Digital Twin Based Battery Management System – A Review

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Abstract:- A battery management system (BMS) is an electronic regulator that keeps an eye on the vital operational parameters during charging and discharging of rechargeable batteries, such as voltages, currents, and the internal and external temperature of the battery. When any of the parameters, such as overcharge, undercharge, high temperature, or fall outside of limitations, the monitoring circuits would generally provide inputs to protection devices that would disconnect the battery from the load or charger. An essential part of electric and hybrid vehicles is the battery management system (BMS). The BMS's goal is to ensure dependable and secure battery operation. State monitoring and evaluation, charge control, and cell balancing are features that have been developed to preserve the battery's dependability and safety in BMS. The study on BMS that has been done in design and analysis is covered in this paper.

Keywords:- *Battery Management System, Cell Balancing, SOH, SOC, Digital Twining.*

I. INTRODUCTION

A lithium-ion battery, often known as a Li-ion battery, is a type of rechargeable battery that stores energy by the reversible reduction of lithium ions. In the 1970s, M. Stanley Whittingham developed the first rechargeable lithium-ion battery based on a titanium disulfide cathode and a lithium-aluminium anode. He also pioneered the idea of intercalation electrodes. While lithium-ion batteries (LIBs) were first commercially developed for portable electronics, they are now widely used in a wide range of applications, including electric cars, power tools, medical devices, smart watches, drones, satellites, and utility-scale storage.

Electric vehicles and related technologies will be very significant in the next years. Battery technology is one of them. Battery pack maintenance is necessary for an electric vehicle to operate safely but failing to do so could have major safety and logistical repercussions. Battery packs, which have a total battery voltage and output power, are made up of many li-ion cells coupled in series and parallel. These cells may be overcharged or undercharged as a result of voltage imbalances. Variations in other factors, such as temperature, can affect the cell voltages and initial charge capacities. Large battery packs provide high output power for the transportation sector without emitting noxious emissions like nitrogen oxides, carbon monoxide, or hydrocarbons that are linked to combustion engines that run on gas. In an ideal scenario, each cell in the pack makes an equal contribution to the system, however not all cells are created equal when it comes to number. The batteries may have variable total capacities, self-discharge rates, internal resistances, and ageing even though they have the same chemistry and are the same size, shape, and weight. These differences all have an impact on the calculation for the overall battery life. These variations put batteries in a difficult situation regarding battery life, which research has shown can be increased by cell balancing; as a result, the battery management system (BMS) is required to carry out cell balancing. The proper regulation of lithium-ion cell functioning will be provided by BMS. Because balance topology is the focus of most current research hotspots, there are few studies on optimizing the battery balance index. In most research, it is assumed that the BMS will activate when the voltage or SOC difference between the battery cells reaches the predetermined level and that it would shut off when it falls below it. These presumptions may determine whether a BMS is turned on or off. The ultimate equalization influence is therefore subpar when voltage is used as the index. Because the goal of cell balancing is to get all the battery cells in the battery pack to have the same SOC, this technique based on the SOC of the battery cell is very promising. In contrast to the voltage of the battery cell, which is easy to measure, it is necessary to estimate the SOC of each battery cell in the battery pack. A battery cell's state of charge (SOC) can only be determined by keeping an eye on factors like voltage, current, and temperature. It is unrealistic to think that achieving an accurate battery pack SOC, a vital BMS technology, will be easy to do. In the former, variations in voltage and current are used to infer the SOC of the battery cell, whereas in the later, a model is used to infer the OCV of the battery cell. The second, however, is reliant on the accurate SOC of the battery pack, whereas the former overlooks the mistake caused by the battery polarization factor. One of the most cutting-edge control systems ever tested is model predictive control, but it is very complicated and requires a lot of time and computing power. In reality, lithium-ion batteries often need a 10-minute or longer balancing phase during which the battery is essentially totally in the steady state. Due to the chemistry of Li-ion batteries, they are particularly susceptible to deepdrain and overcharging, both of which shorten the batteries' useful lives and result in their destruction, posing safety issues.

