# ENERGY STORAGE AND BATTERY MANAGEMENT SYSTEMS IN ELECTRIC VEHICLES – part 2

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# LEARNING OUTCOMES

By mastering this subject, the students will be able to:

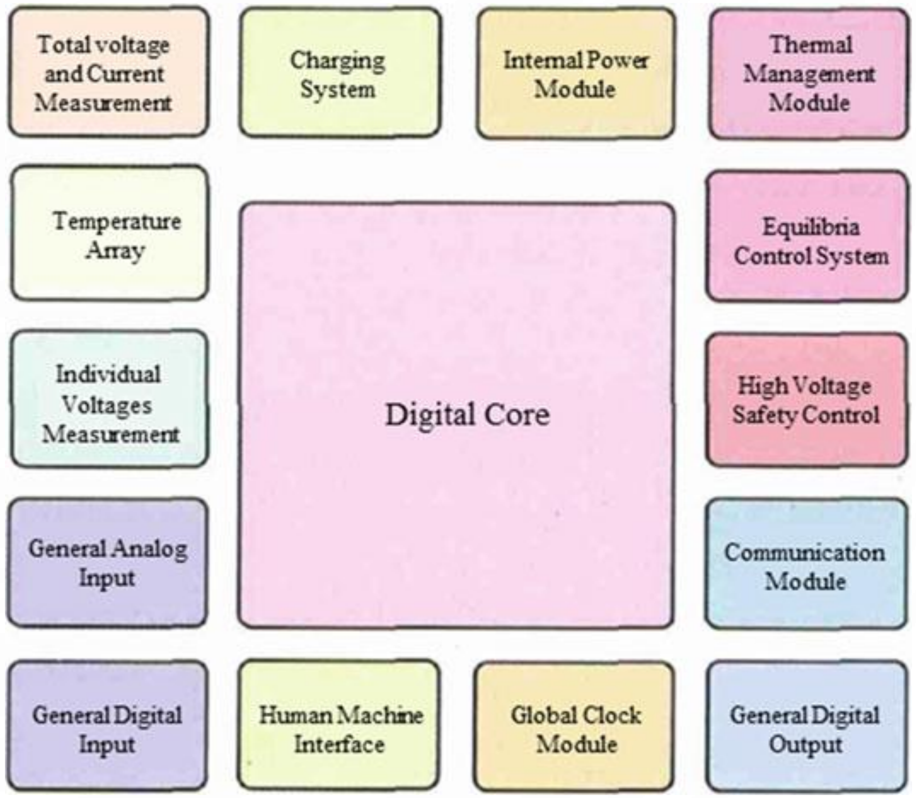
- Understand different storage media for electricity, especially regarding power density, delivered power, maintenance, cost, safety, and environmental impact.
- Understand basic principles and challenges with different charging principles.
- Understand operating principles of battery management systems in electric vehicles.

# SUBJECT CONTENT

1. Introduction on energy storage systems in EV
2. Key technologies of storage media for electricity in EV
3. Basic parameters for evaluating energy storage systems
4. Power batteries as the main energy storage part in electric vehicles
5. Operation Principle and Types of Power Batteries
6. Performance Parameter of Power Battery
7. Battery Model
8. Key Technologies of Battery Management System (BMS)
9. Key parameter calculations with BMS
10. Monitoring and Estimating Battery parameters
11. State Estimation Methods
12. Optimized Charging Management
13. Thermal Management and Thermal Safety
14. Internal and external communication
15. Cloud Battery Management System

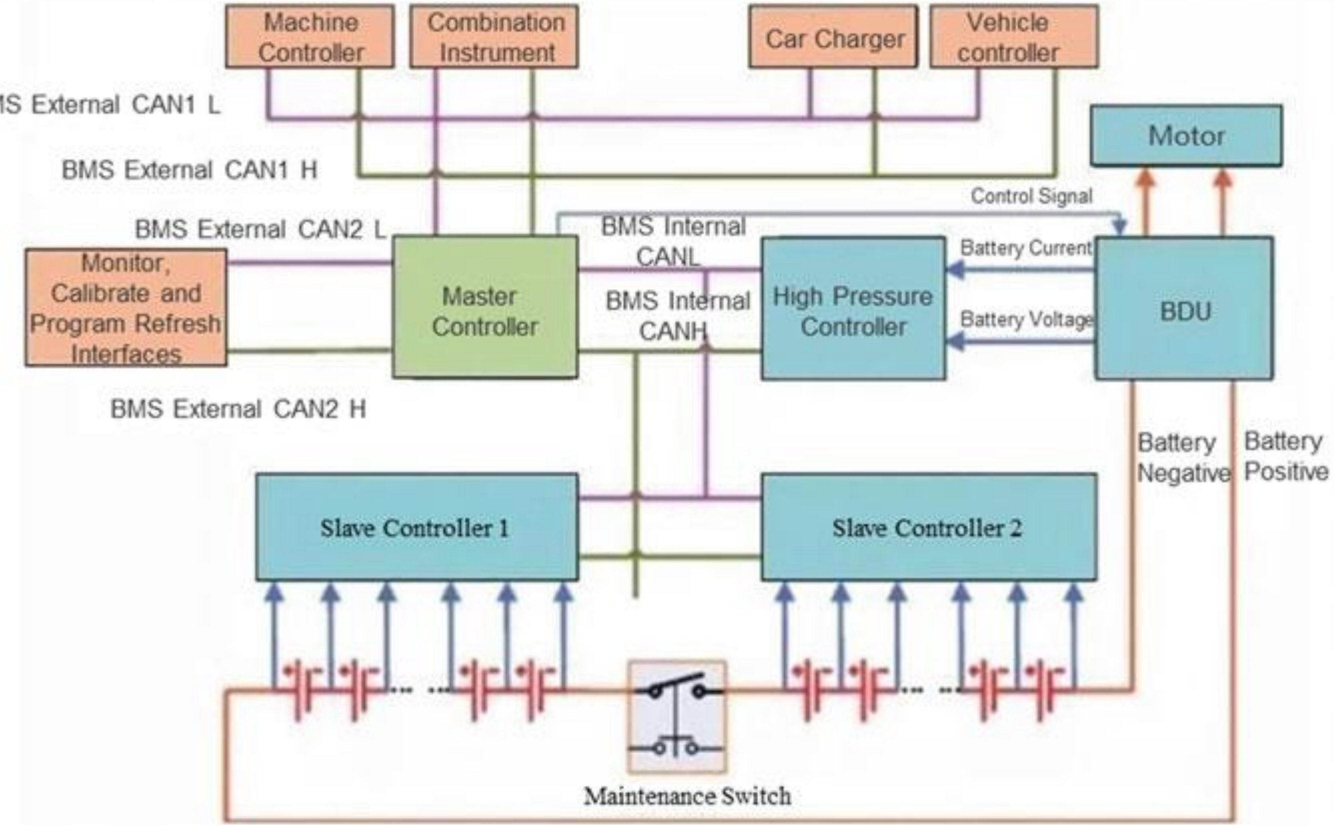
# 8. KEY TECHNOLOGIES OF BATTERY MANAGEMENT SYSTEM (BMS)

