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Battery Management System Life Cycle Estimation and Degradation

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ABSTRACT

An essential component of using electric mobility is a battery management system (BMS), which is used to improve battery quality and guarantee safe operation. To avoid battery failure and minimise potentially dangerous situations, a monitoring system that ensures batteries function properly in the intended application is required. In terms of lifetime, the shelf storage time or calendar ageing discharge rate for primary cells is crucial because it determines how long you can keep the cell in storage before using it. For secondary or rechargeable cells, both calendar ageing and cycle ageing are of interest. The calendar ageing will show how the capacity deteriorates over time, even when the battery cell is not in use. The cycle ageing will show how many cycles the cell can produce at a particular charge and discharge rate. Before the capacity decreased to 80% of the initial Ah value when new, an energy cell would last for 1000 complete cycles and a power cell for 3000 complete cycles. The state of health (SoH) of a battery denotes its practical capacity over the course of its lifespan. It is computed as a percentage decline in comparison to its initial capacity of 100%.

Keywords: *Cycle aging; Charge rate; Discharge rate; Capacity; Battery; Cycles.*

1.0 Introduction

In today's automobiles, effective energy storage is crucial. Due to their high energy density, which is desired for electric vehicle range extension, batteries are the traditional and most promising energy storage component in hybrid electric vehicles (HEV) and electric vehicles (EV). However, a battery cannot alone satisfy all desired characteristics like low power density. The weight and price will increase as the size of the battery pack increase [1-2]. The middle ground is hybrid energy storage, or hybridization, which combines a small battery for average power and a supercapacitor for peak power during acceleration and regenerative braking. Worldwide research into electric-drive vehicles (EDVs), including battery electric vehicles (BEV), hybrid electric vehicles (HEV), and plug-in hybrid electric vehicles (PHEV), has increased as a result of pollution and the energy crisis. Battery technology, which is regarded as the primary source of power for EDVs, has attracted increasing attention [3]. EDV batteries shouldn't be overcharged or over discharged to prevent battery damage, reduced battery life, and fire or explosions.

The battery management systems are incorporated in the electric vehicles to maximise their operation and to safeguard the system components. It performs different operations like estimation of battery state, its health, balancing of cell, battery modelling etc[4]. With regard to voltage, current, and temperature, the primary objective of BMS is to maintain the battery within the safe operating range throughout charging, discharging, and, in specific scenarios, open circuit conditions.

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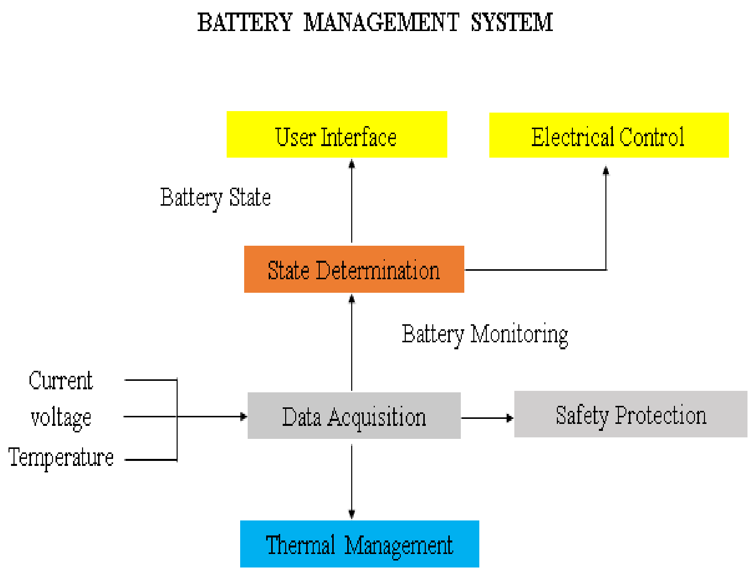
The term "battery" generally refers to the entire pack; nevertheless, in the context of the battery pack assembly, the monitoring and control functions are applied to individual cells or modules, which are groups of cells. With their exceptionally high energy density, lithium-ion rechargeable cells are the norm for battery packs in a wide range of consumer goods, including electric vehicles and laptops. Although they operate exceptionally well, ventilating beyond their designated safe operating area (SOA) can result in severe repercussions ranging from battery degradation to outright danger [5]. The job description of a BMS is undeniably demanding, as its overall intricacy and scope of supervision may encompass numerous fields including electrical, digital, control, thermal, and hydraulic. Degradation of a battery is the progressive deterioration of its capacity to store and discharge energy. This unavoidable progression may cause your device or vehicle to experience a decline in energy capacity, range, power, and overall efficiency.

