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An Overview of BMS Technologies in Electric Vehicles

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Abstract

Batteries are used extensively in high-power applications, including hybrid and electric vehicles (EVs), where the proper battery management system (BMS) is essential to the batteries' dependable and safe performance. The purpose of this study is to provide a quick overview of several important BMS technologies, such as battery charging, state estimation, and battery modelling. The most common battery types utilized in EVs are first examined, and then important BMS technologies are introduced. The most crucial step in determining the energetic range of an EV is the valuation of the electrical properties of batteries. It’s vital to apprehend the variability of battery performance characteristics in order to understand battery behavior in several environments. Finally, the performance characteristics of EV charging and batteries are analyzed to raise the demand for electric vehicles globally.

Keywords: Electric Vehicles, Charging Systems, Battery Management Systems, Energy Storage Systems.

1. Introduction

An electric vehicle (EV) is a type of motor vehicle that is powered by one or more electric motors. Experimental electric automobiles were created by Gustave Trouvé, Thomas Parker, and Andreas Flocken in the 1880s, but it wasn't until the 1890s that the first functional

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battery electric vehicles emerged [1-2]. By 1931, the number of battery-powered milk floats had increased, and by 1967, Britain boasted the largest network of EVs. EVs emerged in the mid-1800s when electricity was among the favoured means of powering automobiles, offering a level of comfort and ease of use unmatched by the gasoline cars of the time. Although internal combustion engines dominated the propulsion of cars and trucks for over a century, electrical power remained widely used in other types of vehicles, including railways and various smaller vehicles.

Owing to developments in technology, an increasing focus on alternative energy sources, and the reduce transportation's contribution to environmental contamination there is growing interest in electric vehicles. Twenty-first-century EVs are experiencing resurgence. Project Drawdown lists driving an electric car as one of the top 100 contemporary ways to mitigate climate change. The expansion of EVs has been hindered by high prices and a shortage of charging stations. The International Energy Agency estimates that 130 million EVs will be in use worldwide by 2030. The increasing quantity of EVs on the road will make controlling EV charging and discharge more difficult over time. Transmission lines and transformer overload can be prevented by managing the charging and discharging of EVs, delaying the premature deterioration of the network's equipment. Capacity of EV charging stations can potentially be utilized to recover important loads and improve grid stability. The efficiency of distribution networks can also be increased as a result of EV charging and discharging [3-4].

When a battery is charged, the chemical reaction that occurred during discharge is reversed. Batteries also play a key role in EVs. To achieve the appropriate voltage and capacity in the final package, an EV battery often comprises a network of parallel and series-connected individual cells. [5-6]. Batteries that can be recharged can be used to power a wide range of devices and platforms. The majority of these need a BMS in order to assure the battery's secure and durable functioning, which includes precise SOC and SOH calculations [7-10]. From here on out, we'll discuss the SOC and SOH estimation methodologies that were employed while developing BESS (Battery Energy Storage System) projects. Regardless of how huge or complex the BMS is, the same strategies will work for it. A BESS is a rechargeable battery-based electrochemical energy storage system. With charge and discharge of batteries in correct times, the system may either store or supply power as needed. Application of electric vehicle incorporating to frequency stability has analysed [11-13]

A BMS manages the whole system. BMS keeps track of cells of batteries health also ensures that they are safe from harm. Developing a BMS [14-15] is a multi-step process that necessitates the creation of a number of subsystems on both the hardware and software levels. The battery technology that your BESS will use is the first thing you should consider when creating a BMS. There are many different types of battery chemistry, each with its own set of properties and features. The best option is to select a battery that meets all of the BESS requirements. Because battery chemistries have different thermal tolerances, the operating conditions of the system are crucial. As a result, lithium-ion batteries aren't resistant to severe temperatures; they only work correctly between 10 and 40 degrees Celsius. A BMS controls charging and discharging by determining the state of charge, preventing premature capacity loss and extending the battery's lifetime. Another useful BMS feature is that helps us to improve the working of batteries by estimating the state of health.

