Battery Management System for Low Power Electric Vehicle

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Abstract: **The rapid growth of electric vehicles has increased the demand for reliable and efficient battery management systems to ensure safe operation, optimal performance, and extended battery life. This work presents the design and development of a comprehensive Battery Management System (BMS) for electric vehicle applications. The proposed system focuses on accurately monitoring cell voltage, current, and temperature, while also providing a reliable estimation of key battery states, including State of Charge and State of Health. Protection mechanisms are implemented to prevent overcharging, over-discharging, overcurrent, and thermal runaway conditions.**

Index Terms—**Battery Management System, State of charge, State of Health, Lithium Ion Battery.**

I. I. INTRODUCTION

The rapid growth of electric vehicles (EVs) has increased the demand for sustainable and flexible charging infrastructures capable of meeting energy, reliability, and environmental requirements. Conventional grid-based charging stations often suffer from high peak loads, limited renewable penetration, and dependency on fossil-fuel-dominated power generation. To address these challenges, hybrid energy infrastructures that integrate renewable sources, energy storage, and advanced charging technologies are gaining increasing attention.

Among various renewable options, photovoltaic (PV) systems provide clean and abundant solar energy, while fuel cells offer reliable and dispatch able power generation with low emissions. The combination of PV and fuel cell systems enables continuous energy availability despite solar intermittency. In addition, Wireless Power Transfer (WPT) technology has emerged as a promising solution for convenient and automated EV charging, eliminating physical connectors and improving user comfort and safety.

The design of a Battery Management System (BMS) is governed by several fundamental principles that ensure the safe, efficient, and reliable operation of battery packs in electric vehicles. These principles focus on monitoring, protection, control, and optimization of battery performance throughout its service life.

- **Accurate Sensing and Monitoring**: The BMS must continuously measure key battery parameters such as cell voltage, pack current, and temperature. High-precision sensors are essential to detect abnormal conditions at an early stage and to provide reliable data for control and estimation algorithms.

- **State Estimation**: Reliable estimation of the State of Charge (SOC), State of Health (SOH), and State of Power (SOP) is a core principle. These estimates enable accurate range prediction, performance control, and maintenance planning. Estimation algorithms should be robust to noise, ageing effects, and varying operating conditions.

- **Protection and Safety Management**: The BMS must protect the battery from unsafe operating conditions, including overcharging, over-discharging, overcurrent, short circuits, and excessive temperatures. Fast and reliable fault detection and isolation mechanisms are essential to prevent battery damage and ensure passenger safety.

- **Cell Balancing**: Individual battery cells tend to develop voltage and capacity differences over time. The BMS should implement effective balancing strategies (passive or active) to equalize cell voltages, improve energy utilization, and extend battery life.

- **Thermal Management Coordination**; Temperature strongly affects battery performance, ageing, and safety. The BMS should monitor temperature distribution and coordinate with thermal management systems to maintain the battery within an optimal temperature range.

- **System Integration and Communication**: The BMS must communicate reliably with other vehicle control units using standard protocols such as CAN. This ensures coordinated control of charging, discharging, and power delivery within the vehicle system.

- **Reliability and Fault Tolerance**: The design should emphasize robustness, redundancy where necessary, and self-diagnostic capabilities. This ensures continuous operation even under sensor failures or harsh environmental conditions.

