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Role of Battery Management System on the Performance of Electric Vehicles

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Abstract

It is possible to monitor and regulate the charging and draining of rechargeable batteries in electric cars using battery management systems (BMS). When it comes to the battery, a management system ensures it is safe and dependable while also increasing its lifespan. In order to keep the battery, voltage, current and ambient temperature in a stable condition, a variety of monitoring approaches are used. A variety of analogue and digital sensors with microcontrollers are used to monitor the environment. The maximum battery capacity, battery health, and battery charge are all discussed in this study. For future issues and answers, a reassessment of all these techniques is necessary.

Keywords: *BMS, Battery health parameter, green energy, management, sustainability*

Introduction

We are currently witnessing a surge in the demand for Lithium-ion batteries for electric vehicles (EVs). As Lithium-ion batteries share a high proportion of overall EV cost, it becomes mandatory to make it more efficient and reliable. However, due to the highly dynamic nature and high sensitivity of Lithium-ion batteries to operating conditions like temperature, C-rate, and DOD %, it is challenging to keep it in safe operating areas.

Therefore, it is required to understand the functions and topologies of the existing Battery Management System as it helps to improve the EV battery performance.

Related Works

Global EV Market Scenario (2020-2030)

As countries work to reduce carbon emissions, the demand of EVs is increasing. According to IEA, the global and plug-in hybrid EV (PHEV) sales share in 2020 was 4 % and 16 % of total vehicles sale. As demonstrated in Fig 1, by 2030, under the state's policies scenario, the EV and PHEV sales will be reached to 16 % and 33%, respectively. Under the sustainable development scenario, EV and PHEV sales will touch 34 % and 31%. Currently, the use of EVs is dominated in the developed like China, USA, France, Japan, Norway, and South Korea. However, this trend is also started to influence many developing countries [1].

Indian EV market: In developing countries like India, the central and states government drafting the policies to support OEMs and consumers. The global EVs market is expected to reach a value of USD 725.14 billion by FY2026 which will have a major impact on the EV company shares in India, as shown in Fig 2. According to CACR, EV market share in India is expected to increase from USD 5.3 billion (2020) to USD 206 billion by 2030. the demand for EV batteries would create an investment opportunity of USD 17 billion. To meet the goal, demand for EV charging infrastructure would create an investment opportunity of USD 3.2 billion in the EV charging stations market. Under FAME II, around INR 193.57 crores were given out as incentives till FY 2021 by the government [2].

Lithium-ion Batteries the backbone of EVs

As we know the Lithium-ion batteries have several prominent features that make it suitable for the use in EV such as high energy/power density, long life cycle, low self-discharge, and no memory effect. Also, their characteristics to support fast charging made it ideal for EV. However, for the safe operation of Lithium-ion batteries it is mandatory to operate it in the safe operating area (SOA). For example, if we operate lithium-ion batteries beyond its temperature range, then it would not be possible to charge it completely. Moreover, if we continued to operate outside its temperature limit, then the problem of thermal runaway may occur and ultimately catch fire. Also, the high depth of discharge (DOD) can easily affect its cycle life. Therefore, to keep the Lithium-ion batteries in the SOA, the electronic chip called battery management system (BMS) is used by the battery manufacturers [3].

Price and demand of Lithium-ion batteries (2010-2030)

Typically, the prices of the battery pack are measured by the cost per kilowatt-hour. The prices of the battery have fallen over the last 10 years, as the production of battery reached economic scale. According to Bloomberg NEF, today's price of battery is $156 per kilowatt-hour, which is around 85% decline in prices from 2010's which was around $1,100 plus/kWh cost. According to Bloomberg NEF, the prices of battery will continue to fall, it will reach below $100/kWh by 2024, as the production and efficiency of battery is continuously improving. The cumulative demand for lithium-ion batteries is also increasing, it was just 0.5 gigawatt-hours in 2010, rises to roughly 526-gigawatt hours in 2020. This enormous increase in demand is expected to continue, which may reach upto 9,300 gigawatt-hours by 2030. That

Section A-Research paper
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demand for batteries will transform into 10s of millions of energy storage, electric vehicles, and consumer devices around the world [4].