2. Types of Batteries Used in EV'S

Battery is a device that uses one or more electrical cells to transform chemical energy into electrical energy. There are two sorts of ELECTROCHEMICAL cells i.e batteries:

A. Primary Batteries
B. Secondary Batteries

2.1 Primary Batteries

These are "single-use" and non-rechargeable. Once the electrolyte in it has been consumed, it cannot be reused. Once these batteries have been discharged, they are no longer useful and must be discarded. Primary cells can be found in remote controls, wall clocks, watches, and other small electrical devices. Some types of primary batteries are

i. Leclanché cell

ii. Mercury cell

2.1.1 Leclanché Cell

In 1866, French scientist Georges Leclanché designed and patented the Leclanché cell, a type of battery. It is a non-rechargeable cell. The Leclanché cell, commonly known as the zinc-carbon battery, is a conventional general-purpose dry cell. The Leclanché cell was commonly used for telegraphy, electric bell, and signalling operations, as well as activities that required irregular intervals and low current. Though this battery cell is inexpensive and long reliability, but has a low energy density and voltage drops slowly when the battery is discharged.

2.1.2 Mercury Cell

The Mercury cell often known as, "Mercury oxide battery", is non-rechargeable and non-reusable electrochemical cell. This type of cells was utilised in watches, hearing aids, and calculators as button cells, as well as in bigger forms for various devices such as walkie-talkies. It has constant voltage of 1.35 V and long shelf time up to 10 years. However, the presence of hazardous mercury and power generating by oxidising zinc with mercury (II) oxide concerns about its disposal in the environment.

2.2 Secondary Batteries

It is possible to replenish these batteries. It is a cell or a collection of cells with reversible cell responses. This suggests that the cell's initial chemical state can be restored by allowing current to flow into it. Different kinds of secondary batteries used in smartphone's, electronic tablets, and autos are, i) Lead Acid battery, ii) Nickel Metal Hydride, iii) Lithium-ion battery and iv) Nickel cadmium Batteries

2.2.1 Lead Acid Batteries

They are invented in 1859 but are still in service, these batteries are the oldest. It can be recycled. These batteries have the benefit of being more affordable and having been around for a while.

- **Working of Lead Acid Battery**

A type of battery known as an accumulator, or secondary cell, stores electrical energy as chemical energy that can be converted back into electrical energy as needed. An external electrical source is used to convert electrical energy into chemical energy during battery charging. The process of transforming chemical energy back into electrical energy to power an external load is known as secondary cell discharge. A battery undergoes chemical changes within it when current is sent through it during charging. Energy is absorbed during the creation of these chemical alterations. The absorbed energy is released when the battery is linked to an external load and chemical processes take place in the opposite direction. The Figure.1 depicts the Lead Acid Batteries.

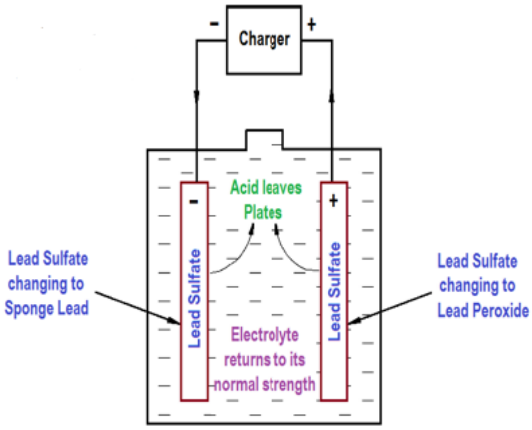


Figure 1. Lead Acid Batteries

2.2.2 Nickel-Metal Hydride

This was first used for commercial purpose in the early 1980's.The nickel-metal hydride battery's offer higher specific energy compared to the lead-acid batteries can operate at potential of 1.2 volts.

- **Working of Nickel Metal Hydride**

Nickel hydroxide is used as the positive electrode in nickel-metal hydride batteries, just like in nickel cadmium batteries. Potassium hydroxide is primarily used as the negative electrode in an aqueous solution containing hydrogen, whereas hydrogen-absorbing alloy is used as the positive electrode. Charging and discharging response of this battery is shown in Figure.2 below. It can be seen from overall response above, a nickel metal hydride batteries fundamental features, include the fact that hydrogen switches its direction when the electrodes are charged and discharged, without the electrolyte participating in the reactions, which means that there is no corresponding rise or fall in electrolytes.

