

# ADVANCES IN BATTERY MANAGEMENT SYSTEM

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**ABSTRACT:** The second-generation hybrid and Electric Vehicles are currently leading the paradigm shift in the automobile industry, replacing conventional diesel and gasoline-powered vehicles. The Battery Management System is crucial in these electric vehicles and also essential for renewable energy storage systems. This review paper focuses on batteries and addresses concerns, difficulties, and solutions associated with them. It explores key technologies of Battery Management System, including battery modelling, state estimation, and battery charging. A thorough analysis of numerous battery models, including electric, thermal, and electro-thermal models, is provided in the article. Additionally, it surveys battery state estimations for a charge and health. Furthermore, the different battery charging approaches and optimization methods are discussed. The Battery Management System performs a wide range of tasks, including as monitoring voltage and current, estimating charge and discharge, equalizing and protecting the battery, managing temperature conditions, and managing battery data. It also looks at various cell balancing circuit types, current and voltage stressors, control reliability, power loss, efficiency, as well as their advantages and disadvantages. The paper also discusses research gaps in battery management systems.

## 1.INTRODUCTION

The effects of fossil fuel depletion on the ecosystem have increased the urgency to transition to renewable energy sources and alternative transportation technologies. The excessive extraction and utilization of fossil fuels result in the generation of significant quantities of CO<sub>2</sub> and other greenhouse gas emissions (GHGE). Utilizing renewable energy sources and electrifying the transportation sector, as shown in Fig.1, can reduce the GHGE by up to 40%. Renewable energy, such as solar, wind, wave, and tidal power provides a greener, more sustainable alternative to fossil fuels [1]. However, the intermittent nature of these energy sources poses a challenge to maintaining a

consistent and reliable power supply. To tackle this challenge, energy storage systems (ESSs) are utilized to store surplus energy generated from renewable sources during peak production periods and release it to the grid during high demand or when renewable energy generation is low.

The ESSs play a crucial part in boosting the viability and stabilizing the power grid of the widespread adoption of renewable energy sources. EV (shown in Fig.2) and hybrid electric vehicles (HEVs) have gained popularity as potential replacements for automobiles powered by internal combustion engines, offering numerous benefits such as reduced greenhouse gas emissions, decreased air pollution, and improved energy efficiency.

EVs and HEVs are powered by batteries, which offer features include high energy density, low environmental impact, and durable performance. The wider adoption of EVs depends on advancements in battery technology. Efforts are being made to enhance energy storage capacity, reduce charging times, and lower costs. Currently, Lithium-ion (Li-ion) batteries are the most prevalent type used in EVs due to their favourable characteristics, but researchers are also exploring other battery chemistries as shown in Fig.3.

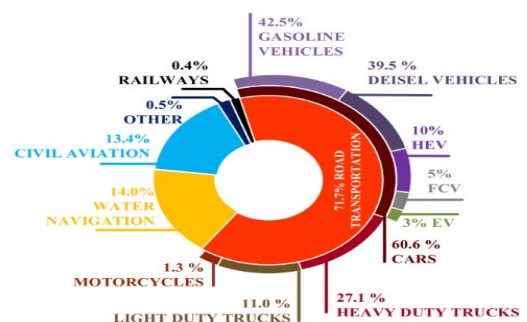
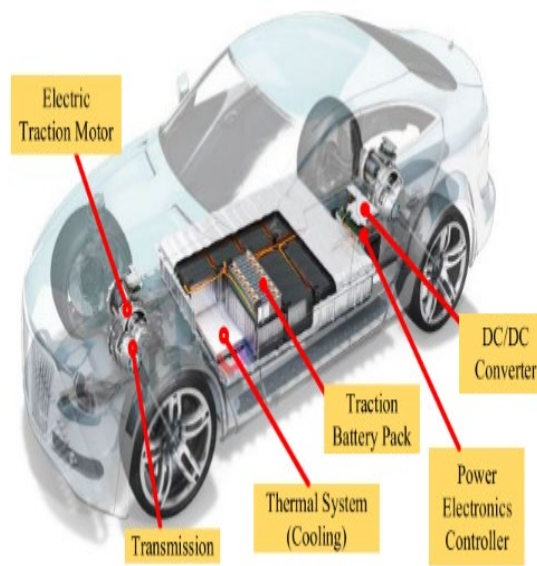
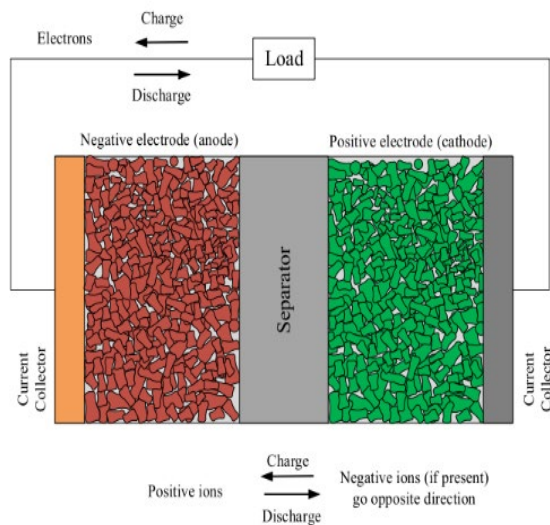