- **Scalability and Modularity**: A well-designed BMS should support different battery pack sizes and configurations. Modular architecture allows easy adaptation to various vehicle platforms and future battery technologies.
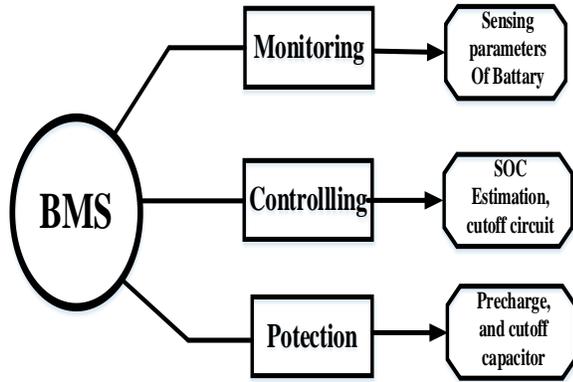

Fig. 1. Basic diagram of BMS

1.2. Battery types in Electric vehicles, and Battery Management System

The safe and effective operation of an electric vehicle (EV) depends on constant monitoring of the vehicle's battery management system

Table1: Types of batteries in Electric vehicles

Type	Li ion	Lead acid	NiCd
Life cycle	600-3000	200-300	1000
Nominal voltage	3.2-3.7	2	1.2
Charging efficiency	80-90	50-85	70-80
Charging temperature (∘C)	0-45	20-50	20-45
Discharging temperature (∘C)	20–60	20–50	20–65

1.3. Working of Battery Management System (BMS)

BMS is organised into three primary tasks: Monitoring, Controlling, and Protection, each responsible for specific operations to ensure safe and efficient battery performance, as shown in Fig. 1.

Along with optimising the EV's performance and driving range, it is also critical to guarantee the battery pack's longevity and safety. As a result, keeping an eye on the BMS is essential to maintaining an electric car. Following the guidelines and maintenance protocols set out by the manufacturer is crucial to ensuring that the BMS operates in a way that is both effective and efficient. A BMS's regulating

and protection chamber is in charge of tasks including cell balancing, temperature monitoring, state of charge (SOC) management, predictive maintenance, and battery protection [12–14]. BMS schematic monitoring, control, and protection, as seen in Fig. 1.

- *Monitoring*

This block represents the sensing function of the BMS. Here, the system continuously measures important battery parameters such as:

1. Cell and pack voltage.

2. Charging and discharging current.

3. Battery temperature.

By sensing these parameters, the BMS obtains real-time information about the operating condition of the battery. Accurate monitoring is essential for detecting abnormal conditions and providing data for further control and protection actions.

- *Controlling*

The controlling block processes the monitored data and makes decisions to regulate battery operation. Its main functions include:

1. **State of Charge (SOC) estimation** – determining how much energy remains in the battery

2. **Driving cut off circuits** – controlling when charging or discharging should stop

This block ensures that the battery operates within safe limits and delivers the required power efficiently during vehicle operation.

- *Protection*

The protection block is responsible for safeguarding the battery and the vehicle against unsafe conditions. It includes functions such as:

1. **Pre charge circuit** – safely charging the DC-link capacitors before full connection to avoid inrush currents.

2. **Cut off capacitor / cut off circuit** – disconnecting the battery during faults like overvoltage, under voltage, overcurrent, or overheating.

This work prevents damage to the battery pack and improves overall system safety and reliability. The methodology for designing a Battery Management System (BMS) for electric vehicles follows a systematic approach that includes battery

modelling, parameter sensing, state estimation, control strategy development, fault detection, and system validation.

II. SYSTEM DESCRIPTION

Model of Battery

Figures 2 and 3 show the redox flow battery's comparable circuit model. An equivalent circuit can be used to represent the redox flow battery's charge and discharge characteristics. Its straightforward design makes it simple to conduct simulation tests and view the results.
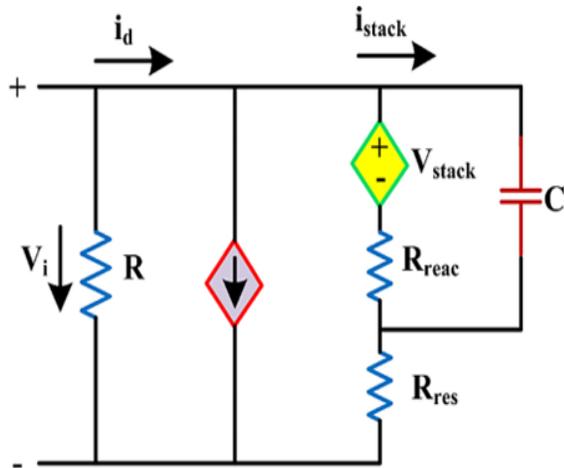