- The main differences between traditional fuel vehicles and electric vehicles are that electric vehicles are powered by batteries. Power batteries are the indispensable parts of electric vehicles.
- Battery Management System (BMS) is the core technique for battery packs.
- BMS is designed to improve safety, reliability of batteries, increase discharge rate, extend lifetime and prolong mileagues.
- BMS is a significant connection of battery pack, whole vehicle system and motor.
- BMS optimize the power and mileague for electric vehicle since single cell has limited capacity and voltage.
- BMS monitors battery modules and manages batteries according to battery parameters such as current, voltage, internal resistance and capacity.



# 8. KEY TECHNOLOGIES OF BATTERY MANAGEMENT SYSTEM (BMS)

- Schematic diagram of BMS distributed architecture

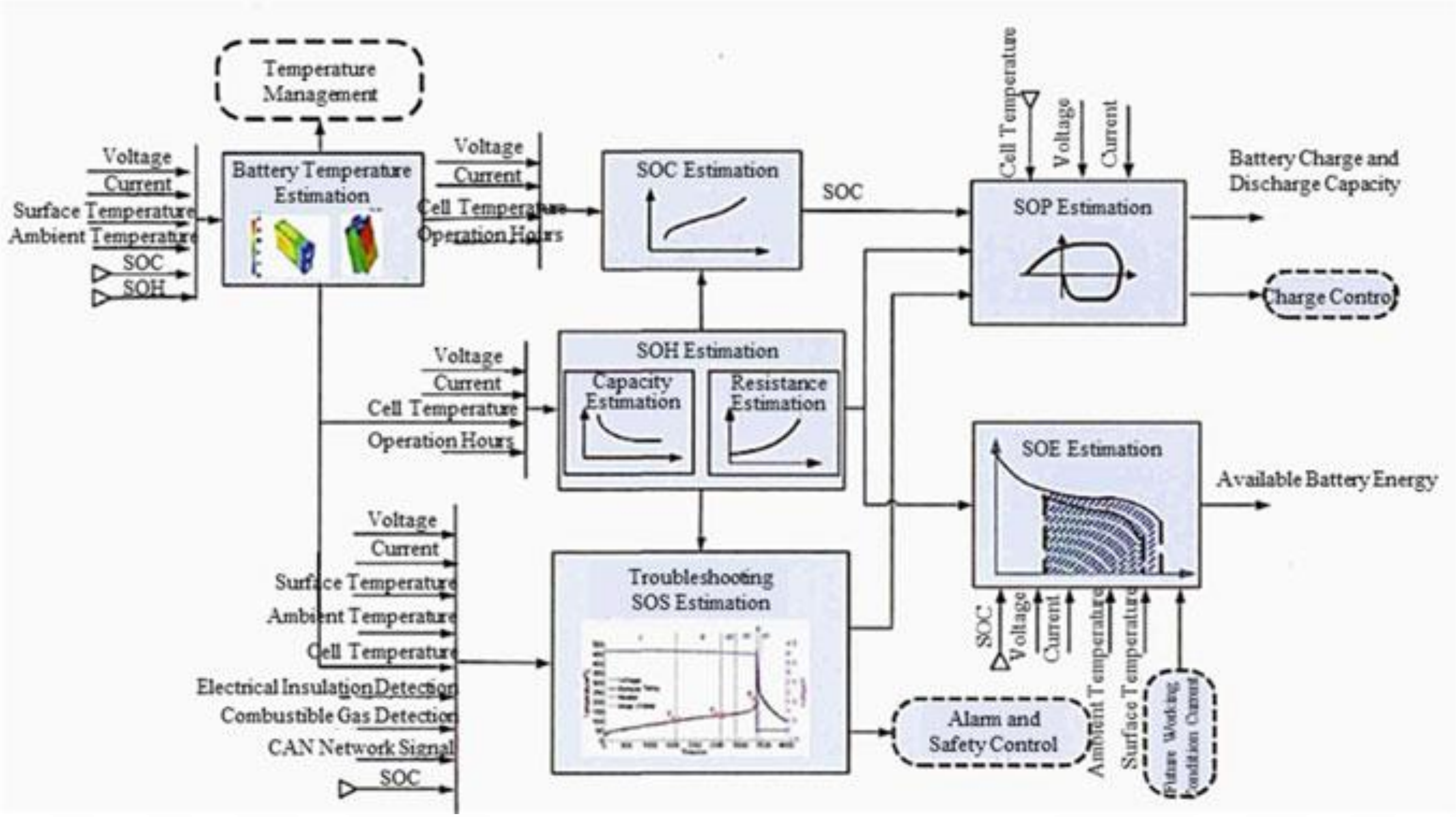


# 9. KEY PARAMETER CALCULATIONS WITH BMS

- There are many parameters to describe battery performances, such as voltage, capacity, internal resistance, temperature and current.
- Information on battery voltage, current, charging state, insulating resistance and switches are collected by main controller.
- Slave controller collects real-time voltage and temperature and upload them.
- Battery states include state of charge (SOC), state of health (SOH), state of power (SOP), state of safety (SOS) and state of energy (SOE).
- SOC is one of the most important parameters of BMS and provides the reference on charge/discharge and balancing controlling. SOH provides information on usage, maintenance and economy. SOS, SOF and SOE describe the battery from the aspects of safety, function and energy, respectively.

