Battery Management Systems and Protection Circuits

A Battery Management System (BMS) is the electronic circuit that protects lithium cells from conditions that cause permanent damage or fire. Understanding what a BMS does - and detecting when one has failed - is essential for maintaining reliable solar-powered LoRa nodes.

What a BMS Does

A BMS monitors cell voltage, current, and temperature in real time and opens a protection MOSFET to disconnect the battery when it detects an out-of-bounds condition. The primary protection functions are:

Protection Function	Trigger Condition	Consequence if Missing
Overvoltage protection (OVP)	Cell voltage > 3.65 V (LiFePO4) or 4.25 V (LiPo)	Electrolyte decomposition, capacity fade, fire (LiPo)
Undervoltage protection (UVP)	Cell voltage < 2.5 V (LiFePO4) or 3.0 V (LiPo)	Copper dissolution, cell permanently damaged (cannot accept charge)
Overcurrent protection (OCP)	Discharge current > rated maximum (the trip point is set per the cell's rating; 1C - 3C continuous is illustrative, not universal — some cells rate higher)	Cell heating, electrolyte venting, cable fire
Short-circuit protection (SCP)	Near-instantaneous high current spike	Cell fire, explosion
Over-temperature protection (OTP)	Cell temp > rated cutoff (commonly ~60 - 65 °C on charge; varies by module, and some BMS modules omit temperature sensing entirely)	Accelerated aging, thermal runaway risk in LiPo
Low-temperature charge inhibit	Cell temp < 0 °C	Lithium plating on anode, internal shorts, reduced cycle life
Cell balancing (multi-cell packs only)	Voltage delta between cells > 20 - 50 mV	Weakest cell reaches cutoff early, reducing pack capacity

Why 18650 Cells Always Need a BMS

Bare cylindrical 18650 cells - including popular Samsung 30Q, LG HG2, and Panasonic NCR18650B - have no built-in protection. They are raw electrochemical cells. Connecting multiple 18650 cells in series or parallel without a BMS creates a serious hazard. If one cell has slightly lower capacity (as all real cells do), it will be over-discharged before the others during a deep cycle, permanently damaging it. On charge, it will be over-charged, potentially causing thermal runaway.

Even for a single 18650 used to power an ESP32 node via a TP4056 charging module, the TP4056 only protects during charging — it does not protect the cell from over-discharge (UVP) or over-current (OCP) when the node is drawing power. The cheapest safe fix is to buy an 18650 holder module that already includes a protection chip (look for "DW01A + FS8205A" or "with protection board" in the listing). A DW01A + FS8205A dual-MOSFET protection IC circuit (commonly integrated into 18650 holder modules sold on AliExpress) is the minimum acceptable protection for bare-cell usage.

Built-in BMS on LiPo Pouch Cells

Consumer LiPo pouch cells sold for drones, hobby use, and electronics (Adafruit, SparkFun, EEMB, Polymer Lithium) typically include a small protection circuit module (PCM/PCB) laminated between the cell and the outer casing. This PCM provides OVP, UVP, and OCP - but usually *not* balancing (since these are single-cell packs) and rarely temperature protection. The PCM is designed for the specific cell and chemistry, with cutoff voltages pre-set at the factory.

When purchasing LiPo cells, verify the datasheet explicitly states "with protection circuit" or "PCM included." Bare (unprotected) LiPo cells are also sold, typically labeled "battery" without "protection" in the listing. Bare cells require an external BMS.

LiFePO4 Packs - BMS Inclusion Varies

LiFePO4 prismatic cells (EVE, CALB, Winston) are sold bare. DIY packs require a separate BMS module. Common choices (prices approximate, as of 2026-06-08 — verify against the manufacturer's current product page):

BMS Module	Cell Configuration	Continuous Current	Features	Approximate Cost
Daly 4S 40A BMS	4S LiFePO4 (12.8 V)	40 A	OVP, UVP, OCP, balancing, UART	$8 - 12
JBD/Overkill Solar 4S 60A	4S LiFePO4	60 A	Bluetooth app, UART, active balancing option	$20 - 35
Ant BMS 4S 100A	4S LiFePO4	100 A	CAN bus, SOC display, temp sensor	$30 - 50
Texas Instruments BQ76920	3S - 5S Li-Ion/LiFePO4	Configurable	IC-level, requires MCU interface; used in custom designs	$4 - 8 (IC only)

Packaged LiFePO4 batteries from Bioenno, Dakota Lithium, and Battle Born include an integrated BMS that protects the cells. The integrated BMS does **not** replace external wiring protection: you still need an inline fuse on the battery-positive lead close to the terminal to protect the cable between the battery and the load from a short circuit, and you must use a correct charger and charge voltage.

Cell Balancing in Multi-Cell Packs

In a series-connected pack, cells must stay at nearly equal voltage. Over hundreds of cycles, manufacturing variations cause cells to drift apart. A balancing circuit periodically bleeds charge from higher-voltage cells (passive balancing) or shuttles charge from high to low cells (active balancing) to keep the pack uniform.

Passive balancing is simpler and more common. The BMS bleeds excess energy as heat through a resistor. Balance current is typically 50 - 200 mA, which is adequate for slowly drifting cells in solar nodes.

Active balancing (capacitor or inductor-based charge shuttling) is more efficient but more expensive. For LoRa nodes with <100 Ah packs, passive balancing from a Daly or JBD BMS is entirely sufficient.

Signs of BMS Failure

- **Node shuts down at higher-than-expected battery voltage:** The UVP threshold may have drifted, or a cell has developed high internal resistance (voltage sag trips protection prematurely).

- **Battery refuses to charge after deep discharge:** Some BMS modules enter a "sleep" or "protection" state when UVP fires and require charge current to be applied to wake up. The charger's output voltage must exceed the battery voltage, or it won't wake the BMS. Use a lithium charger with a 0 V / wake-activation feature, or a current-limited supply set just above the pack's nominal voltage. Do **not** bypass the BMS or apply voltage to a pack of unknown cell condition — a cell sitting below ~2.0 V may be damaged and unsafe to recharge. Always follow the battery manufacturer's reset procedure, and verify polarity before connecting.
- **Pack becomes warm during light loads:** A shorted MOSFET in the BMS or a shorted cell can cause continuous current flow and heat generation.
- **Intermittent disconnection under load:** Worn BMS MOSFETs or a marginal OCP threshold. Measure the current draw and compare to the BMS rating.
- **Cell voltages diverge by >100 mV at full charge:** Balancing circuit has failed or a cell has degraded. The pack capacity is effectively limited to the weakest cell.

Parallel Cell Balancing Considerations

When connecting cells in parallel (e.g., 2P or 4P for higher capacity), cells must be at the same voltage before paralleling. Connecting cells with a voltage difference of >100 mV causes a large equalisation current spike that can damage cells and weld connectors. Always charge all cells to the same voltage (within 10 mV) before forming a parallel group.

Parallel cells naturally balance themselves during use because they share the same terminal voltage. Balancing circuits are only required for series-connected groups in a larger series-parallel pack (e.g., 4S2P). The BMS sees each parallel group as one "cell" and balances between groups.

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