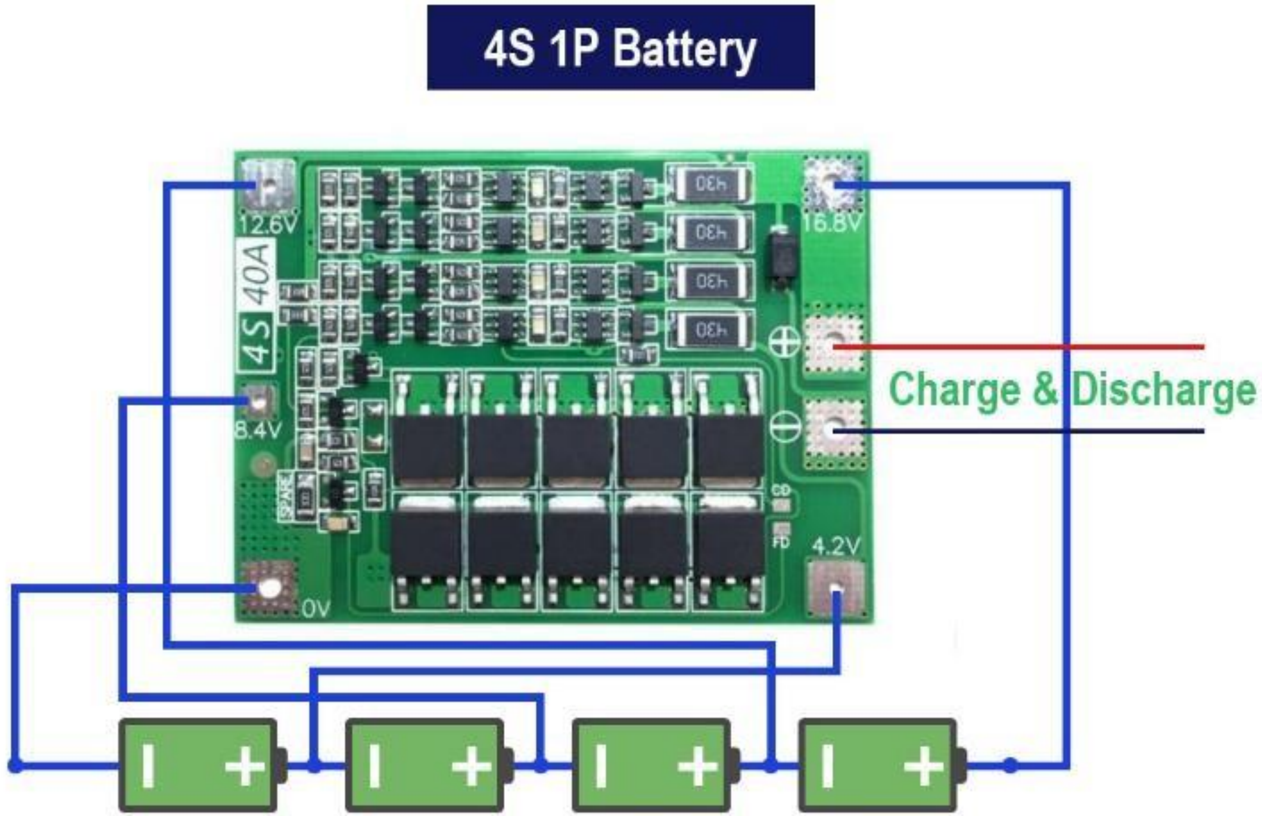
Battery Management System (BMS)



BMS is an embedded system (purpose built electronics and processing to enable specific application)

Components of BMS

Source:Intellipaat,Battery Management Systems

Why BMS?

- To provide operator safety of battery powered EV
  - ✓Detect unsafe operating conditions and immediate respond
  - ✓Disconnecting and isolating the battery pack from load
  - ✓Alert the operator by some means of some display unit
- To protect cells in battery pack from damage or failure cases
  - ✓Active intrusion under software control
  - ✓Dedicated electronic circuit to detect failures
  - ✓Isolate the defected component from pack and load it powers

Source: Gregory L Plett, Battery Management and control

Why BMS?

- To prolong the battery life under normal operating conditions
  - ✓ Coordinating with the controller of the load it powers
  - ✓ Advising it of dynamic limits on power that ensures pack will not be overcharged or over discharged
  - ✓ Controlling the thermal management system
  - ✓ Operating the pack within safe operating region
- To maintain the battery pack in a state in which it can fulfill its functional design requirements
  - ✓ Operating the battery pack in defined SOC region
  - ✓ Limiting overcharge and over discharge phenomena

Source: Gregory L Plett, Battery Management and control

BMS- Functions

1. Sensing and high voltage control

- ✓Measures cell voltages
- ✓Cell temperatures
- ✓Cell currents
- ✓Detect isolation faults
- ✓Control the contactors

2. Protection
   - ✓Over and under voltage, current, temperature protection
   - ✓Cell Short circuit
   - ✓External temperatures

BMS functionalities

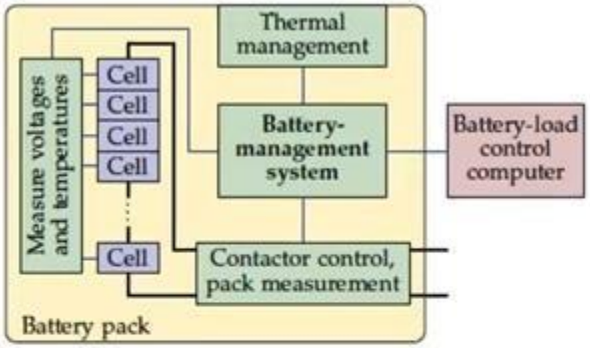
3. Estimation

✓ State of charge (SoC)
✓ State of Energy (SoE)

