lugs noticeably warm or hot under load, a smell of hot insulation, discolored insulation near the lug, more voltage drop under load than expected.

Why. Heat output scales with the square of current, so "a slightly thinner wire" runs a lot more than "slightly" hotter at peak load. A soldered joint fails exactly when it overheats.

What to do. Run the $\text{peakW} / \text{V} \times 1.25$ calculation, gauge table 6.1, hydraulic crimp with a hexagonal die, copper only. After the first loaded cycle, check every connection by hand: none should be warmer than the others.

Mistake 8. A Pack Without Compression

What people do. They set the cells in a box, sometimes just strapped with plastic banding, treating compression plates as "optional tuning."

Symptom. After a few months the cells are noticeably bulged. Capacity falls faster than the rated cycle life implies. Once cells have already swollen, they can't be compressed back.

Why. A cell expands and contracts every cycle. Without external restraint, the electrode layers gradually delaminate and internal contact deteriorates.

What to do. Two rigid end plates, 4 rods, roughly 300 kgf of compression, spacers between cells. Done during assembly and never thought about again.

Mistake 9. A Mistake in the Balance Harness

What people do. They plug in the balance connector without checking the wire order with a multimeter, or connect it to a pack that's already under load, or leave the harness without fuses.

Symptom. Best case, the BMS shows impossible readings (a cell at 0 V, a cell at 6.6 V) and doesn't function. Worst case, the BMS's input circuitry burns out immediately, sometimes with smoke.

Why. Balance inputs are designed for a single cell's worth of difference. Swapped wires feed doubled or reversed voltage straight into the measurement circuits.

What to do. Connect strictly in order starting from B- upward, check the voltage between adjacent connector pins with a multimeter before inserting it (should read about 3.3 V per pair), fit 1-2 A fuses on every line, secure the harness away from the power run.

Mistake 10. Mixing Different Cells in One String

What people do. They replace damaged cells with cells from a different batch or manufacturer and put them in the same series string. Or they add a new cell to a pack that's been running for two years.

Symptom. The pack never balances stably: delta grows cycle over cycle, the same cell keeps "running off" high or low. Capacity is set by the weakest cell.

Why. Different real capacity and different internal resistance mean different fill rates. The balancer spends its time constantly re-correcting instead of maintaining.

What to do. Use cells from the same batch and similar age within one series string. If you have to mix, always run the capacity test (chapter 2) first and match cells so the capacity spread stays within 3-5%. Don't put an old cell into a new pack.

10. First Startup Checklist

Print this page. Check off items in pencil. Don't move to the next block until the current one is fully closed.

A. Before Assembly

- ☐ Every cell visually inspected: no bulging, wrap intact, threads clean
- ☐ Every cell's voltage measured and recorded; nothing below 2.0 V goes into the pack
- ☐ Voltage spread on arrival doesn't exceed 0.10 V
- ☐ Capacity verified (full test or simplified version); spread within 3-5%
- ☐ Top balancing completed: parallel, 3.65 V, held until current stops falling plus another 6-12 hours
- ☐ After balancing, voltage spread within 0.005-0.010 V
- ☐ Compression plates and rods ready, spacers in place between cells

B. Assembly

- ☐ Jewelry removed, tools insulated, safety glasses on, extinguisher nearby
- ☐ Each cell's polarity checked before fitting the busbar
- ☐ Total pack voltage matches the calculation (cell count x 3.42 V)
- ☐ Bolt length checked: 6-8 mm of thread engagement, doesn't bottom out
- ☐ All terminals torqued with a torque wrench: M6 = 4-6 Nm, M8 = 8-12 Nm
- ☐ Washer order correct: busbar, flat washer, spring washer, bolt
- ☐ Wire gauge from the table is at least the fuse rating
- ☐ Lugs crimped with a hydraulic press, pull test passed
- ☐ Heat-shrink installed, color coding in place

C. BMS

- ☐ Cell count (S) and chemistry (LFP) set correctly
- ☐ Pack capacity entered from the test result
- ☐ Cell thresholds: OVP 3.65 V / release 3.55 V, UVP 2.80 V / release 3.00 V
- ☐ Current thresholds calculated via $\text{peakW} / \text{V} \times 1.25$, delays long enough for inverter startup
- ☐ Lower charge limit 5 C set, release at 10 C
- ☐ Upper charge limit 50-55 C, discharge limit 60 C; lower discharge limit -20 C
- ☐ Balancing: start 3.40 V, delta 0.010 V

- ☐ Temperature sensors physically secured to the cells
- ☐ Balance harness checked pairwise with a multimeter before connecting
- ☐ 1-2 A fuses installed on the balance lines
- ☐ Settings saved and recorded (screenshot or paper log)

D. Protection and Switching

- ☐ Main fuse on the positive lead, no more than 20 cm from the pack terminal (Class T only for 51.2 V)
- ☐ Fuse rating from the calculation, rounded up along the 40/60/100/125/150/200/250 A series
- ☐ Fuse rating doesn't exceed the wire's allowable current
- ☐ DC main switch installed after the fuse
- ☐ Separate fuses on each branch (inverter, charger, small-load line)
- ☐ Pre-charge circuit provided
- ☐ Enclosure grounded, pack negative not bonded to the enclosure
- ☐ No load connected to the pack's negative bypassing the BMS