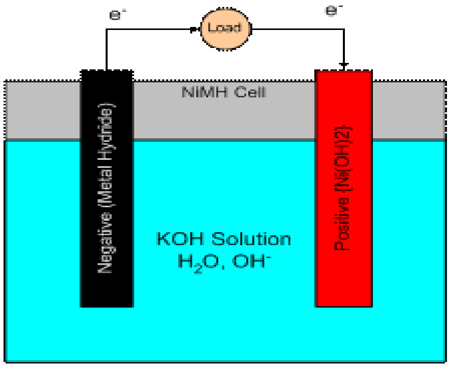


Figure 2. NiMH Batteries

2.2.3 Lithium-ion Batteries

Lithium batteries, which have a higher energy density than other batteries but were not commercially available until the 1990s, were introduced. When not in use, they almost never lose their charge

- **Working of Lithium-ion Battery**

Lithium ions as shown in Figure.3 below go from the positive electrode to the negative electrode during the charging process through the electrolyte. Electrons flow from the positive to the negative electrodes around the outer circuit. Ions and electrons work together to deposit lithium at the negative electrode. The batteries are fully charged and ready for use when there are no more ions to flow.

Through the electrolyte, the ions return when the battery is depleted. Ions travel across the surrounding electrical circuit in addition to moving from the negative electrode to the positive electrode when the current travels backwards from the negative electrode to the positive electrode. The battery is considered fully charged if every ion has moved back to its previous location.

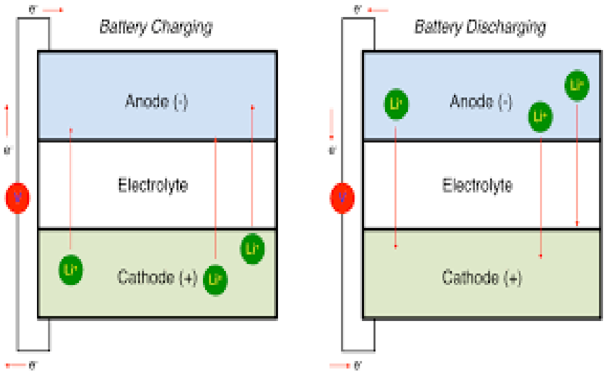


Figure 3. Lithium-Ion Batteries

2.2.4 Nickel-Cadmium Battery

After Waldemar Junger's invention of the Nickel cadmium rechargeable battery in Sweden in 1899, the first of these products was introduced in 1900s. Portable computers, drills, camcorders, and other small battery-powered devices employ Nickel-Cadmium batteries, which are rechargeable.

- **Working of Ni-cd Batteries**

It has extra positive and negative plate in which, the positive plates of battery are electrically connected to the battery's containers; when the battery is fully charged. The positive plate is composed of Ni $(OH)_4$, and the negative plate is composed of cadmium. Potassium hydroxide (KOH) ions are split into K+ & OH- ions during cell discharge; the cathode receives hydroxyl ions, while the anode receives potassium ions. Figure.4 depicts the Nickel-Cadmium Battery. The Table1. Illustrates the comparison of secondary batteries.

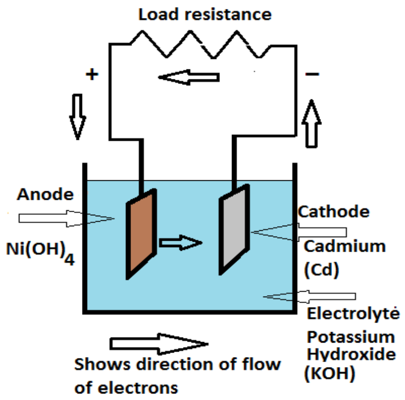


Figure 4. Nickel-Cadmium Battery

Table1. Comparison of Secondary Batteries

Type	**Rated Capacity [Ahr]**	**No. of cycles [SOH 80%]**	**Charge/Discharge Current [A]**	**Working Temp. [0C]**	**Nominal voltage [V]**
Lead Acid	225	600	0,1/2	-20/40	6
Nickel-Cadmium	180	500	1/15	-20/50	6
Nickel Metal Hydride	6.5	800	1/5	-20/50	201.6
Lithium-Ion	33.1	1000	5/30	-20/50	360

3. EV Charging

Charging times for electric vehicles (EVs) depend on the type of charger used. Some hybrid vehicles may need external charging, depending on whether they're plug-in hybrids or traditional regenerative hybrids. Let's explore the different charging options for EVs below.