# 9. KEY PARAMETER CALCULATIONS WITH BMS

- BMS state estimation algorithm framework



# 10. MONITORING AND ESTIMATING BATTERY PARAMETERS

Monitoring and estimating battery parameters refers to the processes of measuring and predicting the key states and parameters of a battery in real time, usually within the Battery Management System (BMS).

- Monitoring (directly measurable parameters) - These are quantities that can be measured with sensors:
  - Cell/pack voltage (V) – fundamental parameter, used for control and protection.
  - Current (A) – measured via shunt resistor or Hall-effect sensor.
  - Temperature (°C) – crucial for safety and thermal management.
  - Pressure / expansion (in some chemistries) – additional safety indicator.

  Monitoring provides basic measurable data, but it is not enough to describe the internal condition of the battery.
- Estimating (internal parameters and states) - These are not directly measurable and must be estimated using models/algorithms:
  - State of Charge (SoC) - Estimate of how much energy remains in the battery (%)
  - State of Health (SoH) - Degree of degradation compared to a new battery (%)
  - State of Power (SoP) - Maximum power the battery can currently deliver or accept
  - State of Energy (SoE) - Remaining usable energy, often used alongside or instead of SoC
  - Internal Resistance / Impedance - Key for thermal calculations and degradation assessment

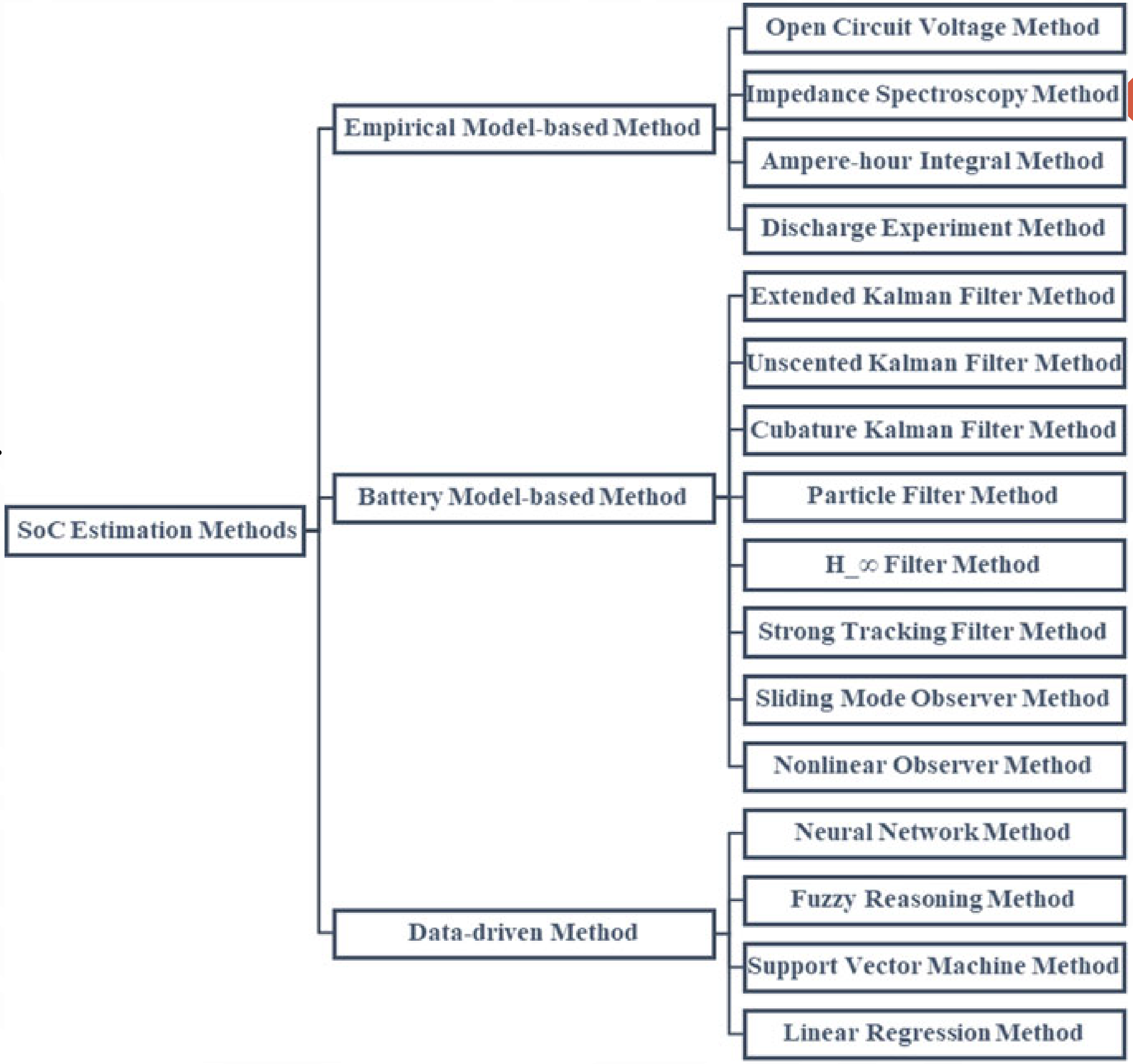
# 10. MONITORING AND ESTIMATING BATTERY PARAMETERS

- Estimation methods and algorithms
  - Model-based:
    - Equivalent Circuit Models (Thevenin, RC models),
    - Physics-based Electrochemical models.
  - Observer-based:
    - Kalman filters (EKF, UKF, Adaptive KF),
    - Luenberger observers.
  - Data-driven / AI-based:
    - Machine Learning,
    - Neural Networks,
    - Fuzzy Logic – increasingly applied in modern BMS.