E. First Startup

- ☐ Polarity at the inverter's input checked with a multimeter **before** connecting
- ☐ Inverter connected through pre-charge, no spark when closing the switch
- ☐ BMS shows all cells, total voltage, and zero current
- ☐ Charger's final voltage set to 3.50-3.55 V per cell (not 3.65)
- ☐ Charge current within 0.2-0.5C
- ☐ First charge carried out under supervision, start to finish
- ☐ Delta doesn't exceed 0.020 V at the end of charge
- ☐ All terminals, lugs, and busbars checked for heat under load
- ☐ One full discharge cycle completed under observation: no cell falls off ahead of the others
- ☐ After a week of operation, all terminals retorqued with the torque wrench

F. Record and Save

- ☐ Cell table: number, voltage on arrival, measured capacity, internal resistance
- ☐ Screenshot of BMS settings
- ☐ Wiring diagram with fuse ratings and wire gauges
- ☐ Date of commissioning

Appendix A. System Sizing Formulas

These are the formulas the calculator on the website uses. They're given here so you can check the result by hand.

1. Continuous power.

$$\text{contW} = \text{sum}(\text{power_i} \times \text{count_i})$$

Add up the rated power of everything running at the same time.

2. Peak power.

$$\text{peakW} = \text{contW} + \text{max}(\text{startup_i} - \text{rated_i})$$

Take the largest single startup increment, not the sum of every startup surge: two motors practically never start in the same millisecond.

3. Required energy.

$$\text{requiredWh} = \text{contW} \times \text{hours} / 0.8 / 0.88$$

- **0.8 (DoD, depth of discharge).** The pack isn't discharged to zero: 80% is the tradeoff between available energy and cycle life.
- **0.88 (inverter efficiency).** Typical efficiency for a good pure-sine inverter at medium load. The losses go to heat.

Example: 500 W for 8 hours is $500 \times 8 / 0.8 / 0.88 = 5682 \text{ Wh}$.

4. Choosing the pack voltage.

Try in order: 12.8 V (only if contW doesn't exceed 600 W), then 25.6 V (contW up to 1500 W), then 51.2 V. Take the first option where $\text{Ah} = \text{requiredWh} / \text{V}$ doesn't exceed 314 Ah (the largest common cell). If none fits, go with 51.2 V and parallel strings: $\text{number of strings} = \text{round up}(\text{Ah} / 314)$.

For the example above: 5682 Wh at 500 W continuous power. 12.8 V works on power, but $5682 / 12.8 = 444 \text{ Ah}$, which is more than 314. Go with 25.6 V: $5682 / 25.6 = 222 \text{ Ah}$. That fits, so 8s with 280 Ah cells.

5. BMS current.

$$\text{BMS current} \geq \text{peakW} / \text{V} \times 1.25$$

6. Inverter power.

$$\text{inverter power} \geq \text{max}(\text{contW} \times 1.3, \text{peakW})$$

The inverter needs both to carry the continuous load with a 30% margin and to swallow the peak.

7. Wire and fuse.

$$\text{current} \geq \text{peakW} / \text{V} \times 1.25$$

Round the fuse up along the series 40 / 60 / 100 / 125 / 150 / 200 / 250 A, and **the wire is chosen from the fuse rating**, not the calculated current: from table 6.1 (30 A / 6 mm², 50 A / 10 mm², 80 A / 16 mm², 100 A / 25 mm², 150 A / 35 mm², 200 A / 50 mm²), take the gauge whose continuous rating is at least the fuse rating.

If the inverter will run continuously at its full rated power, first calculate the real current with efficiency accounted for: $W / 0.88 / V$, then, as in step 5, multiply by the 1.25 margin, and only then choose the wire and fuse (section 5.3).

Appendix B. Reference Values

Value	Figure
LiFePO4 nominal cell voltage	3.2 V
Maximum charge voltage	3.65 V
Recommended working upper limit	3.50-3.55 V
Resting voltage at 100% SoC	approximately 3.40-3.45 V
Resting voltage at 50% SoC	3.28-3.32 V
Recommended lower limit	2.80 V
Absolute minimum	2.50 V
Threshold below which a cell isn't recovered	2.00 V
Storage voltage (approximately 50% SoC)	3.28-3.32 V
4s pack	12.8 V nominal
8s pack	25.6 V nominal
16s pack	51.2 V nominal
Recommended charge current	0.2-0.5C
End-of-charge (taper) current, single cell	0.02-0.05C
End-of-charge current when balancing in parallel	2-4 A for the whole assembly
Charge temperature	+5...+50 C (physical limit 0 C)
Discharge temperature	-20...+60 C
Storage temperature	-20...+45 C
Cycle life at 80% DoD	approximately 3000-6000 cycles
Inverter efficiency for calculations	0.88
Working depth of discharge (DoD)	0.8
Margin for BMS, wire, and fuse	1.25

VERSTAT Power. This guide is provided as reference material. Always cross-check against the documentation for your specific equipment.