**BATTERY MANAGEMENT SYSTEMS-OVERVIEW**

**INTRODUCTION**

Successful adoption of EVs will require high-performance batteries (high energy and power density with long cycle life) and an advanced Battery Management System (BMS). BMS, an electronic system, protects battery from overcharging/over-discharging which ensures the safe operation of EVs. In the context of a fast growing EV market in India, it is important to develop a comprehensive and mature BMS programme.

For the long-term scenario, indigenously developed advanced BMSs will enable large-scale EV manufacturing in India and safe operation of EV fleets. Under the Make in India initiative, in-house manufacturing capability of LIBs along with BMS will help in reducing the total cost of EVs. The Government of India set an ambitious target of 6-7 million electric vehicles (EVs) by the end of 2020 under the National Electric Mobility Mission (NEMM) Plan 2013. This is an effort towards ensuring EV manufacturing leadership and national fuel security.

Awareness about BMS operation will enable smooth EV adoption and safe driving conditions. Further, for the indigenisation of EV manufacturing in India, it is important for stakeholders and consumers to know about global BMS suppliers. The latest research and development trends indicate that the next generation of high energy lithium-ion battery (LIB) systems will soon be available for electric transportation. However, high costs and low awareness, especially related to the safety features and drive range provided by EV batteries, are considered to be the key barriers in EV adoption. Among all the components of EVs, the battery packs which include a battery and BMS, alone account for 40% of the total cost of a vehicle. Currently, Indian EV manufacturers like Ashok Leyland and Mahindra and Mahindra depend on imported LIBs and BMS, which result in high costs. BMSs are widely used in portable electronics, such as laptops, computers and mobile phones, but these BMS variants do not qualify for EV application. The number of cells required for an EV’s battery pack is quite large, as compared to that required in portable electronics. Therefore, the BMS of an EV needs to be designed in such a manner that it can monitor the data generated by each cell present in the battery pack.

**BRIEF MARKET OUTLOOK**

BYD, Youtong, Proterra and EBUSCO make “intelligent BMS” for electric buses. On the other hand, Wuzhoulong Motors outsource BMS manufacturing to the largest lithium iron phosphate battery manufacturer company, Optimum Nano. In India, KPIT Technologies introduced the first smart electric bus in 2015; aligned with the government’s Make in India initiative .KPIT also develops BMSs in-house. Ashok Leyland introduced electric buses in India in 2016 with batteries and BMSs imported from France. There is a need to conduct detailed feasibility analyses of the short-term options for indigenous EV manufacturing with imported batteries and BMSs. For the long-term scenario, indigenously developed advanced BMSs will enable large-scale EV manufacturing in India and safe operation of EV fleets. An advanced BMS can be developed in India through carefully structured R&D. Under the Make in India initiative, in-house manufacturing capability of LIBs along with BMS will help in reducing the total cost of EVs.

**FUNCTIONALITIES**

The basic functions of a BMS include:

(a) Signaling the state of the health which includes safety, usage, performance and longevity of the battery;

(b) Identifying the fault of any individual cell and control it within the battery pack;

(c) Alerting the user under any unusual condition such as over-voltage or overheating;

(d) Monitoring the system temperature for better power consumption management.

Current BMSs have limited data cataloguing functions to update the state of charge. The data cataloguing function classifies each data generated by the BMS. Moreover, it has limitations in terms of estimating the state of health and remainder life span, which are required for scheduling battery replacement .State-of-the-art BMSs have the ability to measure most of the important characteristics of a battery pack (voltage, current and temperature).

Similar to the engine management system in a gasoline car, a gauge meter should be provided by the BMS in EVs .BMS indicators should show the state of the safety, usage, performance, and longevity of the battery. Due to volatility, flammability and entropy changes, a lithium-ion battery could ignite if overcharged. This is a serious problem, especially in EV and HEV applications, because an explosion could cause a fatal accident. Moreover, over-discharge causes reduced cell capacity due to irreversible chemical reactions. Therefore, a BMS needs to monitor and control the battery based on the safety circuitry incorporated within the battery packs. Whenever any abnormal conditions, such as over-voltage or overheating, are detected, the BMS should notify the user and execute the preset correction procedure. In addition to these functions, the BMS also monitors the system temperature to provide a better power consumption scheme, and communicates with individual components and operators. In other words, comprehensive BMS should include the following functions:

• Data acquisition

• Safety protection

• Ability to determine and predict the state of the battery

• Ability to control battery charging and discharging

• Cell balancing

• Thermal management

• Delivery of battery status and authentication to a user interface

• Communication with all battery components

• Prolonged battery life

**BATTERY EVALUATION IN BMS**

Battery evaluation issues refer to the estimation and prediction of SOC, SOH, and SOL of the EV battery.

