



Introduction to BMS

Course 3 | Module 1

Agenda

1. Cell Fundamentals & Operating Principles
2. Battery Basics
3. What is a BMS and its components
4. BMS Topologies



Agenda

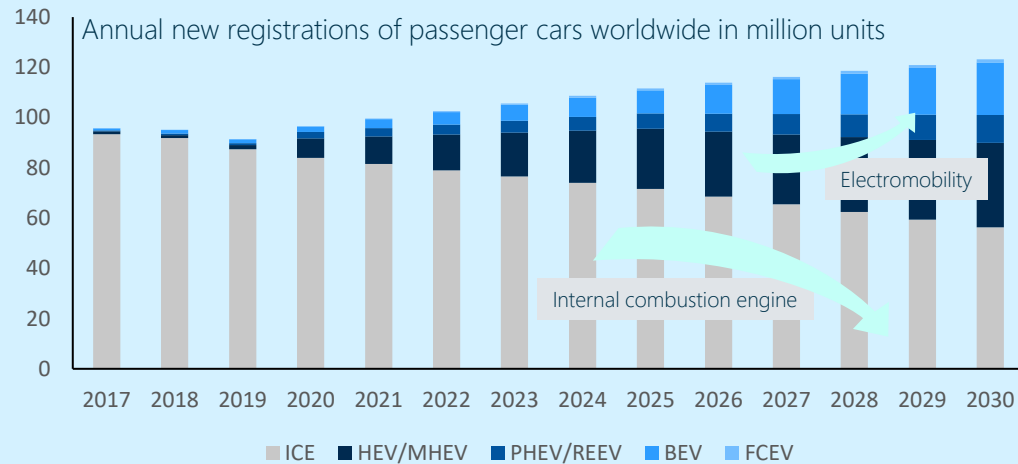
1. Cell Fundamentals & Operating Principles

- 2. Battery Basics
- 3. What is a BMS and its components
- 4. BMS Topologies



We are on the verge of change

The share of electromobility will increase.

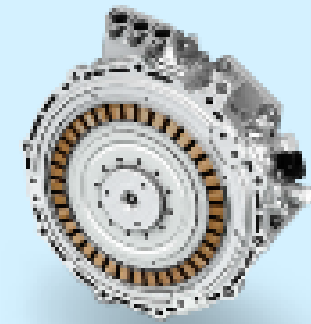


In the year 2030, 50% electric mobility is predicted.

Up to 95% fewer parts are expected.



vs.



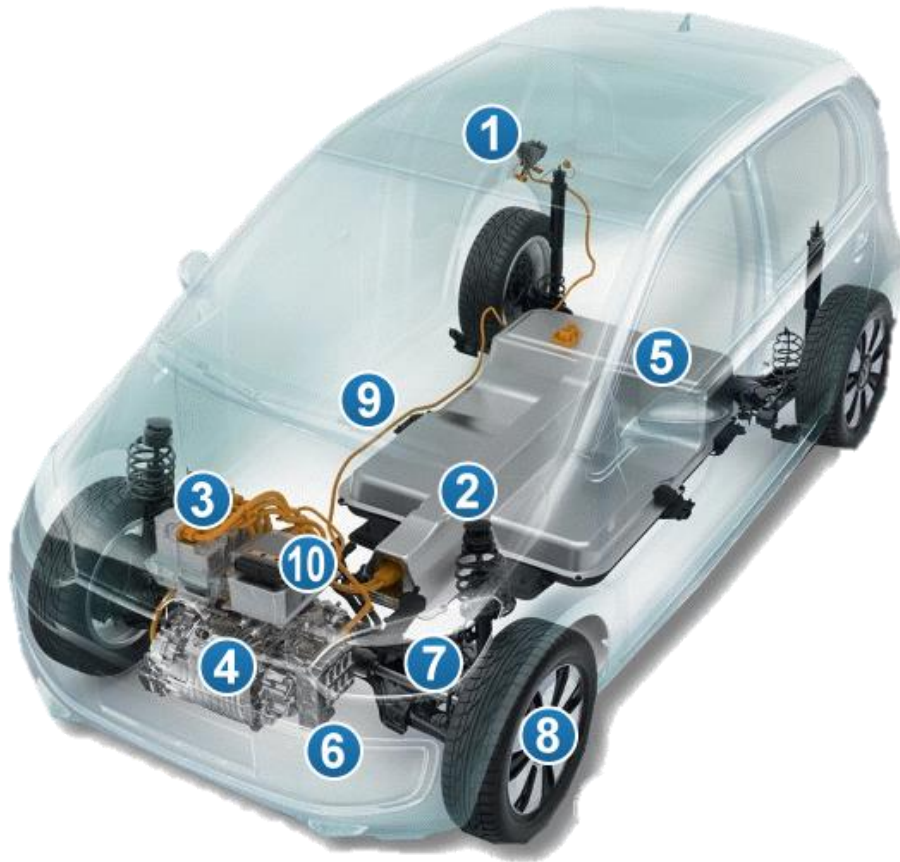
Internal combustion engine:
approx. 1.400 parts

Electric motor:
approx. 50 parts

In total, over 2000 parts will be eliminated from the system.

How can this change be addressed in your company?

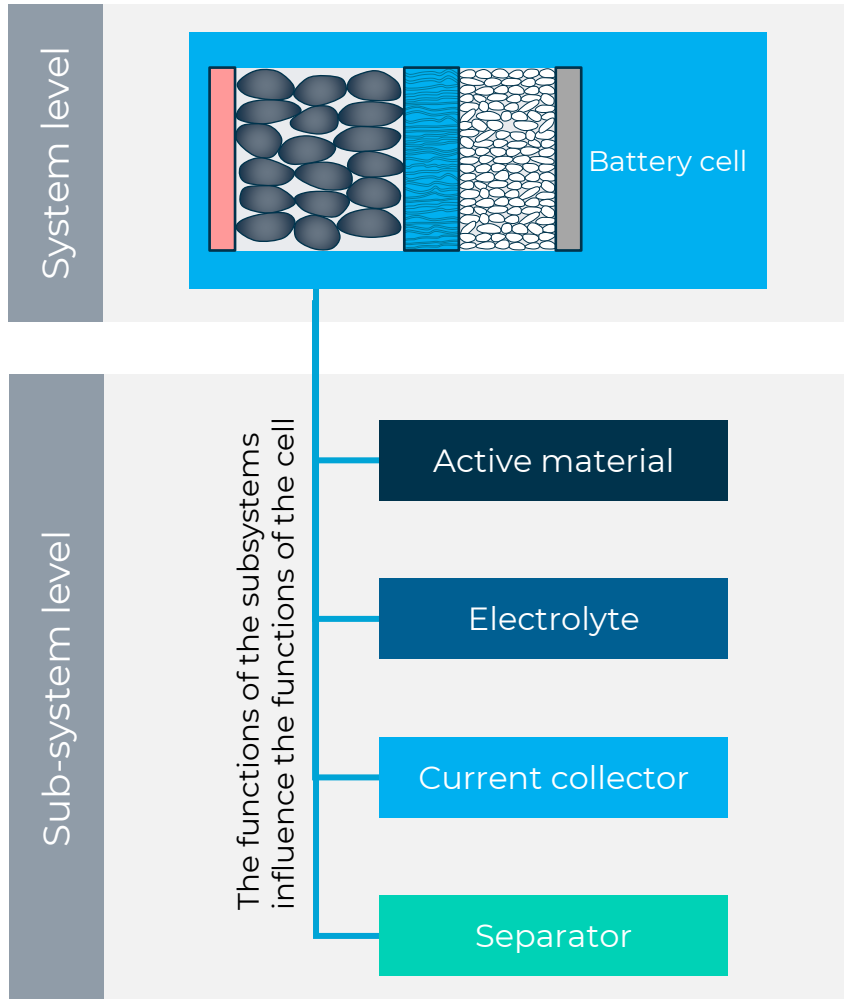
Basic Structure Of An Electric Vehicle



Source: Volkswagen

- 1 Charging connection
- 2 High-voltage (lithium-ion) battery
- 3 Power electronics
- 4 Electric motor
- 5 Battery management system
- 6 Engine compartment (drive & auxiliary units)
- 7 ABS & ESP
- 8 Recuperative braking system
- 9 High-voltage cables
- 10 Low-voltage battery (12 V, DC converter)

