Journal Publication of International Research for Engineering and Management (JOIREM)
Volume: 03 Issue: 12 | Dec-2025
ISSN (O) 3107-6696

Intelligent Battery Optimization Framework for Electric Vehicle Power Systems

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Abstract - Electric vehicles (EVs) require efficient battery management systems (BMS) to handle the high voltage batteries used as power sources. A comprehensive BMS not only estimates the remaining battery capacity but also prevents hazards caused by improper use. This paper reviews contemporary battery management systems focusing on their functions such as cell balancing, thermal management, and performance optimization in EVs.

Keywords: BMS, Battery, Electric Vehicles

INTRODUCTION:

Electric vehicles operate using rechargeable battery packs as energy sources, which must be managed carefully to ensure safety, longevity, and reliable performance. The BMS plays a vital role in coordinating the power delivery, protecting the battery from damage, and facilitating efficient energy use. Key components of electric vehicles include the high-voltage battery, electric motor, power electronics, and associated control systems.

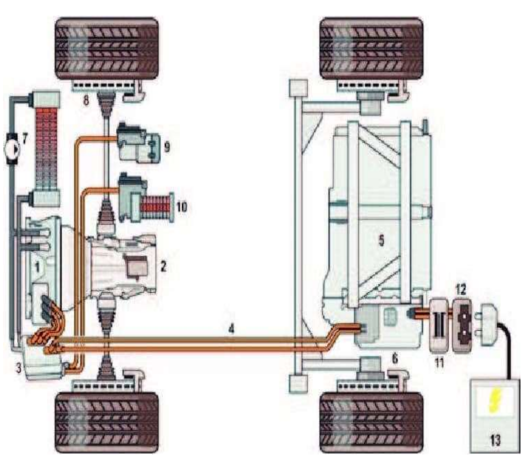

Figure 1. Electrical Vehicle Components

Components:

The main components of electric vehicles are illustrated in Figure 1 and they form the entire propulsion and power system. These components are as follows:

1) Electric motor
2) Transmission
3) Power electronics
4) High voltage cables
5) High voltage battery
6) Battery management electronics
7) Cooling system
8) Brakes
9) High voltage compressor
10) High voltage heating
11) Charger
12) Charging connector
13) External power source

BATTERY MANAGEMENT SYSTEM:

The battery management system (BMS) in electric vehicles is typically installed within the vehicle dashboard and plays a critical role in linking the battery to the vehicle's operational systems. Its primary functions include enhancing battery performance and ensuring the vehicle operates safely and reliably. For electric vehicles, the development of a sophisticated and robust BMS is essential, comparable to the engine management system in traditional internal combustion vehicles. Important parameters monitored by the BMS include the battery's safety status, operational usage, optimization, performance, and lifespan. These help minimize risks such as ignition caused by overcharging and capacity loss due to frequent deep discharges. Additionally, the system oversees and controls the electronic components associated with the battery pack to ensure overall system health. When the BMS detects irregular conditions such as excessive voltage or overheating, it alerts the user and can autonomously implement predefined corrective actions. Efficient electricity management and effective communication with other vehicle systems require the BMS to continuously monitor the

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battery's temperature.

The essential functions of a BMS include the following:

- Data acquisition
- System protection
- Estimation of battery capacity and condition
- Regulation of charging and discharging processes
- Cell balancing
- Thermal management
- Displaying battery status
- Communication with all battery components

A typical BMS is composed of several functional units, including field-effect transistors (FETs), state-of-charge indicators, cell monitoring and balancing circuits, temperature sensors, and a real-time clock.
a) Field-Effect Transistors (FETs): These components manage the connection and disconnection of the battery during vehicle operation or charging by monitoring real-time battery voltage, current, and circuit conditions.
b) State-of-Charge Indicator: This module displays the battery's remaining charge, which is determined by calculating the product of current flow and operation time.
c) Cell Monitoring and Balancing: To maintain battery health, the voltage of each individual cell within the battery pack is continuously monitored. Each cell operates within a specific voltage window defined by its chemistry; for example, lithium-ion cells usually range between 2.5V and 4.2V. Deviations from this range accelerate battery degradation and reduce cell lifespan.
d) Temperature Monitoring: Batteries in electric vehicles deliver substantial current at stable voltages, generating heat as a byproduct. Without proper management, elevated temperatures can lead to battery fires or explosions due to volatile chemical components. Physical damage such as impacts or punctures can also cause thermal incidents by exposing reactive chemicals to air. Temperature sensors, often thermistors with internal reference voltages paired with analog-to-digital converters, provide accurate temperature readings for each cell, enabling the BMS to manage charging and discharging safely and effectively. This rephrased content addresses your request ensuring originality while maintaining the technical meaning of the original text