FIGURE 1. Vehicle CO<sub>2</sub> emission levels.



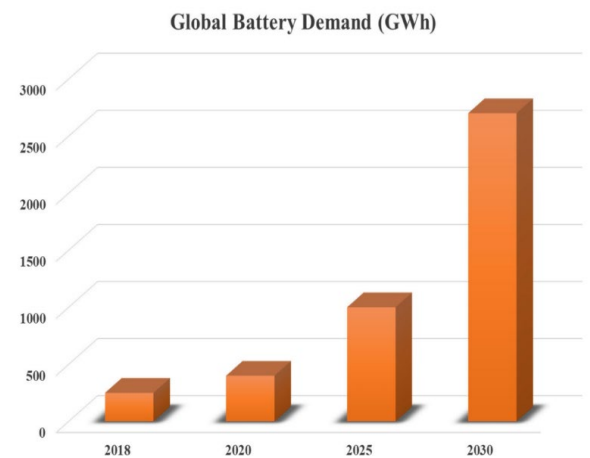
**FIGURE 2. A standard electric vehicle.**



**FIGURE 3. Schematic diagram of Li-ion cell.**

This concept allows EVs not only to consume energy but also to function as energy storage systems, actively engaging with the electrical grid. During periods of low demand or high renewable energy generation, EVs can supply stored electricity back to the grid, thereby assisting in balancing supply and demand and promoting grid stability. Fig. 4 demonstrates the worldwide battery industry's explosive expansion, projecting a surpass of 2500 GWh within the next decade [17]. Fig. 4 (b) showcases the increasing demand for batteries

across different applications and regions, with electric mobility being a major driving force behind the growth of the modern battery industry. The popularity of electric and alternative fuel vehicles is accelerating the research and development of battery materials and automotive technology, which supports smart mobility. China has made plans to meet its peak emissions before 2030, in keeping with the global goal of achieving carbon neutrality. To make electric vehicles comparable to fossil fuel vehicles, Li-ion Batteries (LIBs) are expected to come to an energy density goal of approximately 500 Wh kg<sup>-1</sup> for EV applications. Numerous electric car models have made extensive use of both Li-ion batteries and nickel-metal hydride (Ni-MH) batteries [2]. The popularity of Li-ion batteries stems from their improved reliability, power density, energy density, and efficiency [3]. Additionally, the decreasing manufacturing costs of Li-ion batteries have contributed significantly to their widespread commercialization, enabling their adoption across multiple industries. Efficient battery management is crucial to ensure safe use, increase driving range, improve power management techniques, lengthen battery life, and lower costs. Batteries require specific attention in electric vehicle applications. Overcharging, over discharging, or other improper activities can pose serious safety threats to the batteries, hasten their ageing process, and potentially result in fire or explosion accidents [4]. Battery systems in electric vehicles not only power the electric motor but also different electrical components. These vehicles often operate under complex conditions characterized by frequent acceleration and deceleration, and human charging behaviour can be unpredictable.