Fig. 2. Circuit diagram of battery

Rreac and Rres stand for the equivalent internal resistance loss, R for the fixed resistance losses, C for the dynamic response capability, and Vi for the open-circuit voltage, terminal current, ip for the current, and Vstack for the stack voltage and stack current in Figure 2. In relation to the overall charge the battery may achieve, SOC represents the proportion of the battery's maximum charge that is still accessible [22].

Cell balancing

Because of the architecture of the cell string, cell imbalance in battery systems is a problem to be addressed and a critical determinant in the battery system's lifespan. A battery system may result in overcharged or undercharged cells if a balancing technique is not used [24, 25]. Li-ion cells are particularly affected by this. However, battery consistency issues result from ageing effects, ambient temperature variations, and corresponding changes in internal resistance and capacitance of batteries. These issues reduce battery pack safety, longevity, and efficacy [26]. Therefore, developing a fair and efficient equalisation control strategy is crucial to resolving these battery inconsistency problems. The uneven distribution of cells to voltages, which causes either an overcharge or an undercharge of cells, is seen in Fig. 5. Active and Passive Balancing The battery pack equalisation control mechanism is divided into two categories: balancing approaches and balancing approaches. Every battery structures its dissipation equalisation method using parallel resistors, which has disadvantages such as slow equalisation speed, high power consumption, heat dissipation, and low efficiency [27]. There are two ways to further accomplish passive balancing:

switched shunt and fixed shunt. A resistor is always connected across the cell in a fixed shunt, which results in significant power loss. Additionally, with a switched shunt, the excess energy held in the cell is released as needed via a switch. With the assistance of the AFE IC, the MCU controls this switching. On the other hand, the non-dissipation Active equalisation method equalises quickly, efficiently, and with little energy. It is made to make use of circuits for energy transfer, such as capacitors or inductors.
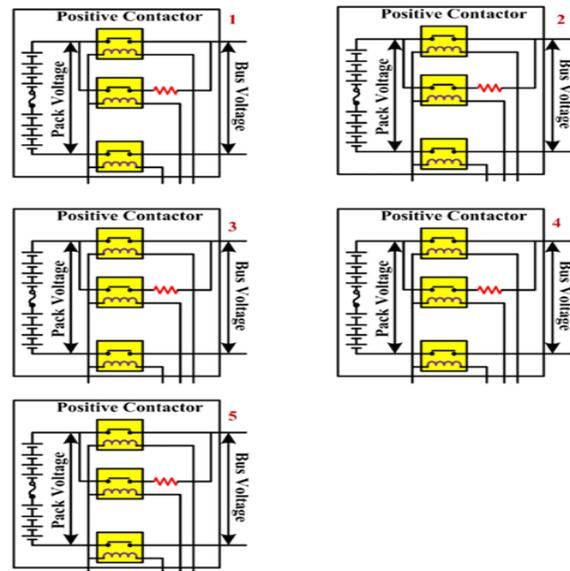

Fig. 3. Cicuit diagram of battery contactor

Active cell

The active cell balancing technology transfers charge from a high-charged cell to a low-charged cell by means of capacitive or inductive charge transfer [28]. In order to balance out variations among cells in series, active balance techniques move electrical energy from higher SOC cells to lower SOC cells. Maintaining a steady charge distribution throughout a battery's series-connected cells over time—ideally without causing any energy losses during the equalisation process—is the fundamental goal of an active balancing strategy. This is further complicated by the fact that the basic idea behind all active balancing methods is the transfer of charge from cells with higher SOC to cells with lower SOC via switched capacitors acting as intermediary storage banks. The active cell balancing technique ensures that all of the energy stored in the battery is used up, maximising its useable capacity in contrast to the passive balancing method.