3. BATTERY BALANCING METHODS

For an ideal battery management system that would not need balancing, all cells would need to have the same voltage, internal resistance, aging degree and similar connection mode. But the properties of each cell differ and the differencecomes from the manufacturing process. These differences in propertiescan lead toconsiderable imbalances over time resulting in reduced battery life. Due to the way these batteries are built being often spot welded it makes it impossible to change defective cells requiring replacement of the entire battery.To optimize a similar system requires a process of measuring the parameters of each cell but involves a high cost for the battery manufacturer. In order to allow the communications between the components of the vehicle management system, the CAN bus protocol is generally used, this protocol is already used in classic vehicles and is also adopted in electric vehicles.
Different methods are used to balance the batteries, below are explained two methods being the most practical.

1) First method: Balancing by individual cell loading

To balance or charge an individual cell it is necessary to apply a charging algorithm that uses a constant current and voltage individually for each cell. It requires the presence of voltage sources that have a floating mass (reference), which requires a galvanically isolated supply for each cell to the rest of the cells and to the general source. This is a disadvantage that leads to impracticality in modules with more than 3 cells, and the galvanic insulation mentioned above limits the maximum charging current. Thus, each cell is optimally charged resulting in a charge independent of the other cells (Figure 2). By using this method,the capacity of eachcell can be carefully monitored and premature wear or overheating can be determined

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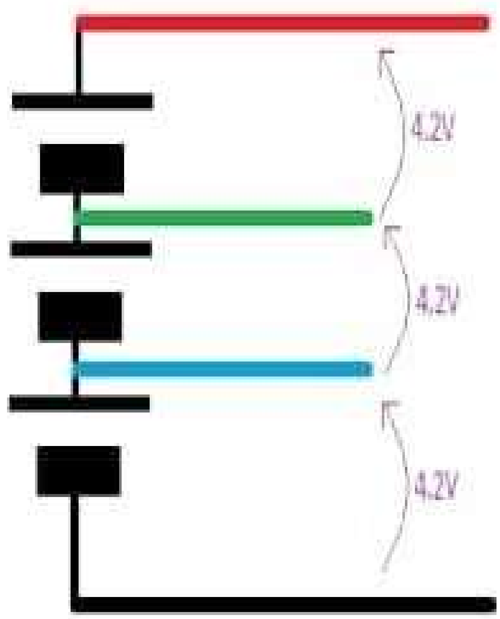

Figure 2. Individual cell loading

2) Second method: Balancing by individual cell discharge To balance the battery by individually discharging the cells it is necessary to apply a charging voltage to the ends of the battery(power heads) and the excess power will be discharged using resistors in parallel with the battery cells (Figure 3).

Therefore, if one cell charges faster than the other (if it has a smaller capacity than the other cells), it connects a load in parallel until the voltage drop is similar to the cell voltage

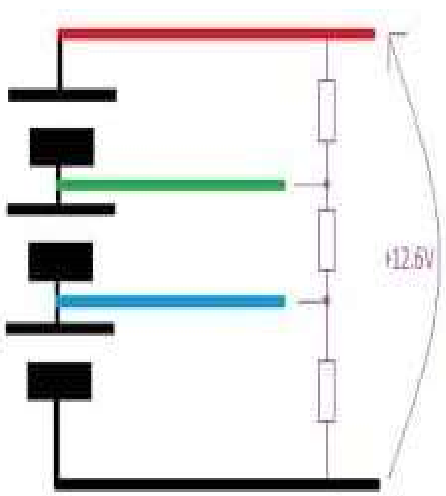

Figure 2. Individual cell discharge.