**FIGURE 4. Global battery industry Growth.**

Additionally, because the battery is an electrochemical system, state determination is

quite challenging due to the battery high nonlinearity and time-varying characteristics [5]. Therefore, creating precise and dependable BMS technologies is still a challenging effort to guarantee that batteries and the associated energy systems operate in a secure manner and function to the best of their abilities. This paper aims to give detailed review is Focuses on a Battery management system and key technologies for BMS in Section.II. The typical batteries used in EV are reviewed in Section.III. Discussed Various types of Battery Modelling the typical batteries used in EV in Section.IV. Various SOC estimation Techniques are discussed for Battery Cell and Battery Pack in Section V. Comprehensive review of Various Battery SOH estimation in Section.VI. Several Important and Conventional battery charging Strategies are covered, along with the related optimization techniques in Section VII. Focuses on various cell balancing topologies has been recommended in recent years in Section VIII. It provides an overview of the most recent advance in LIB thermal management for high charge/discharge cycles in Section VIII. The problems with BMS are discussed. the viewpoint of BMS improvement is examined in Section IX. A summary of the viewpoints of the current study and the Suggested future research activity of BMS is Provided in Section.X. Finally, the conclusion of the paper is summarized in Section XI.

## II. BATTERY MANAGEMENT SYSTEM

The state of charge (SOC), state of health (SOH), state of energy (SOE), state of power (SOP), and state of life (SOL) are just a few examples of estimations covered by battery management technologies (SOL). Among these, SOC and SOH monitoring are particularly crucial as they serve as the foundation for enhancing reliability and ensuring safety. A software and hardware device called a BMS is intended to control batteries and optimize their performance [6], as depicted in Fig. 6. The BMS software serves as the central component of the system, responsible for controlling hardware operations and analyzing sensor data to make informed decisions. Online data processing plays a critical role in detecting most faults, and intelligent data analysis is necessary to provide timely battery malfunction warnings. Data collection is of paramount importance to identify potential issues before they manifest as faults. Hardware components within the BMS, such as sensors, make it easier to measure battery voltage and current. The general block diagram of a BMS is illustrated in Fig. 7. A BMS comprises various functional units, including cell voltage balancing, temperature monitoring, current sensing, and communication

interfaces. Cell voltage balancing guarantees that each battery pack's individual cells are maintained at consistent voltage levels, maximizing the overall pack performance and extending its lifespan.

Temperature monitoring is crucial for preventing overheating and managing thermal conditions within the battery. Current sensing enables accurate measurement and monitoring of the battery electric current is going in and out. Communication interfaces facilitate the information transfer between external devices and the BMS such as the vehicle's control system or a battery management network. To protect the battery from potentially harmful circumstances, the BMS also includes safety functions including over-current protection, over-voltage protection, and under-voltage protection. Furthermore, The BMS is in charge of managing the charging and discharging procedures, ensuring they are carried out within safe and optimal parameters. In the market, there exist various types of integrated BMS chips that offer different functionalities. These chips are designed to perform specific tasks within the BMS architecture. Some of the common functional components found in BMS chips are a fuel gauge monitor, a cut-off field effect transistor, a cell voltage monitor, a state machine, temperature

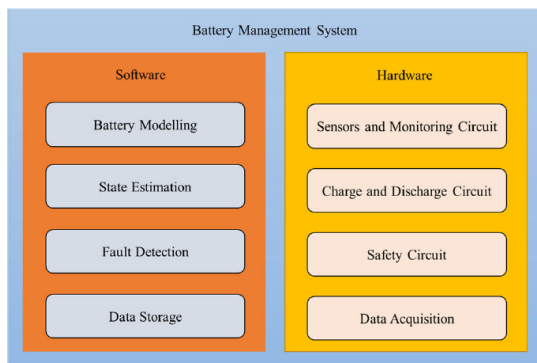
monitors, and a real-time clock [7]. The organization and integration of these components can vary depending on the specific BMS chip. BMS chips can range from simpler analog

front ends with microcontrollers capable of monitoring and balancing to fully integrated solutions that can operate autonomously. The level of integration and complexity depending on the applications needs the desired functionality of the BMS. In EVs, Different types of actuators, controllers, and sensors can be included in BMS. These components work together to ensure the safe and wide range of actuators, controllers, and sensors can be used with BMS. The BMS also performs accurate monitoring of battery parameters, providing valuable information for battery health assessment, state of charge estimation, and overall battery performance

optimization [8]. In terms of hardware architecture, there are three basic types of topologies that are frequently employed in BMS: modular architectures, centralized systems, and distributed systems. BMS can also be categorized according to the particular features they have [9]. These ideas offer a comprehensive framework with fundamental functionality for BMS design. Within the battery pack, various sensors are strategically placed to collect data at the monitoring layer