# 11. STATE ESTIMATION METHODS

- SOC Estimation - Battery state of charge (SOC) is the ratio between the battery's remaining charge and the total charge capacity. The SOC is not directly measurable. It can be calculated under a fixed discharge rate according to the 'Battery Test Procedure for Electric Vehicle' by the Advanced Battery Consortium of America:

$$SOC(t) = SOC(0) - \int_0^t \frac{\eta_i i(t)}{Q_N} dt$$



# 11. STATE ESTIMATION METHODS

- SOH Estimation - The battery energy and power capacities will decrease with ageing. The ageing indicator, state of health (SOH), is of great significance to the battery safety, the EV's performance and the user's driving experience. Once the SOH drops below a threshold value, the battery needs to retired from EV to prevent safety hazards.
- The battery's capacity and resistance, which determine the battery's energy and power capacities, are widely used for SOH estimation in practical applications.
- SOH definition using capacity (Qaged is the current capacity, and Qnew is the nominal capacity at beginning of life)

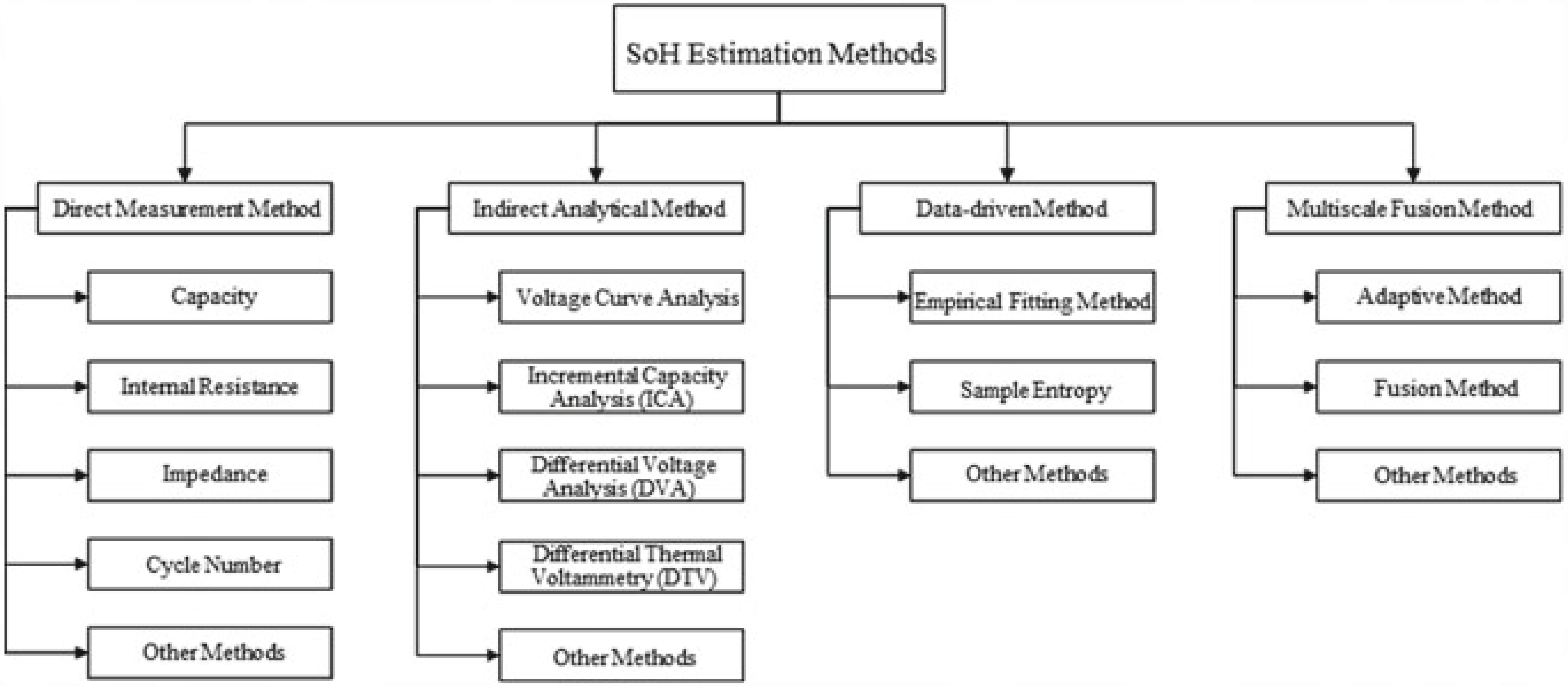
$$SOH = \frac{Q_{\text{aged}}}{Q_{\text{new}}}$$

- SOH definition using resistance ($R_{EOL}$ is the battery resistance at end of life, Rnew is the resistance at beginning of life, and R is the current resistance)