SOC is critical, but it is not measurable given the current onboard sensing technologies. The ratio of the currently available capacity to the maximum capacity can be expressed as SOC. It reflects the amount of remaining charge that is available to the battery. It is used to determine the driving distance remaining in EVs,

SOH describes the physical condition of a battery, ranging from internal behavior, such as loss of rated capacity, to external behavior, such as severe conditions. A general definition of SOH is that it reflects the health condition of a battery and its ability to deliver specified performance compared to a fresh battery

SOL is also known as the remaining useful life (RUL) of a battery. Accurate SOL predictions will facilitate failure prevention and maintenance to prolong the service life of batteries.

**CONCERNS**

The estimation of some characteristics like voltage fluctuations and capacity fading by a BMS need to be more accurate. Further research on BMS can definitely overcome the drawbacks and improve its performance for an enhanced EV experience by the consumer, leading to increased EV penetration in Indian markets. As per the Global and China Power Battery Management System Industry Report, 2016-2020, the market size of BMSs would reach USD 7.25 billion by 2022 from the USD 1.98 billion mark as reported in 2015. This is estimated at a compound annual growth rate of 20.5%. North America held the largest share of the BMS market in 2015, followed by Europe, Asia Pacific and the rest of the world. Aiming for large-scale EV deployment in India by 2030 under NEMM, Indian EV manufacturers can import different components of EV along with the BMS. In addition, global EV manufacturers can set-up their integrated plant operations in India in the longer term. Most electric bus manufacturers develop their own BMSs.

With the increasing prices of gasoline and continuing breakthroughs in battery technology, EVs and HEVs were reintroduced in the early 1990s and became main stream in the 2000s. Because of its promising properties, such as high energy density, long life cycle, and low self-discharge, lithium-ion battery technology has been widely developed and applied in the past decade when the development of BMSs for EVs has been slow and insufficient. This lag has been caused by the following difficulties: (a) battery state evaluation; (b) battery modeling; and (c) cell balancing.

Battery State Evaluation: Knowledge of the battery state not only helps to determine whether the operational environment is safe and reliable, but also provides information about the charge-discharge operation, which is especially important for cell balancing. Usually, the battery state includes SOC and SOH determination.

SOC is similar to the fuel usage indication in gasoline cars, but the battery is inaccessible for measuring and experiences aging, varying environmental conditions, and charge-discharge cycles, which will makes it difficult for a BMS to provide an accurate SOC estimation.

SOH describes the percentage of battery life remaining. However, there is no consensus on the definition of SOH because it does not correspond to the measurement of a specific physical quality. Although the ratio of the current capacity to the maximum capacity that the battery can hold is usually viewed as a health indicator, more parameters referring to the field performance must be considered during SOH evaluation. The actual formula of the SOH for a specific application is often a trade secret. SOL is referred to in the literature as the time when the battery must be replaced It is similar to SOH, but quantifies the remaining time until the battery will be unable to perform.

Prediction of battery performance helps the engineer to plan maintenance strategies, and handle disposal and replacement issues.

**Battery Modeling**: Establishing a battery model is difficult due to the complicated electrochemical mechanisms of batteries. From the perspective of chemical characteristics, Scrosati and Garche presented voltage-to-capacity profiles of several Li/Li+ materials.

For example, LiFePO4 has a long flat trend when charging, while the voltage profiles of LiMn3O4 and LiCo1/3Mn2/3O2 gradually increase without a flat region. They showed that a generic model for a battery family does not work well for general applications.

Currently, battery modeling for SOC determination is commonly developed from various equivalent circuit (RC network) models, which are distinct for different material characteristics and accuracy requirements .Cheng and Tremblay adopted the generic battery model that was integrated in MATLAB. However, the generic model is based on the assumption that the internal resistance is constant during charge and discharge cycles. Thus, the accuracy of this model is subject to challenge.

While taking into account SOH estimation, the battery degradation model based on capacity fade was simulated and built. These model parameters were predominantly achieved in terms of the physical characteristics of the specific anode and cathode. However, the external factors, such as environment temperature and discharge current load, will make these stationary models inaccurate in a dynamic environment. As a result, model selection is always focused on in a BMS.

**Cell Balancing In EVs and HEVs:** cells are wired in parallel to form a block to satisfy the requirement of high capacity while several blocks (or cells) are connected in series to provide a high voltage .Each cell is distinct due to manufacturing and chemical offset. Thus, the cells in a series have the same current but different voltage.

During charging, capacity fade in cells may result in danger if a cell comes to its full charge easily. In other words, it will suffer from overcharging while all the rest of the cells reach their full charge. Similarly, over-discharge may happen on the weakest cell, which will fail before others during the discharging process.