4. Balancing
    ✓ Cell, module and pack balancing
    ✓ Cell Short circuit
    ✓ External temperatures

5. Interface
    ✓ Communication interface
    ✓ Reporting cell , module and pack parameter
    ✓ Status of pack

6. diagnostics
    ✓ State of Health estimation
    ✓ Detecting battery misuse
    ✓ State of life estimation



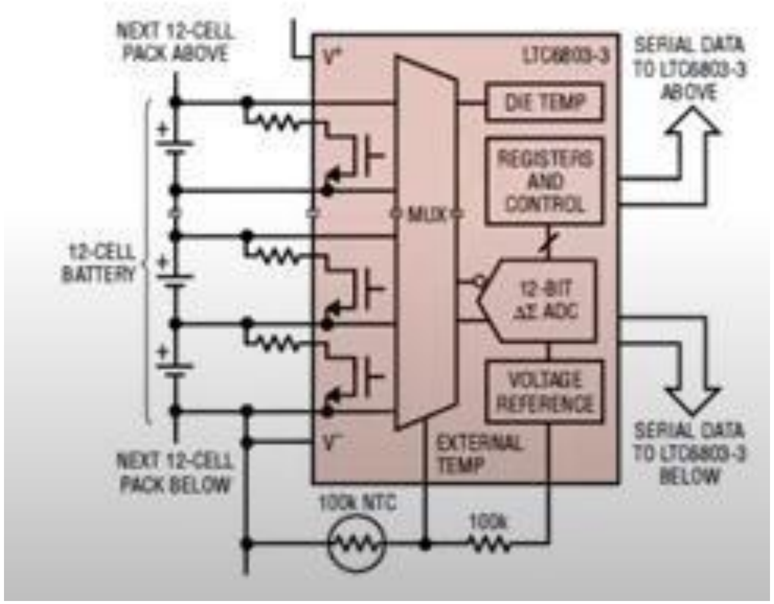
Cell voltage measurement

- All the voltages of the series combination are required to be measured
- Voltage measurement required for
  - ✓Over voltage fault sensing
  - ✓Under voltage fault sensing
  - ✓Balancing algorithm
  - ✓State of charge estimation of the battery
- IC "chipsets" are used for cell voltage measurement
  - ✓A single IC can be used t measure the number of cells in series
  - ✓Example: LTC 6803

Cell voltage measurement

- Two IC's are placed in parallel to measure more cells in series

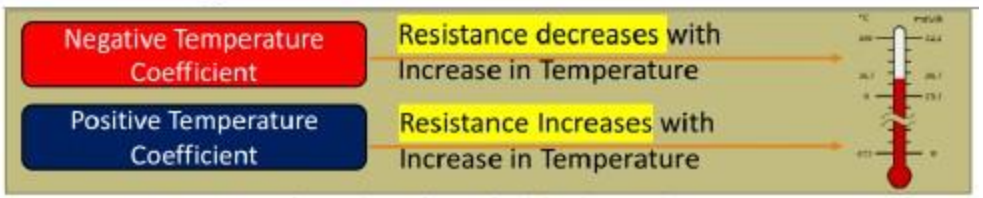
Example: LTC 6803



Cell temperature measurement

- Sensing cell temperature
  - ✓ Battery cell costs around 40% of the total cost of EV
  - ✓ It is important to keep batteries cool for their longer life and safety purpose

- ✓ Lithium-ion cell dynamics are strong functions of temperature (15^{o}C-45^{o}C)
- ✓ Know cell temperature to predict cell performance and degradation
- ✓ Example: Thermistor, Thermocouple



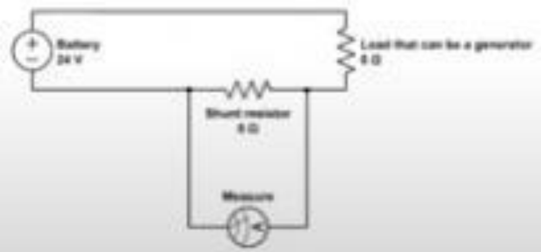
Resistor R_1 is user selected, with negligible dependence on Temperature.

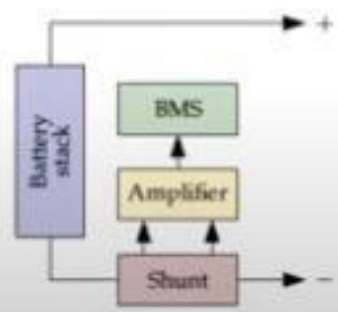
Cell current measurement

- Battery current is critical input to SoC and SoH estimation algorithms
- Battery back current measurement is used for
  - ✓ Over current fault sensing
  - ✓ Short circuit fault sensing

✓State of charge estimation of the battery

- Methods used for cell current measurement





✓Current shunts (low value and high precision resistor are placed in series with the battery back usually at the negative terminal (to minimize power loss I^2R loss) ✓Hall effect sensors

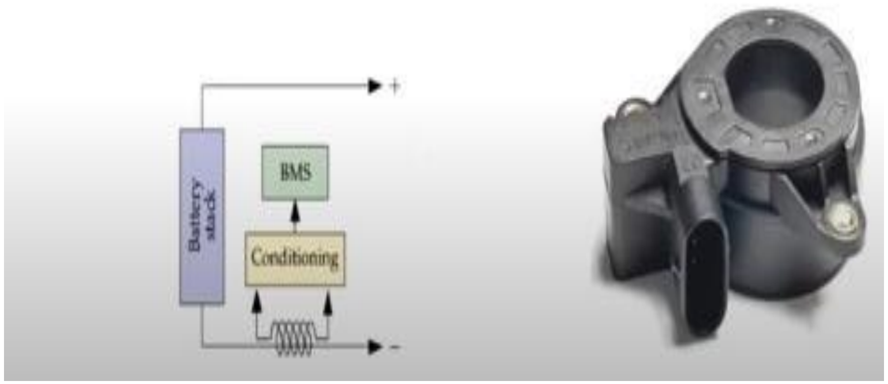
Cell current measurement

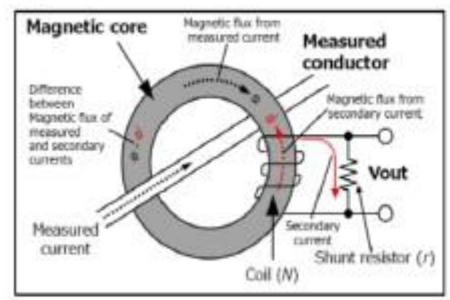
- Methods used for cell current measurement