$$SOH = \frac{R_{\text{EOL}} - R}{R_{\text{EOL}} - R_{\text{new}}}$$

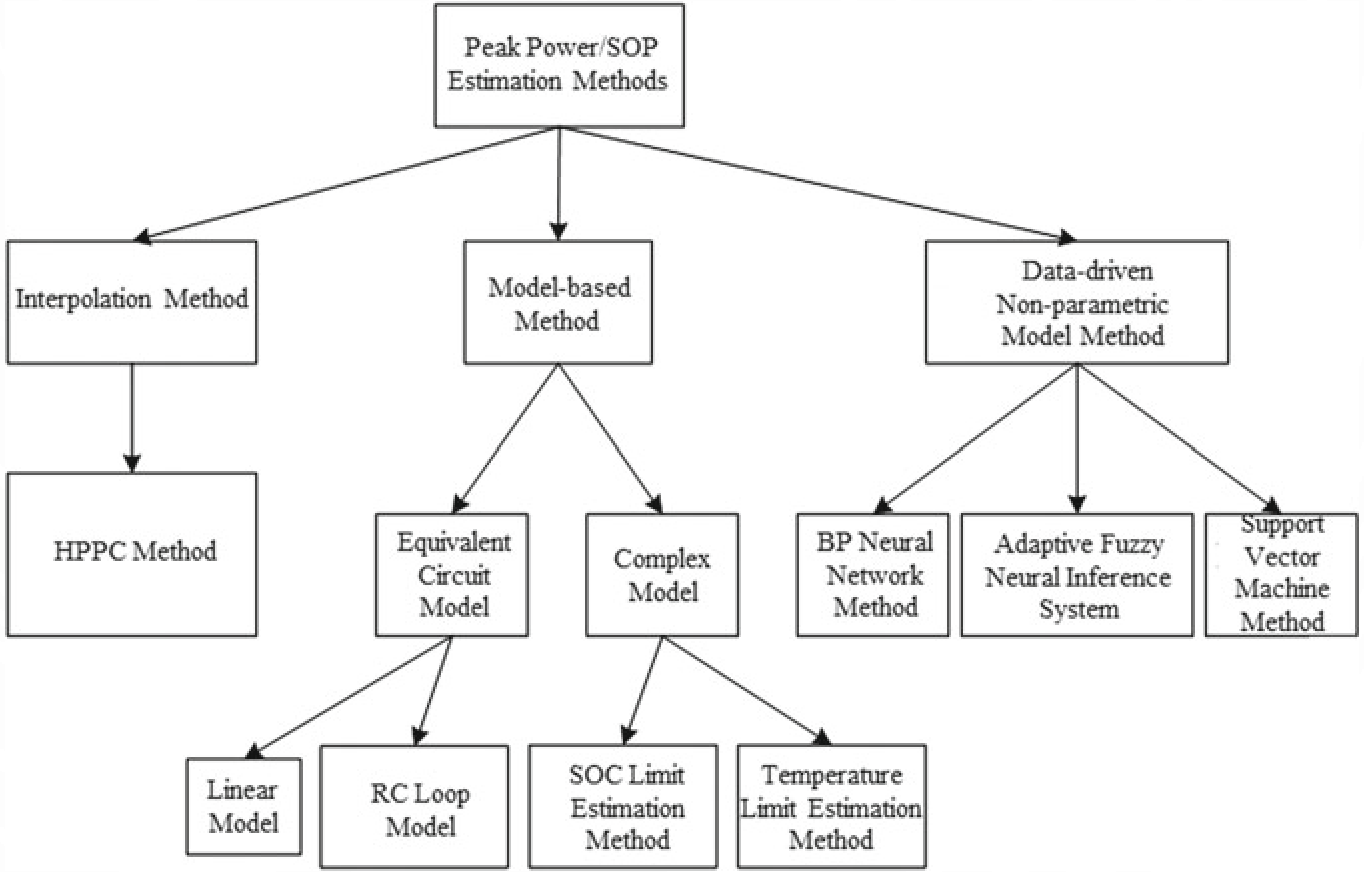
# 11. STATE ESTIMATION METHODS

- Classification of SOH estimation methods



# 11. STATE ESTIMATION METHODS

- SOP Estimation - State of power (SOP) is an important parameter for EVs, especially hybrid EVs, for safety control and regenerative braking. SOP represents the battery's peak power capacity within a time window. The accurate SOP estimation is important for optimizing the power management of the vehicle while ensuring battery safety during acceleration, regenerative braking and climbing.



# 11. STATE ESTIMATION METHODS

- SOE Estimation
  - State of Energy (SOE) Estimation - The SOE is the ratio between the battery's remaining energy to the nominal energy.

$$SOE = \frac{E_{remaining}}{E_{rated}}$$

  - Erated is the nominal energy. Erated is the total output energy of the battery from fully charged state to end of discharge at a specific current rate.
  - Eremaining is the battery's remaining energy, which is the total energy output of the battery from current state to end of discharge at the specific current rate.