4. TYPES OF BATTERIES USED FOR ELECTRIC VEHICLES:

The most common source of energy storage for electric Vehicles is batteries. The mode of operation of these Batteries is given by the chemical reactions that take place during discharge or charging. Chemical reactions gradually to reduce the capacity of the batteries by only degrading the chemical structure until the battery becomes unusable. This battery degradation can be delayed by the way the battery is used. For example, subjecting batteries to extreme temperatures during charging or use results in a shorter lifespan than those that operate under normal temperature conditions.

The safety of the batteries is given by the operation in the parameters offered by the manufacturer and any deviation from the limits given by it can represent a danger for the user. For the safety of the user and a safe operation of these batteries, the conditions specified by the manufacturer must be observed, thus maintaining the limits of the charging and discharging currents, voltage and temperature.

Monitoring the battery voltage does not involve monitoring their remaining capacity. The energy left in the battery depends on the state of charge (SOC) being an essential parameter for monitoring the remaining capacity in the battery. The current capacity of the battery divided by the nominal capacity defines the SOC parameter.

Monitoring the SOC parameter is essential to avoid battery failure in over load conditions without indicating the remaining battery life. The use of batteries for electric vehicles depends on their type depending on the required and conditions in which they are operated. Most internal combustion vehicles use a Pb-Acid battery, these batteries have a stable chemical composition but their weight is high and are often used in stationary electricity storage systems.

Li-Ion, Li-Polymer or LiFePo4 batteries are commonly used to provide electricity for the electric vehicles. These batteries have an unstable chemical composition and an improper use leads to overheating and explosion.

1) Lithium-Iron phosphate batteries (LiFePo4)

This type of rechargeable battery uses LiFePo4 for the cathode

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and for the anode uses a carbon electrode that has a metal collector. Thus, being ideal to be used in electric vehicles for the high energy density/kg. It is worth mentioning that these batteries withstand a large temperature range, have a long life and an

Increased resistance to overheating and explosions.

Characteristics:

- Specific energy: 90-110Wh / kg
- Energy density: 220Wh / L
- Lifespan: 2000 cycles
- Rated voltage: 3V - 3.3V
- Maximum voltage: 3.65V

2) Li-Polymer batteries (Li-Poli)

This type of rechargeable battery is derived from Li-Ion batteries and a polymer is used for the electrolyte. The specific energy is higher than other batteries with a similar chemical composition and its usage is vast covering mobile devices, laptops and electric vehicles.

Characteristics:

- Specific energy: 100-265Wh / kg
- Energy density: 250-750Wh / L
- Lifespan: 1000 cycles
- Rated voltage: 3.7V - 3.85V
- Maximum Voltage: 4.2V - 4.4V

3) Lithium-Ion batteries (Li-Ion)

This type of rechargeable battery is one of the most used in the electric vehicle industry for its high energy density, stable chemical composition and for economic reasons. An important feature of these batteries is that they keep their balance from the factory. A battery pack consisting of such cells requires little maintenance, it should be noted that the batteries are equipped with an over pressure valve being found in the upper part on the positive terminal and the role of this valve is to mechanically and electrically disconnect the cell from the rest of the cells, if pressure is accumulated in these kinds of cells.

Characteristics:

- Specific energy: 00-265Wh / kg
- Energy density: 250-680Wh / L
- Lifespan: 1000 cycles
- Rated voltage: 3.6V - 3.85V
- Maximum voltage: 4.1V - 4.4V

5. CONCLUSIONS

Battery management systems are specifically designed only for a certain type of battery that has known number of serial cells and this involves high production costs. Even though the system is modular, it is not designed to accommodate a wide variety of serial cells. The battery management system ensures the proper functioning of the entire battery in the charging or discharging conditions by monitoring its voltage, current and temperature. It is worth mentioning that the system is able to prepare the battery for a more intense use or for a faster charge by changing its temperature, voltage and current.

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