[10]. All of the battery pack's elements and the vehicle control processor are connected to the BMS. Safety has always been a top priority for BMS. The suggested BMS designs, however, use more sensors than the safety circuits now in use, allowing for

improvements like accurate warnings and controls to prevent overcharging, over discharging, and overheating. A system of sensors is necessary to track and quantify battery properties such as cell voltage, current, and temperature. However, the practical viability of these measurements is hindered by space limitations and the cost of devices. As a result, accurate measurements of current, temperature, and voltage are crucial to improving state tracking capabilities in practical applications. Based on these data, SOC, SOH, State estimations were been obtained. Also the surface temperature is measured to attain the thermal characteristic and the impact of temperature with the battery SOC and SOH were obtained. Along with this the battery joint state estimation has been measured using the above two data. This joint state



**FIGURE 6.** Overview of the BMS hardware and software components.

estimation is a important measure for the battery to effectively manage and operate the battery and increases the battery life span in different types of applications such as electric and fault diagnosis. The various steps like, obtaining the appropriate data, modelling, data collection, and data storage as shown as a block diagram in Fig.8. One part of the system that controls the charge-discharge cycle is the charge controller. A variable resistor could be needed to maintain cell balance or check internal resistance. Cell balancing management, which aims to balance the battery pack's cells and accurately gauge the battery health, is one of the most crucial design factors. BMS subsystems must communicate internally because they are independent modules. A Controller Area Network (CAN) bus is used as the main means of communication within the BMS for the transfer of data. By implementing intelligent batteries with embedded microchips that can communicate with users and chargers, more information can be obtained. In order to increase connection between the battery and charger, radio and communication technologies are also being rapidly included into charging systems. Because temperature variations can have an impact on cell imbalance, dependability, and performance, a

thermal management module is required. Reduced temperature differences between cells are critical, ensuring they operate under appropriate temperature conditions to maintain optimal performance and longevity. Different sensors, actuators, controllers, and signal lines are all included in BMS. Its main job is to make sure that the battery stored energy is used safely and optimally while giving the car's energy management system reliable information about the battery condition. In the sample circuit depicted in Fig.6 [15], Using the gating signal that is received from the control circuit as a starting point, the primary goal is to measure current, voltage, and temperature. The control circuit utilizes advanced algorithms to estimate the SOC, SOH, SOP, and SOL of the batteries. These estimates are obtained from measurements of battery current, voltage, and temperature, which are converted from analog signals. The resulting information is then sent to the vehicle controller, giving key deciding elements for the management and distribution of power in vehicles [11], [12], [13]. The functionality of a BMS can be categorized as follows [14]:

1. Protection: This entails preventing the battery from being damaged by high temperatures, overcharging, overcurrent, and short circuits.
2. In the field of "high-voltage control and sensing," tasks including measuring temperature, voltage, current, thermal management, contactor control, pre-charge functionality, and ground-fault detection are included.
3. Diagnostics: The SOL estimate, SOH estimation, and abuse detection functions of the BMS are used to assess the battery overall health and condition.
4. Performance Management: This encompasses tasks such as power-limit computation, cell balancing or equalization, and SOC estimation, which is crucial for optimizing battery performance.
5. Interface: The BMS facilitates data recording, reporting, communications, and range estimation, allowing for effective communication and integration with other vehicle systems.