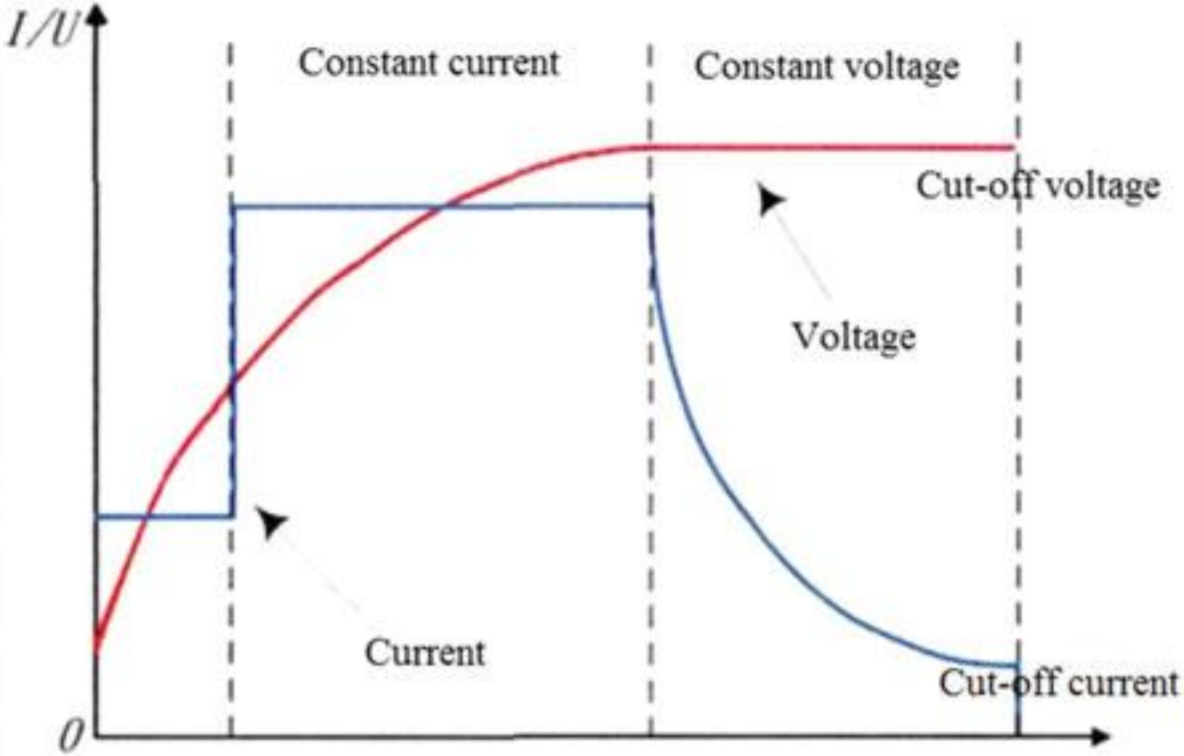
# 11. STATE ESTIMATION METHODS

- SOS Estimation
  - State of Safety (SOS) Estimation - Fault diagnosis is key to ensuring battery safety. According to the BMS standard IEC/TR361431, the BMS in EVs must have diagnostic functions, including ageing diagnosis and early warning of battery failures.
  - The BMS needs to evaluate the battery's SOS and the fault level, which is key to battery monitoring. The thermal runaway is the major cause to severe battery accidents. Therefore, there is an urgent need for accurate SOS estimation methods for thermal runaway prediction. The main causes to thermal runaway include overtemperature, over discharge and internal short-circuit, etc. The boundary conditions of battery thermal runaway can be obtained by studying the mechanisms of battery overtemperature and internal short-circuit.

# 12. OPTIMIZED CHARGING MANAGEMENT

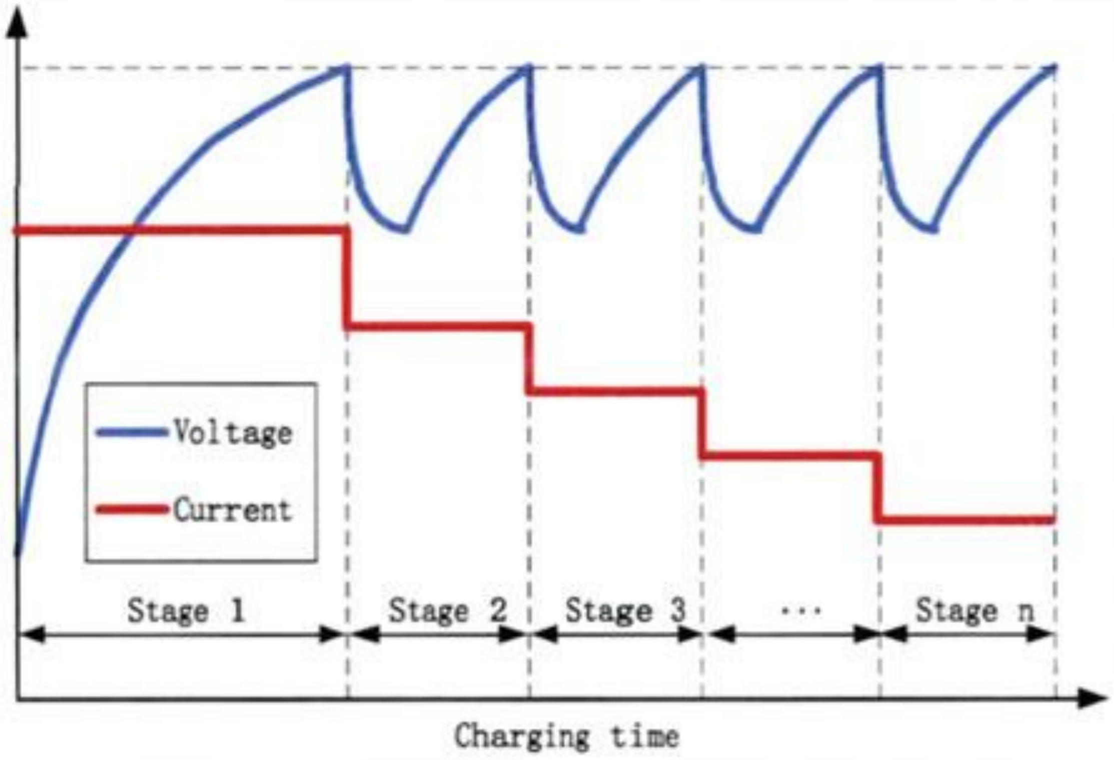
- The charging protocols for electrical vehicle include constant current – constant voltage (CC-CV) charging, multi-stage constant-current charging and pulse charging.

  - Constant Current-Constant Voltage (CC-CV)



# 12. OPTIMIZED CHARGING MANAGEMENT

- The charging protocols for electrical vehicle include constant current – constant voltage (CC-CV) charging, multi-stage constant-current charging and pulse charging.
  - Multi-Stage Constant-Current Charging



