Chapter 8
Overview of Battery Management Systems in Electric Vehicles

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1 Introduction

Nowadays, the usage of batteries has been in a wide range. All the consumer electronics devices, such as laptops and mobile, are powered by the use of batteries. Even batteries are incorporated in the electric vehicle. But the hybrid vehicle consists of both the electric power and IC engine, leading to the state of polluting devices.

To overcome this issue, the globe has been looking for a completely electric vehicle, which doesn't employ any fossil fuels. The full-scale electric vehicle runs on an onboard battery. So, the management and monitoring of batteries have been an essential factor in running the system effectively and in a reliable manner. However, due to the less lifetime and high cost, the growth in the electric vehicle has been dropped. To make the system effective with high life, the battery management part needs to be improved significantly. The battery management system is a system, which has software and hardware part such as various electronic components to perform multiple objective functions. Since the old decade, the batter is a component that has to be monitored in-depth to avoid damage to the human personnel.

The battery management system (BMS) growth is expected to increase by 15% during 2020–2025. Through the Increased sales of electric vehicles, there will be a growth in the automobile sector, which supplies a significant share to the battery management system market globally. Especially for lithium-ion batteries, a BMS system needs to be incorporated that too in electric vehicles. Owing to the safety concerns when using lithium-ion batteries, BMS has a wide application in electric

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M. Kathiresh et al. (eds.), *E-Mobility*, EAI/Springer Innovations in Communication and Computing, https://doi.org/10.1007/978-3-030-85424-9_8

vehicles. Increased adaptation of electric vehicles and focusing on increased efficient usage of batteries are expected to drive the demand for battery management systems. However, the initial cost of electric vehicles has also restricted the growth of BMS. In China and Japan, the growth of electric vehicles and BMS has exponentially increased.

This increased growth has been due to the continuous efforts taken by the government to mitigate the emission of greenhouse-impacting gases. Furthermore, further discussions about the BMS communication platform are carried out, which plays a vital role in optimizing and controlling battery performance. Finally, conclusions and specific limitations on the battery management system are mentioned.

2 Battery Maintenance Parameters

The type of battery employed for certain applications has a significant impact on battery maintenance as in Fig. 8.1. Since each type of battery has its own operating characteristics, some have a particular reaction behavior evolving with gases concerning their volumetric component. In cases where the battery volume changes, it leads to complexity in sealing the battery; in those cases, various chemicals or regular water are employed to reduce the evolution of gasses. On the other hand, an air-tight sealed battery does not have an option to incur any environmental changes. As a result, these batteries are user-friendly and have less maintenance when compared to the batteries that react with surrounding chemicals. That's why most of the batteries in use are air-tight, as they don't need additional maintenance. Whereas other batteries like lead-acid require significant maintenance at a particular schedule.

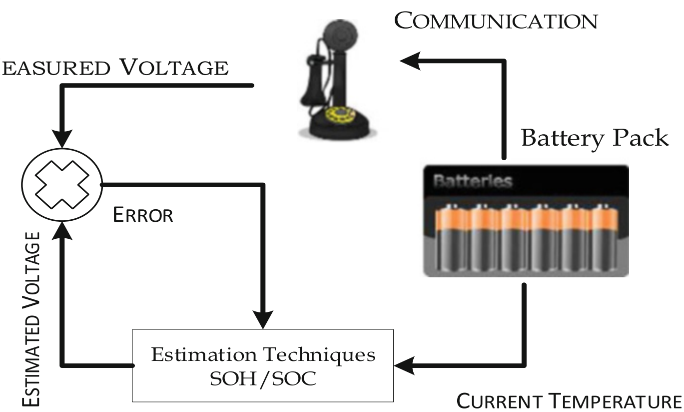

Fig. 8.1 Block diagram for monitoring battery parameters

The battery management system (BMS) is an enlightened package comprising hardware and software systems, which is almost needed for high-module battery packs [1].

The general utility of the BMS consists of:

- Measuring the voltage in cell and control when needed
- Controlling the contactors
- Thermal Monitoring and control actions
- Calculation of State of health
- Monitoring Isolation
- Communicating the operating state or actions needed.

