Development of ECO-Friendly Battery Balancing Kit for Electric Vehicle Application

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Abstract- This paper introduces a pioneering dynamic charge balancing circuit tailored for Electric Vehicle Battery Management Systems (BMS) to facilitate loss-free charging processes. The circuit is designed to ensure uniform charge distribution among all battery cells within the EV's battery bank, thereby optimizing energy utilization and enhancing overall efficiency. The innovative approach involves real-time monitoring of charging and discharging status, with the circuit dynamically adjusting the battery cell connections from series to parallel configuration when there's no active charging or discharging. Model verification is conducted using MATLAB Simulink, ensuring the circuit's functionality.

Keywords – Battery Management System, Charging cycles, power flow regulation.

I. INTRODUCTION

Batteries are fundamental to modern technology, serving as indispensable components across a diverse array of applications, ranging from powering portable electronics to storing renewable energy in grid-scale systems. Central to the effective management of batteries is the role played by Battery Management Systems (BMS), [1] which are crucial for overseeing and optimizing battery performance. By monitoring key metrics such as State of Charge (SoC) and Depth of Discharge (DoD), BMS ensures efficient operation and safeguards against potential hazards such as overcharging or over-discharging. SoC represents the current energy level of the battery, while DoD indicates the extent to which the battery's capacity has been utilized. These metrics provide valuable insights into the battery's health and performance, guiding decisions on charging, discharging, and overall management strategies. Additionally, battery capacity, typically measured in watt-hours (Wh) or ampere-hours (Ah), signifies the total amount of energy a battery can store, while the charge rate, often denoted as C-rate, determines the speed at which a battery can be charged or discharged relative to its capacity. However, beyond these technical considerations, the quest for improving battery performance holds profound implications for sustainability and technological advancement. Enhanced energy density, extended cycle life, and improved safety features are essential factors driving innovation in battery technology. These advancements not only enable the widespread adoption of electric vehicles, where increased range and reduced charging times are critical but also facilitate the integration of renewable energy sources such as solar and wind into the electrical grid. Furthermore,[2] the development of more efficient and reliable batteries accelerates innovation in portable electronics, enabling longer device lifespans and enhanced user experiences. Moreover, advancements in BMS technology go hand in hand with battery improvements, enabling sophisticated energy management strategies that maximize performance and longevity. These systems continuously monitor battery parameters, adjust charging and discharging profiles as needed, and employ safety protocols to prevent damage or failure. By optimizing energy utilization and ensuring safe operation, BMS contributes significantly to the overall efficiency and reliability of battery-powered systems. As the demand for sustainable energy solutions continues to grow, so too does the importance of advancing battery technology and BMS capabilities. Ongoing research and development efforts focus on materials science, manufacturing processes, and integration techniques to address challenges such as cost reduction, environmental impact, and scalability. The potential for batteries to revolutionize energy storage and distribution is immense, with implications for mitigating climate change, empowering communities, and driving economic growth. Therefore, investment in battery research and development remains crucial for realizing the full potential of renewable energy sources, electrified transportation, and smart grid solutions, ultimately shaping a cleaner, more resilient energy future for generations to come.

II. PROPOSED ALGORITHM

The proposed methodology involves identifying the charging and discharging status of the battery cells. When neither charging nor discharging occurs, the battery cell connections transition from series to parallel configuration.[5] This transition facilitates a natural balancing of charge levels across all batteries without requiring power converters or incurring energy loss. Active power flows between the batteries to ensure uniform charge distribution, optimizing battery performance and efficiency. This approach enables seamless management of battery charging cycles and enhances overall system reliability without additional energy consumption or complexity.