✓Current shunts (low value and high precision resistor are placed in series with the battery back usually at the negative terminal (to minimize power loss I^2R loss)

✓ voltage across resistor is sensed and amplified and latter goes into the ADC of MCU

Hall effect sensor





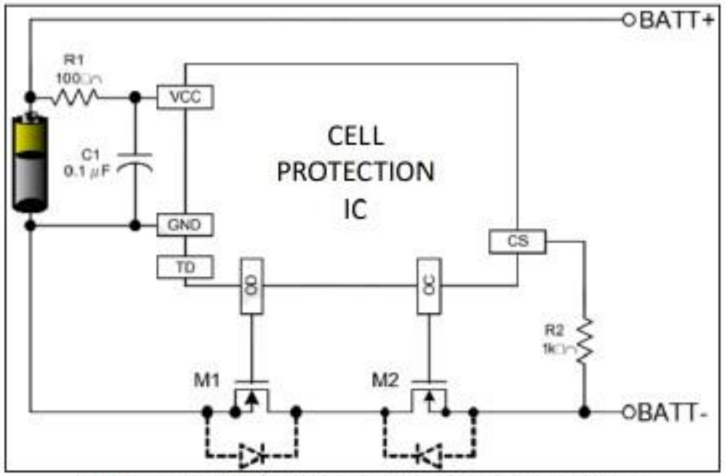
✓If a coil is wrapped around a primary current carrying conductor, the electromagnetic field produced by the conductor induces a secondary current in the coil

✓ Hall effect sensors measures induced current to infer the primary current

Protection mechanism

- The electronics and software of the BMS are integral parts of an overall risk management strategy
- In a battery pack, the protection must address the following:
- Battery back current measurement is used for ✓ undesirable events or conditions
  - ✓ Excessive current during charging or discharging
  - ✓ Short circuit
  - ✓ Over voltage or under voltage

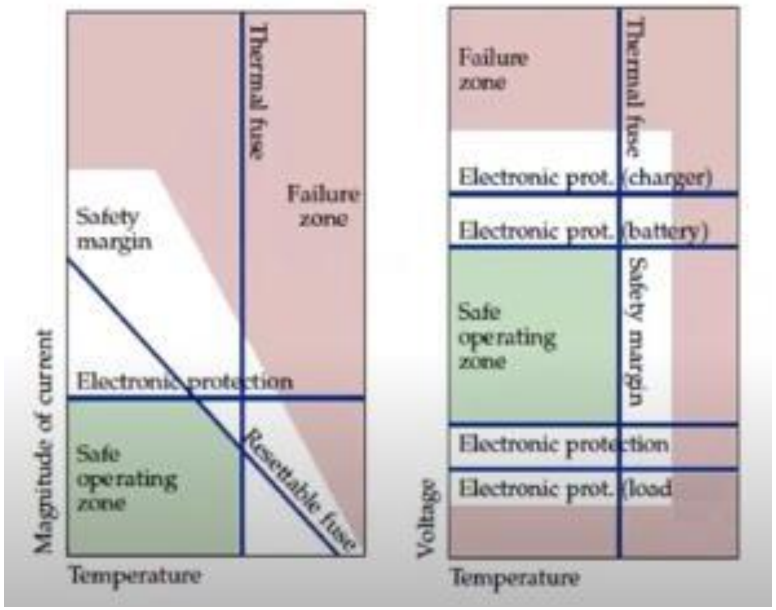
- ✓ High ambient temperature or over heating
- ✓ Loss of isolation and abuse
- ✓ Protection devices : thermal fuses, Conventional fuses, electronic fault detection devices



Cell Protection Circuit. Source: Fortune Semiconductor Corp. – DW01A IC

Protection mechanism

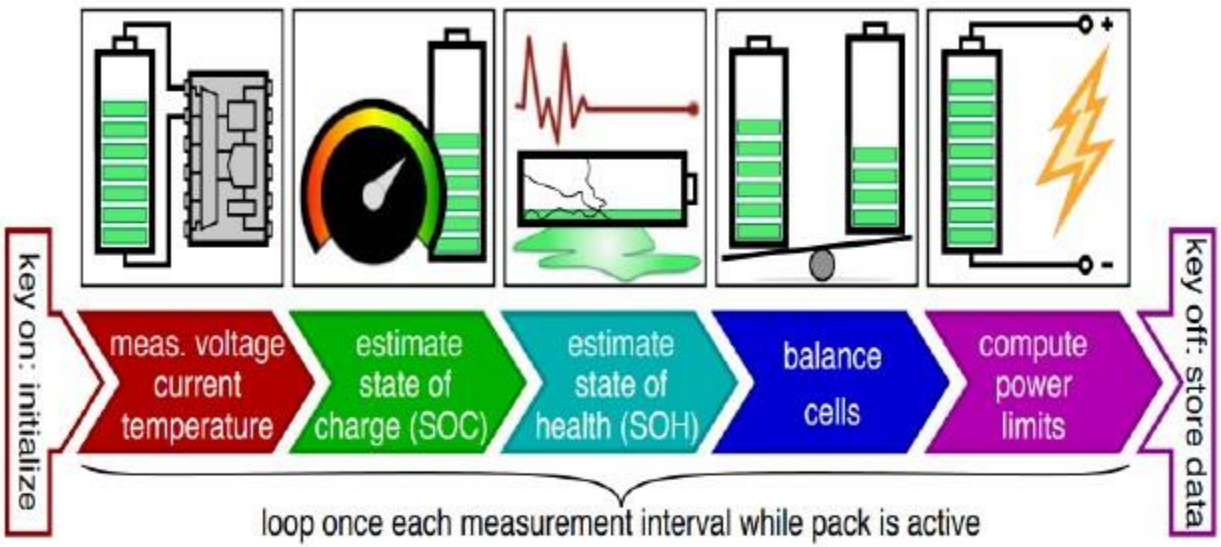
- One way to think about designing protection mechanism for a battery pack are:
  - ✓Current and temperature are input variables
  - ✓Voltage and temperature are input variables (Three degree of protection- V, I, T)