Passive cell

It is easier to use the passive cell balancing method than the active cell balancing method. Because the excess energy in the cells is released as heat via a dissipative bypass pathway until the charge is equal to that of the lower cells in the pack or charge reference, this approach will affect the battery's run time [29]. There is no energy transmission between cells because of the dissipative nature of passive balancing, which resistors make possible. This is because cell energy is lost as heat. Because of this, this method is ineffective and generates a lot of heat when the charge is released into the atmosphere via a resistor. Because the excess charge of cells with high SOC is lost as heat through a resistor, the conventional passive methods of cell balancing lead to worse energy efficiency. However, when equalisation is achieved without active control, this method performs well in low-cost system applications. It cannot be utilised with lithium-based batteries due to the high danger of explosion [30]. The balancing rate is determined by the size of the resistor, which is connected in parallel to each cell in this way. We may observe the presence of a shunt resistor and a shunt MOSFET. When the cell voltages of analogous cells are out of balance, the MOSFET is driven.
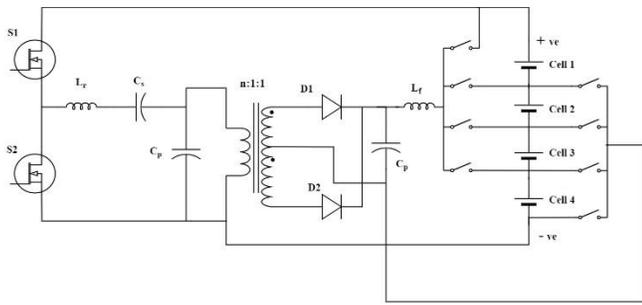

Fig. 4. DC-DC Active charge balancing

Table 2: The simulation design parameters of the resonant converter are shown in the table 2

Component Type	Parameters
Switching Frequency	20 KHz
Resonant Inductor (Lr)	184 uH
Series Capacitor (Cs)	2.368 uF
Parallel Capacitor (Cp)	403 nF

The modes of operation of the proposed converter are discussed below

Mode-1:

S1 is turned ON and S2 remains OFF. The entire battery string has been discharged by the inductor of the resonant circuit Fig 5a.

Mode-2:

The inductor current rises and the voltage of the parallel capacitor starts decreasing Fig 5b.
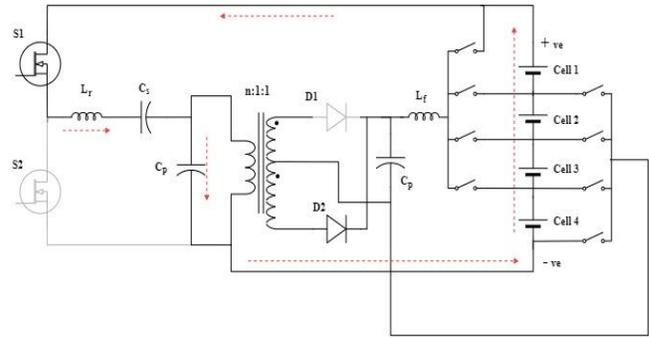
Mode-3:

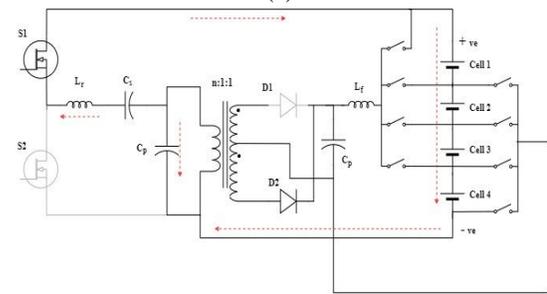The parallel capacitor (Cp) starts charging. The diode D1 and D2 are turned OFF Fig 5c.