II. LITERATURE REVIEW

Batteries are other types of rechargeable batteries used in electric vehicles. Batteries' electrical capacity, or "electric charge," is measured in ampere hours or coulombs, with the total energy being expressed in kilowatt-hours (kWh). Since deep-cycle batteries are made to provide power for extended periods of time, they set themselves apart from starting,lights, and ignition (SLI) batteries.[12] Smaller, lighter batteries are preferable since they reduce the weight of the vehicle and hence increase its performance. Electric vehicle batteries are distinguished by their relatively high power-to- weight ratio, specific energy, and energy density. The majority of today's battery technologies have substantially lower specific energies than liquid fuels, which frequently affects the cars' maximum all-electric range. Due to their high energy density in relation to their weight, lithium-ion and lithium polymer batteries are the most popular battery types in contemporary electric vehicles. Lead-acid ("flooded", "deep-cycle," and "valve-regulated lead acid"), nickel-cadmium, nickel-metal hydride, and, less frequently, zinc-air and sodium nickel chloride ("zebra"). Lithium-ion battery technology has advanced since the late 1990s as a result of demands in market for portable products. These improvements in performance and energy density have benefited the EV and HEV market. Lithium-ion batteries, in contrast to prior battery chemistries like nickel-cadmium, allow for daily discharge and recharge at any level of charge.[13] A EV or HEV's battery pack accounts for asizable portion of the cost. Since 2010, the price of electric vehicle batteries has decreased 87% per kilowatt-hour as of December 2019. As of 2018, vehicles like the Tesla Model Sthat have an all-electric range of more than 250 miles (400 km) are commercially available in a wide range of vehicle segments. because EVs are more energy efficient, their running costs are lower than those of comparable internal combustion engines because they use less power.[12]

➢ *Battery Management System*

Any electronic device that controls a rechargeable battery (cell or battery pack), such as by safeguarding it from operating outside of its safe operating range, monitoring its condition, calculating secondary data, reporting that data, controlling its environment, authenticating it, and/or balancing it, is referred to as a battery management system (BMS).The "brain" of a battery pack is said to be the battery management system (BMS).A smart battery pack is one that was constructed along with a battery management system and an external communication data channel. A smart battery charger is required to recharge a smart battery pack. The BMS is a group of circuitries that keeps track of and controlsevery aspect of the battery's operation.[12] The battery is prevented, most crucially, from functioning outside of its safety parameters. For the battery to operate safely, to work optimally, and to last a long time, the battery management system is essential. The development of EV and HEV technology has accelerated in recent years.[13] Electric cars (EVs) and hybrid electric vehicles (HEVs) are commonly recognized as the most promising alternatives to traditional internal combustion (IC) engine-based vehicles. Due to their benefits including high energy density, low environmental pollution, and long cycle life, batteries are frequently used as the power source for EVs and HEVs. However, in EV applications, batteries need to be handled with special caution. The batteries will experience serious safety issues as a result of improper operations like over-current, over-voltage, or over-charging/discharging.[16]

These improper operations will also notably hasten the ageing process and may even result in fire or explosion. Consequently, the battery management system (BMS) is essential for guaranteeing the performance and safety of batteries. Many battery-management functions, including as charge/discharge control, battery capacity monitoring, information on remaining runtime, and charge-cycle counting, are necessary for a battery-powered vehicle's design. These characteristics influence the battery pack's performance and the dependability of electric vehicles (EVs), as well as the cycle life (the number of times a cell or battery can be charged under circumstances before the available capacity in ampere hours (Ah) fails to meet performance criteria of the cells.[13] The system is separated into five primary components to monitor and regulate the battery's charging and discharging as well as the working temperature. Which is made up of a complex rapid acting energy management system (CASM) with a current analyzing and State of charge/State of health (SOC/SOH) estimating module where the current is handled and the cell's SOC/SOH is estimated, a MOSFET control module, which is used to regulate the switch on/off of the battery to maintain it secure, a Voltage temperature analyzing module (VTAM), which receives the data obtained by the DPs sample circuits and performs additional analysis, A battery pack that has been divided up into multiple little sections and a display module are both introduced in order to show consumers the current, voltage, temperature, SOC, SOH, and amount of battery life left in the battery.[13][14] The battery pack in this BMS model has been divided into small subpacks with significantly fewer cells in each subpack, making it much easier to control and monitor the cells in each subpack due to the hundreds of cells that need to be monitored. Each module in the VTAM operates independently, receiving data samples from each IC embedded in each sub-battery-module, sending them to the CASM through the data bus for analysis, and notifying the monitoring its state (MOSFET) controller through the direct channel to microchip (MC) when there is any emergency. This ensures that any anomaly can be promptly addressed.[14]