Any battery cell consists of four components



Core function of a battery cell

- + Reversible storage of electrical energy in chemical form

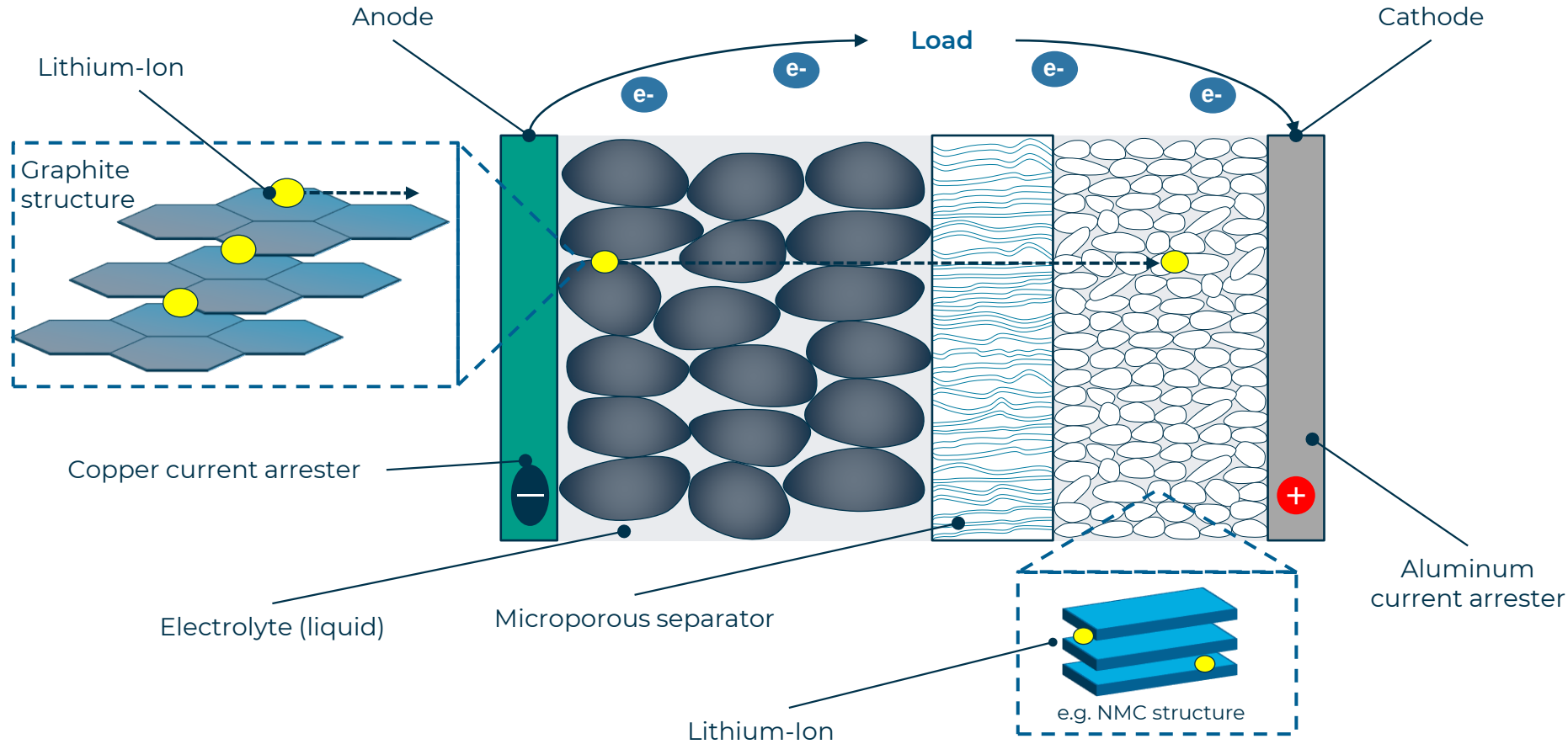
Any lithium-ion cell, regardless of its cell type, consists of four components:

Active material	Electrolyte	Current collector	Separator
+ Task: Storage	+ Task: Transport	+ Task: Transport	+ Task: Electrical isolation
+ Place of chemical reaction	+ Enhancing ionic conductivity	+ Enhancing the electronic conductivity	+ Allows exchange of ions, but not electrons
+ Cathode: NMC	+ Electrical insulator	+ Anode side: Copper	+ Polyethylene (PE)
+ Anode: Graphite	+ Consists of lithium salt (e.g. LiPF_6) and organic solvent (e.g. DMC)	+ Cathode side: Aluminum	+ Polypropylene (PP)
		+ Thicknesses: 8-20 μm	+ Thicknesses: 15-30 μm

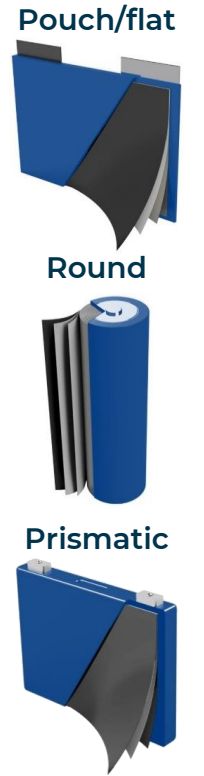
Structure Of A Lithium-ion Cell

Section through the cell

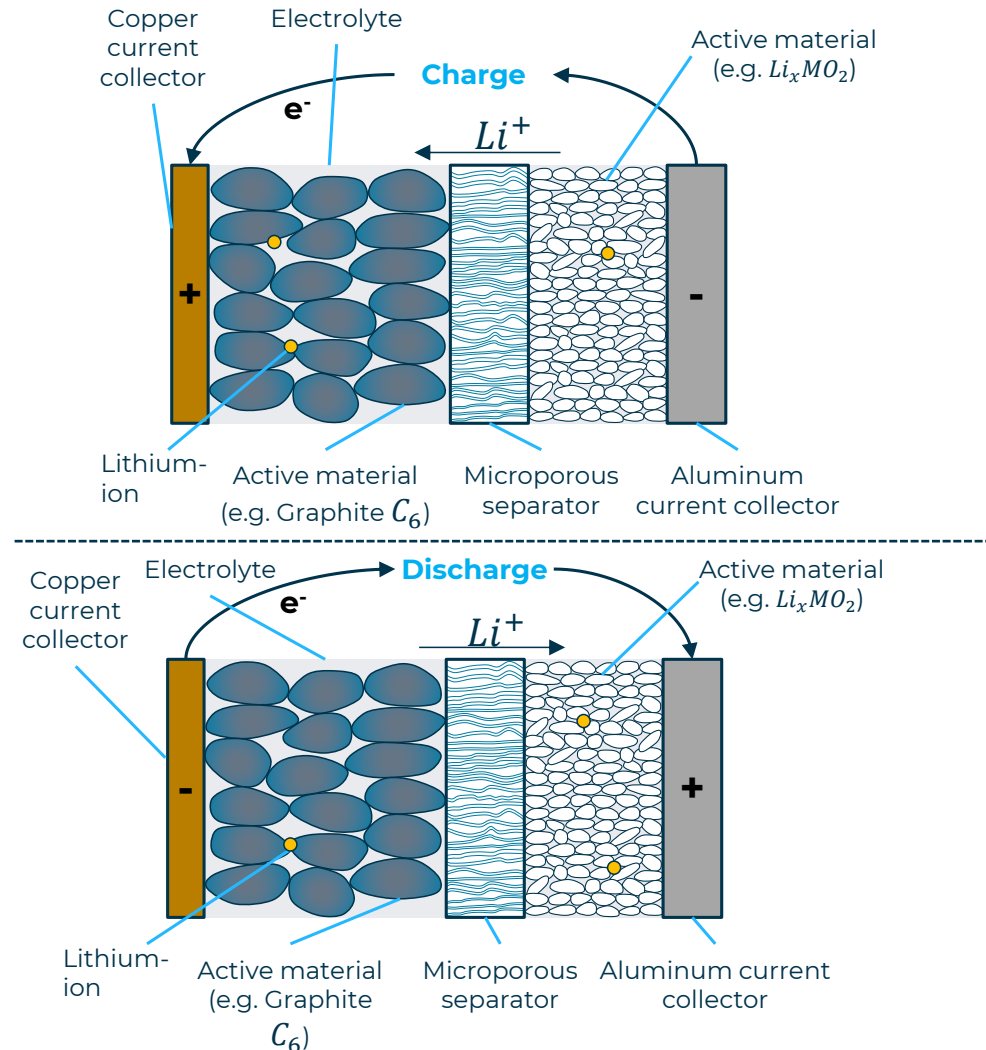
Structural design



Cell design



Operating Principle Of A Lithium-ion Cell



Operating principle

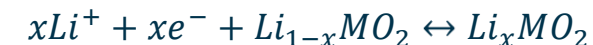
- + Energy storage through **storage and removal of lithium ions** in the molecular lattices of the anode or cathode (intercalation / deintercalation)
- + The electrode at which the oxidation dominates during discharge is named the **anode** (negative pole), and the other, where the reduction dominates, is the **cathode** (positive pole). This nomenclature is valid only for the discharging reaction; for the charging reaction the names are reversed.

- + Simplified electrochemical reactions (e.g. Discharge):

- + Negative electrode (during discharge "Anode")



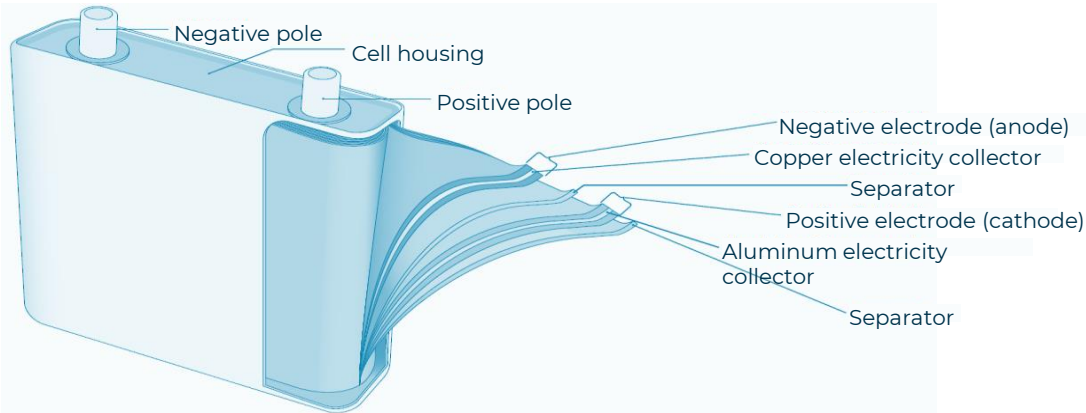
- + Positive electrode (during discharge "Cathode")