The BMS balances the battery charging accordingly based on the loading and continuous monitoring of the operating state of the battery.

By monitoring the voltage fluctuations, charging capability, and communication with the BMS interfaces, a real-time battery health monitoring technique, the BMS extends the battery life and increases the battery's efficiency.

BMS undergoes different methodologies such as distributed, centralized, and modular.

Distributed BMS

It has a cell board in each cell and has a single point of communication between the controller and battery through a communication cable.

Centralized BMS

It has only one controller, and with the aid of communication wires, it is connected to the battery.

Modular BMS

It has several controllers through which the cells communicate with each other, and it can handle a certain number of cells in a battery pack.

This communication topology is a must needed for thermal management to operate the vehicle safely and adjust the battery life with the vehicle performance. These functions are discussed in the following section from the perspective of lithium-ion battery packs.

2.1 Measurement of Cell Voltage and Controlling

Monitoring voltage is another essential function of BM. The battery management system is designed in a way to monitor the voltage across the group of cells. The increased voltage expedition occurring due to the increased voltage and over-discharging ultimately impacts battery life and safety concerns. The better state of charge (SoC) and state of health needs an effective battery cell balancing algorithm.

For neglecting the impact of overvoltage, the cell voltage should be monitored at most care. Compared to these batteries, lithium-ion type of batteries must not be overcharged. Overcharging of cells will lead to a rise in temperature, and specific chemical reactions will occur. This chemical reaction ruins the battery life.

In accumulation, overcharging increases the cell heat sufficiently, which leads to fire hazards. Overcharges can be reduced by adequately monitoring the voltage and managing the charging state by incorporating the BMS system. The battery pack design must be robust to monitor cell voltage to make certain overcharge and over-discharge conditions in certain rare cases.

2.2 Contactor Control

This is cultivated by utilizing switches at access boards and extra electrical connector sticks that are acclimated electrically to work out if a connector has been eliminated. In direct execution, the coil power shuts the high-voltage contactors travels along a meandering way through every client passageway inside the high-voltage framework. Suppose any access point has been breached or opened. In that case, the conductor is broken, and therefore, the contactor coil power is removed, leading to the opening of the same thereby high-voltage module gets de-energized. This direct execution isn't conventional in current-age vehicles because it generates undesirable failure modes. If such a faulty establishment or switch will de-energize the high voltage module unexpectedly, and this may put occupants in danger while on transit if the vehicle system stops unexpectedly.

2.3 Monitoring the Isolation Parameter

Only when current is given to the human body from an electrical medium, the process works in terms of reflexes, and there's a return path as well to reduce the magnitude of voltage range from the medium. Because of these, the circuit requires two faulty sections even before it reached the human body—one permits electrons to leave away the circuit and flow into the body. A second must permit the electrons to leave the body and rush back to the circuit [2].

These parametric circuits regularly counter files the resistance between the high-voltage system and, therefore, the chassis. Typical guidance denotes the value must be greater than 100 Ω/volt for electricity (DC) systems (ISO 2011) [2]. Thus, system should maintain a resistance above 35 kΩ between the high voltage system and the chassis. This ensures that the current will be as per the IEC standards. There are a variety of methods for measuring isolation on the vehicle. The circuit accustomed to measure isolation shouldn't have any failure modes that allow the isolation monitoring safety circuit to become the source of isolation failure.

2.4 Temperature Control

The BMS is typically accountable for both assembly and thermal behavior of the same, also the temperature is one important consideration in design aspects with regard to safety and life implications [3]. The monitoring strategy for controlling thermal stress on cells is exclusive to every application. But, the BMS should have necessary data about thermal variation across the assemble to permit the control process to regulate heating, cooling, or pack power levels as needed.