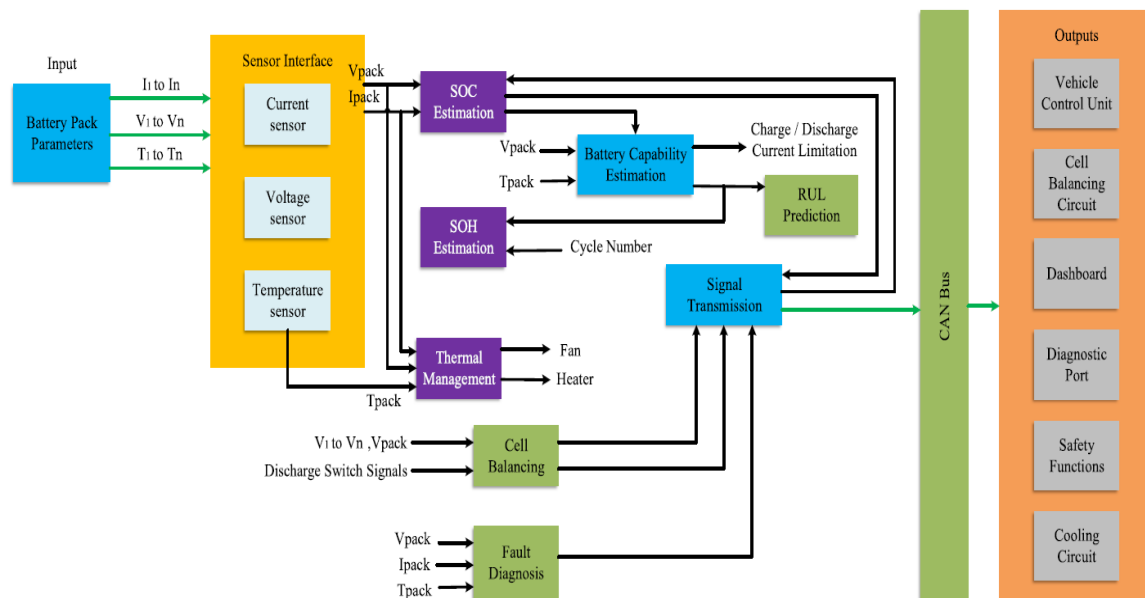
By fulfilling these functions, the BMS ensures the battery system's effectiveness, dependability, and safety while providing essential information for the management and utilization of vehicular energy.

### III. STATE OF CHARGE

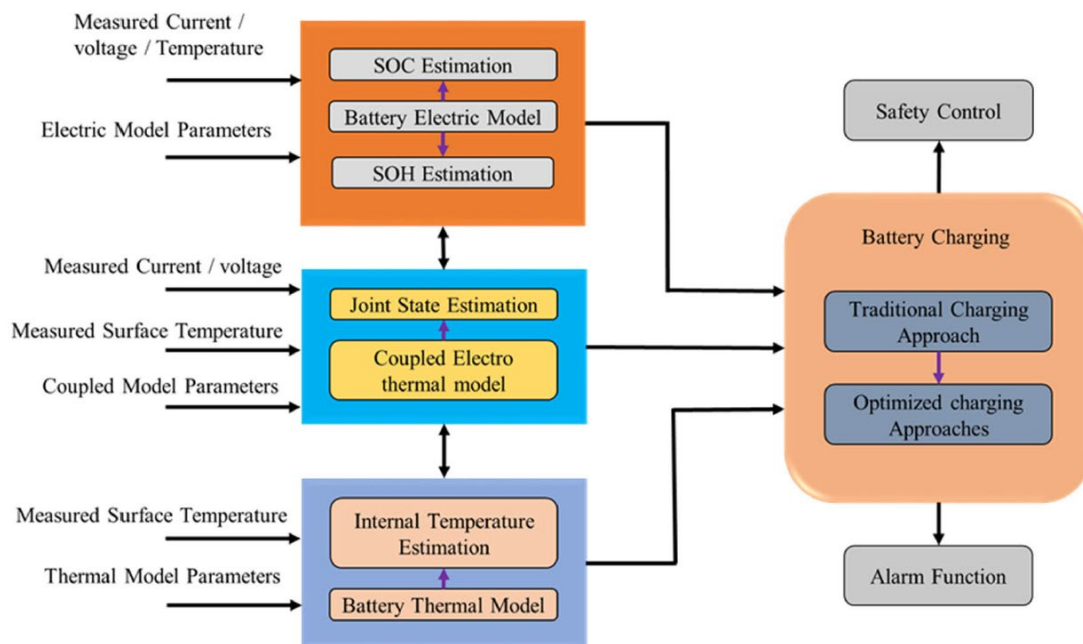
Battery charging requires careful consideration and effective measures to ensure a smooth and efficient process. The SOC is a crucial factor in battery operation, representing the level of charge relative to the battery capacity comparable to a fuel gauge in a gasoline-powered car, SOC indicates the remaining amount of energy in a battery to power an EVs. Various critical performance aspects, such as range and fuel economy, heavily depend on SOC. Battery SOC estimate is an essential component of battery management systems, and fusion models and

algorithms may greatly improve SOC prediction accuracy by merging data from many sources. Here Extended Kalman Filter (EKF): The EKF is a Kalman filter modification created to handle nonlinear systems. By integrating voltage and current data with a battery model that accounts for

are a few fusion models and methods that are frequently employed for estimating battery SOC. the nonlinear relationship between SOC and battery voltage, it is frequently used to estimate battery SOC.



