LiFePO4 Battery Cell Balancing

Passive vs Active Balancing Systems

Why Regular Full Charge & Deep Discharge Cycles Are Critical

and How Sigenergy SigenStor Active Balancing Eliminates This Burden

Technical Reference Document

Prepared: July 2026

1. Introduction

Lithium Iron Phosphate (LiFePO4 or LFP) batteries have become the dominant chemistry for residential and commercial energy storage systems due to their exceptional safety, long cycle life, and stable chemistry. However, the very characteristic that makes LFP cells so reliable — their remarkably flat voltage discharge curve — also creates a significant challenge for battery management: cell balancing.

This document explains why owners of standard LiFePO4 battery systems with passive balancing must periodically perform full charge and deep discharge cycles to maintain cell balance, and how the Sigenergy SigenStor system's active balancing architecture eliminates this maintenance burden entirely.

2. The LiFePO4 Flat Voltage Curve Challenge

Understanding why balancing is so difficult in LFP batteries requires understanding their unique voltage behaviour.

2.1 The Flat Voltage Plateau

A single LiFePO4 cell has a nominal voltage of approximately 3.2–3.3 V. Unlike NMC or NCA lithium chemistries, the LFP cell exhibits an extremely flat open-circuit voltage (OCV) curve across the majority of its state of charge (SOC) range. Between roughly 20% and 80% SOC, the cell voltage changes by only 50–100 mV, hovering in a narrow band of approximately 3.20 V to 3.30 V.

This means that a cell at 30% SOC and a cell at 70% SOC may display virtually identical terminal voltages — often within 20–30 mV of each other. For a Battery Management System (BMS), which relies on voltage readings to assess cell state, this flat curve makes it effectively impossible to detect imbalance during normal operating conditions.

2.2 Where Voltage Differences Become Visible

Cell voltage differences only become measurable and actionable at the two extremes of the SOC range:

- Top of charge (above approximately 3.45 V per cell): As cells approach full charge, the voltage curve steepens sharply, and even small SOC differences produce measurable voltage gaps.
- Bottom of discharge (below approximately 3.0 V per cell): Similarly, as cells approach depletion, the voltage curve drops steeply, revealing which cells have less remaining capacity.

This characteristic is the fundamental reason why passive BMS systems can only perform meaningful balancing at the very top or very bottom of the charge curve, and why users must deliberately cycle their batteries to these extremes.

3. Passive Balancing — How It Works and Its Limitations

3.1 The Mechanism

Passive balancing, also known as dissipative or bleed balancing, is the most common cell balancing method found in budget and mid-range BMS modules. The mechanism is straightforward: when any cell in a series string reaches a set voltage threshold (typically 3.55–3.65 V for LFP), a small shunt resistor is switched across that cell to bleed away excess charge as heat. This allows the lower-voltage cells to continue charging and "catch up" to the others.

The typical passive balancing current is deliberately small — usually between 30 mA and 200 mA — to avoid excessive heat generation. This means that passive balancing is inherently slow. A significant imbalance of 100 mV or more can take many charge cycles to correct. For large-capacity cells of 200 Ah or more, passive balancing currents are far too small to correct meaningful capacity differences in a reasonable timeframe.

3.2 Top Balancing — Why You Must Charge to 100%

Top balancing is the process of equalising all cells at their fully charged voltage. For passive BMS systems, this is the primary balancing mechanism, and it only activates near the top of the charge curve — typically when cell voltage exceeds 3.45–3.55 V. This is the only region where the BMS can reliably detect voltage differences between cells.

If a battery system is routinely operated within a partial SOC window (for example, 30–80%), the passive BMS never encounters the steep portion of the voltage curve. As a result, the balancer never triggers, and cell imbalances accumulate silently over weeks and months. Periodic full charges — allowing the battery to reach 100% SOC — are therefore essential to trigger the top balancing function and allow the BMS to correct any drift between cells.

Recommended practice: Most manufacturers and battery specialists recommend performing a full charge cycle at least once every one to three months to allow the BMS to recalibrate its SOC estimation and balance cell voltages.

3.3 Bottom Balancing — Why You Must Discharge to 20%

Bottom balancing is the complementary process of equalising all cells at the low end of their discharge range. While the BMS itself does not typically perform active bottom balancing, regularly discharging the battery to a low SOC (approximately 20% or below 3.0 V per cell) serves two critical purposes:

- SOC Recalibration: The BMS uses the known voltage-to-SOC relationship at the steep lower portion of the curve to recalibrate its internal SOC counter. Without this reference point, the BMS's coulomb counting can accumulate errors over time, leading to inaccurate capacity readings.
- Exposing Hidden Imbalance: Cells with lower actual capacity will reach their discharge cut-off voltage earlier than stronger cells. By reaching the low end of the SOC range, the system reveals which cells are weaker and allows the BMS to adjust its calibration accordingly. If the battery is never discharged below 50%, these capacity differences remain invisible.