Mode-4:

The inductor current (I_{Lr}) starts decreasing and the Diode D1 is forward biased Fig 5d.
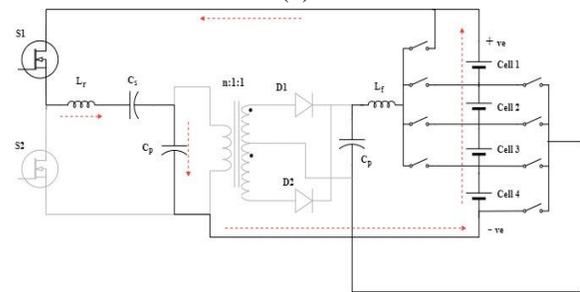
Mode-5:

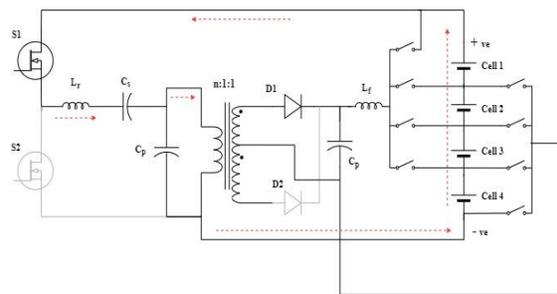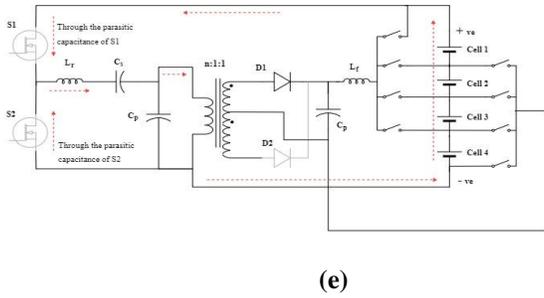S1 is turned OFF, and after ZVS condition is achieved Q2 is turned ON Fig 5e.

(a)

(b)

(c)

(d)

(e)

Fig. 5. Modes of operation of the cell balancing LCC converter

III.RESULTS AND DISCUSSIONS

Passive Balancing of the cells are performed in-order to understand the time taken for balancing and the temperature rise of the cells. The Graph shows the SOCs of 4 cells in the battery stack during passive balancing. Fig.6.1
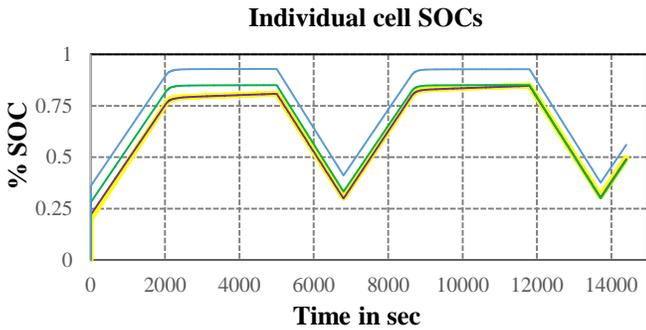

Fig. 6. SOCs of the cells during passive balancing

The four cells' initial SOCs are assumed to be 0.2, 0.22, 0.28, and 0.36. The cells are let to cycle between charging and discharging at a steady current of around 4A (Fig. 6.2). With reference to the TI datasheets, the balancing resistor is assumed to be 20Ω.

The balancing of the individual cell voltages and the current flow through the battery stack is shown in the Fig.6.2 and Fig.6.3.