Thermal fuse
Failure zone
Safety margin
Electronic protection
Safe operating zone
Resettable fuse
Magnitude of current
Temperature
Failure zone
Thermal fuse
Electronic prot. (charger)
Electronic prot. (battery)
Safe operating zone
Safety margin
Electronic protection
Electronic prot. (load
Voltage
Temperature

Estimation of cell parameters

FUNCTIONS OF BMS



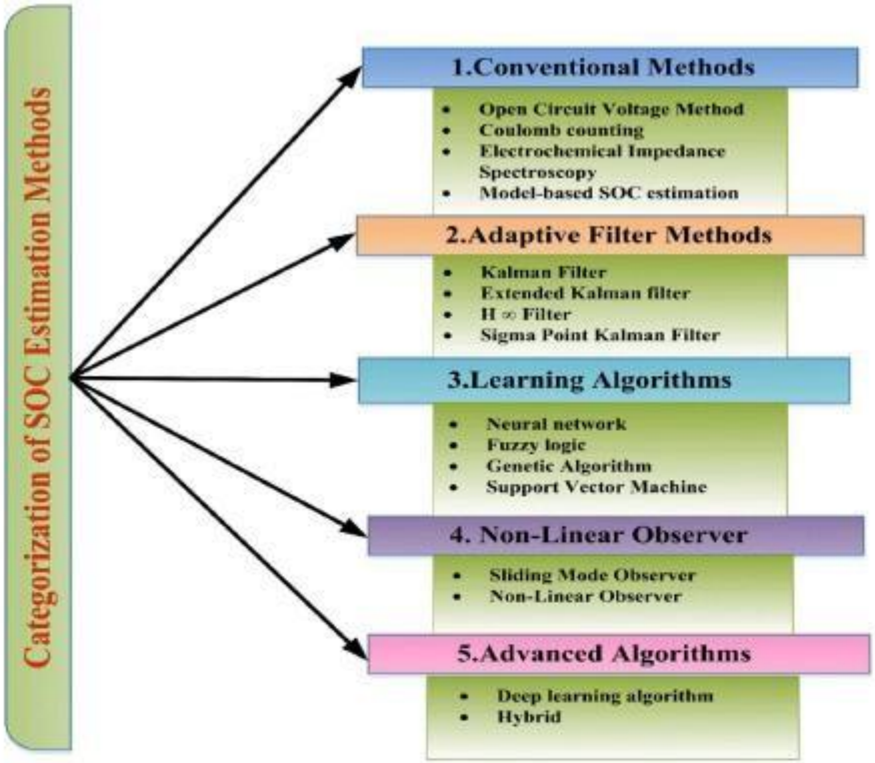
Source: Gregory L Plett, Battery Management and Control

SOC Estimation

- Why estimation of SOC?

- ✓ SOC for the battery back is equivalent to fuel gauge in BEV, HEV, PHEV etc.
- ✓ Estimation of vehicle range
- ✓ Estimation of energy consumption
- ✓ Charge sustaining and depletion modes in HEV
- ✓ To make the cell work in best operating conditions
- ✓ To analyze the battery performance & reliability
- ✓ To increase the life time of the battery
- ✓ Cell parameters are direct functions of SOC
- ✓ Cell balancing strategies are solely dependent on the cell SOC

SOC Estimation strategies



1.Yang, B.; Wang, J.; Cao, P.; Zhu, T.; Shu, H.; Chen, J.; Zhang, J.; Zhu, J. Classification, summarization and perspectives on state-of-charge estimation of lithium-ion batteries used in electric vehicles: A critical comprehensive survey. J. Energy Storage 2021, 39, 102572.

Voltage based strategies

- SOC estimation based on voltage lookup based strategy

- ✓ Converts battery voltage to SOC using the known standard discharge curve
- ✓ Voltage Vs SOC of the battery

- Cons:-
- Voltage is highly affected by the following parameters
  - ✓ Current
  - ✓ Temperature
  - ✓ Chemical kinetics
  - ✓ Operating process
- How to make it more effective?
  - ✓ Can be made more accurate by compensating voltage reading by a correct term proportional to the battery current
  - ✓ By using a look up table of battery 's OCV Vs temperature

Coulomb counting strategy

- SOC estimation based on current integration strategy
  - ✓ Also known coulomb counting methodology
  - ✓ Calculate SOC by measuring the current and integrating it in time
- cons:-
  - ✓ No measurement can be perfect
  - ✓ Suffers from long term drift
  - ✓ Lack of reference point
  - ✓ SOC must be recalibrated on a regular basis- resetting the SOC to 100% to 0%

State of Health

- State of Health is a numerical value of the batteries condition compared to its ideal condition