Algorithms that Constitute an EV BMS

Battery parameters such as voltage, current and temperature are actionable data points that need to be processed in order to derive certain metrics. For instance, battery voltage can be used to compute the distance an electric vehicle can cover before the battery gets exhausted.
A battery management system does several such calculations for which algorithms are written. Let's understand two of these:

- **Cell Balancing Algorithm:** We discussed about how different cells in a battery pack can develop different capacities with time. A battery cell might reach a maximum of 3.7 volts compared to others that reach up to 4.2 volts. That cell will also be the first to discharge. As a result, the pack cannot be used at its max potential. The cell balancing algorithm comes to rescue in such circumstances. Two kinds of cell balancing technique are deployed- **active and passive cell balancing.** In the active balancing technique, the stronger cells are used to charge the weaker cells so that their potential is equalized. Passive balancing works by discharging the excess voltage of the stronger cells by connecting them with a load.
- **Communication Algorithms:** Different ECUs in an electric vehicle require battery parameters in order to work efficiently. For instance, the BMS communicates with the EV motor controller to ensure that it is drawing current in an optimized manner. Similarly, the BMS communicates with an external charging device to pass on the required current and output voltage information. It also controls when the charging starts and stops. If there is any out-of-spec issue, BMS cuts off the connection and stops the charging. In order to facilitate this communication, various communication protocols such as CAN, J1939, CHAdeMO, Bharat EV specifications, etc. are employed.

Sources of safety hazards in Lithium-ion batteries used in EV

There are different sources of safety hazards in EV batteries during their long life such as manufacturing defects, thermal abuse, electrical abuse, and mechanical abuse as shown in Fig 4. Cell with manufacturing defect caused by the contamination of the chemical is hard to identify after the battery pack development and may trigger the thermal runway. Thus, it is always recommended to adopt rigorous quality control procedure in the battery assembly line. As Lithium-ion batteries is highly sensitive to temperature and rising the temperature beyond the defined limit may trigger the thermal runaway due to undesirable side reactions. Also, the heat generation during thermal stress cannot be controlled. Mechanical stress commonly occurs during accident and it may cause due to many reasons such as compression, punching and twisting of cells connected the battery pack and damage of shell casing. The electrical abuses that commonly occurs in the EV batteries are due to malfunctioning of the protection circuitry and mishandling are:

- *over-voltage*
- *overcharge*
- *over-current*
- *external short circuit*
- *charging outside of the accepted*
- *over-discharge, and fast charging of over-discharged cells*
- *deep discharging*

If the EV battery remains in the electrical abuse condition for longer/multiple time, it will increase the thickness of SEI layer and form the dendrite on the surface of electrodes. Due to SEI layer thickness increment, the internal resistance of the battery will increase. Other side, with the formation of dendrites, the separator can be punctured, and internal short circuit will occur. The mechanical, electrical, and thermal abuses are the main cause of triggering of thermal runaway and fire of EV batteries. However, With the use of BMS EV batteries can be protected from the thermal runaway to some extent.

The functionality of BMS and existing topologies

BMS is an electronic system that serves as the brain of the battery system. As shown in Fig 1, some of the key functions of BMS are charge and discharge control, thermal management system, cell monitoring, and balancing, fault diagnosis and health management, data acquisition, and modeling and state monitoring. The economic advantages of BMS are extensions of battery lifetime and lowering the cost. For example, BMS shares only 8% of the total battery pack cost for a 22 kWh mid-size EV battery pack. Standardization of BMS for EVs and proper implementation of the standards in EVs can reduce risks and hazards associated with BMS significantly.

Fig 1. Functions of the battery management system

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Data Acquisition: The data acquisition includes the monitoring and storing of the most relevant battery data for decision-making units of BMS. The most relevant battery data are the measured voltage of every battery-connected battery cell, the current flows in parallel connected modules in the battery pack, and the temperature of each battery cells. The proper sampling frequency of voltage and current measurement is always required to capture the transient response of the battery cells.

Thermal management system: LIBs are very sensitive to temperature. The increase in temperature has two effects on the performance of Lithium-ion batteries. With the increase in temperature, the Lithium-ion battery's performance improves and works more efficiently. Therefore, to maintain the temperature within the safe operating temperature range, the thermal management system is generally equipped with a battery pack.

Safety and Protection: To protect the battery cells or battery pack from malfunctioning and permanent damage, different sensors are incorporated with BMS. With the help of sensor signals, the battery cells can be protected from overcharge, undercharge, insulation fault, uniformity fault, over-fast temperature rise, and low temperature. When the faults are diagnosed, the sensor signals are transmitted to the vehicle control unit to handle the faults. Under a serious fault condition, the vehicle control unit disconnects the battery pack from the power supply also.

Charge and discharge control: All batteries have limited numbers of charge and discharge cycles, so this function of battery should be properly managed for better life backup. Along with this, the most harmful thing that can happen to the battery is overcharging.