The Active balancing is carried on two conditions.
1) Battery is on rest neither charging nor discharging
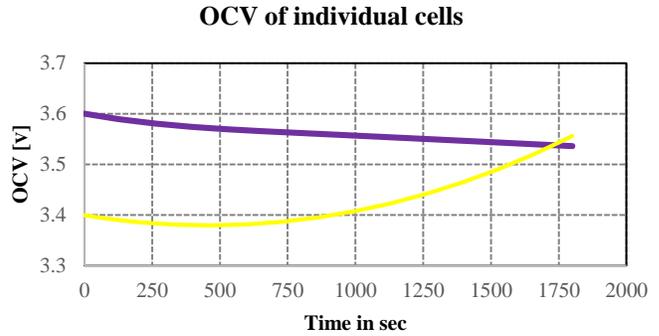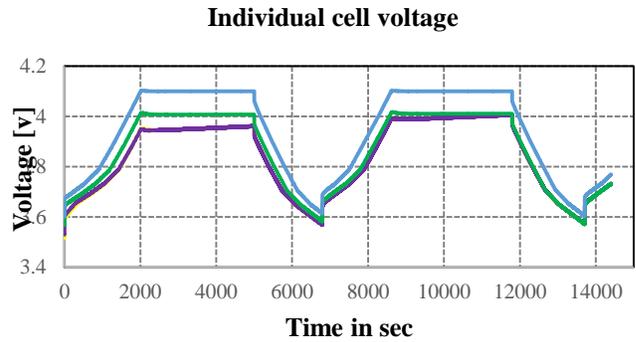2) Balancing is done by comparing the OCVs.

Fig. 7. Individual cell voltage and OCV of individual celss

The balancing time is almost 10 times smaller compared to the passive balancing. OCV and SOC have a non-linear characteristic, and the 200mV difference in OCV the minimum difference in SOC can be 10%. The threshold OCV can be selected such that SOCs can be matched with a tolerance of 5%. The balancing time on comparing with the passive balancing is found to be nearly 10 times less and the SOCs with respect to their OCVs have a large difference compared to the one taken in the passive balancing. The balancing of the OCVs of the cell is shown in fig 6
In the simulation model four cells are taken where the OCV of cell 4 is around 200mV lesser than other cells. The balancing of the cells is found to be happening less than 30 min. The current and the voltage waveform of the resonant converter are shown in fig 6and, fig 7
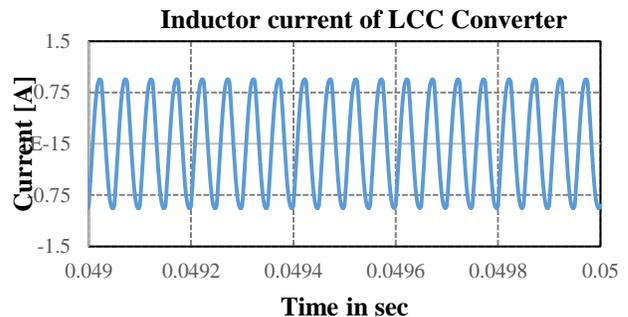

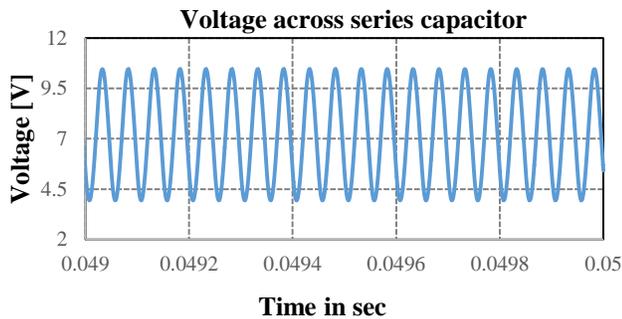Fig. 8. Inductor current of the LCC converter

Voltage across series capacitor

Fig. 9. Volatge across of the LCC converter

IV. CONCLUSION

The Battery Management System is the heart of the batteries and in that charge, equalization is a serious issue which must be given consideration. AFE handles the cell monitoring which include the sensing of cell temperature and the cell voltage. It also handles the cell balancing which can be done either passive or active. The battery cut off switch along with the gate drivers connects or disconnects the battery with pack and thus it is a bi-directional switch. A microcontroller is put as a bridge between the AFE, Gate drivers, CAN Transceiver, and other sensing which controls all the functionalities of BMS. Thus, collectively BMS takes care of everything related to the battery and takes care of the constraints which affect the lifecycle.This work shall be further investigated on the following points