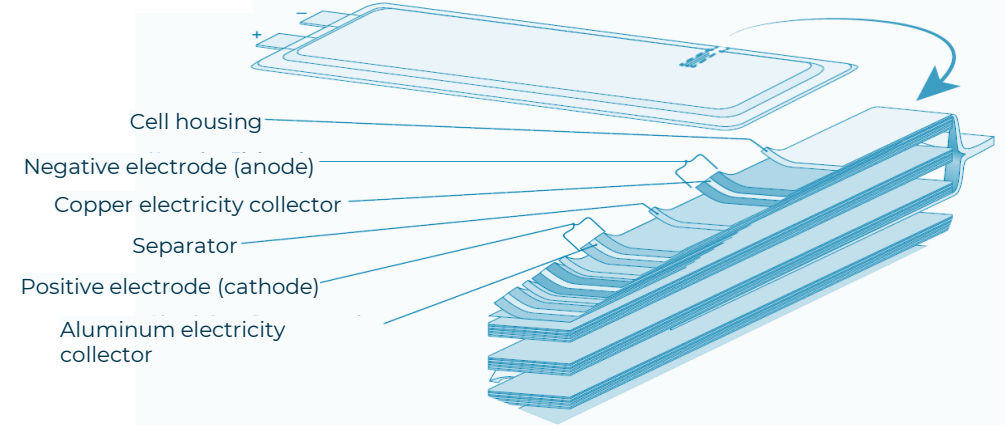
Construction Of A Lithium-ion Battery Cell+

Same structure in all cell formats due to principle

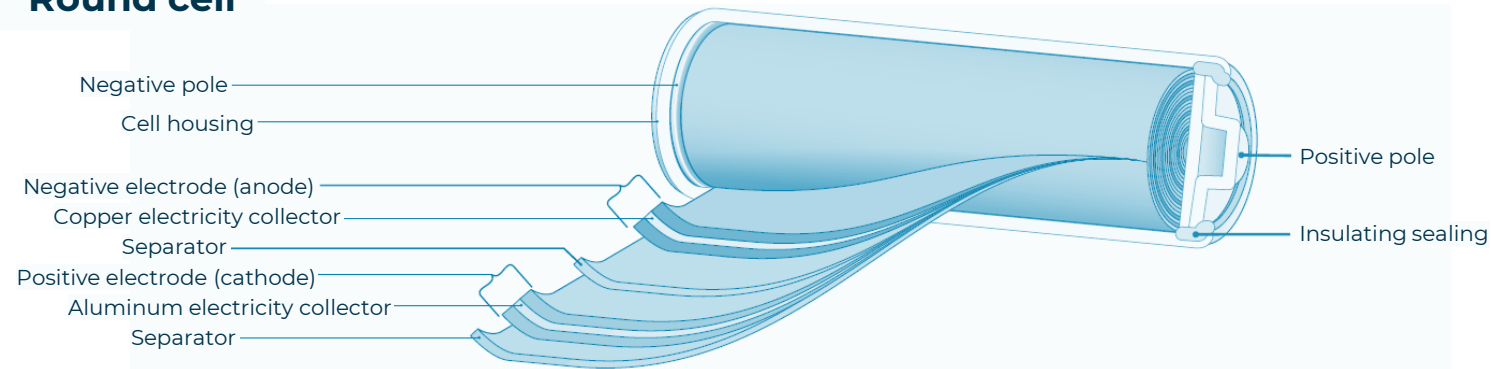
Prismatic cell



Pouch cell



Round cell



Advantages And Disadvantages Of Used Cell Formats

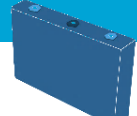
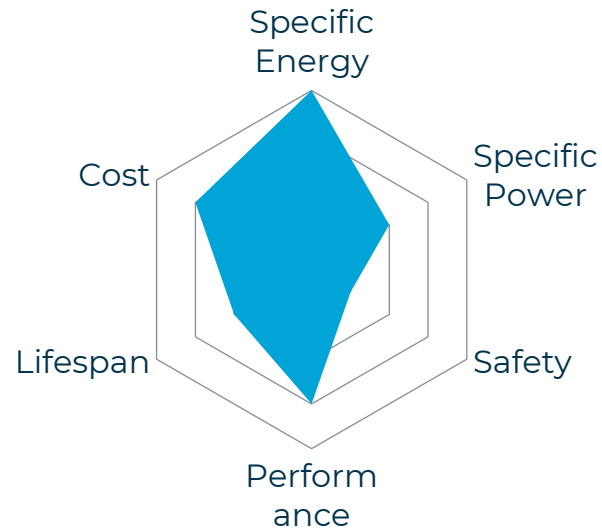
	 Pouch cell	 Round cell	 Prismatic cell
Energy density	High at module level	Low at module level	Medium at module level
Life	Unconfirmed concerns	High	Good
Case	Aluminum foil	Metal	Plastic / Metal
Dimensions	+ Versatile design + Efficient use of space + High packing density	+ Lack of versatility + Inefficient use of space + Low packing density	+ Versatile design + Efficient use of installations + High packing density
Sturdiness	+ Low long-term tightness + Unstable housing + Swelling under pressure + Superstructure + Sealing very complex	+ High tightness + High rigidity + Mechanical robust + Resists certain internal pressure without deformation	+ High tightness + Higher strength than pouch cell + Lower mechanical stability than round cell
Thermoregulation	+ Good surface-to-volume ratio + Efficient temperature control	+ High-energy cells: low heat dissipation	+ Surface-to-volume ratio better than round cell, worse than pouch cell
Special features of the production process	+ Difficult stacking	+ Extensive experience in the production process + Low manufacturing costs	+ Modules without additional housing possible + Pressure on cells necessary for joining + Cell contacting only 1 step
Example	 Nissan Leaf	 Tesla Model S	 BMW i3

Image sources: BMW, Tesla, Nissan

All three cell formats are used in various electric vehicles.
With increasing maturity, a trend towards pouch cells is discernible.

Lithium-ion Chemistries, Applications, Benefits And Disadvantages

Lithium ion Cobalt Oxide (LCO)



Applications

Consumer Electronics as cell phones, laptops, and digital cameras

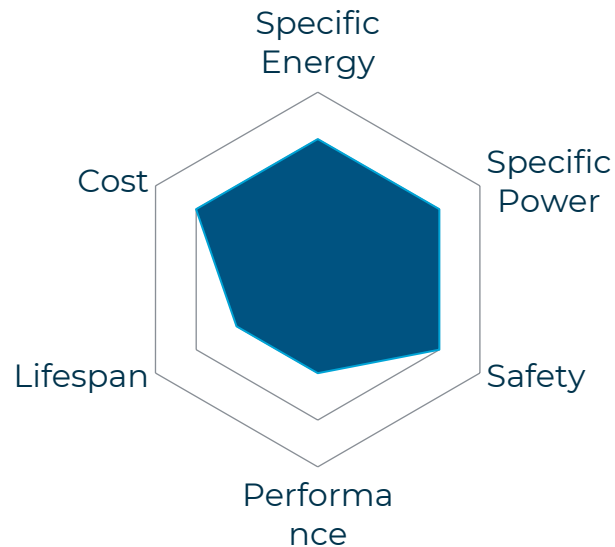
Benefits

High energy density resulting in smaller batteries

Disadvantages

Affected by high temperatures, short lifespan, typically last 500-1000 cycles

Lithium ion Manganese Oxide (LMO)

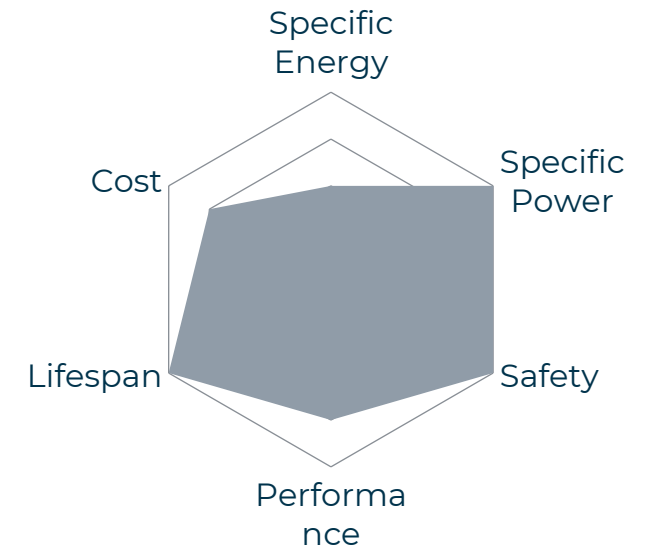


Power tools, medical devices, electric vehicles, and consumer electronics

Fast charging, high specific power, thermal stability, safety, and flexibility

Short lifespan of 300–700 charge cycles.

Lithium iron phosphate battery (LiFePO₄)



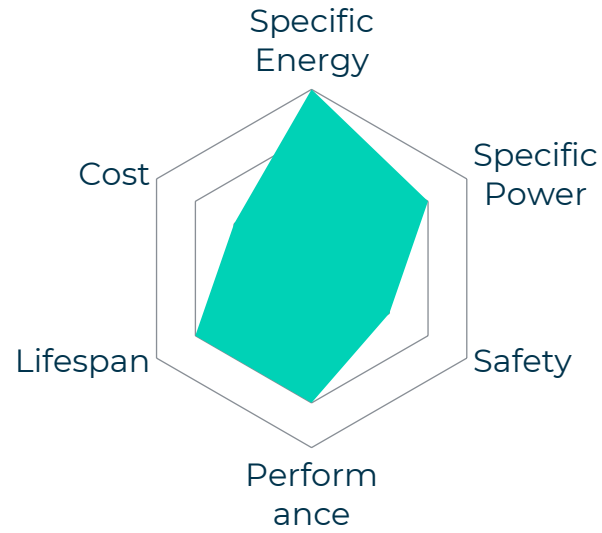
Energy Storage Systems, EVs, Marine and Backup Power Systems.