2.0 Battery Management System

The hardware and software control system for the battery pack is called the Battery Management System (BMS)[6]. This crucial element measures battery pack current, cell temperatures, and voltages. Additionally, it controls the contactors and the thermal management system and detects isolation faults. The battery management system guards against overcharge, over-discharge, overcurrent, cell short circuits, and extreme temperatures for both the user of the battery-powered system and the battery pack itself.

Figure 1: Battery Management System Schematic



Typical oversight provided by a BMS comprises:

- Observation of the battery
- Implementing battery safeguards
- Assessing the operational condition of the battery
- Constantly enhancing battery functionality
- Communicating the status of operation to external devices

2.1 Master and slave BMS

Decentralised BMS architecture is composed of several slave PCB boards and one main controller. Decentralised BMS's benefits include lower wiring costs and high scalability due to its modular design, while its disadvantages include the need for more slave PCBs[7]. The slave board is equipped to perform tasks like monitoring voltage, temperature, and cell balance. It receives task messages from the primary BMS (master) and sends cell measurements infrequently. The slave board may also be known as:Cell Sensor Circuit and thus, the benefits of decentralised BMS include lower wiring costs and high scalability due to its modular design, while the disadvantages include the need for additional slave PCBs.

2.2 Centralised BMS

The centralised BMS, which is frequently used on smaller battery packs for commercial vehicles, has all general functions (cell Voltage/Temperature/Series Current sensing, cell balancing, etc.) integrated into a single control module or board. The benefit of centralised architecture is the absence of the need for slave PCBs, which lowers the cost of electronic components. Accuracy is another benefit, as all cells in centralised BMS use the same offsets [9]. System control is effectively provided by the coordination structure, which is clearly defined. Such a topology has disadvantages, including more complicated wiring that could increase the risk of short circuits. Additionally, in the event of a failure or malfunction during operation, the primary battery controller may lose all information regarding the battery cells.

A critical component of hybrid vehicles, the Battery Management System (BMS) oversees and controls the operation of the traction battery. The battery management system (BMS) guarantees the preservation, dependability, and security of the battery pack, a critical component in the hybrid vehicle's overall performance. The following are essential features and functions of a battery management system found in hybrid vehicles:

- Cell Analysis: Individual battery cell voltage, current, and temperature monitoring components. Detects and regulates intercellular imbalances in order to maintain consistent performance and avert the excessive charging or discharging of specific cells.
- Estimation of the State of Charge (SOC) and State of Health (SOH): Computes the SOC in order to ascertain the battery's available energy. Determines the SOH in order to evaluate the battery's overall health and deterioration over time.
- Temperature Control: Regulates the battery pack's temperature in order to maximize its efficiency and prevent it from overheating. Maintains the battery within a temperature range that is safe for use, thereby extending its lifespan.
- Cell Balancing: Active or passive balancing is performed in order to equalize the charge of each individual cell. Balancing contributes to the maintenance of consistent cell voltages and increases the battery pack's overall efficiency.
- Control of Charge and Discharge: Overseas the charging and discharging procedures in order to maximize the battery pack's overall efficiency. Managing the flow of electricity from the battery to the electric motor/generator in response to varying driving conditions.

The operational efficacy, safety, and efficiency of hybrid vehicles are profoundly impacted by the Battery Management System's performance. The ongoing progress in BMS technology is of utmost importance in augmenting the functionalities and dependability of hybrid and electric vehicles.