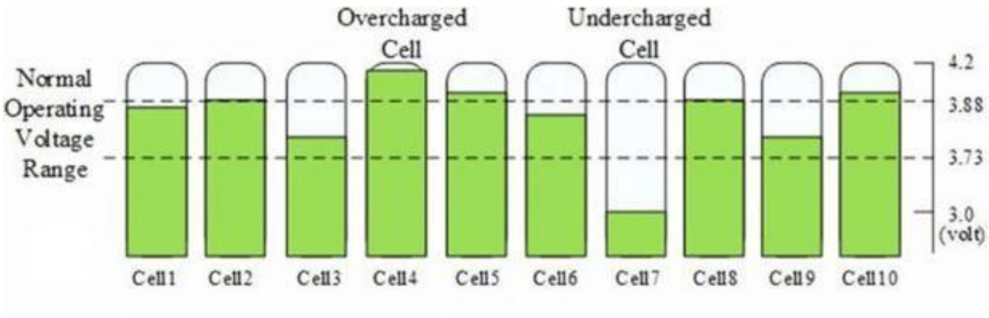
- ✓ 100% SOH means that the battery matches factory specifications
- ✓ Q_{actual} and $Q_{nominal}$ stand for actual capacity and nominal capacity

$$SOH = \frac{Q_{actual}}{Q_{nominal}}$$

Cell balancing

- Why cell balancing?
  - ✓ A battery back is usually made of multiples of individual cells
  - ✓ In practical applications, cell will not have same operating voltage-imbalanced battery pack
  - ✓ Some cells will get overcharged and some cells will under charged

✓ Causes of imbalance: different columbic efficiencies in each cell, difference in discharge current and variation in internal resistance, temperature gradient between cells

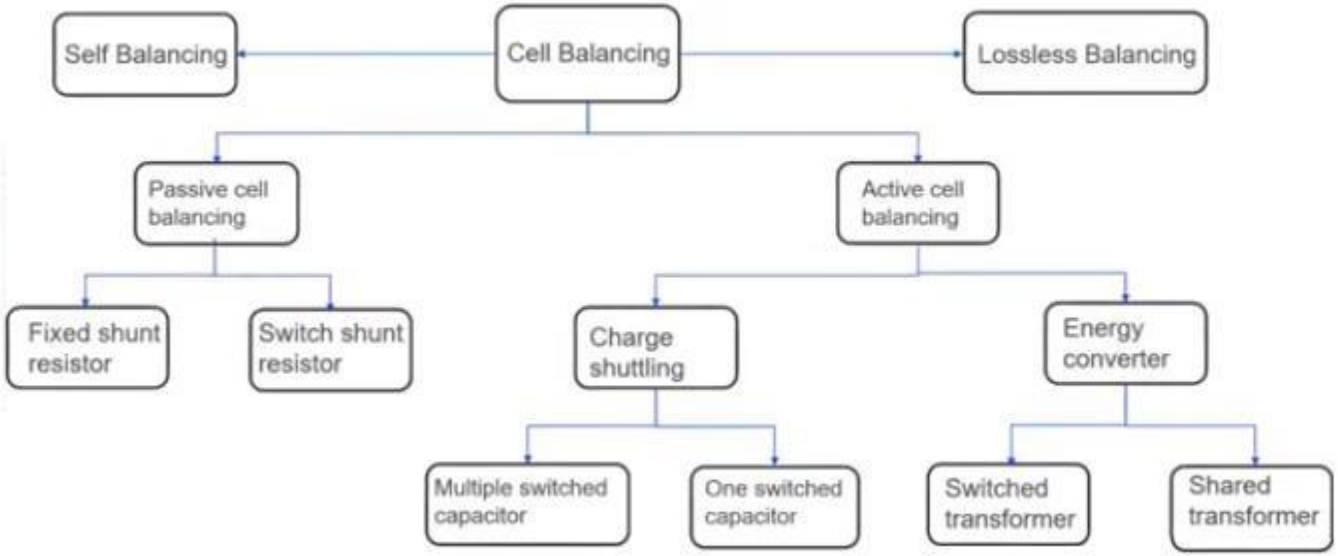


Effects of imbalance:

- ✓Reduction in overall operational life
- ✓Low voltage cell- deep discharge zonePermanent failure
- ✓Over voltage -thermal runaway and gasing Complete voltage profile of battery backcannot be achieved

Cell balancing- Types

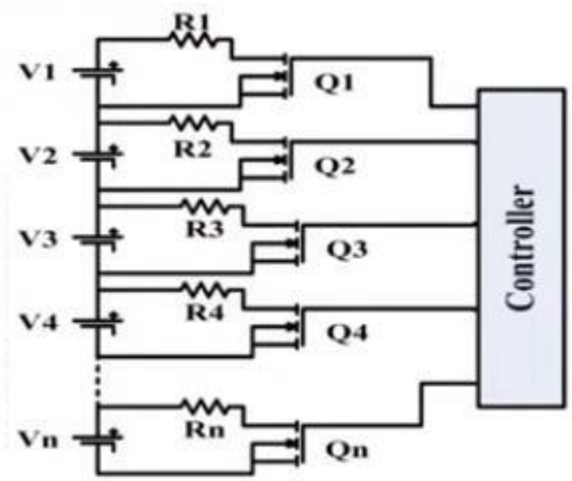
A balanced battery pack is one in which, at some point in its cycle, all the cells are at exactly the same SOC