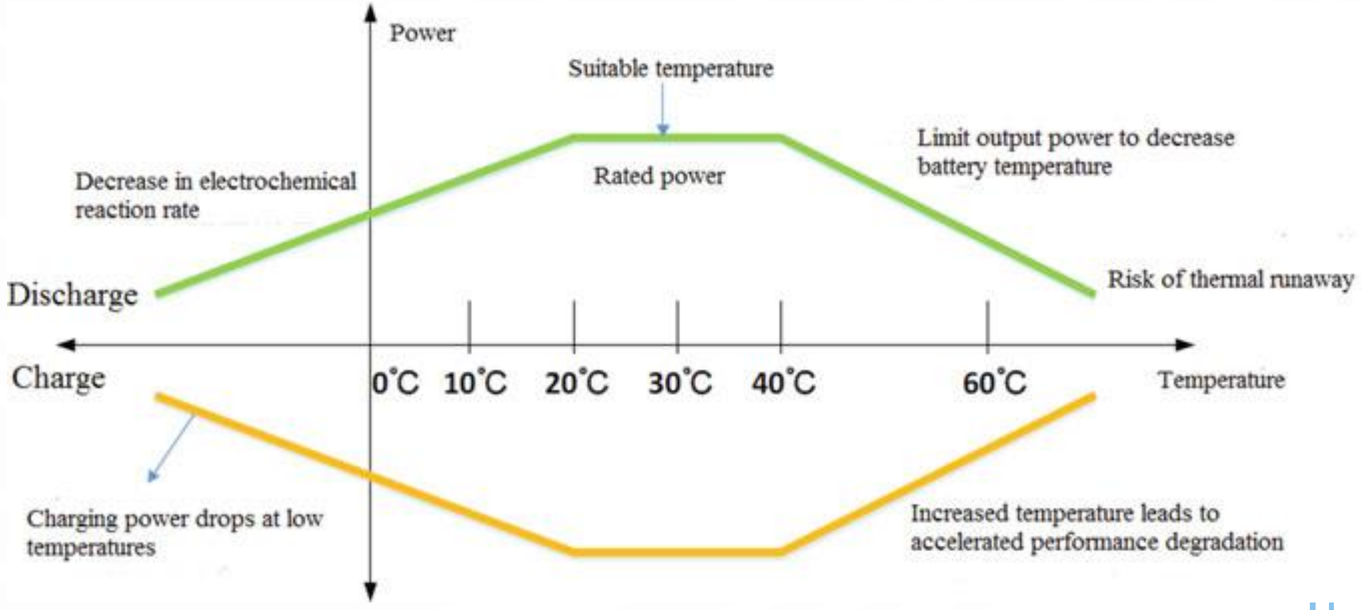
# 12. OPTIMIZED CHARGING MANAGEMENT

- Model-Based Charging Optimization Method
  - The key aspects in battery charging management include reducing charging time, prolonging cycling lifetime and improving stored energy.
  - To Shorten the Battery Charging Time as the Optimization Goal (The charging time can be optimized by limiting maximum current, temperature and side reaction rates.) – Usage of fuzzy controllers etc.
  - To Extend the Battery Cycle Life as the Optimization Goal (Cycling lifetime has always been a bottleneck for the development of lithium-ion battery. The lifetime is relevant with the working condition and charging methods etc. Optimized charging technique considering the cycling lifetime is a significant aspect of the charging scheme.)
  - To Improve Battery Storage Energy as the Optimization Goal (Stored energy (or energy density) of lithium-ion battery is considered the most significant on certain applications, which cannot be realized by CC-CV charging. Optimization charging protocols targeting at energy density is to be developed.)
    - Dynamic optimization based on electrochemical models
    - Optimization based on preset currents

# 13. THERMAL MANAGEMENT AND THERMAL SAFETY

- Temperature has a significant effect on capacity, impedance, maximum charge/discharge rate and degradation of lithium-ion battery.
- The thermal gradients will accelerate the inhomogeneity within the battery and are detrimental to battery performances.
- Generally, the effects of temperature on electrical vehicles are:
  - discharge performance is exasperated in low temperature,
  - degradation is accelerated in high temperature,
  - inhomogeneity can be increased and
  - safety reliability is reduced.

The influence of temperature on the temperature and safety of lithium-ion batteries

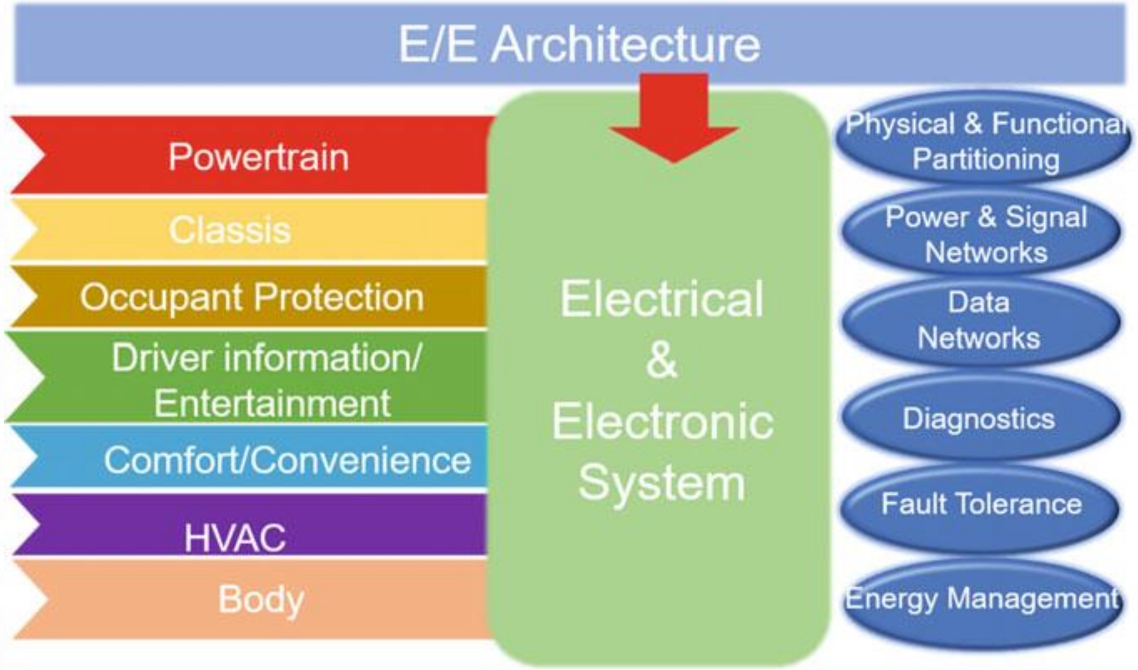


# 14. INTERNAL AND EXTERNAL COMMUNICATION

- Data communication is one of the most significant parts of BMS.
- Apart from the real-time communication between motherboard and slave board, there are communication inputs to BMS from vehicle controller, charging controller, DCDC, dashboard, gateway and motor etc. Until now, CAN is adopted for external communication. CAN is a serial communication way that supports distributed control or real-time control.
- CAN and daisy chain are adopted for internal communication. CAN is robust but its cost is high. Daisy chain is not suitable for long-range communication and is applied more in HEV.
- Wireless communication or power line carrier can be made on intelligent battery modules. Both ways reduce BMS space and reduce the complexity of internal circuits.