2.5 Communication

One important BMS functionality is to have communication with additional controllers in the vehicle system. For data communication BMS often use CAN bus and RS485 because of the interfacing units [4]. The BMS frequently request changes in system operation to bring under the surveillance in battery assembly conditions and might forecast its capability in near future. Transfer of information is also necessary to produce the same to the driving force, like vehicle range, operating mode, and any faults. Finally, with regard to contact establishment with respect to off-vehicle, Off-board DC chargers will be utilized to have an improved charging rate without putting the load on to the vehicle in every possible aspect like weighing capacity and difficulty of inbuilt charges inside the system.

2.6 Battery SoC Measurement Principle

The determination of battery SoC becomes a posh task that depends on the kind of battery and its application. To enhance the reliability, lifetime, and performance of electric batteries, accurate SoC estimation is an important task. SoC is defined because the available capacity is expressed as a percentage of rated capacity or percentage of current capacity (i.e., latest charge-discharge cycle). Because the cell ages, its actual power will start decreasing, and towards the tip of the cell's life, it reaches nearly 80%. Hence for accurate measurement of remaining charge in every battery, the aging and environmental factors should be considered as in Fig. 8.2 [5].

State of Charge Estimation Techniques:

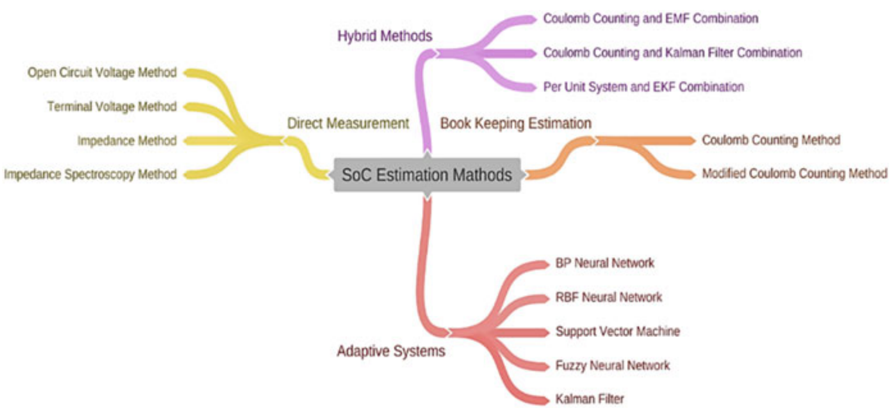

Fig. 8.2 Estimation of SoC methods

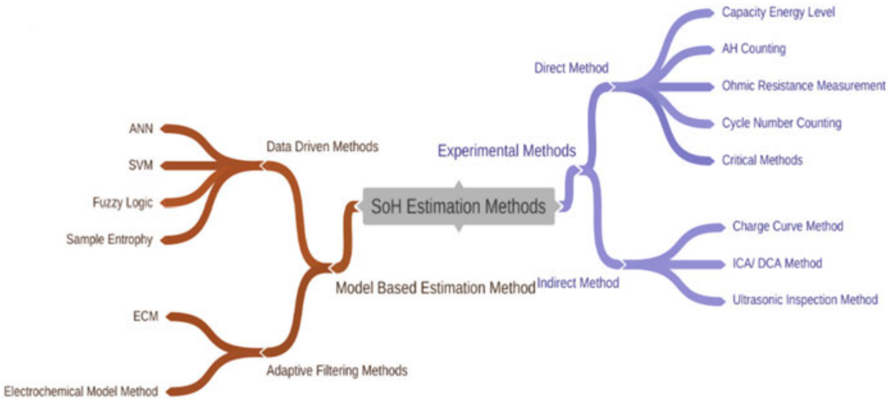

Fig. 8.3 Classification chart on different SoH estimation methods

3 State of Health Estimation Techniques

SOH refers to the performance index calculator of the electric battery, which conveys this state of battery compared with the initial stage of the battery. It notifies the battery aging and ruin state and alerts when the battery needs to get replaced. Different SOH estimation methods are available based upon various features. During this chapter, the SOH estimation methods are classified as experimental methods and model-based estimation methods as in Fig. 8.3 [6].