Long Lifespan of 2000-4000 cycles, and less prone to overheating

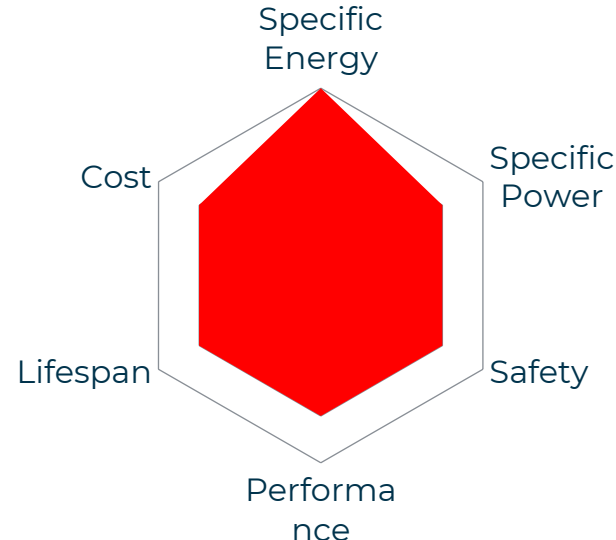
Lower energy density results in a heavier batteries

Lithium-ion Chemistries, Applications, Benefits And Disadvantages

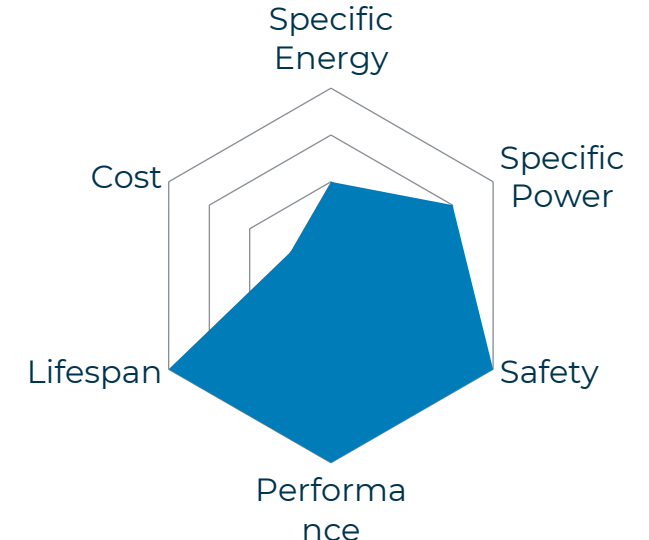
Lithium Nickel Cobalt Aluminum Oxide (NCA)



Lithium Nickel Manganese Cobalt Oxide (NMC)



Lithium Titanate Oxide (LTO)



Applications

EVs, Energy Storage Systems, industrial applications

Benefits

High energy density resulting in smaller batteries and good lifespan

Disadvantages

Performance drops in extreme cold or hot conditions, high cost

EVs, Energy Storage Systems, Portable electronics, Industrial equipment

High energy density, ratios of chemistries can be adjusted

Susceptible to capacity loss under high-stress conditions .

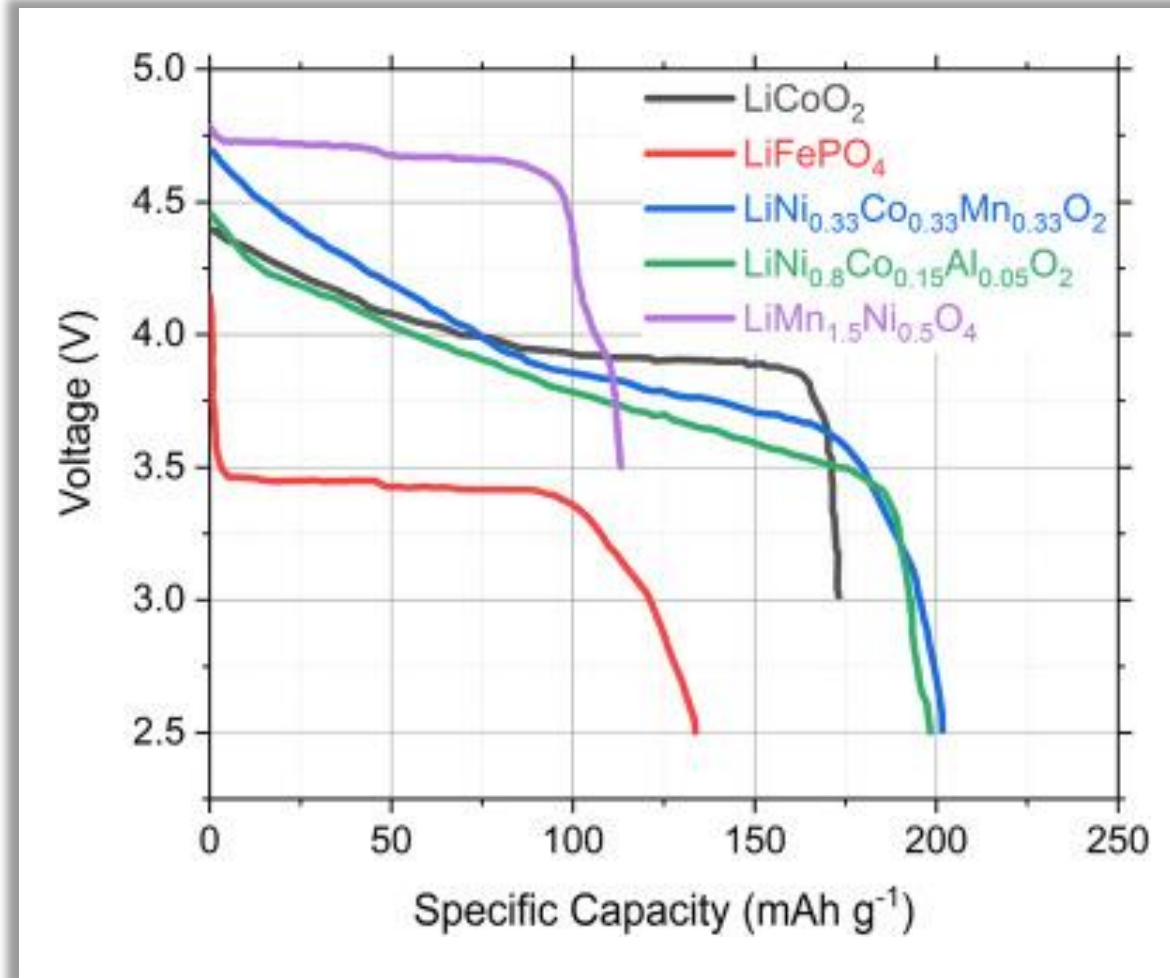
EVs, requiring fast charging and durability, military and aerospace

Lifespan of 7000-20000 cycles, Wide Temperature range, Discharge Rates

Higher cost and low energy density



The discharge curve varies based on the cell's chemistry



<https://www.sciencedirect.com/science/article/pii/S0378775322009260>



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The **cells** are assembled in several manufacturing steps, first into a **module** and then into a **pack**.

1

Battery cell

Battery cells are stacked (prismatic, pouch) or fixed in a **tray** (round).

2

Battery module

The cells are mounted and connected in the Battery module.

3

Battery pack

The modules are then assembled in the **battery pack** together with the **peripheral system components**.

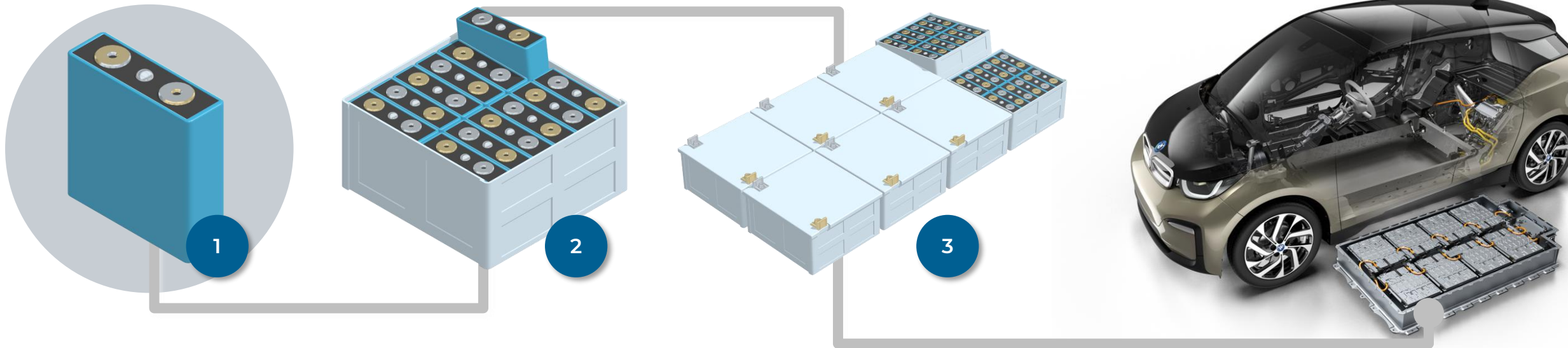
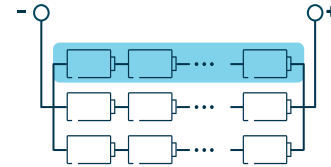
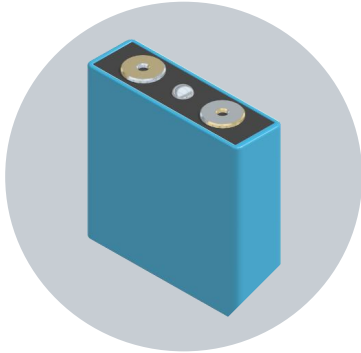