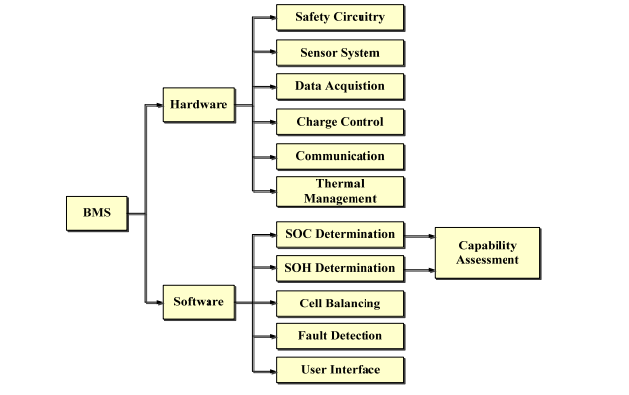
When the battery consists of multi-cells in series, it will be subject to a higher failure rate than any single cell due to a series network. To reduce this effect for prolonging the battery life, an effective cell balancing mechanism that would keep the SOC levels of individual cells in a battery pack as close to each other, should be developed.

The mainstream methods of cell balancing can be separated into two kinds: dissipative and non-dissipative. Both of those methods are dedicated to alleviating or even eliminating cell voltage imbalance.

However, dissipative equalizers used by resistors facilitate the dissipation of excess energy or current through heat with low efficiency. Non-dissipative equalizers are usually implemented by transformer, inductor or capacitor .They are considered more efficient than dissipative equalizers. However, the exchange of charge or energy among cells makes their charge-discharge profile much more complicated than the conventional profiles. These balancing techniques depend on determining the SOC of each individual cell in the battery.

**IDEAL BATTERY MANAGEMENT SYSTEM**

The weaknesses of current BMSs are identified through a comprehensive review of the existing approaches. To tackle these weaknesses, we suggest that a comprehensive and mature BMS should contain the components shown below as basic functions.



**Hardware**

Safety circuitry has long been used in BMSs. However, since more sensors are used in the proposed BMS, improvements in current safety circuitry designs can be implemented, such as the addition of accurate alarms and controls to prevent overcharge, over-discharge, and overheating.

The sensor system consists of different sensors to monitor and measure battery parameters including cell voltage, battery temperature, and battery current. Some researchers have proposed adopting EIS to monitor internal impedance. However, both space constraints and device cost hinder the feasibility of these measurements outside laboratory environments. Thus, current, voltage, and temperature should be measured to improve the capability of state tracking in real life applications. Data acquisition (DAQ) and data storage are critical parts for the software in the BMS to analyze and build a database for system modeling.

Charge control is a subsystem governing the charge-discharge protocol. Batteries are often charged by the constant current/constant voltage method (CC/CV) and will thus need to include a potentiostat and a galvanostat.

A variable resistor may be necessary to help balance cells or perform internal resistance measurements. Cell balancing control is still a critical design feature with room for improvement in order to equalize the battery pack and estimate the battery status in an efficient way.

Most subsystems in a BMS are stand-alone modules, and hence, data transfer throughout the BMS is required. Communication through a CAN Bus is a major way to transfer data within the BMS. With the development of smart batteries, more data can be collected to communicate with the user and the charger through the microchips incorporated within the battery.

In addition, wireless and telecommunication techniques are gradually being incorporated into charging systems that facilitate communication between the battery and the charger. A module for thermal management is critical because temperature differences have an impact on cell imbalance, reliability and performance. It is important to reduce the temperature difference among cells, which must be monitored and operated under proper temperature conditions.

**Software**

The software of the BMS is the center of the whole system because it controls all hardware operations and analyses of sensor data for making decisions and state estimations. Switch control, sample rate monitoring in the sensor system, cell balancing control, and even dynamic safety circuit design should be handled by the software of a BMS.

Moreover, online data processing and analysis are required for continually updating and controlling battery functions. Reliable and robust automated data analysis is a key factor for success because the analysis determines state estimation and fault detection. This information will be shown to the user through a user-friendly interface with appropriate suggestions.

The specific functions of the BMS software are discussed below. Determination of SOC and SOH will be integrated into a capability assessment, which also presents the life status of the battery and sets the operating limits according to state-of-the-art algorithms, such as fuzzy logic, neural networks, state-space-based models, and so on.

The objective of cell balancing is to maximize battery performance without overcharging or over-discharging. Its nature is to make the SOC levels of cells closer to each other. The controller will control the charge process based on a comprehensive strategy that depends on the SOC of each cell. Thus, the accurate SOC estimation of each cell is basic for improving the balancing.

Most soft faults will be discovered through online data processing. An intelligent data analysis is required in order to provide battery fault warning and indicate out-of-tolerance conditions. Historic data will be recorded and provide the pre-alarm condition before the possible faults. The user interface should display the essential information of the BMS to the users. The remaining range should be indicated on the dashboard according to the SOC of the battery. Additionally, abnormal alarming and replacement suggestions are needed to inform the users in terms of the estimation and prediction of the battery.

**CHALLENGES**

Capacity Estimation under Varying Loads and Environmental Temperatures-Due to varying temperatures

Estimation of Maximum Capacity-Since the battery will not be always discharged at a constant discharge current and will not be depleted to the cut-off voltage every time

Assessment of Battery Health

Battery Disposal and Recycling-Manufacturers frown upon a recycling stragegy as it’s not pocket friendly

Communication Mechanisms-Due to heterogeneous nature of the manufacturers