**FIGURE 7. Battery management system functional block diagram.**



**FIGURE 8. Key technologies of BMS.**

| Battery Type | Nominal Voltage (V) | Power Density (W.kg <sup>-1</sup> ) | Energy Density (W.h.kg <sup>-1</sup> ) | Charging Efficiency (%) | life cycle | Self-Discharge rate (%.month <sup>-1</sup> ) | Charging Temperature (°C) | Discharging Temperature (°C) |
|--------------|---------------------|-------------------------------------|----------------------------------------|-------------------------|------------|----------------------------------------------|---------------------------|------------------------------|
| Li-ion       | 3.2-3.7             | 250-680                             | 100-270                                | 80-90                   | 600-3000   | 3-10                                         | 0 to 45                   | -20 to 60                    |
| NiCd         | 1.2                 | 150                                 | 50-80                                  | 70-90                   | 1000       | 20                                           | 0 to 45                   | -20 to 65                    |
| Lead Acid    | 2.0                 | 180                                 | 30-50                                  | 50-95                   | 200-300    | 5                                            | -20 to 50                 | -20 to 50                    |
| NiMH         | 1.2                 | 250-1000                            | 60-120                                 | 65                      | 300-600    | 30                                           | 0 to 45                   | -20 to 65                    |

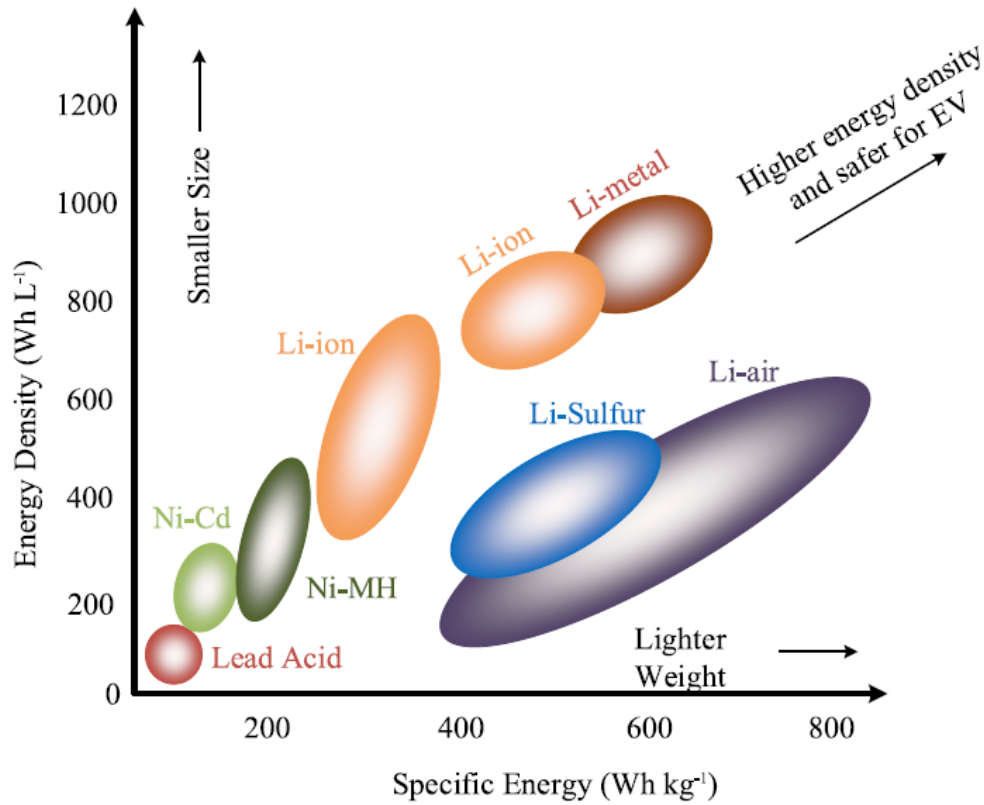
**TABLE 1. Key details of batteries used in EV [1]**