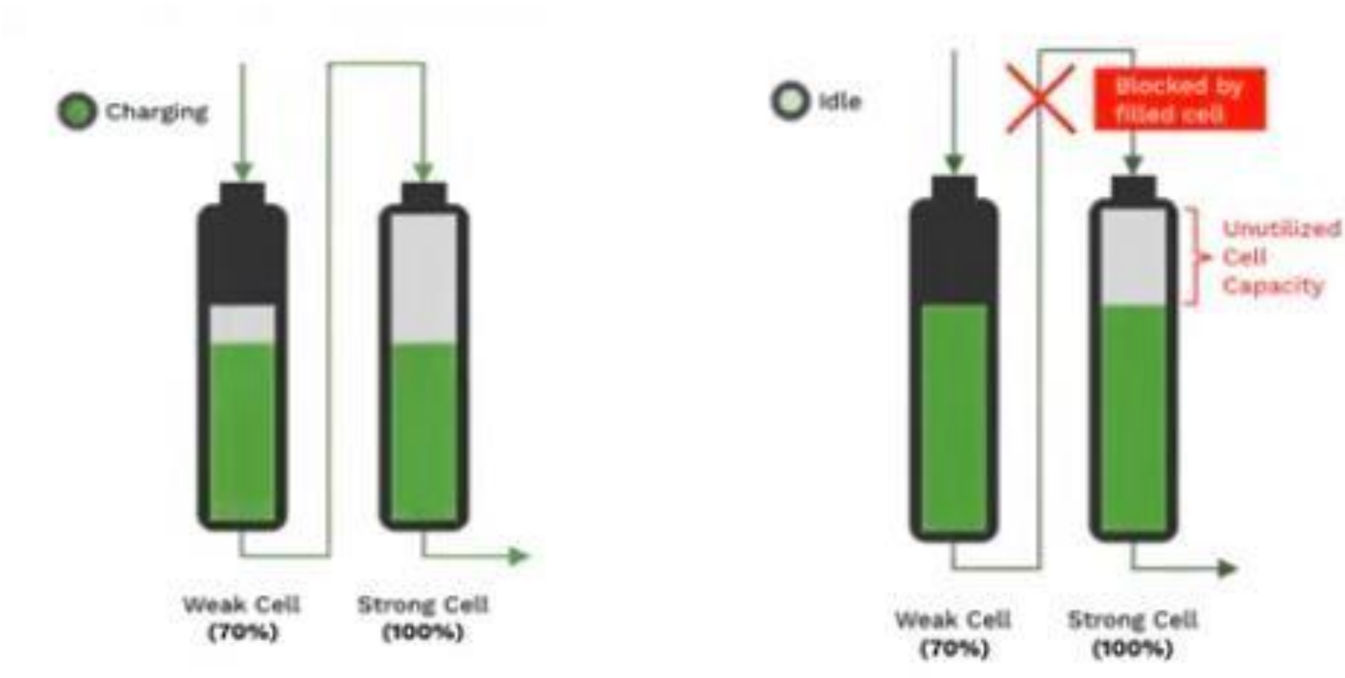
Passive balancing

- Passive balancing works by draining the charge from cells having too much charge with respect to balancing condition and dissipate the drained energy as heat
- Passive circuit element are used to balance the cells

- However, contemporary dissipative balancing circuits uses active components and controls (transistor switching circuits), we prefer the term dissipative balancing to passive balancing



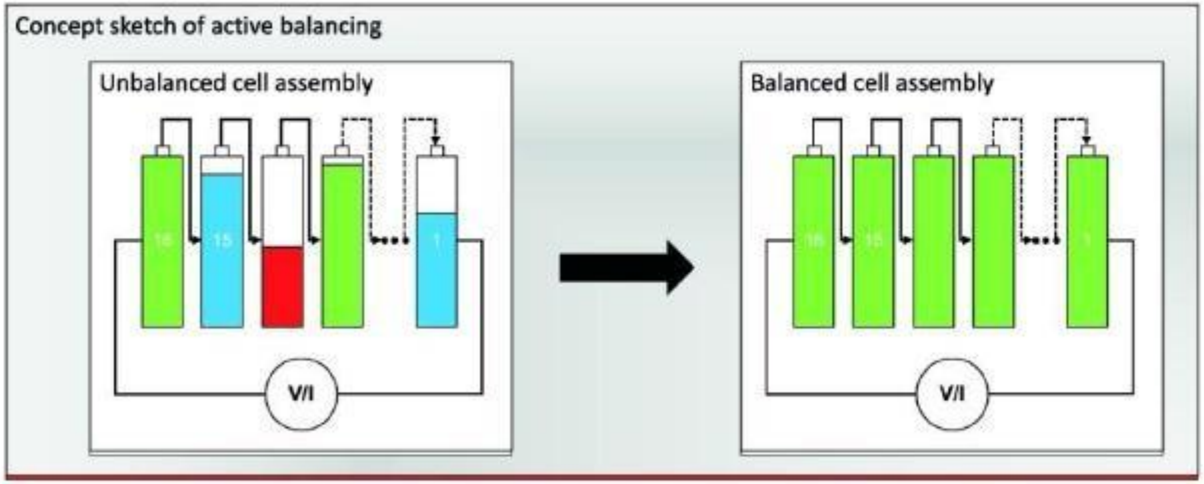
Drawbacks of Passive balancing



Source: https://igrenergi.com/dynamic-balancing/

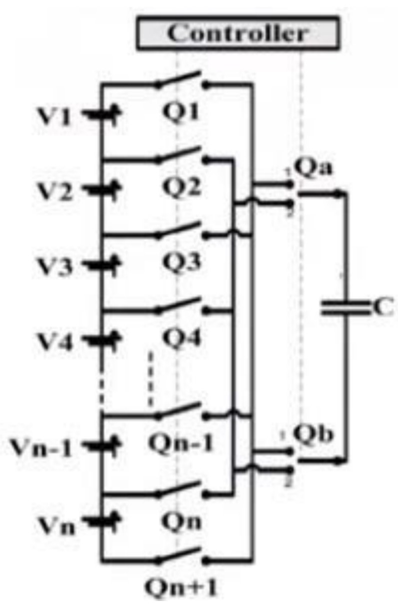
Active balancing

- Non dissipative balancing works by moving the charge from cells having too much charge either to the cells having too little charge or to an auxiliary load circuit
- While dissipating balancing wastes the unusable electrochemical energy stored in some cells by converting to it heat
- Non dissipative balancing attempts to conserve energy by redistributing the charge among cells so that more energy is available to load



Active balancing- single capacitor

- Single capacitor is in parallel with series of cells
- A switch is used to direct flow of energy between the two cells
- Controller responds only difference in energy between two cells by closing the switch
- Energy flow from cell with higher SOC to cells with lower SOC be



- Efficient method and only two cells will be balanced at a time and control is complicated

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Communication protocols

Effective communication interfacing BMS and the application being powered by battery pack

- Charger control
  - ✓ Must be capable of handling random charges
  - ✓ Must be adaptable to different rate of charging depending on electric utility grid
- Communication protocols determines the transmission speed, priority settings, transmission sequence, error detection, and handling control signals
  - ✓ CAN protocol is universally used for on-board vehicle messaging
    - ✓ CAN has an electric specification and packet control.