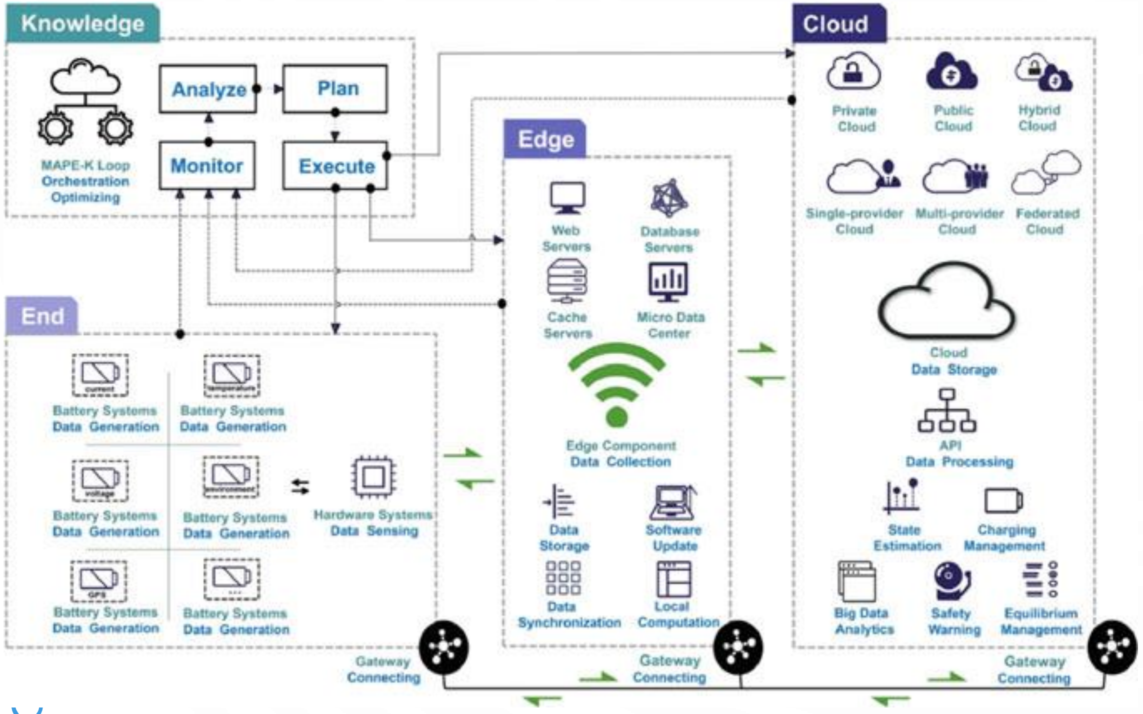
# 15. CLOUD BATTERY MANAGEMENT SYSTEM

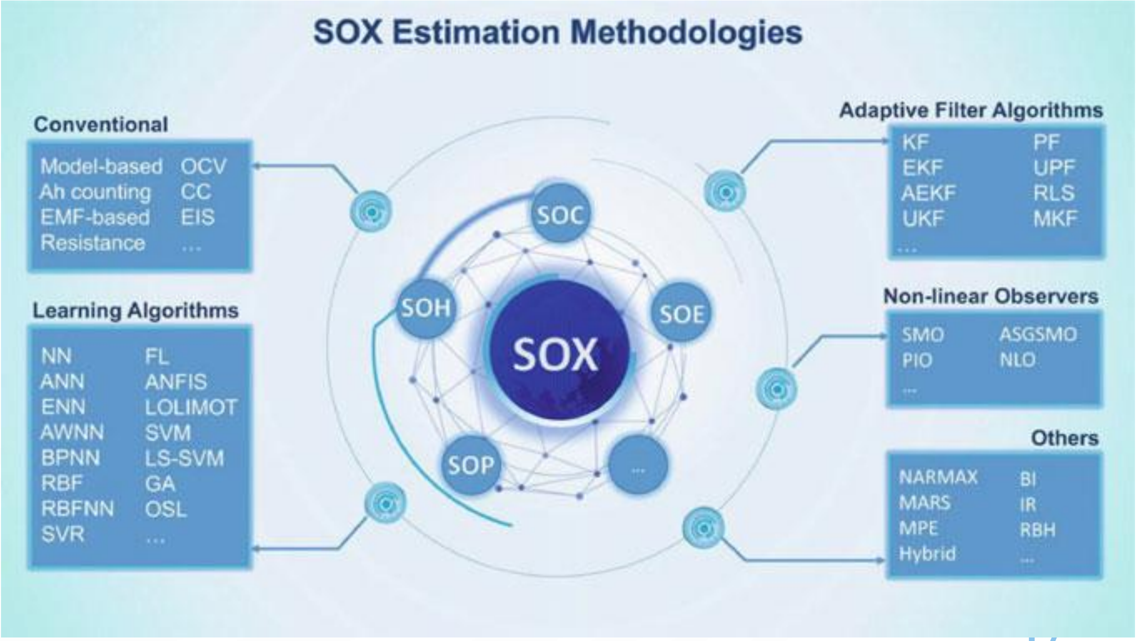
- An intelligent battery management system is a crucial enabler for energy storage systems with high power output, increased safety and long lifetimes.
- With recent developments in cloud computing and the proliferation of big data, machine learning approaches have begun to deliver invaluable insights, which drives adaptive control of battery management systems (BMS) with improved performance.
- Cloud-based BMS leverages from the Cyber Hierarchy and Interactional Network (CHAIN) framework to provide multi-scale insights, more advanced and efficient algorithms can be used to realize the state-of-X estimation, thermal management, cell balancing, fault diagnosis and other functions of traditional BMS system.



# 15. CLOUD BATTERY MANAGEMENT SYSTEM

- Cloud Battery Management System Module and Function



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