Basically, there are three types of EV charging

- Level 1 (slow charging)
- Level 2 (fast charging)
- Level 3 (rapid charging)

Level 1 and Level 2 chargers are AC types, while Level 3 is DC. As charging levels increase, speed decreases. Higher-power charging means faster charging times. A standard EV charging cable includes two ports: one for the vehicle and one for the charge point. Table.2 shows the comparison of EV charging. Figure .5 shows the types of EV charging on basis of range and application.

Table2. Comparison of EV Charging

Charging Type	**AC Charging Level 1**	**AC Charging Level 2**	**DC Fast Charging Level 3**
Number of Pins	5	7	4
Capacity	1-1.8 kW	3.9-19.2 kW	24 kW - 300 kW
Voltage Rating	230 V	230 V/400 V	500 V
Current Rating	Up to 32 A	Up to 63 A	125 A
Time to charge kWh	30-40 hours	2.5-4.5 hours	30-40 minutes

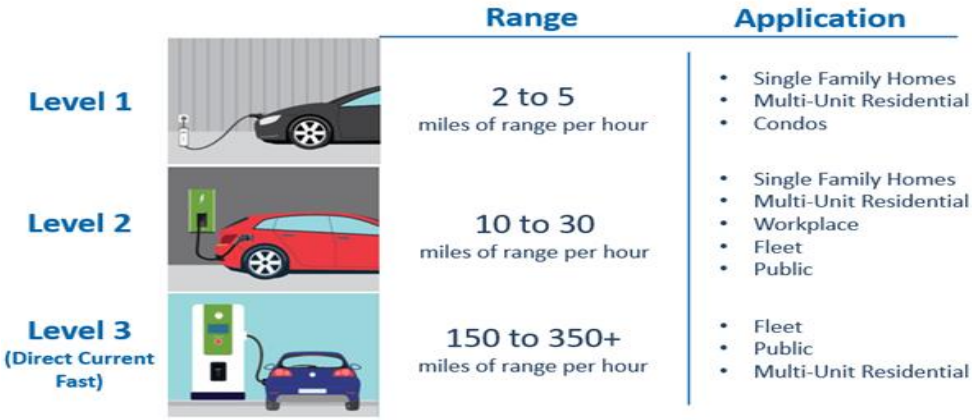


Figure 5. Types of EV Charging on Basis of Range and Application [3]

4. Battery Management System

A battery management system is an electrical device that oversees and controls the operation of rechargeable batteries. Along with maintenance planning, battery performance enhancement, failure detection and/or avoidance, data collection and analysis, and temperature, voltage, and current monitoring are covered. The main function of a BMS for electric vehicles is to protect the battery by preventing it from running outside of its safe operating range. Battery packs are monitored by determining their State-Of-Charge (SOC) and State-of-Health (SOH) during charging and discharging.

In electric vehicles, a BMS extends the life of the battery cells. This is an efficient mechanism for measuring and controlling the voltage of the cell. It provides stability and reliability.

Applications involving single or multiple cell lithium-ion batteries can employ BMS. A BMS is required for Lithium-Ion battery. This device monitors temperature and voltage, determines state of charge, connects to external devices, operates every battery cell in real-time, and performs a variety of other functions. BMS prevents the battery from being overcharged or over discharged voltage, and so on. It is not safe to use a lithium-ion battery without a BMS. Overcharge protection is available for one cell. However, 2 cell (7.4 V) and 3 cell (11.1 V) packs require a BMS to completely charge the battery.