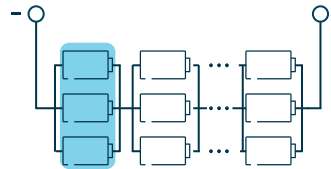
Image source: BMW

The cells are stacked to achieve desired voltage and current capacity



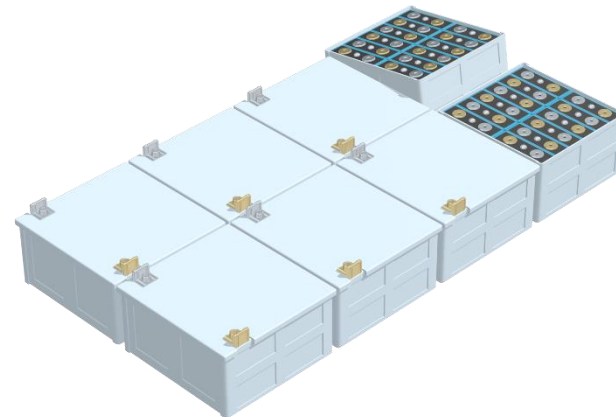
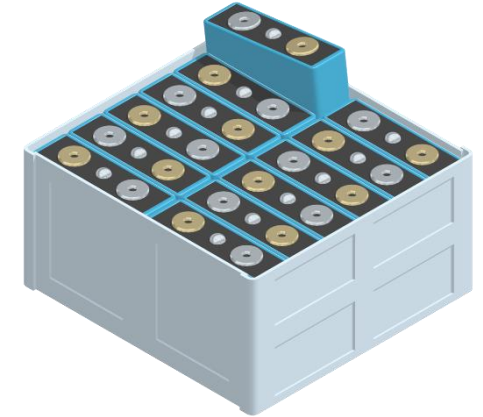
Serial Connection: In a battery module, the module voltage is equal to the voltage of a single cell multiplied by the number of cells connected in series.

$$V_{module} = N_s \cdot V_{cell}$$



Parallel Connection: In a battery module, the current capacity is equal to the current of a single cell multiplied by the number of cells connected in parallel.

$$I_{module} = N_p \cdot I_{cell}$$



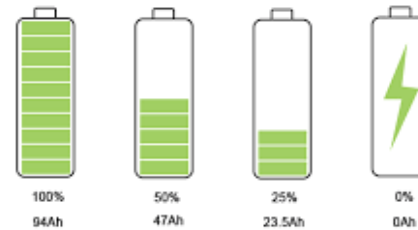
The modules connected in series determine the battery pack voltage, and the modules connected in parallel determine the battery pack current capacity

$$V_{PACK} = N_s \cdot V_{module}$$
$$I_{PACK} = N_p \cdot I_{module}$$

Battery Terminology

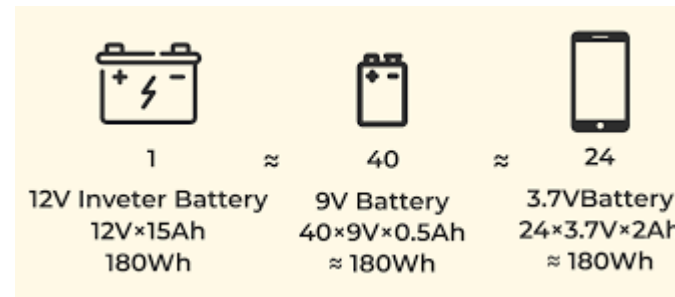
Capacity [Ah]

- + The maximum amount of charge a battery can store and deliver. It Indicates the amount of charge the battery can deliver at a particular discharge rate. It can be measured in Ampere-hour (Ah)
- + Capacity of 5Ah, means can be discharged for 1 hour at 5A



Energy [Wh]

- + Represents the total power (work) a battery can provide. It can be calculated with the product of capacity and nominal voltage



Battery Terminology

C Rate [C]

- + Represents how quick the battery is charged or discharged with a constant current in relation to its maximum capacity. It is expressed as a multiple of the battery's rated capacity
- + For example, in a **5Ah battery**:
 - + **1C** rate indicate the battery charge or discharge at **5A**, the process will finish in **1 hour**.
 - + **2C** rate indicate the battery charge or discharge at **10A**, will finish in **0.5 hours**.
 - + **0.5C** rate indicate the battery charge or discharge at **2.5A**, will finish in **2 hours**.



Energy Density [Wh/L, Wh/kg]

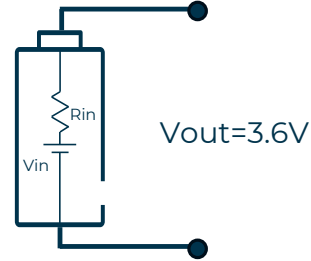
- + The amount of energy can be stored in a determined volume or mass. A higher value of this parameter means smaller and lighter battery pack.
 - + **Volumetric Energy Density**: Energy stored in a given volume, typically measured in watts-hour per liter (**Wh/L**)
 - + **Gravimetric Energy Density**: Energy stored in a given mass, typically measured in watts-hour per kilogram (**Wh/kg**)

Battery Terminology

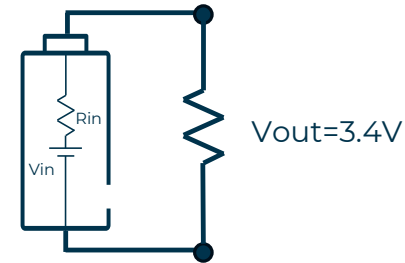
Open Circuit Voltage [V]

+ The voltage when there is no load connected to the battery (no current flowing).

Open Circuit Voltage

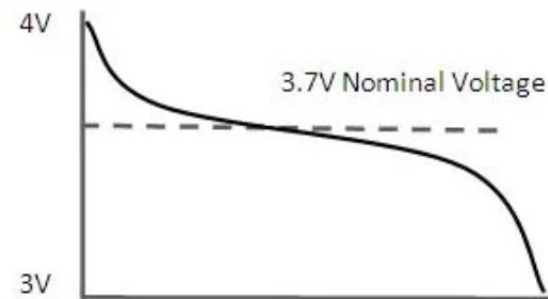


Closed Circuit Voltage



Nominal Voltage [V]

+ It is the average voltage when the battery is operating under typical conditions.

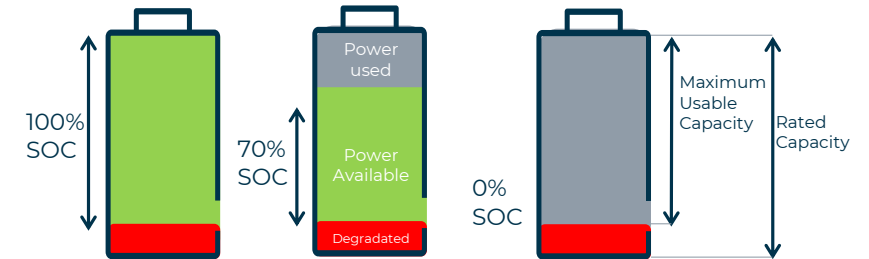


Battery Terminology

State of Charge (SoC) [%]

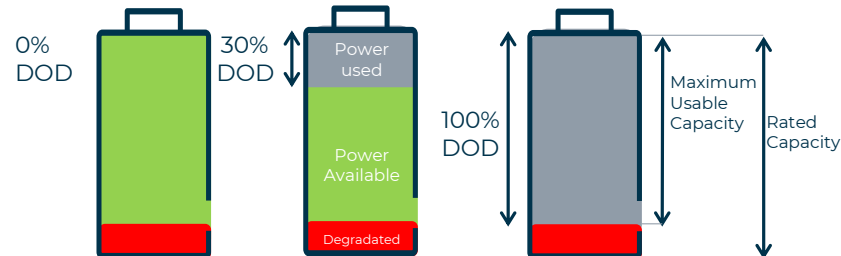
- + Represents the current charge level of energy stored in a battery, it is expressed as the percentage of its capacity.

$$SoC = \frac{\text{Available Capacity [Ah]}}{\text{Maximum Capacity [Ah]}} \times 100\%$$



Depth of Discharge (DoD) [%]

- + Indicates the percentage of the battery that has been discharged relative to its capacity.



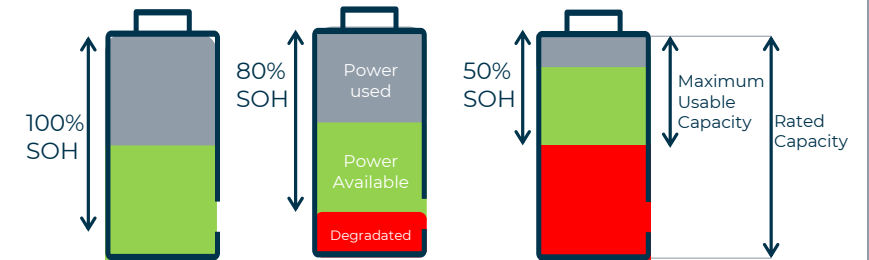
$$DoD = 100\% - SoC$$

Battery Terminology

State of Health (SoH)

- + Metric used to compare the condition of the battery compared to its new or ideal state.

$$SoH = \frac{\text{Maximum Capacity [Ah]}}{\text{Rated Capacity [Ah]}} \times 100\%$$



Battery Terminology

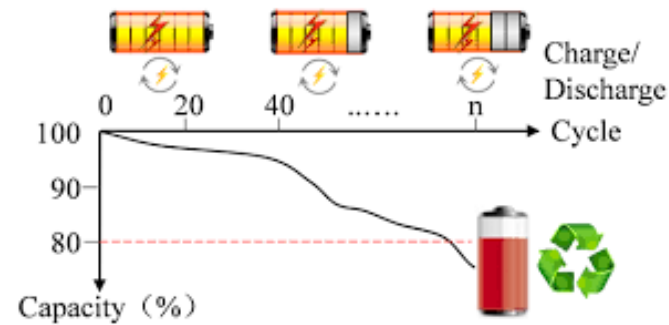
Cycle

+ To the full process of charge and discharge is called cycle



Cycle Life

+ The total number of cycles a battery can perform before its capacity falls to a specified percentage of its original capacity.