CELL BALANCING is a technique that lengthens the life of batteries by maximizing the capacity of a battery pack by connecting several cells in series and guaranteeing that all of its energy is used.[3] Dissipative and non-dissipative approaches are the two primary types of cells balancing techniques. Dissipative techniques typically discharge a cell by connecting a resistor across it; they are often slow acting, inexpensive, and small. Power electronic circuits are used in non-dissipative techniques to transfer energy between cells. They might respond faster and use less energy, but they also make the BMS more expensive and larger.[4] The voltage balancing of the cells is extremely important in lithium-ion battery systems. The SOC of the cells with marginally lower capacities than the others will gradually diverge over a number of charge and discharge cycles. If the SOC of every cell isn't balanced or equalized on a regular basis, some cells will eventually be overcharged or over discharge, causing damage and ultimately leading to the failure of the entire battery stack. The MOS tubes integrated into the LTC6802-1 are used to control power resistance to achieve higher-voltage cell balancing.[5] The disadvantage of this type of circuit balancing is the loss of battery energy, but the benefits include a simple design, ease of implementation, low cost, and excellent application effect. On dissipative cell balancing, a more advanced balancing method, redistributes charge between battery cells during charge and discharge cycles. This technique extends system runtime by increasing the total amount of usable charge in the battery stack, cutting charge time compared to passive balancing, and reducing heat produced during balancing.[6] The energy is transferredfrom higher cell to lower cell on the string or pack using an active cell balancing system, also known as a non-dissipative balancing system, which uses passive components like a capacitor, inductor, and transformer.[9] The consistency of the ESD string pack was added as a result of the enhanced balancing efficiency in this system. In non-dissipated balancing, there are two groups inside the energy conversion system. Capacitor, inductor, transfer, and converter-based balancing is one of them. Another is balance from cell to cell, cell to pack, pack to pack, and cell to pack to cell (C2P2C).[10]

- *CELL TO HEAT*

This passive balancing or cell-to-heat balancing system is very simple. Here, excessive energy of the higher capacitive cell is diminishing bye resistor or a transistor with that workon the whole battery lifetime.[10] In this method energy has been not distribute to the other cells in the battery string, pack, or module science wasted by heat from. In these methods, produce lots of heat in the air render through the resistor and low efficiency. However, these methods have low cost, simple control, and easy to apply.[11]

- *CELL TO CELL*

In the cell-to-cell balancing topology, the excessive energy from the higher cell is transferred to the lower cell by the capacitor, inductor, and converter in the battery cell string. This balancing can be achieved by the energy storage components. Cell-to-heat balancing, Fixed shunt balancing; switches shunt balancing; analogue shunt balancing circuit balancing circuits required closed-loop control, and some are required an open-loop control system.[3] Though the balancing circuit structure is simple, fast balancing process, and good efficiency some of the circuits are complex control systems as well as accurate SOC or voltage sensing. Besides, this balancing circuit has been strong scalability, but it required a large number of switches, balancing components. C2C balancing topology can be divided into two groups: Adjacent cell balancing and direct cell-to-cell balancing.[4]

- *CELL TO PACK*

In this balancing topology energy from higher capacitance cell in the ESD pack id transfer over the pack through of capacitor, inductor, and transformer.[3] A cell monitoring circuit continuously monitors the cells in the pack. When a single cell voltage is higher than the average cell voltage on the pack then it executes the balancing process. When the energy transfers through transformer, then the excessive energy stored in the primary winding side and secondary side, transmit this energy in the pack. This balancing circuit has few components and simple structures.[4] This balancing topology faces some switching trouble during transferring the energy. In this balancing topology, only higher energy capacitive cell transfers the energy but lower cell on the string remains hampered so that overall medium efficiency.[3]

- *PACK-TO-CELL*

The battery pack transfers its energy to the weaker cell on thecell string through the peripheral balancing circuit. A cell monitoring circuit continuously monitors the cells in the package. When a single cell voltage is lower than the average cell voltage on the pack, then it executes the balancing process.[4] When this balancing process is excused through the transformer, the battery pack is connected with the secondary winding and primary winding individually connected with the cell.[5] These balancing circuits are bidirectional and work on charging or discharging mode, voltage/charge balancing variance is comparatively high, and overall efficiency is slightly improved. The C2P balancing circuits are single winding transformer, multi winding transformer, multiple winding transformer, and flyback converter.[5]