4.1 Basic Structure

The battery pack, which makes about 40% of the total cost of an electric automobile, is one of its most important parts. A BMS system keeps an eye on lithium-ion cells, which are utilized in battery management. A control unit is present. Control algorithms are used to measure and process the temperature and current of each cell. The results include outputs such as power optimization, temperature control, state-of-charge (SOC), and state-of-health (SOH). All this information is communicated with other ECUs also it is sent to the display unit. First one cell monitoring if the charging as well as the discharging of the battery cells need to be monitored so it involved in the form of SOC and SOH of a cell. State-Of-Charge is indicator of power in the battery. State of Health (SOH) indicates overall health of the battery so this information is useful for battery maintenance and lifespan management. Power management SOC and SOH parameters must be maintained under the specified limit. During charging BMS Determines current permitted in each cell. And during discharging BMS makes sure the voltage does not go much low. There can be a leak or thermal runaway which can result in hazard due to voltage temperature and current fluctuations. Diagnostics: BMS diagnostics identifies faults stores these issues as trouble code to fix later. Figure.6 shows the basic structure of BMS.

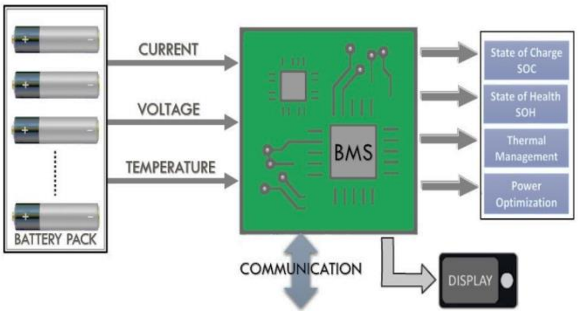


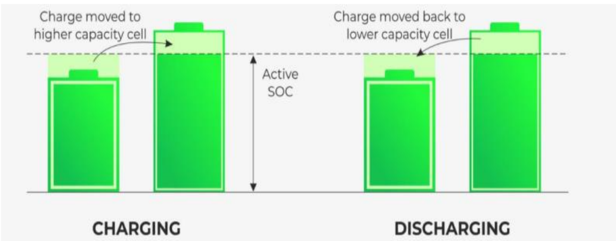
Figure 6. Basic Structure of BMS

4.2. Performance Management

The multi-point control unit comprises measurements of voltage, temperature, and current. Protection and performance management, are mandatory for all BMSs

a. Cell Balancing

Cell balancing shown in Figure.7 and 8 is a technique for extending the life of a battery pack by increasing the capacity of numerous cells connected in series and ensures that all of the energy is available for use. Higher capacity cells are charged and discharged completely during balancing. The cell with the smallest capacity is a weak point without cell balancing.



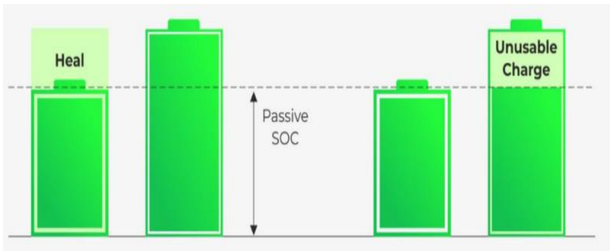


Figure 7. Active Balancing

Figure 8. Passive Balancing

b. Power Save Mode

Lithium-ion batteries can't be discharged any further than a certain point. When a battery is left entirely depleted over an extended period of time, the BMS should detect this and enter power-saving mode.

The Safe Operating Area (SOA) is critical to the safe operation of a battery pack. It is described as the voltage, current, and temperature settings at which the device will run without self-damage. An intelligent BMS must protect its battery pack from external threats like overheat and thermal protection. These circumstances may result in failure and damage. BMS ensures that the battery is performing in a safe operating area to avoid such situations.

4.3 Auxiliary Functions

a. Pre-Charge Function

If the battery is linked to a system with a high input capacity, this function is required. A large inrush current may flow into the load, potentially damaging the input capacitors or the high-power relay. Two relays are connected in parallel to lower current peaks. The pre-charge relay, for example, has a series resistor that reduces the peak current. The input capacitor gets charged after sometime, allowing the main switch to be closed without causing excessive currents.

b. Cooling Control

A battery used in high-power applications may experience significant heat dissipation inside the cells on a regular basis. To maintain the safe operation of the battery, it must be provided with active cooling system under the control of BMS.

