

Introduction to battery management systems

Prof. Dr. Fabrizio Sossan

Slides compiled on: October 9, 2025

Anatomy of a grid-connected battery system (blackboard development)

Definition and purpose of a battery management system

A Battery Management System (BMS) is an embedded system that:

- Monitors the battery state, up to individual cells
- Protects the safety of the battery and battery application by detecting unsafe operating conditions and responding
- Keeps the battery in a correct operational state (cell balancing and thermal management)
- Informs the upper-level controller (typically the EMS) on the power limits
- Control contactors (open when the BESS is off) that deliver voltage to the battery terminal
- Implements a communication interface to communicate information to and receive commands from the outer world

Definition and purpose of a battery management system (cont'd)

A BMS is present in large batteries (or battery modules); not present in small ones.



RJ45 connectors are to communicate with the BMS.



Large cables are for power, small cables are for cell balancing.

BMS: monitoring requirements

Three quantities of interest (per cell):

- Voltage
- Current
- Temperature

Monitoring voltage

All cells' voltage are measured with the objective of:

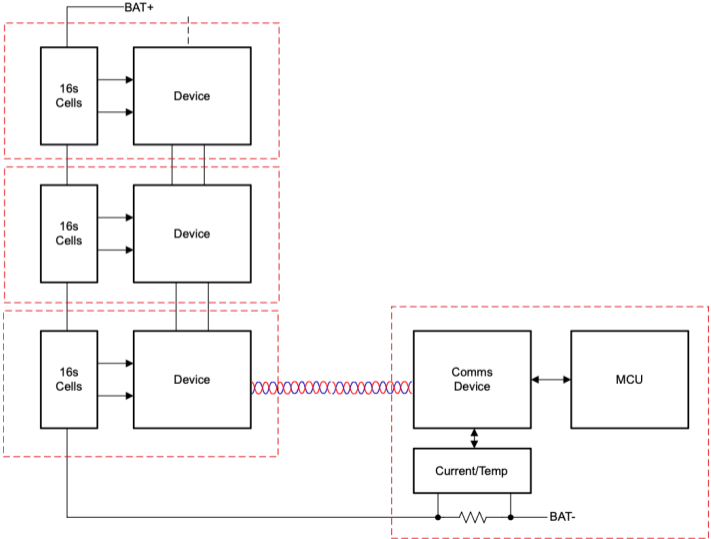
- Enabling correct balancing (and preventing overcharging, which might lead to thermal run-away)
- To provide information to various state estimation procedures (e.g., state-of-charge and state-of-health)

Voltage is measured by analog-to-digital converters (ADC), which converts the analog voltage into a numerical (digital), readable by software

ADCs are characterized by the resolution (number of bits), the number of channels, type of channels (single-ended or differential), sampling rate (samples per second)

Voltage measurements of the DC bus (i.e., resulting from connecting all the cells in series and parallel) are also performed.

Specialized chips for voltage monitoring (e.g., TI BQ79616)



Measuring current

Currents in cells are measured to enable monitoring of their performance

Solutions to measure current:

- Resistive shunt: the voltage drop on a resistance with known value is measured, and current retrieved by Ohm's law. A four-wire connection (two cables for power, and two for the voltage signal to measure) is required to avoid influences from the power cable's resistance. Pros: No offset currents. Cons: not isolated from the battery.
- Hall-effect sensor measures the magnetic field generated by the current and outputs a voltage. Pros: isolated from the battery. Cons: come with offset currents.
- Are current transformers an option?

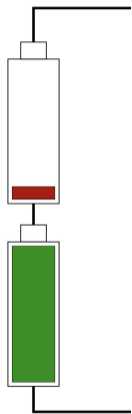
Measuring temperature

Temperature affects battery performance and is measured to ensure safe operations and feed estimation models and state-of-health models.

Options to measure temperatures:

- Thermistors (Negative Temperature Coefficient NTC / Positive Temperature Coefficient PTC)
- Thermocouple (output voltage as a function of the temperature)
- Specialized Ics with integrated signal treatment (e.g., LM35), flipside: larger footprint

Cell balancing



- Cell unbalancing occurs when the states of charge of the cells within a battery system diverge from each other.
- Unbalanced cells in a battery limits the energy storage capacity it can offer (consider the extreme example on the left, why the battery is stuck?)
- Cell balancing refers to keep the cell charge at the same level to avoid this shortcoming.