Example - Battery cell Datasheet

$$+ \text{Capacity} = 4.9 \text{ Ah}$$

$$+ \text{Energy} = 4.9 \text{ Ah} \times 3.6 \text{ V} \\ = 17.64 \text{ Wh}$$

3. Nominal Specifications (*1)

Item	Specification
3.1 Standard discharge Capacity	Min 4,900mAh - Charge : 0.5C(2,450mA), 4.2V, 0.02C(98mA) cutoff @ RT - Discharge : 0.2C(980mA), 2.5V cutoff @ RT * 1C = 4,900mA
3.2 Rated discharge Capacity	Min 4,753mAh - Charge : 0.5C(2,450mA), 4.2V, 0.02C(98mA) cutoff @ RT - Discharge : 1C(4,900mA), 2.5V cutoff @ RT
3.3 Charging Voltage	4.2V
3.4 Nominal Voltage	3.6V
3.5 Charging Method	CC-CV (constant voltage with limited current)
3.6 Charging Current	Standard charge: 2,450mA
3.7 Charging Time	Standard charge: 3hours
3.8 Max. Charge Current	4,900mA (not for cycle life)
3.9 Max. Discharge Current	9,800mA (for continuous discharge) 14,700mA (not for continuous discharge)
3.10 Discharge Cut-off Voltage	2.5V
3.11 Cycle life	Capacity $\geq$ 3,802mAh @ after 500cycles (80% of the Rated Discharge Capacity @ RT) - Charge : 0.5C(2,450mA), 4.2V, CCCV 0.05C(245mA) cut-off @ RT - Discharge: 1C(4,900mA), 2.5V cut-off @ RT
3.13 Recovery characteristics	Capacity recovery (after the storage) $\geq$ 4,278mAh (90% of the Rated Discharge Capacity @ RT) - Charge : 0.5C(2,450mA), 4.2V, 0.02C(98mA) cutoff @ RT - Storage : 30 days @ 60°C - Discharge : 1.0C(4,900mA) 2.50V cut-off @ RT
3.14 Cell Weight	69g max
3.15 Cell Dimension	Cell height : Max.70.80mm Diameter : Φ Max.20.25mm

Samsung
INR21700-50E

Calculte the Energy Density

$$\text{Energy Density} = \frac{17.64 \text{ Wh}}{0.069 \text{ kg}} = 255.65 \frac{\text{Wh}}{\text{kg}}$$

Example - Battery Pack Datasheet

14S8P Battery Pack

48V Li-ion Rechargeable Battery

Specifications

ELECTRICAL		OPERATING CONDITIONS	
Nominal Voltage:	50.4 V	Operating Temperature (Discharge)	-20 °C to +60 °C
Cut-off Voltage:	37.8 V	Operating Temperature (Charge)	0 °C to +45 °C
Charge Voltage:	58.8 V	Storage Temperature (3 months)	1 yr: -20 to 25°C 3 mth: -20 to 45°C 1 mth: -20 to 60°C
Typ. Capacity:	39.2 Ah	Cycle Life:	500 cycles at 80% capacity
Min. Capacity:	39.2 Ah	MECHANICALS	
Energy:	197.6 Wh	Weight:	12 kg
Discharge Current:	40 A (cont.) 80 A (peak)	Size (L x W x H):	385.9 x 137.7 x 162.5 mm
Charge Current:	10 A (cont.) 40 A (max)	OTHER	
CERTIFICATIONS		Features:	SOC Display, CAN communication
Cells:	UN 38.3 IEC 62133-2:2017		

$$+ \text{Pack voltage} = 3.6V \times 14 = 50.4V$$

$$+ \text{Pack Capacity} = 4.9Ah \times 8 = 39.2Ah$$

$$+ \text{Pack Energy} = 39.2Ah \times 50.4V = 1.583kWh$$

Calcule the Energy Density

$$\text{Energy Density} = \frac{1.583kWh}{12kg} = 164.64 \frac{Wh}{kg}$$

Agenda

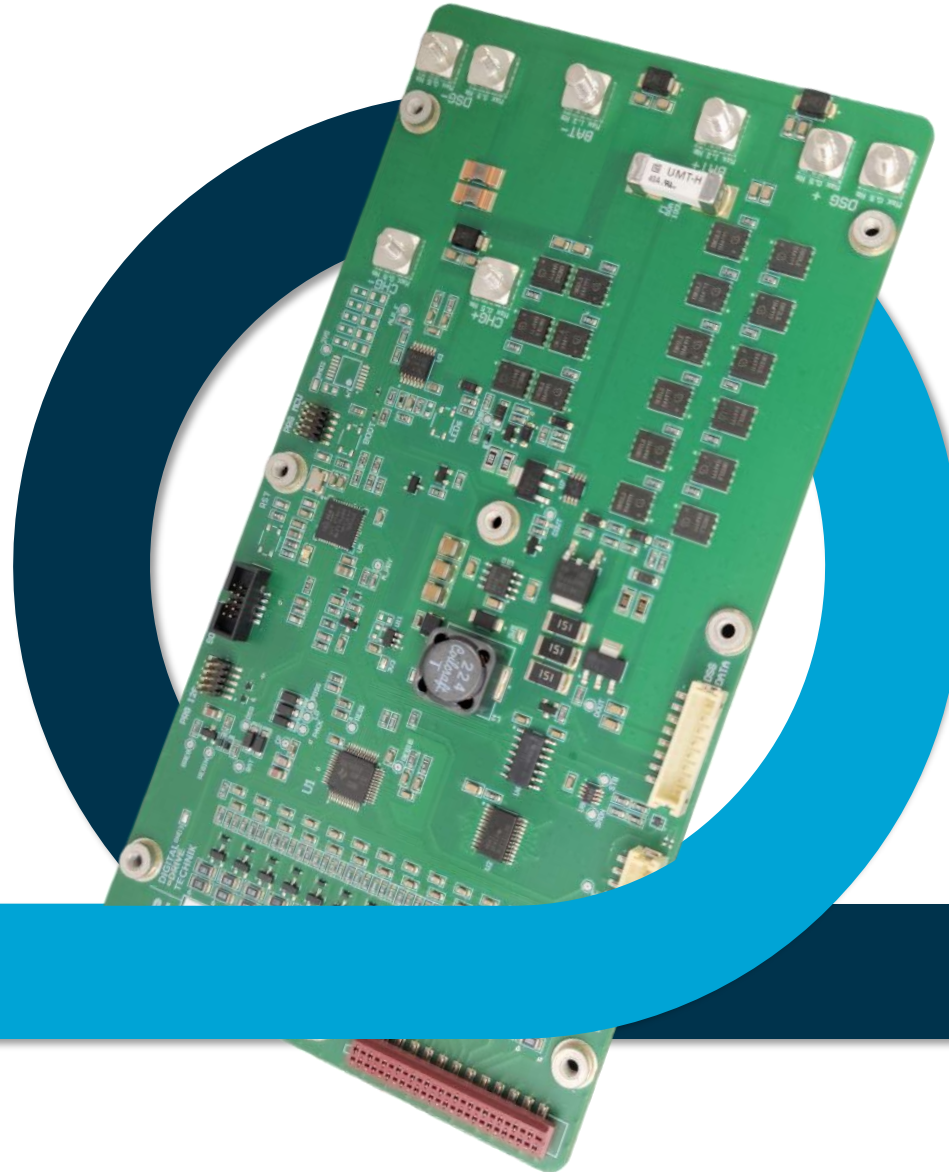
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Battery Management Systems (BMS)

What is a BMS?

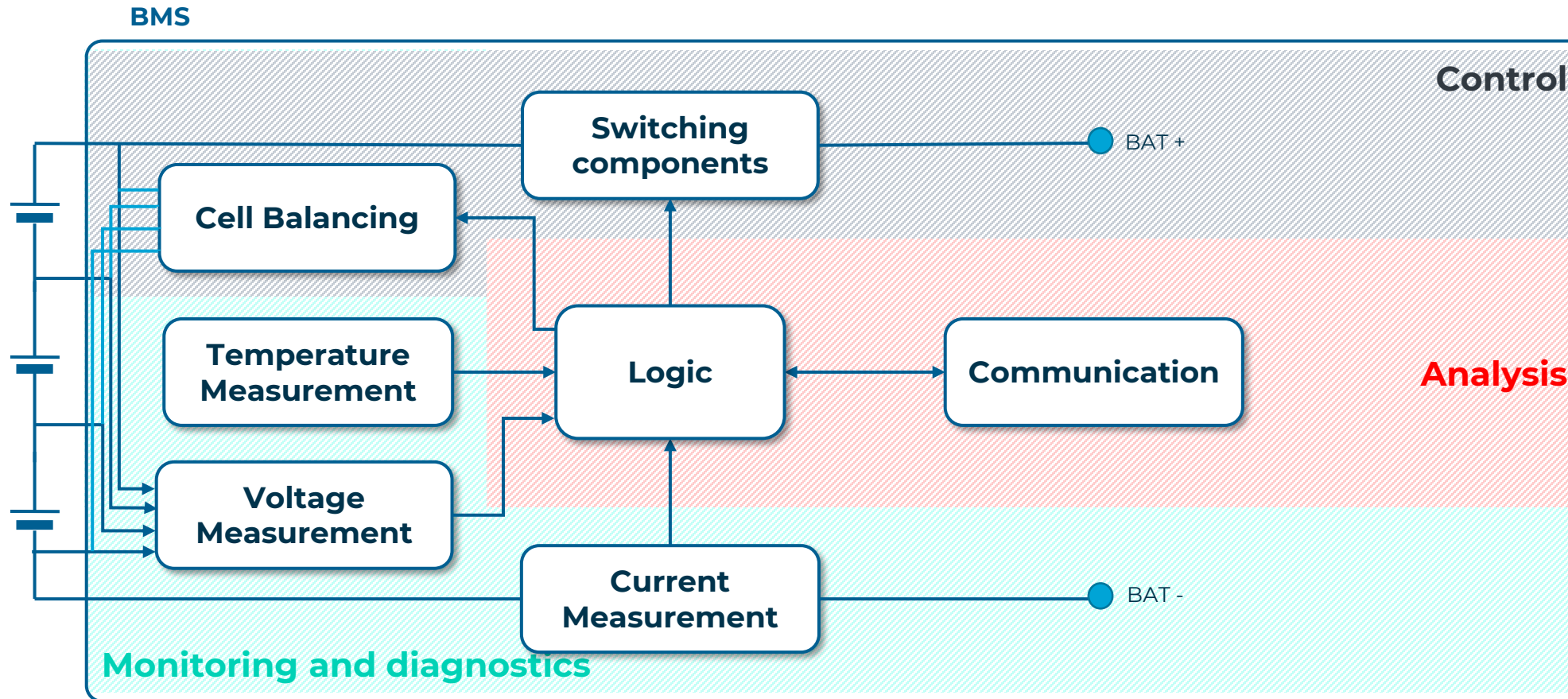
- The Battery Management System (BMS) is a component that monitors, controls and protects the battery pack.
- It is an essential part of the battery, without its management the battery and specially the user are unprotected from malfunctions of the battery, as over-charging, over-discharging, short-circuits, over-heating, etc.