1) The SOCs of the cells will be considered for balancing
2) State space model will be used for designing an algorithm to balance the battery packs
3) The balancing circuit will be compared with other topologies in efficiency and balancing time parameters

V. REFRENCES

1) S. M. More and B. M. Gupta, "Design & Development of Battery Management System for Electric Vehicles to Minimize Various Faults," *2024 Second International Conference Computational and Characterization Techniques in Engineering & Sciences (IC3TES)*, Lucknow, India, 2024, pp. 1-6, doi: 10.1109/IC3TES62412.2024.10877533.
2) MunishManas, Ravish Yadav, Rajesh Kumar Dubey,Designing a battery Management system for electric vehicles: A congregated approach,Journal of Energy Storage,Volume 74, Part A,2023.
3) H. Tomar, S. Singh, P. Gupta and K. Sireesha, "Design and Analysis of Thermal Management Systems for an Electric Vehicle Battery," *2025 First International Conference on Advances in Computer Science, Electrical, Electronics, and Communication Technologies (CE2CT)*, Bhimtal, Nainital, India, 2025, pp. 320-324, doi: 10.1109/CE2CT64011.2025.10941560.
4) Z. Yu, M. Zhang and J. Yang, "Design of Energy Management Systems for Mobile Power Station of Electric Vehicles," *2009 International Conference on Information Management, Innovation Management and Industrial Engineering*, Xi'an, China, 2009, pp. 250-253, doi: 10.1109/ICIII.2009.521.
5) Yeqin Wang and Yixing Liu, "Electronic control system design and test of pure electric vehicle battery management system," *2011 Second International Conference on Mechanic Automation and Control Engineering*, Hohhot, 2011, pp. 1289-1292, doi: 10.1109/MACE.2011.5987178.
6) C. Masjosthusmann, N. Decius, U. Köhler and U. Büker, "Smoothing the battery current in battery electric vehicles using a quantitative feedback theory designed MIMO-controller," *IET Hybrid and Electric Vehicles Conference 2013 (HEVC 2013)*, London, 2013, pp. 1-6, doi: 10.1049/cp.2013.1892.
7) C. S. Si, "Development research about the power battery management system of pure electric vehicle," *2011 International Conference on Consumer Electronics, Communications and Networks (CECNet)*, Xianning, China, 2011, pp. 276-279, doi: 10.1109/CECNET.2011.5769003.
8) S. Jinlei, L. Wei, T. Chuanyu, W. Tianru, J. Tao and T. Yong, "A Novel Active Equalization Method for Series-Connected Battery Packs Based on Clustering Analysis With Genetic Algorithm," in IEEE Transactions on Power Electronics, vol. 36, no. 7, pp. 7853-7865, July 2021, doi: 10.1109/TPEL.2021.3049166.
9) X. Qi, Y. Wang, Y. Wang and Z. Chen, "Optimization of Centralized Equalization Systems Based on an Integrated Cascade Bidirectional DC–DC Converter," in *IEEE Transactions on Industrial Electronics*, vol. 69, no. 1, pp. 249-259, Jan. 2022, doi: 10.1109/TIE.2021.3055134.
10) Marcos, D., Garmendia, M., Crego, J., &Cortajarena, J. A. (2021). Functional Safety BMS Design Methodology for Automotive Lithium-Based Batteries. *Energies*, *14*(21), 6942.
11) M. A. Hannan, M. M. Hoque, A. Hussain, Y. Yusof and P. J. Ker, "State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations," in *IEEE Access*, vol. 6, pp. 19362-19378, 2018, doi: 10.1109/ACCESS.2018.2817655.