Cell Balancing: Due to inconsistency among the battery cells, the small imbalance in voltages of the battery cells is always present. Due to imbalance in voltage, overcharging and deep discharge case may be occur in few cells. This also impact the performance, operation, and safety of battery pack. To outperform this, the cell balancing circuit is available in BMS. Generally, there are two types of cell balancing methods are used in BMS such as active cell balancing and passive cell balancing. Passive cell balancing is also known as dissipative cell balancers and active cell balancers as non-dissipative cell balancers.

Battery States monitoring: For development of robust and efficient BMS, various battery states need to monitor accurately such as State of Charge (SOC), State of Health (SOH), State of Power (SOP) and State of Energy (SOE). However, these states of battery cannot be measured directly through any electrical instruments. Therefore, these states are estimated through various methods using measurable quantities of batteries such as battery terminal voltage, current and operating temperature.

BMS Topologies

Selection of suitable topology in large size BMS is very crucial task to optimize the cost. BMS topology defines the connections between the individual cells to monitor, control structure and communication architecture. The BMS topologies can be classified into three categories as Centralized, Distributed, and Modularized or Master-Slave, as shown in Fig 2. Further, the properties of different properties are listed in Fig 3.

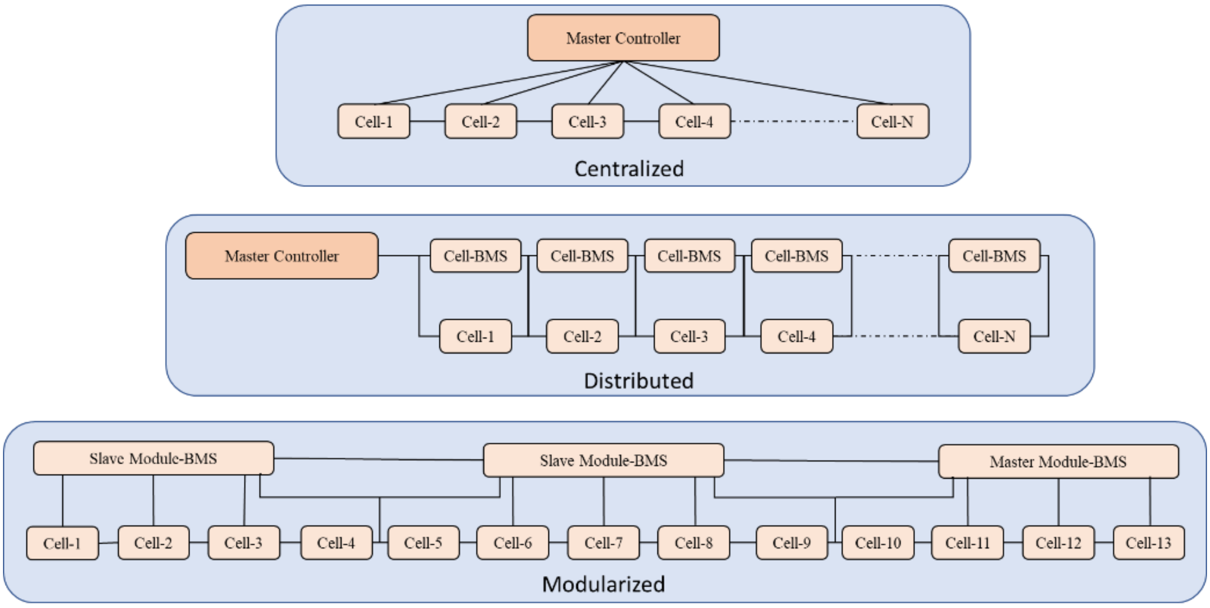

Fig 2. Schematic of different BMS topologies

Centralized BMS Topology: One master controller is monitoring each cell and control the overall functioning of battery pack.
Distributed BMS Topology: All the cells have its BMS that sends signals to Master controller to control the functioning of battery pack.
Modularized BMS Topology: Different identical slave module BMS connected with individual batteries or battery cells for monitoring and controlling. In which, one of the modules BMS serves as Master BMS and control the overall functioning battery pack based on the signals send by the slave BMS.