| Battery Types                                      | Cathode Material | Anode Material | Nominal Voltage (V) | Life Cycle | Energy Density (Wh.L <sup>-1</sup> ) | Cost   | Safety                       |
|----------------------------------------------------|------------------|----------------|---------------------|------------|--------------------------------------|--------|------------------------------|
| Lithium Iron Phosphate (LiFePo4)                   | LiFePo4          | Graphite       | 3.2                 | High       | Low                                  | High   | Safest Li-ion cell Chemistry |
| Lithium Cobalt oxide (LiCoO2)                      | LiCoO2           | Graphite       | 3.6                 | Medium     | High                                 | Low    | Highest safety concern       |
| Lithium Nickel Manganese Cobalt oxide (LiNiMnCoO2) | LiNiMnCoO2       | Graphite       | 3.6                 | Medium     | High                                 | Medium | Good Safety                  |
| Lithium Manganese oxide (LiMnO2)                   | LiMnO2           | Graphite       | 3.7                 | Low        | Low                                  | Medium | Good Safety                  |
| Lithium Nickel Cobalt Aluminum oxide (LiNiCoAlO2)  | LiNiCoAlO2       | Graphite       | 3.6                 | Medium     | High                                 | Medium | Safety Concern Required      |

**TABLE 2. Li-ion battery types [16].**

| S.No | Model                                                                                 | Merits                                                                                                                                                                    | Demerits                                                                                                                                      |
|------|---------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------|
| 1    | Extended Single Particle (ESP) Model.                                                 | The electrode is reduced to a single active particle. PDEs are solved using the approximate solution method or curve fitting. Increases the effectiveness of computation. | The complexity of the model rises                                                                                                             |
| 2    | Reduced order model or Single particle (SP) model                                     | Simple model that reduces the electrode to a single particle and ignores the liquid phase.                                                                                | The solid-phase Li-ion concentration in the SP model still requires the solution of radial-domain PDEs. Precision at high C rates is lacking. |
| 3    | P2D electrochemical model or Doyle-Fuller-Newman (DFN) Electrochemical battery model. | High accuracy                                                                                                                                                             | High Computational Complexity                                                                                                                 |

**TABLE 3. Comparison of various electrochemical models of battery.**



**FIGURE 7. Energy density and specific energy of various batteries at cell level.**

## CONCLUSION:

The BMS plays a pivotal role in the efficient operation of BESS within EVs. This paper offers a comprehensive review of critical BMS aspects, with a primary focus on battery modelling, state estimation, and battery charging. The significance of accurate battery modelling and precise internal state estimation cannot be overstated, as they provide invaluable insights into operational conditions and enable the optimization of charging strategies. Nevertheless, the road to fully realizing the potential of BMS technology is not without its challenges, particularly in terms of validating these systems under real-world conditions. This paper identifies these challenges and underscores the importance of addressing them to facilitate the seamless integration of BMS into EVs. In light of this, the paper outlines promising future directions for BMS advancement. Foremost among these is the conception of a universal BMS, a concept that holds the potential to standardize BMS technology across various platforms and manufacturers. Furthermore, the integration of improved predictive techniques and hybridized intelligent algorithms emerges as a pathway to enhance the accuracy of BMS operations. Concurrently, the paper advocates for the development of effective prototype designs, an essential step toward translating theoretical

advancements into practical, reliable solutions. Another intriguing avenue for BMS innovation lies in its virtualization. By creating virtual BMS frameworks, researchers and engineers can simulate a range of scenarios, facilitating more thorough testing and validation. As the paper points out, such virtualization could significantly expedite the refinement of BMS technologies, thereby accelerating their adoption within the EV industry. It is abundantly clear that surmounting the current obstacles is imperative for the successful mainstream integration of EVs. The insights and recommendations presented in this research are of immense value to vehicle engineers and EV manufacturers, guiding them towards the development of safer, more efficient, and more reliable BMS systems. Looking to the future, the paper underscores the need for a dynamic, data-driven electro-thermal model.

This innovative model holds promise for real-time status prediction, health diagnosis, and precise charging control. By harnessing the power of such a model, the EV industry can move closer to achieving its goals of enhanced operational efficiency, prolonged battery lifespan, and widespread EV adoption. In essence, this paper not only encapsulates the current state of BMS technology

but also sets the stage for its evolution. By addressing challenges, suggesting forward-looking strategies, and highlighting the potential of novel

approaches, the research serves as a guiding light for the ongoing development of BMS in the context of EVs.

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