12) W. Zhang, L. Wang, L. Wang, C. Liao and Y. Zhang, "Joint State-of-Charge and State-of-Available-Power Estimation Based on the Online Parameter Identification of Lithium-Ion Battery Model," in *IEEE Transactions on Industrial Electronics*, vol. 69, no. 4, pp. 3677-3688, April 2022, doi: 10.1109/TIE.2021.3073359.
13) T. Ouyang, P. Xu, J. Lu, X. Hu, B. Liu and N. Chen, "Co estimation of State-of-Charge and State-of-Health for Power Batteries Based on Multi Thread Dynamic Optimization Method," in IEEE Transactions on Industrial Electronics, vol. 69, no. 2, pp. 1157-1166, Feb. 2022, doi: 10.1109/TIE.2021.3062266.
14) C. Zhang et al., "An Adaptive Battery Capacity Estimation Method Suitable for Random Charging Voltage Range in Electric Vehicles," in IEEE Transactions on Industrial Electronics, vol. 69, no. 9, pp. 9121-9132, Sept. 2022, doi: 10.1109/TIE.2021.3111585.
15) S. W. Moore and G. MacLean, "Control and management strategies for the delphi high power lithium battery," in Proc. 18th Int. Battery, Hybrid and Fuel Cell Electric Vehicle Symp. and Exhibition, 6D, 2001, pp. 1–10
16) L. Lu, X. Han, J. Li, J. Hua, and M. Ouyang, ''A review on the key issues for lithium-ion battery management in electric vehicles,'' J. Power Sour., vol. 226, pp. 272–288, Mar. 2013.
17) H.R. Eichi, U. Ojha, F. Baronti, and M. Y. Chow, ''Battery management system: An overview of its application in the smart grid and electric vehicles,'' IEEE Ind. Electron. Mag., vol. 7, no. 2, pp. 4–15, Feb. 2013.
18) J. Meng et al., "An Overview and Comparison of Online Implementable SOC Estimation Methods for Lithium-Ion Battery," in IEEE Transactions on Industry Applications, vol. 54, no. 2, pp. 1583-1591, March-April 2018, doi: 10.1109/TIA.2017.2775179.
19) W. Han, C. Zou, C. Zhou, and L. Zhang, "Estimation of cell SOC evolution and system performance in module-based battery charge equalization systems," IEEE Trans. Smart Grid, vol. 10, no. 5, pp. 4717–4728, Sep. 2019.
20) J. Wei, G. Dong, Z. Chen, and Y. Kang, "System state estimation and optimal energy control framework for multicell lithium-ion battery system," Appl. Energy, vol. 187, pp. 37–49, Feb. 2017
21) G. S. Misyris, D. I. Doukas, T. A. Papadopoulos, D. P. Labridis and V. G. Agelidis, "State-of-Charge Estimation for Li-Ion Batteries: A More Accurate Hybrid Approach," in *IEEE Transactions on Energy Conversion*, vol. 34, no. 1, pp. 109-119, March 2019, doi: 10.1109/TEC.2018.2861994
22) M. Einhorn et al., "A current equalization method for serially connected battery cells using a single power converter for each cell," IEEE Trans. Veh. Technol., vol. 60, no. 9, pp. 4227–4237, Nov. 2011.
23) Yuang-Shung Lee and Ming-Wang Cheng, "Intelligent control battery equalization for series connected lithium-ion battery strings," in IEEE

Transactions on Industrial Electronics, vol. 52, no. 5, pp. 1297-1307, Oct. 2005, doi: 10.1109/TIE.2005.855673.

24) D. Roosevelt S and S. Singh, "Battery Management System for Li-Ion Batteries in Electric Vehicles," *2023 IEEE Renewable Energy and Sustainable E-Mobility Conference (RESEM)*, Bhopal, India, 2023
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