In a system using only passive balancing, the combination of periodic full charges (top balancing trigger) and periodic deep discharges (bottom calibration reference) is the only way to maintain long-term cell health and accurate SOC reporting.

3.4 Limitations of Passive Balancing

- Energy waste: All excess energy from higher-voltage cells is dissipated as heat through resistors, reducing overall system efficiency.
- Thermal stress: The heat generated by passive balancing adds to the battery pack's thermal load. In warm environments or enclosed installations, this can accelerate electrolyte decomposition and SEI layer growth, contributing to premature aging.
- Slow correction: With typical currents of 50–200 mA, correcting a significant imbalance in a large-capacity pack can take dozens of charge cycles.
- User dependence: The system relies entirely on the owner remembering to perform maintenance cycles. Failure to do so leads to progressive cell drift, reduced usable capacity, and potentially premature BMS shutdown events.
- No mid-range detection: Between 20% and 80% SOC, the BMS is effectively blind to cell imbalance, meaning problems can grow undetected for long periods.

4. Active Balancing — The Superior Approach

4.1 The Mechanism

Active balancing, also known as redistributive or non-dissipative balancing, takes a fundamentally different approach. Instead of wasting excess energy as heat, active balancing systems use DC-DC converter circuits, inductor shuttles, or capacitor-based charge-transfer circuits to move energy from higher-voltage (stronger) cells to lower-voltage (weaker) cells.

This energy transfer is bidirectional and far more efficient than passive dissipation. Typical active balancing systems operate at 1–5 A or more, which is 10 to 100 times faster than a passive balancer. Critically, active balancing can operate continuously — not just at the top of charge, but also during discharge, idle periods, and across the entire SOC range.

4.2 Advantages Over Passive Balancing

- Energy efficiency: Energy is transferred rather than wasted, preserving overall system capacity and reducing electricity costs.
- Continuous operation: Active balancing monitors and corrects cell imbalance 24/7, regardless of whether the battery is charging, discharging, or sitting idle. This overcomes the flat voltage curve problem entirely.
- Faster correction: Balancing currents of 1–5 A can resolve significant imbalances in hours rather than weeks or months.
- Reduced thermal stress: Because energy is transferred rather than dissipated, active balancing generates far less heat. Studies indicate active balancing produces roughly 2.3 W of heat in a 16-cell pack compared to 46 W for passive balancing — a 95% reduction.

- No user maintenance: There is no need for the owner to perform deliberate full charge or deep discharge cycles for balancing purposes. The system self-manages.
- Longer effective lifespan: By maintaining more uniform cell wear and preventing capacity-limiting drift, active balancing extends the usable life of the entire battery pack.

5. Sigenergy SigenStor — Active Balancing in Practice

5.1 System Overview

The Sigenergy SigenStor is a modular, all-in-one residential and commercial energy storage solution that integrates five core components into a single platform: a hybrid solar inverter, battery power conversion system (PCS), $LiFePO_4$ battery packs, an energy management system (EMS), and an optional 25 kW EV DC charger. The system uses LFP cells rated for over 6,000 full charge-discharge cycles (with some configurations achieving 10,000+), and carries a warranty of up to 15 years with performance guarantees of minimum 70% capacity retention.

5.2 DC-DC Optimiser per Battery Pack

What sets the SigenStor apart from conventional battery systems is its inclusion of a dedicated DC-DC optimiser in each battery pack. This optimiser enables true active balancing at the pack level. Rather than treating all battery packs as a single undifferentiated string — where the weakest pack limits the entire system — each pack is individually managed and optimised.

This architecture eliminates the "cask effect" (also known as the "barrel effect"), where the weakest cell or pack determines the total system capacity. With per-pack optimisation, each battery module contributes its full available capacity, regardless of age, SOC, or state of health (SOH).

5.3 Mixed Battery Support

One of the most significant practical advantages of Sigenergy's active balancing architecture is its support for mixed battery configurations. The DC-DC optimiser allows users to connect battery packs of different ages, capacities, SOH levels, and even from different cell vendors in parallel. This is impossible with passive balancing systems, which require all packs in a string to be closely matched.