-
- Logbook functions
  - ✓ For warranty and diagnostic purpose, BMS must store a log of a typical and abuse events.
  - ✓ Mostly stored in a flash memory

Communication protocols

Common protocols used by BMS

-

✓ UART

✓ Serial Peripheral Interface (SPI)

✓ I2C

✓ Control Area Network (CAN) CAN benefits over other protocols:

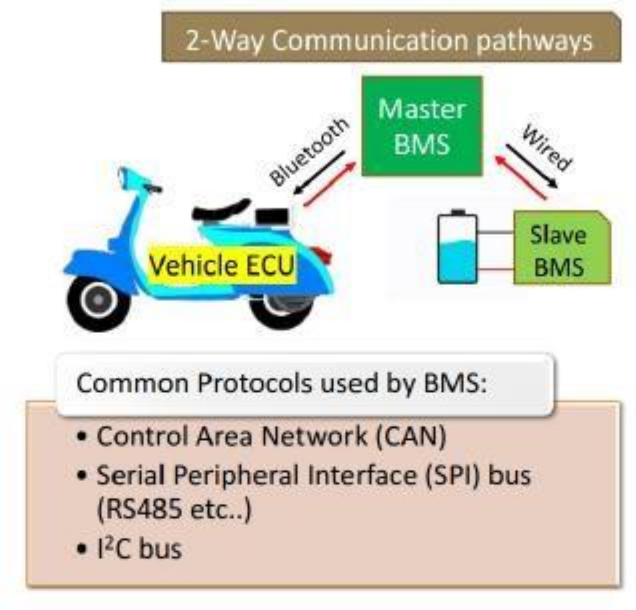
✓ Simple & low cost

✓ Fully centralized

✓ Extremely robust

✓ Efficient

✓ Each ECU is called node, between which the communication occurs



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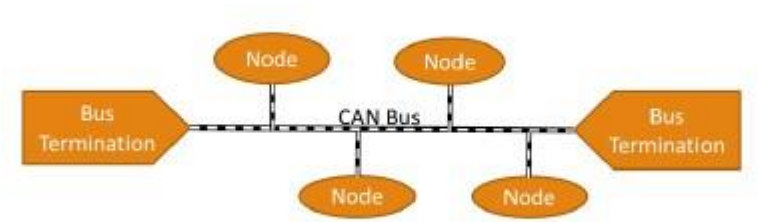


✓

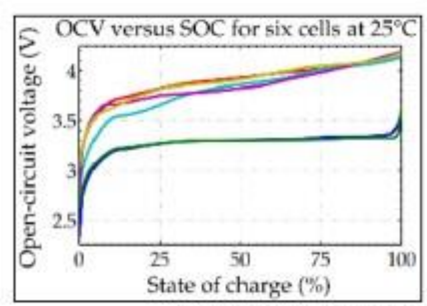
Battery pack performance management

BMS must report regularly regarding

- State of charge
  - ✓ Depends on the average particle concentration on the electrodes
  - ✓ Estimated using the current, coulombic efficiency and cell total capacity

W or kW

- ✓ Mostly stored in a flash memory



Source: BMS, Vol.2, Gregory Platt

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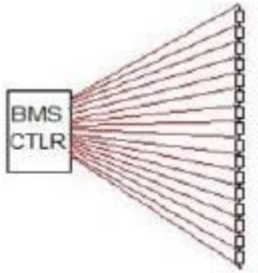
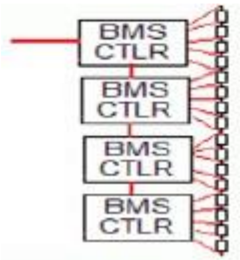
- Energy available
  - ✓ Ability to do work measured in kW or kWh, estimated as a function of OCV and state of charge
  - ✓ Critical input for measuring range of the EV
- Power estimate
  - ✓ Rate at which energy can be moved from the batteries measured in

BMS topology- Application based



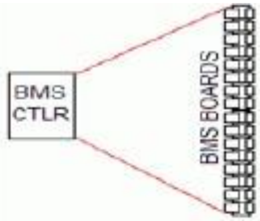
Centralized:

A single controller is connected to the cells through a multitude of wires



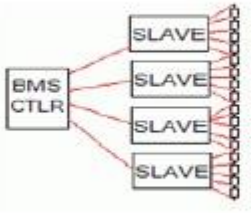
Modular:

A few controllers each handling certain number of cells with communication between the cells



Distributed:

A BMS board is installed at each cells, with only communication cable between battery & controller



Master- Slave:

One master controller is connected to the slaves and the slaves are connected to cells

BMS topology- Pros.& Cons.

BMS Topology	PROS	CONS
Centralized	1.Compactness 2.Feasibility	It can caus complications while troubleshootin and maintenance due to more wires, cables and ports

Modular	1.Reduces computational efforts Increases the room for adding 2.more functionalities	1. Higher overa 2. cost Duplicated unused functionalitie as per application

Distributed	1. Reduces cable bundling 2. Autonomously handle communications and processing	1. High 2. maintenance 3. Higher cost Difficult to troubleshoot because of it deep routing

Master-Slave	1.Lower cost 2.Simpler functionalities	1. Less feature 2. options Not suitable for scaling operations

Management Controller Unit (MCU)

MCU is the brain of the BMS. It is in the form of microcontroller, which takes care of:

- ✓State determination
- ✓Data acquisition &logging
- ✓Pack control- Electrical & Thermal
- ✓Safety protection
- ✓Communication