Causes of unbalances (and which aren't)

- Different current levels contributing to the Coulombic charge

$$\text{Charge}(t + 1) = \text{Charge}(0) + \frac{\Delta_T}{3600} \sum_{t=0}^t i(t)$$

(assuming unitary Coulombic efficiency), the current i “making it” to the charge is:

$$i(t) = i_{\text{cell}}(t) - i_{\text{self-discharge}}(t) - i_{\text{leakage}}(t).$$

- Different Coulombic efficiencies

They are not causes of imbalances:

- Differences of internal resistances
- Different energy capacities

Types of cell balancing

There are two:

- Passive. As simple as adding a resistance and a switch in series to each cell.
- Active. Achieve active energy transfer between unbalanced cells. Realized by way of power-electronics circuits embedded at the cell level.

Battery ageing

Ageing

Ageing is manifested by two main effects:

- Capacity fading (loss of Ah compared to original conditions). Typically due to loss of active material (Lithium).
- Increase of the internal resistance. Due to growth of materials on the battery electrodes and degradation of the electrolyte.

Ageing is due to a wide variety of parasitic electrochemical reactions happening within the cells, and degradation of the battery electrodes and electrolytes. For example, storing Lithium-ions cells at high state of charge (voltage) causes oxidation of the electrolytes, resulting in capacity loss. High temperature typically typically accelerates ageing due to increased chemical rates (Arrhenius equation).

Lithium plating

Lithium-ions battery rely in the principle of positively charged Lithium-ions intercalating in the latex structure of the electrodes.

If these ions, instead of being “intercalated”, are “deposited”, lithium starts to grow on the electrode.

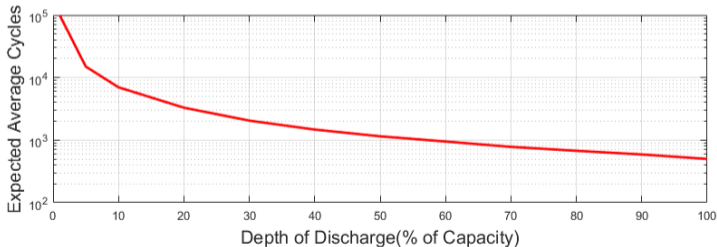
This is called lithium plating. It causes a loss of active material and might cause internal short-circuits.

Ageing: calendar and cycle ageing

Two types of degradation:

- Calendar ageing depend on calendar life.
- Cycle ageing depends on the use.

Example of cycle life [GL65]: Up to 7000 cycles* (At 80% DoD), Up to 4000 cycles* (At 100% DoD), where the footnote (*) says: Predicted. Dependent on specific charge conditions.



Example of cell specs: [Leclanche GL65](#), [Leclanche LT34](#)

Battery end of life

A battery is considered at its end of life once it has reached 80% of the original energy capacity. Below this limit, it was generally found that the battery behaviour becomes difficult to predict and degradation might happen at a much faster rate.

Second-life battery applications refer to re-purposing a used battery from the first application it was designed for to a second where the remaining energy capacity is deemed sufficient. (e.g., EV → stationary battery for grid applications).

Recycling processes for lithium-ions battery can recover approx. 25% to 96% of the raw materials of a lithium-ion battery cell.

Battery failures

Classification of causes of battery failures

- Mechanical abuse
- Electrical abuse
- Thermal abuse

Thermal runaway in lithium-ions batteries

Thermal runaway is the activation of chain exothermic reactions within a cell. Heat generates at a faster rate than it can be dissipated, leading to a rapid increase of the cell temperature.

With temperature rates of $\approx +20^{\circ}$ C per minute, thermal runaway is likely to occur.

Effects of thermal runaway:

- Separation of the electrolyte into volatile flammable compounds
- Rise of the cell's internal pressure
- Swelling
- Rupture of the envelope
- Venting
- Fire