This capability has major implications for system longevity and cost of ownership. When a single pack degrades or fails in a conventional system, the entire battery bank may need replacement to maintain balance. With SigenStor, a degraded pack can be supplemented or replaced with a new one without disrupting the remaining system.

5.4 AI-Driven Battery Management

The SigenStor's BMS leverages AI and machine learning through the mySigen cloud platform to continuously optimise charge and discharge patterns. The active balancing function eliminates the need for regular SOC calibration cycles, and the AI-assisted energy planning further enhances efficiency by adapting to the household's energy consumption patterns, solar generation profile, and utility tariff structures.

5.5 No Maintenance Cycling Required

Because the active balancing system operates continuously across the full SOC range, SigenStor owners are freed from the requirement to periodically charge to 100% or discharge to 20% for balancing purposes. The system autonomously maintains cell equalisation regardless of how the battery is used day to day. This is a fundamental operational advantage over passively balanced systems, particularly for households that may use their battery within a partial SOC window for grid arbitrage or time-of-use optimisation.

6. Side-by-Side Comparison

The following table summarises the key differences between passive balancing as found in standard LiFePO4 battery systems and the active balancing approach used by the Sigenergy SigenStor:

Feature	Passive Balancing (Standard LiFePO4)	Active Balancing (Sigenergy SigenStor)
Balancing Method	Dissipates excess energy as heat via resistors	Transfers energy between cells via DC-DC converters
When Balancing Occurs	Only near top of charge (above ~3.45 V/cell)	Continuously — during charge, discharge, and idle
Balancing Current	30–200 mA (very slow)	1–5 A or higher (fast correction)
Energy Efficiency	Low — energy is wasted as heat	High — energy is redistributed, not lost
Thermal Impact	Generates heat; risk in warm environments	Minimal heat generation
User Maintenance Required	Periodic full charge and deep discharge cycles needed	No SOC calibration or cycling required
Voltage Curve Detection	Cannot detect imbalance in flat 20–80% SOC range	High-precision chips detect imbalance at any SOC
Mixed Battery Support	Not possible — all packs must match	Supports mixed old/new packs and capacities
Capacity Utilisation	Weakest cell limits the pack	Each pack optimised independently
Cycle Life Impact	Cell drift degrades capacity over time	Uniform wear extends total cycle life
SOC Calibration	Requires periodic full charge/discharge to recalibrate	Automatic and continuous via AI-driven BMS
Pack Scalability	Limited — all packs must be identical	Modular, stackable, mix-and-match

7. Practical Recommendations

7.1 For Owners of Passively Balanced LiFePO4 Systems

- Perform a full charge to 100% SOC at least once every one to three months to allow the BMS to trigger top balancing and recalibrate its SOC estimation.
- Allow the battery to discharge to approximately 20% SOC periodically to expose any hidden cell capacity differences and provide the BMS with a low-end voltage reference point.
- Monitor individual cell voltages through your BMS interface. A static deviation greater than 50 mV between cells is a warning sign; deviations exceeding 100 mV may require manual intervention.
- Avoid exclusively operating within a narrow SOC band (e.g., 40–70%) for extended periods, as this prevents the BMS from performing any balancing at all.
- Ensure your battery installation has adequate ventilation, as passive balancing generates additional heat during the charging phase.

7.2 For Prospective Battery System Buyers

- Consider active balancing as a key differentiator when evaluating battery systems. The long-term benefits of reduced maintenance, better capacity utilisation, and extended cycle life can significantly outweigh any higher upfront cost.
- Systems with per-pack DC-DC optimisation — such as the Sigenergy SigenStor — offer future-proofing through mixed battery support and modular expansion without compatibility constraints.
- Evaluate the total cost of ownership, including potential early capacity loss due to cell drift in passively balanced systems versus the maintained capacity of actively balanced systems over a 10–15 year period.

8. Conclusion

The flat voltage characteristic of LiFePO4 cells, while contributing to their operational stability, creates a genuine maintenance burden for systems using passive balancing. Regular full charge and deep discharge cycles are not optional luxuries — they are essential maintenance procedures required to keep the BMS functioning correctly and prevent progressive cell imbalance that reduces usable capacity and accelerates degradation.

Active balancing systems, such as those implemented in the Sigenergy SigenStor with its per-pack DC-DC optimisers, fundamentally resolve this challenge. By continuously monitoring and redistributing energy between cells across the entire SOC range, active balancing eliminates the need for maintenance cycling, maximises usable capacity, supports mixed battery configurations, and extends the effective service life of the entire installation.

For residential and commercial energy storage applications where long-term reliability, minimal maintenance, and maximum return on investment are priorities, an actively balanced system represents a meaningfully superior engineering approach.