4.4 Communication Functions

Due to the communication between components, a Battery Management System (BMS) executes all key functions promptly, including monitoring, collecting data on cell parameters, and conducting circuit diagnostics. The chosen communication medium is determined by the specific requirements of the application. Additionally, information on battery and vehicle performance is provided to the driver in electric vehicles, enabling them to take appropriate action.

4.5 Diagnose Functions

In a battery, SOC acts as power indicator. The ratio of the available capacity to the maximum possible charge that may be held in a battery is known as the State-Of-Charge. State-Of-Health (SOH) indicates overall health of the battery so this information is useful for battery maintenance and lifespan management. This helps us to study the variations between tested battery and new battery, taking cell aging into account.SOH is the ratio of the maximum battery charge to the nominal capacity of the battery.

i. State of Charge (SOC) Controller

It is defined as the quantity of electric charge that can be drained from a battery. It's commonly measured as a percentage of the battery's maximum charge capacity. There are a range of percentages used to express charge levels, from 0-100. The state-of-charge indicator allows users to see what resources are available and then when the battery has to be recharged. The State of Charge (SOC) can be assessed using the following parameters: potential difference, current, capacity, impedance, charging and discharging rates, and temperature.

a. Open Circuit Method:

b. Coulomb counting (Current Integration)

c. Kalman filter

d. Alternative estimators of SOC

  i. Terminal voltage method

  ii. Impedance method:

  iii. Neural networks

ii. State of Health

The current condition or ability of a battery is referred to as its state of health (SOH) when contrasted to its ideal state. SOH can assist you figure out how much battery life you have left. As a result, when computing the SOH, you can rely on: Inbuilt resistance, number of cycles, strength, and aging, energy output, temperatures, rate of self-discharge , and voltage. The SOC is a more general feature connected to the strength, age and degree of wear of the battery. Although the SOH battery parameter cannot be directly measured, it can be calculated by measuring related physical parameters.

a. Internal resistance Method

b. Internal impedance method

c. Counting charge/Discharge

iii. Safe Operating Area (SOA)

A BMS ensures that batteries are used safely and reliably. It can, for instance, safeguard a battery against overheating or under heating, as well as overcharging or over discharging. The temperature and voltage should continually be within SOA as seen in the voltage versus temperature graph below. Because multiple systems are available, the value in the graph should always follow the BMS manufacturer's data sheet. An over-temperature condition occurs when the battery's temperature surpasses the SOA owing to very warm or hot conditions. It's dangerous since it can melt cells and circuits. Cold or freezing temperatures can induce an under-temperature state, affecting the battery's ability to provide power. Overcharging occurs when the voltage surpasses the battery's ideal state limitations and increases over the SOA, causing the battery to be damaged and rendered useless. It's called an under-charge when the voltage falls below the state limit. A trustworthy BMS monitors each cell in the circuit and protects the battery by stopping its charge if any of the ideal states are exceeded.

iv. Temperature

The temperature range of 25°C to 40°C is outstanding for Li-ion batteries, while temperatures beyond 50°C are lethal to the batteries' existence; Even a single immature cell can knowingly impair the inclusive performance and efficacy of the battery pack. Temperature has a considerable impact on lithium-ion battery performance and also restricts their use. The range of electric vehicles (EVs) is temporarily reduced by cold weather. The chemical and physical interactions that make batteries work, particularly conductivity and diffusivity, are slowed by cold temperatures, resulting in decreased battery performance. The rate of Li battery degradation is known to be influenced by temperature. Temperature impacts the rate and effectiveness of chemical processes inside a battery, which is one of the main reasons it is so important. Higher temperatures (or higher voltages) result in faster responses. At greater temperatures, the "unwanted" chemical interactions that cause batteries to breakdown occur more quickly.

5. Conclusion

Key technologies in the BMS of EVs have been reviewed in this paper, especially in the fields of state estimation and battery charging. A comparison of battery charging and secondary batteries has discussed to review the applications and capacity for an electric vehicle. Moreover, Electric vehicle charging trends will primarily focus on fast charging, contactless charging, and charging from sustainable or renewable energies. Although it is estimated that electric vehicles will become the main means of transportation in the future due to their environmental benefits, the proportion of EVs is now low in Australia and around the world. The BMS supports longer battery life, lowers the rate of damage, and maximises the capacity, effectiveness, durability, and dependability of battery stacks.

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