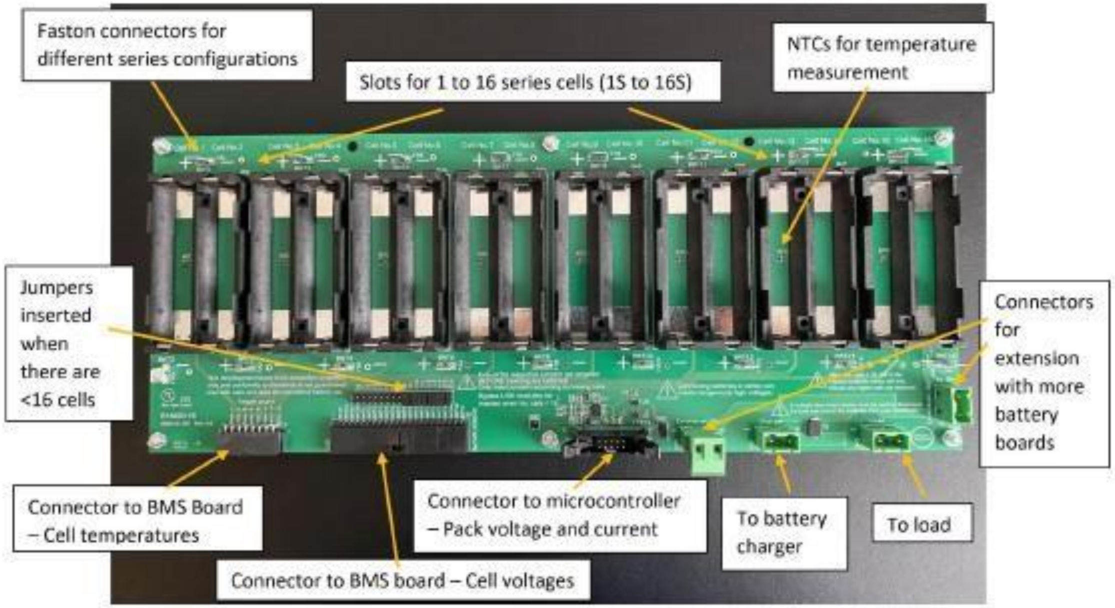
Source: Mouser.com

A BMS usually contains a Master& Slave MCU for redundancy purposes

Latest MCUs can perform wide range of activities like sensing, prediction, control in single SoC

Battery pack

- ✓Allows a flexible setup for the BMS software development
- ✓Multiple boards can be simply connected in series or parallel
- ✓Ease of connecting charger/loads
- ✓Ease of connecting to BMS manufacturer development boards



Source: Using Altair Embed® to Develop a Battery Management System for Electric Vehicle Applications - Embed - Altair Products - Altair Community

POPULAR BMS AVAILABLE IN THE MARKET

- ✓This BMS is perfect for charging a single Li-ion cell.
- ✓The charge current is 1A and supplied by the TP4056 IC and D01 battery protection
- ✓It automatically disconnects the battery from the power supply when finished

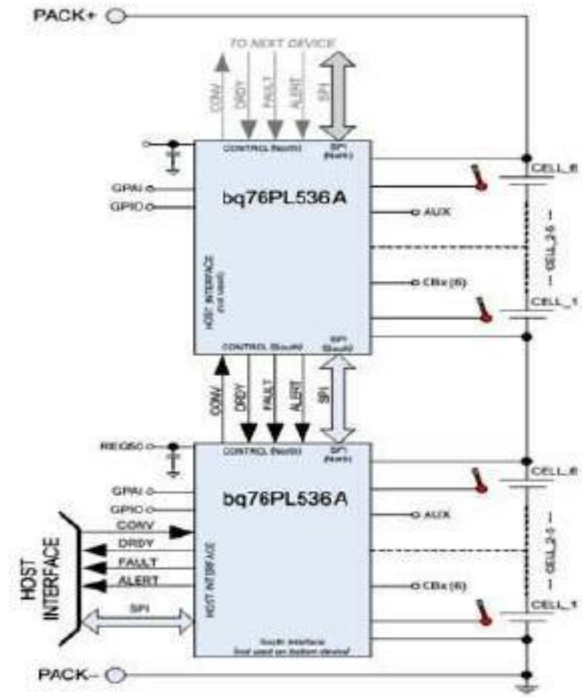
- ✓It is one more popular BMS for single Li-ion batteries
- ✓It comes with short circuit, over-current, over voltage and over discharge protections

Source: Tesla Model S Battery System: An Engineer's Perspective (circuitdigest.com)

BMS used in Tesla Model -S

✓BMS used by Tesla in Model-S is based around Texas Instruments bq76L536A-Q1 3 to 6 series- cell Li-ion battery monitor and secondary protection.

✓The BMS is integrated into every module and monitors the battery life, temperature and charge-discharge cycle of cells.



✓It is a stackable battery monitoring system and uses a high- speed Serial Peripheral Interface (SPI) for data communications. The image shows a simplified system connection of the BMS

- ✓The BMS can communicate with each other using SPI communication
- ✓All the module's BMS act as a slave BMS and communicate with a master BMS via an isolation barrier, the master BMS communicates with the ECU and charger and controls the main contractors

✓The BMS is placed on a side of every battery module and the cell voltage measurement is performed using wire welded to the connecting plates of the parallel connection.

Summary- BMS Design

A Well designed BMS :

- Good Resolution of Measurements @ Cell & Pack Level.
- Maintain equal SoH in every Cell.
- Highest Safety Level – Actively Shut Down in extreme scenarios.
- Predict & warn user of degrading Events.
- Control Auxiliary Systems for Efficient Pack Operation.

It can Measure:

- Voltages
- Current
- Temperatures (Cell and Ambient)
- SoC
- SoH

Can Maintain connection with

- ECU
- Motor
- Sensor feedback
- Slave units

Avoids the battery pack from:

- Abuse
- Accidents
- Thermal runaways
- And give proper log of every activity