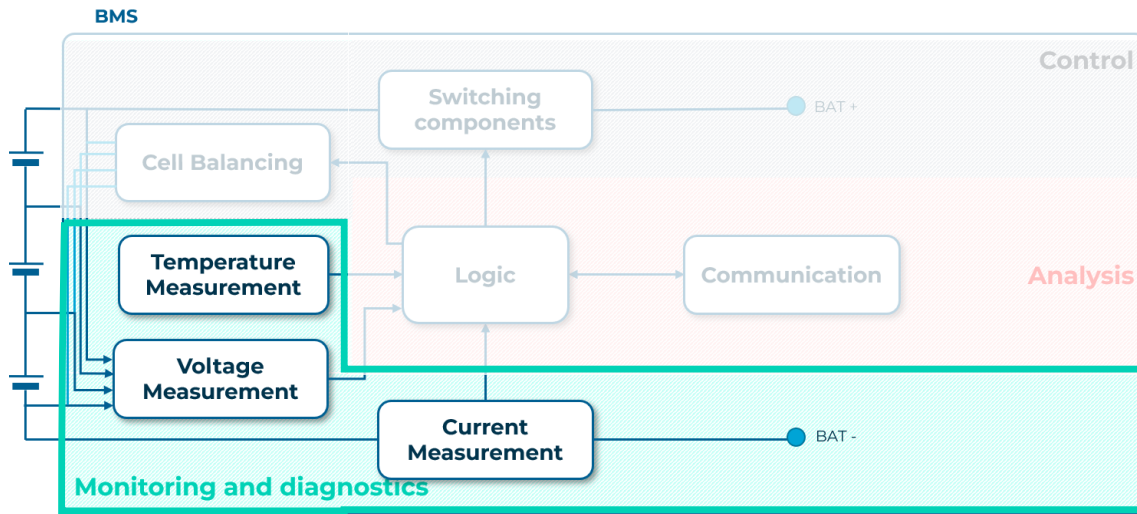
Key functions and features

- Battery Monitoring
- Battery Control
- Battery Estimations
- Communications

BMS is composed by 3 principal parts: Control, Analysis, Monitoring and diagnostics



Monitoring and Diagnostics



Core Features

- + High-resolution measurement of cell voltage, temperature, and current
- + Integration of sensors for accurate readings.
 - + Pack Voltage and Current
 - + Cells Voltage
 - + Cells Temperature
 - + Insolation
- + Real-time detection of anomalies, including overvoltage undervoltage, and thermal irregularities.

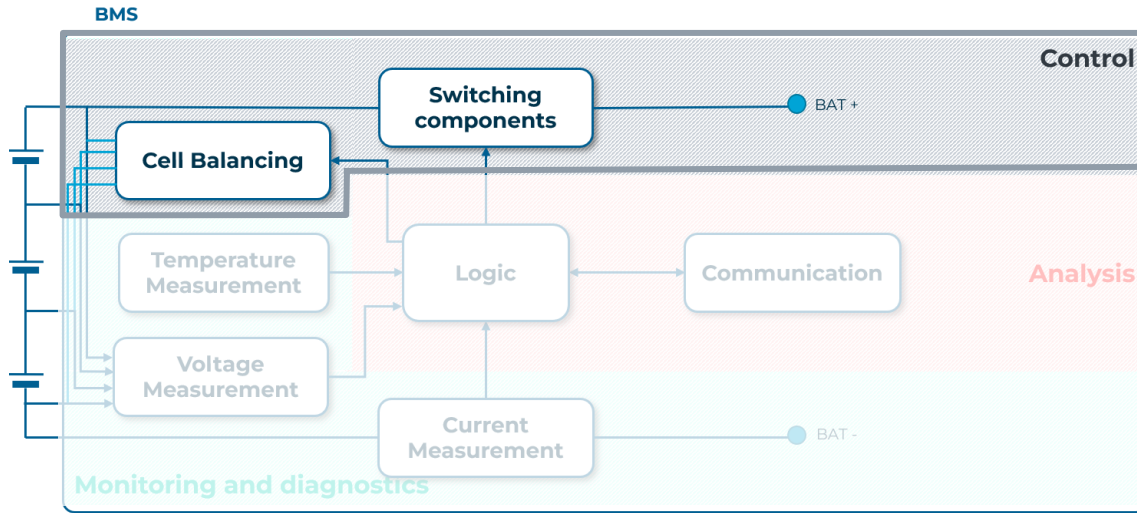
Definition

- + Continuously measures and collects critical data, such as cell voltage, temperature, and current.
- + Includes all BMS sensors, providing real-time battery state.
- + Identifies deviations from normal operation to detect potential issues.

Remarks

- + High precision is vital to prevent undetected system faults.

Control and Protections



Definition

- + Ensures the safe operation of the battery pack by enforcing operational limits and implementing safeguards.
- + Protects against critical risks like overvoltage, undervoltage, overcurrent, and thermal runaway.
- + Maintains the health and performance of the battery pack by controlling energy flow and cell balancing.

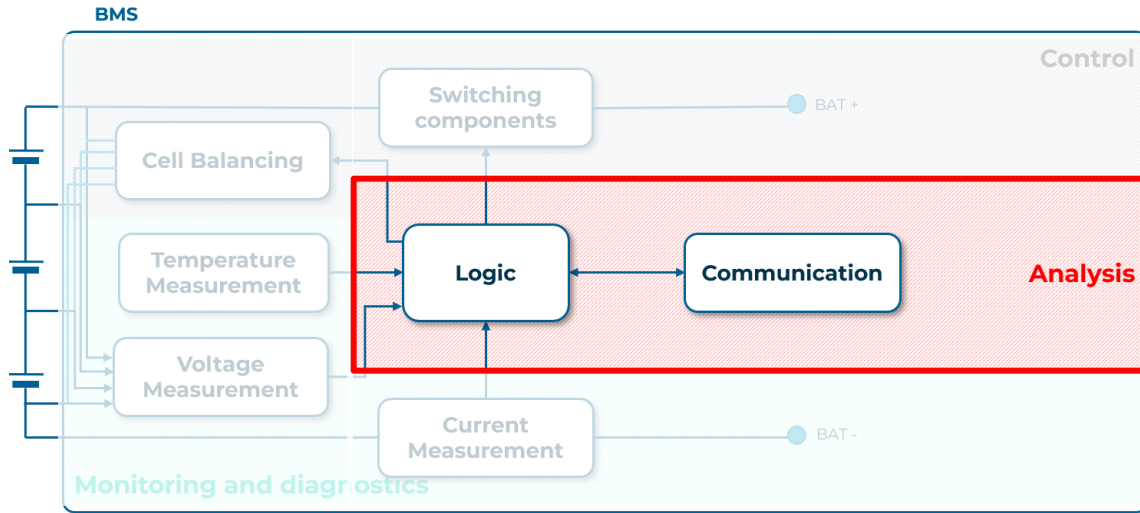
Core Features

- + Dynamic control over power flow to optimize energy usage.
- + Activation of emergency disconnects during unsafe conditions as:
 - + Short circuit
 - + Overload
 - + Overcharging
 - + Overheating
- + Management of cell balancing to maintain uniform SOC across the battery pack.

Remarks

- + Effective protections significantly reduce the risk of catastrophic failures.

Analysis



Definition

- + Processes collected data to provide information of the battery performance.
- + Estimates critical parameters like SOC and SOH using advanced algorithms.
- + Facilitates seamless integration with external systems through communication protocols..

Core Features

- + Estimations for battery performance tracking:
 - + State of Health (SoH)
 - + State of Charge (SoC)
- + Communication via industry-standard protocols such as CAN, LIN, and Ethernet.

Remarks

- + Estimation accuracy is key to optimizing battery performance and lifecycle.
- + Robust communication protocols ensure reliability in interconnected systems.