Properties	Topologies		
	Centralized	**Distributed**	**Modularized**
Complexity	High	Low	Low
Cooling	Easy	Difficult	Difficult
Independent Operation	No	No	Yes
Reliability	Low	Low	High
Installation and Maintenance	Difficult	Depend on type of cells	Depend on type of cells
Cost	Low	High	High

Fig 3. Properties of different BMS topologies

Selection criteria for right BMS

- **Compatible with desired battery chemistry:** As the characteristics of different chemistry batteries vary greatly from each other. Hence, the BMS must support the desired chemistry according to the battery pack.
- **Number of series cells:** BMS must have the feature to support the maximum number of cells in series available in a battery pack.
- **Max. Current and Voltage Rating:** Selected BMS current and voltage rating must be slightly higher than the continuous current rating and maximum voltage so that it doesn't struggle from the demand of the controller, respectively.
- **Max. Balancing Current:** Large balancing current results in less time required for balancing of battery pack but it may also cause thermal problems if thermal management is not well supported.
- **Estimated SOC accuracy:** Better SOC accuracy results in less drifting of SOC, if BMS have less SOC drift from actual SOC, prevents battery from deep discharge or overcharge conditions.
- **Sensor's accuracy:** Selected BMS must have a better sensor rating for better measurement of temperature, voltages, and current values which are also used in SOC estimation of battery.
- **Communication method:** CAN 2.0 is necessary for the automobile domain, BMS must be able to support UART communication for wireless peripherals such as Bluetooth, wifi, or an IoT device, according to customer requirements.
- **Maximum channel per slave:** Depending on the battery pack voltage range, the requirement of the voltage channels per slave generally varies.
- **Programmable input and output:** Programmable input and output pins result in large numbers of application or safety-related parameters for BMS such as ignition signals, low charge signals, external wakeups signal, etc. Higher the number of programmable pins the better the application of BMS.

Future Scope of Next-generation BMS

Next-generation BMS should be different from traditional BMS in different aspects to improve the life cycle and performance of EV Lithium-ion batteries. Some of the features of next-generation BMS are:

- It should have the capability to celebrate with real-time data instead of laboratory data.
- It should be capable to work with a 5G high-speed information system and bandwidth so that the advantages of big data and cloud computing will be fully utilized. So, the limitations of computation power ad storage capacity in traditional BMS will be reduced significantly.
- It should have the feature to adjust the degree and rate of charge based on health especially during fast charging.
- In the next generation BMS, the concept of digital twin should be utilized to improve the data logging.

- With the application of an advanced co-estimation algorithm for SOX (SOC, SOH, SOP, and SOE) estimation in next-generation BMS more reliable and cost-effective Lithium-ion battery pack will be developed.

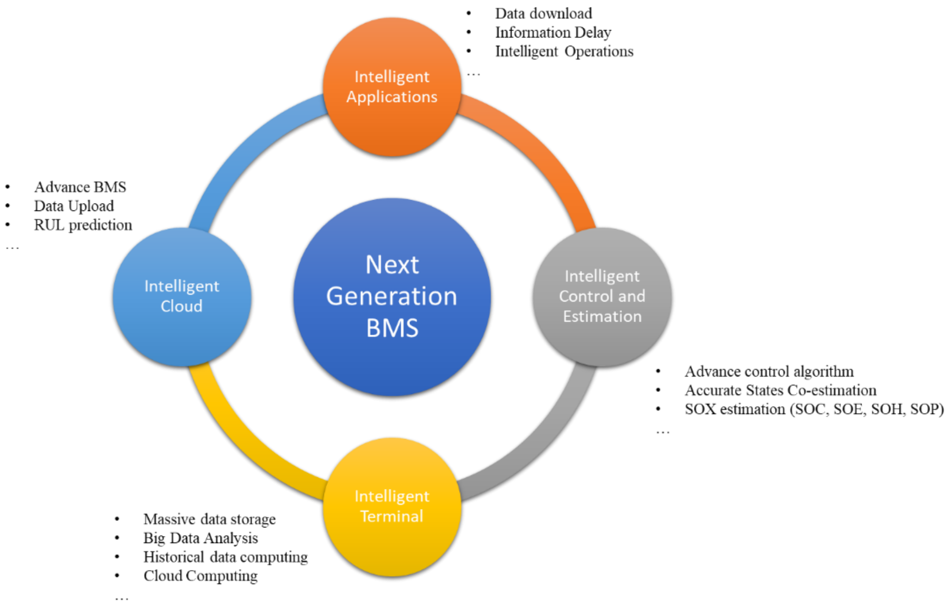

Fig. 4. Features of the next generation of BMS

Conclusion

In this way, we are developing the system model for battery management in an electric vehicle by controlling the crucial parameters such as voltage, current, state of charge, state of health, state of life, and temperature. It is very important that the BMS should be well maintained with battery reliability and safety. This present paper focuses on the study of BMS and optimizes the power performances of electric vehicles. Moreover, the target of reducing greenhouse gases can greatly be achieved by using a battery management system.

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