- *CELL-TO-PACK-TO-CELL*

C2P2C is a compacted and complex balancing circuit. In thisbalancing process, energy transfer into C2P, P2C, or pack topack (P2P) through the capacitor, indictor, and transformer. C2P2C balancing systems are single switches capacitor, single inductor, single winding transformer, multi-winding transformer, multiple transformers, and flyback converter-based balancing circuit. A single switch capacitor or single indicator is used to transfer the energy from one pack to another pack. In this balancing system, battery pack size has become enormous, and balancing circuit size is comparatively small but takes a long balancing time. Also, coaxial and double layer multi-winding transformer is used to transfer the energy from C2P and P2C.[5] When a cell has excess energy over the battery pack, it passes through the transformer’s energy to the lower cell on the battery pack. For the double layer transformer, the energy comes from the cell that mutually transfers the package's two groups. This balancing process is simple, and balancing speed is fast, but, in this process, excess energy is supplied in a group, but weak cells on the group directly cannot get this energy.[6] Acoaxial multi-winding transformer balancing system can distribute the energy in two or more cells at a time, and this balancing can be transferred to the energy with high-speed. However, the manufacturing process of this balancing system is very complicated.[5]

- *SOC*

The battery's SOC can be simply described as the battery's remaining capacity in relation to its nominal capacity. Numerous techniques were suggested for calibrating the SOC. A modularized charge equalization based on the open circuit voltage (OCV) battery model was presented by Kim et al. to estimate SOC.[20] The current maximum capacity, or SOH, is determined by charge and discharge cycles. Eventhough SOH fluctuates. The ability more slowly than SOC, SOH is nevertheless regarded as a crucial indicator of batteryavailability.[11]

- *SOH*

SOH can be used to detect gradual or abrupt battery cell deterioration and to stop the potential breakdown of the electric system and, consequently, the vehicle. Even though the SOH is extremely important, neither the scientific community nor the industry have come to an agreement on what it is or how to measure it.[13][14] It is a metric that shows the current state of the battery cell in terms of percentage, with 100% being a brand-new cell. One the one hand, a battery is deemed unusable for an electric vehicle and ought to be removed when its capacity has dropped to 80% of its original rated capacity.[15] On the other hand, under some circumstances, an increase in internal resistance may be greater than a reduction in battery capacity. The calculation of the battery SOH must account for both battery capacity deterioration and impedance growth. Unfortunately, Li-ion batteries are difficult to comprehend as systems, and the mechanisms that cause them to age are even more difficult[14]. Capacity loss and power fading are the result of many different processes and how they interact rather than one single cause. The examination of ageing mechanisms is further complicated by the fact that the majority of these processes occur at similar timescales and cannot be investigated independently.[7]

III. APPLICATION OF BMS

Battery banks are utilized in numerous industries, and batterymanagement systems (BMS) are used to monitor and managethem. Lithium Ion (Li-Ion) batteries predominate in the majority of energy storage applications, making BMS the crucial enabler from a functional and safety standpoint. Electric vehicles, which can be classified as electric automobiles, lorries, off-road vehicles like golf carts, as well as electric-powered equipment like forklifts.[1] Typically, the forklift, vehicle, and bus battery banks use the Control Area Network (CAN) to interact with the battery control module.

Battery banks are used in the grid power infrastructure to provide backup power or to protect against grid power fluctuations. Cell phone towers, A/C power substations, Internet infrastructure tools, aviation ground support systems, tower communications, weather stations, and distributed energy resources are just a few examples of the applications. The latter application, which includes solar and wind power facilities, is a sizable industry in and of itself.[2]

- *CHALLENGES IN BMS*

BMSs are still in their early stages, according to a literature analysis. The reliability of BMSs would still raise end customers' suspicions even if cutting-edge algorithms and monitoring techniques were created and implemented in EVs. As of bms only focuses on whole battery pack and not on individual cell as it become more complex to monitor individual cell of battery pack but due to uneven charge in cells causes the deterioration of whole battery pack.[8][18] As well as Future research should therefore focus on closing the gap between laboratory tests and actual requirements. Rarely has the performance of BMSs been investigated in operational situations such vibration from rough roads and temperature extremes from snow, rain, or summer heat.[19]

IV. SUMMARY

The studies of researchers, it was discovered that balancing measures provide an overview of studies on the construction and modelling effect of BMS conducted by various researchers. On analyzing battery cell or development pack with active balancing method helps to maintain battery life and efficiency for longer period. Study shows numerous methods to improve battery pack efficiency, and it has a very broad range of applications. Also, it can be indicated from the literature that BMS can be employed for numerous applications and has vast future scope in future and there is still much more to learn about it.

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