3.1 Experimental Method

In this method, the battery behavior is estimated within the laboratory founded with a more significant number of continuous experiments to evaluate the SoH, which is also a drawback of this method because it differs from the driven data. But this could be used as a study component to ascertain the model-based estimation methods. Experimental methods are classified as the direct measurement method and indirect measurement method—battery health state pointers like impedance, energy, and ampere counts. Cycle count is the parameter that is held as a base for the direct measurement method. Collection of information, analysis and processing of knowledge are required during this indirect measurement method.

1. Direct Measurement Method:

    (a) Capacity or energy level: The battery capacity data is required to estimate the achievable mileage of an electric vehicle. The energy that may be stored inside A battery is that the critical information of this measurement. So, this measuring technique may be used only in laboratories. But the capacity of the running vehicle can't be determined by this method. If the battery capacity is understood in real-time, then that becomes the particular SOH estimator. Therefore, online prediction methods are available to comprise the battery capacity which can be further discussed.

    (b) AH counting: Using the appropriate technique, the charge transferred during charging and discharging of battery approximation is required for SOH estimation. The computation formula for SOH is SOH = Q_MAX/Q_N × 100%, where QMAX refers to the maximum available capacity of the current condition. QN refers to the nominal capacity of the battery. Long-run monitoring and continuous updating of battery current are required to obtain accurate results, but it costs a lot of your time and energy. Also, high-care sensor is mandatory to get the precise remaining capacity. Though this method isn't applicable to be utilized in real-time, it may be the ECM method for SOH estimation.

    (c) Resistance/impedance measurement: The internal resistance is a significant parameter that defines the ability of the battery to test and operates within the safety voltage range; the present stage value is applied to its rated voltage thereby, measurement can be done [6]. Different techniques are available to live the resistance. The resistance is additionally influenced by some external factors like temperature and aging. This pulse methodology [7] is employed, which relates the effect of temperature on the electrical phenomenon. Electrochemical impedance Spectroscopy is the other method available to live the electrical phenomenon. This method is employed within the laboratory to test the electrochemical process inside the battery by using the characteristic response obtained when a sinusoidal signal is applied to the cell, which measures the impedance. EIS generally measures the battery impedance in a vast frequency range, which may measure other parameters like double-layer capacitance, charge transfer resistance, etc.

(d) Cycle number counting: The life model of the battery measure of cycles gone through undercharging and releasing interaction will be estimated by utilizing the counter. Electronic items like telephones, workstations are being used for this SOH sign-in battery. The balance cycle number provides the SOH measurement directly from the compared data of the current cycle number and manufacturer-provided cycle number. Complete depth of discharge is utilized as an essential estimating boundary where conversion co-efficient are wont to convert the various depth of discharge under charging and discharging to the unique, complete depth of charge/ discharge.

(e) Critical methods: The miniature structural changes that occur during the maturing cycle might be controlled by specific techniques like Raman Spectroscopy, X-ray Diffraction, scanning microscope, etc. The structural change happens to the changes within the active material and stress. Dismantling of batteries is needed to breakdown the maturing instrument, which can forever harm the batteries. So these techniques are utilized uniquely inside the research center testing.

2. Indirect Measurement method:

This method involves multistep analysis of parameters related to the battery degradation parameters like capacitance and resistance. From the connection between the health parameters and degradation parameters, SOH estimation will be done.

3.2 Model-Based Estimation

Although the scientific method finally at last winds up inexact information, real-time data processing is required, which may be achieved by utilizing this model-based assessment strategy. The model-based estimation method is surveyed upheld the computation technique as adaptive filtering method and information-driven technique. The model-based estimation method is an expansion strategy where continuous preparing happens and assesses different trademark boundaries of the battery using different approaches like filtering and intelligent algorithms.

3.2.1 Adaptive Filtering Methods

The adaptive filtering method utilizes the ensuing models like equivalent circuit model and electrochemical process, which is that the most reformist technique in estimating the boundaries.

Equivalent Circuit Model Method: This technique relies upon the electrical attributes of the battery. The most commonly utilized models are the Rint model, Thevenin model, PNGV model, RC model, and composite model [8].