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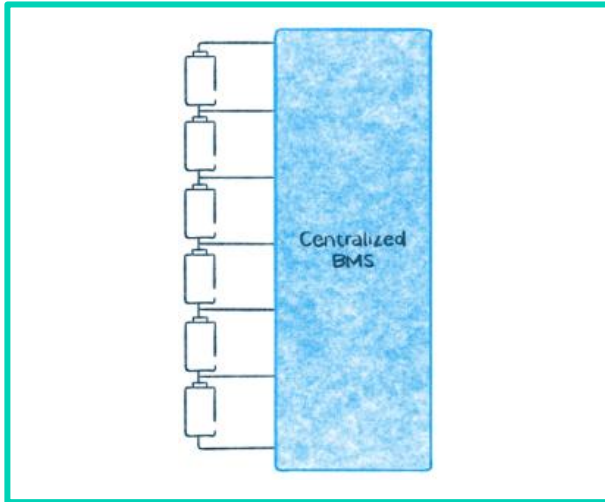
4. BMS Topologies



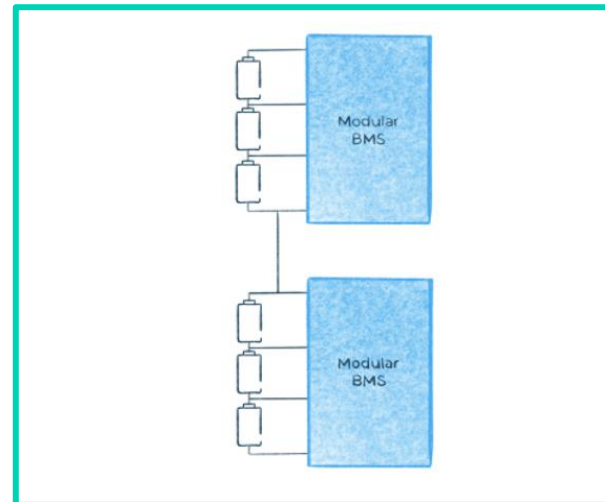
BMS Topology

Depending on the Battery requirements, the BMS can be designed with the following topologies

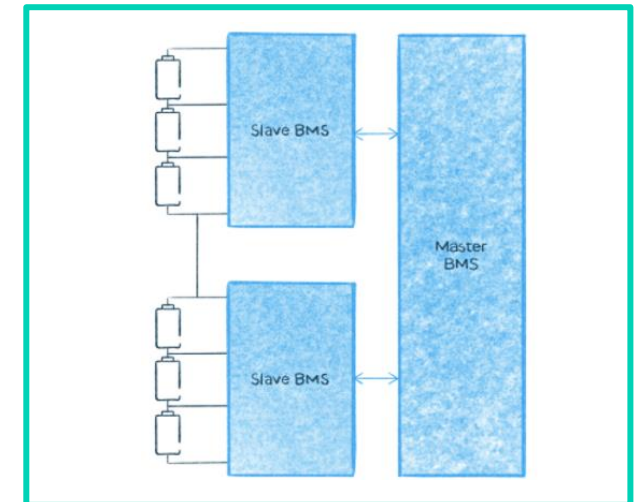
Centralized



Modular



Master-Slave



Centralized Topology

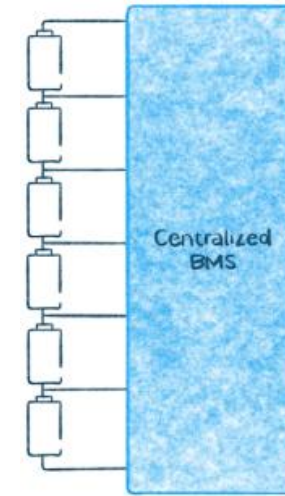
Operation

All the battery cells or modules are managed by only one BMS



Use Cases

The most common use of this kind of topology is in smaller and less complex battery systems. In 2-3 wheeler vehicles this option is the most prevalent choice.



Advantages

- + The design of a system with the control and monitoring in only one central unit simplify and reduce the work time
- + Reduce the time and effort on designing, assembling and maintaining, also reduce the cost of this kind of BMS
- + Communication with only one board ensures higher and synchronous data collection

Disadvantages

- + Is not a suitable option for larger battery packs or escalable cases
- + Any malfunction in this component could potentially damage the entire battery.
- + Connecting all the sensors of the battery to the centralized BMS create a complex wiring design.

Modular Topology

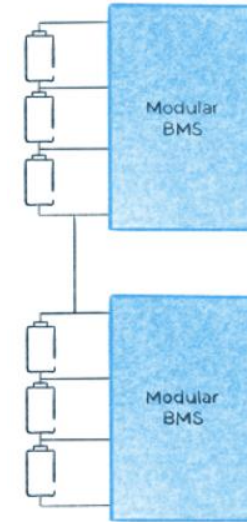
Operation

The battery pack is divided into multiple modules, and each one is monitored and managed by a different BMS.



Use Cases

This topology is especially useful in applications where the battery size can vary over time, like grid energy or backup power systems.



Advantages

- + Since each module functions independently, expand or reduce the system is made adding or removing modules.
- + If one of the modules fails, the rest of the system keeps working normally
- + Wiring complexity is reduced, each module only needs to connect to a section of the complete battery

Disadvantages

- + The implementation can be more challenging because each module works independently while still maintaining coordination between them
- + The cost is higher than the centralized BMS, while each module needs its own manufacturing and components
- + The autonomy of cell groups can complicate balancing efforts

Master-Slave Topology

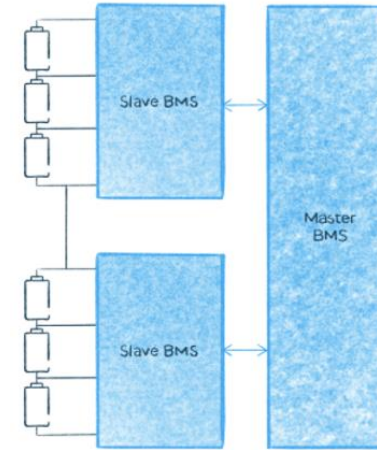
Operation

Adopts a master-slave configuration. Battery cell monitoring is distributed across multiple slave boards, which communicate with the master to manage the entire battery pack.



Use Cases

The distributed topology is most used in large applications, as energy storage systems, aerospace field and electric cars.



Advantages

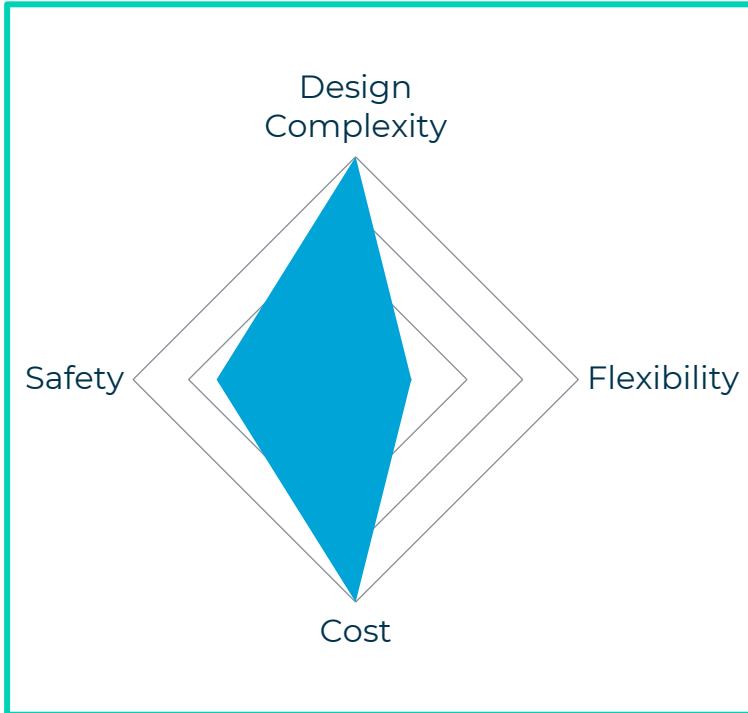
- + The system can be scaled by simply adding more slaves BMS.
- + Slave modules handle localized monitoring and control, reducing computational load on the master.
- + The master provide a single point of control and data simplifying decision-making.

Disadvantages

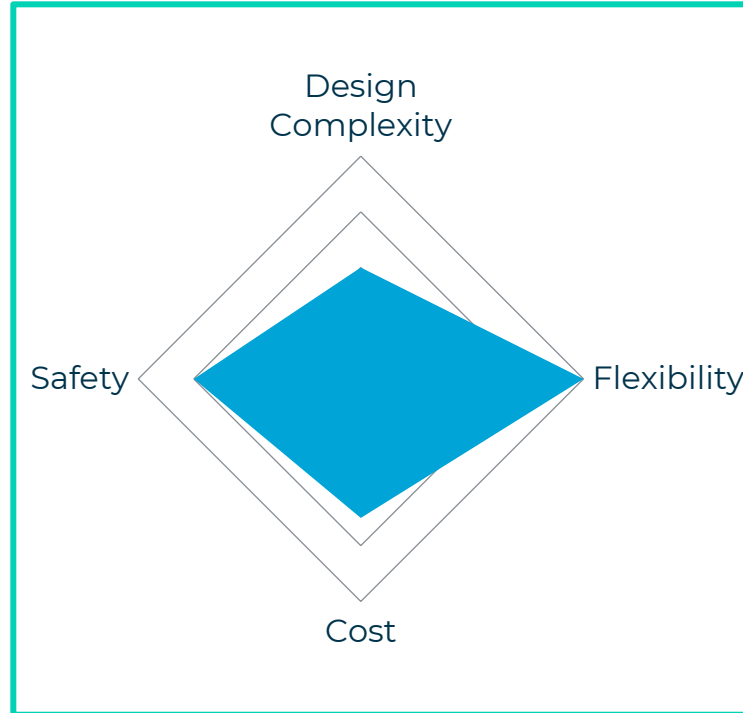
- + If the master unit fails, the entire system's functionality may be compromised.
- + Communication between the master and slaves requires robust design, adding complexity.
- + The inclusion of multiple slave modules increases the overall system cost compared to simpler topologies.

BMS Topology Comparison

Centralized



Modular



Master-Slave