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3.0 Cycle Life Degradation & Cell Aging

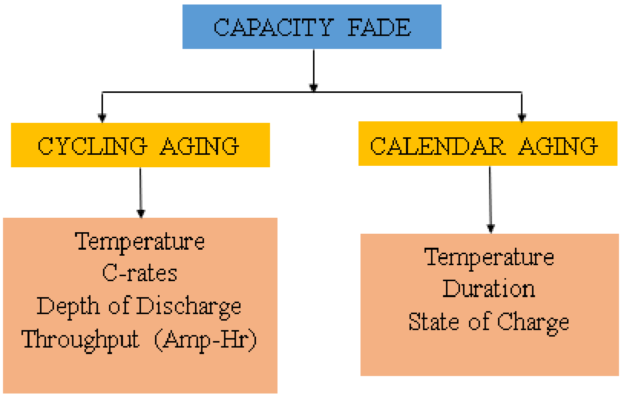
The maximum number of cells in the system is strictly pre-defined in the system development stage due to the system's limited flexibility and scalability. In other words, since the BMS input pins are already mapped to each corresponding cell from the initial design, adding more cells to the pack is not possible [10]. A battery can age in two different ways:

- Capacity fade is the reduction in energy available at a specific discharge rate.
- Internal resistance building up: As internal resistance builds up, the voltage drops under load. As a result, less power will be available before the voltage drops below a certain level. Additionally, the cell's I^2R heating will rise.

Cycle Life Degradation- where cells are put through a full charge-discharge cycle at various fixed temperatures. The quantity of charge and discharge cycles that a battery can complete prior to experiencing a substantial decline in capacity. A longer cycle life signifies a battery with an extended lifespan.

- Time
- High Temperature
- High Voltage/SoC
- Current Load
- Low Temperature
- Stoichiometry
- Mechanical Stress
- Low Voltage/SoC

Figure 2: Factors Affecting Cycle Life



SOH Monitoring: State of Health (SOH) quantifies the battery's present condition in relation to its initial capacity. SOH is continuously monitored and estimated by battery management systems using charge-discharge cycles, voltage, and temperature as inputs.

Depth of Discharge (DoD): The proportion of the battery's total capacity that is consumed after a discharge cycle has been completed. Degradation typically occurs more quickly when deeper discharges are present. It is possible for BMS to control DoD in order to prolong battery life and manage degradation.

Cell Balancing: Maintains a consistent charge and discharge across all of the cells, thereby preventing any individual cells from being overcharged or over discharged. In addition to extending the life of the battery, proper cell balancing helps to counteract imbalances.

Calendar Aging: Regardless of the number of charge-discharge cycles, the battery will eventually age over time. Calendar aging is influenced by a number of factors, including temperature, storage conditions, and chemistry. It is possible to reduce the effects of calendar aging through proper storage and thermal management.

Improved battery chemistries, manufacturing techniques, and battery management system (BMS) functionalities are the focus of research and development efforts as technology continues to advance. The goal of these efforts is to extend the life cycle of batteries used in hybrid and electric vehicles and improve their durability. In order to address these challenges, ongoing innovations are being developed with the goal of making electric and hybrid vehicles more appealing and environmentally friendly options.

4.0 Conclusion

An electric vehicle's battery pack is closely monitored by the battery management system. It guarantees the safety of the battery pack and safeguards the vehicle in the event that any of the cells are malfunctioning. It also calculates the vehicle's range and aids in extending the battery pack's overall lifecycle. A battery management system (BMS) is used to enhance battery quality and ensure safe operation, and it is essential to the use of electric mobility. The battery management system is a necessary component which will supervise and make sure that the batteries will perform properly and manage to avoid the hazardous scenarios like battery failure. The assessment of battery degradation and life cycle estimation holds significant importance for both vehicle manufacturers and consumers in the context of hybrid vehicles. The health and longevity of the battery pack have a significant influence on the overall performance and cost-efficiency of hybrid vehicles.

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