The ECM-based estimation method involves the subsequent stepwise procedures

- Choosing out the suitable ECM
- ECM parameter identification
- Solving out SOH using some filters.

4 Thermal Management

The occurrence of heat during operation is the most critical parameter to be monitored in all industrial operating devices. The excess production of heat is normal, but it has to be within a specific limit. For example, suppose the rate of rising heat exceeds the nominal operating parameter. In that case, the thermal management system needs to be incorporated to effectively monitor the thermal production and control with the assistance of thermodynamics. The flow of electrons is termed as the flow of current. Each conductor has a resistance in it, which limits the flow of current. If excess current flows, the passage of the conductor has a temperature rise, which in turn develops variation in thermal values and is also not limited to fluctuations. As per the Arrhenius law, the variation in chemical reaction rate leads to an exponential increase in temperature [5, 9].

According to the above-said law, there will be increased power from the battery when the temperature rises. When this criterion is noted from one point, it seems to be an advantage, but indirectly, this scenario causes various chemical reaction changes, which can't be reverted to normal operating conditions, leading to permanent damage to the battery. The perennial destruction occurs to the battery when its operating temperature exceeds the upper limit, and finally, the battery becomes dead. Every battery has its own boiling and freezing point; if these limits are crossed, it leads to the breakdown of insulation and even explosion.

The criterion where the battery yields good reliable performance is when operating above the electrolyte freezing point. Working the battery at freezing point regardless of the mentioned battery specs affects the battery life, which ultimately reduces the battery cycle. These battery characteristics show that it needs to be operated within specific limits for superior battery life. As in Fig. 8.4. for designing a proper thermal management system, the heating and cooling constraints need to be considered.

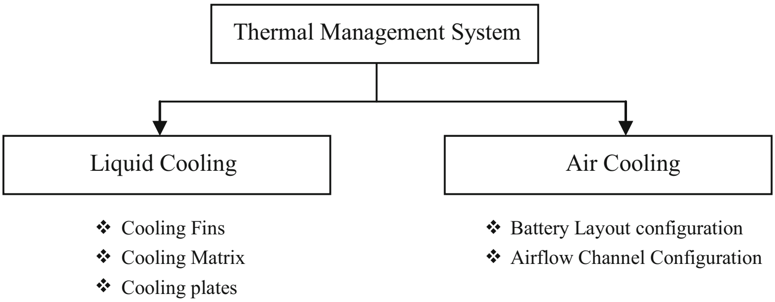

Fig. 8.4 Different thermal management system classification

4.1 Liquid Cooling

The liquid cooling is categorized into cooling fins, cooling matrix, and cooling plates. For pouch and prismatic rectangular type cells, cooling fins are the best thermal management device. For cylindrical cell-type batteries, the cooling matrix can be adopted. Cooling plates are placed below the cells.

4.2 Air Cooling

Air cooling technique has a better safety side with reliable operation. Even though it is not fir to be used for high duty performing batteries, since air cooling provides uneven temperature distribution in the battery pack, batteries can only be adopted for batteries that perform the light-duty operation. The high dense battery modules handle excess power, which requires high specific heat capacity to maintain the thermal limits. As the air has low specific heat capacity, it must precondition the air meant for cooling purposes and other methods of increasing the cooling air velocity for achieving the optimal cooling mechanism [9]. But the air-cooling mechanism can be used for all battery types wisely by undergoing modifications such as altering the airflow valve and battery configuration.

5 Summary

The battery management system (BMS) incorporated for a lithium-ion battery is an intricate system, even though it provides a meaningful contribution to safety and reliable performance. The software and hardware design plays a significant role in overcoming this constraint, while the cost incurred for development is often underrated. The plug-in hybrid vehicles in the present scenario have been designed for recycling energy to some extent. Through a suitable battery management system, the energies from the battery can be fed back to the grid. For battery parameter estimation, various methodologies had been deliberated in this chapter. But based on connected load and accuracy level, adopting the correct technique is an imperative chore. The machine learning techniques can be used for predicting the proper methodology. For the IoT-based devices for processing the big data analysis, BMS is a crucial technique for all-electric vehicles.

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