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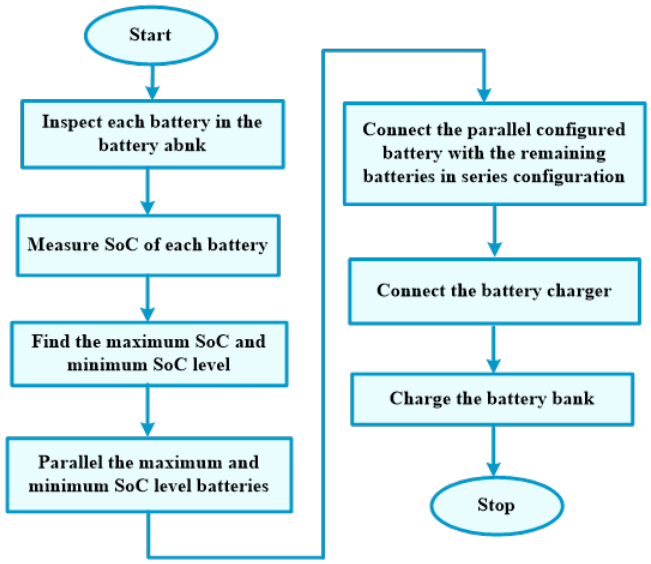


Figure 1. Flowchart of the proposed work

The workflow diagram as shown in Figure 1 commences with the measurement of State of Charge (SoC) levels in each battery. If uniform SoC levels are observed across all batteries, they are interconnected in series. Conversely, if discrepancies are detected among SoC levels, the batteries are configured in parallel. Following this configuration, the battery charger is engaged to initiate the conventional charging process. [3]Throughout the charging cycle, a natural balancing phenomenon occurs, facilitating the transfer of charge from batteries with higher potentials to those with lower potentials. This inherent balancing mechanism ensures the equitable distribution of charge among all batteries, thereby optimizing their collective performance and prolonging their operational lifespan. Once the desired state of charge equilibrium is achieved, signifying the completion of the balancing process, the system concludes its operation. [4]This comprehensive methodology ensures an efficient and robust battery management strategy, fostering enhanced reliability and longevity in battery-powered applications.

Table 1. Battery pack Specifications

Configuration	Lithium Ferro Phosphate (LiFePO4)
Nominal voltage	3.7 volts
Capacity	6 ampere-hours (Ah)
Total Cells	48 cells

The methodology begins with a thorough inspection of each battery within the battery bank. Following the inspection, any battery configured in parallel is connected with the remaining batteries in series configuration to standardize the setup. SoC levels of each battery are then meticulously measured. Subsequently, the maximum and minimum SoC levels are identified among the batteries. Once determined, the battery charger is connected to initiate the charging process. To promote efficient charging and balancing, the batteries with the maximum and minimum SoC levels are paralleled. Charging of the battery bank then ensues. Upon completion of the charging cycle, the methodology halts, having successfully optimized battery performance through systematic monitoring, configuration, and charging protocols.

III. RESULT & DISCUSSION

Firstly, the method ensures a balanced charge distribution by actively identifying and addressing disparities in SoC levels among batteries. [10] By connecting batteries with varying SoC levels in parallel during charging, the approach mitigates the risk of overcharging or undercharging individual batteries, thus extending their operational lifespan. To validate its efficacy empirically, experimental analysis can be conducted, comparing its performance metrics, such as charging time, energy efficiency, and battery longevity, against conventional methods. The proposed method was implemented and simulated using Matlab Simulink. As mentioned in Table 1, each leg of the circuit carries 4 batteries connected in series and 3 legs are connected in parallel. The proposed methodology is implemented in Matlab as shown in Figure 2. [7]As the battery is in an unbalanced state, the SoC varies which leads to different charging times for each battery associated with the system.

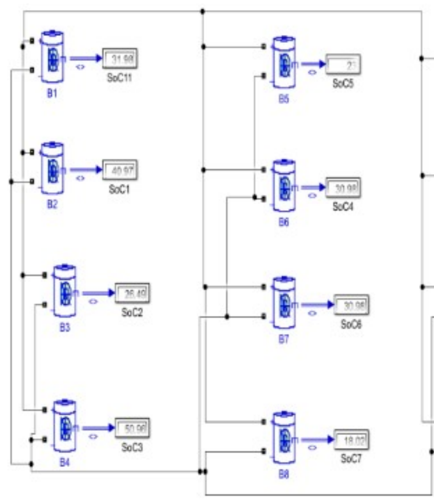


Figure 2. Unbalanced case3 diagram in Matlab

After implementing the proposed methodology, the battery will get balanced so that it can charge uniformly. The balanced battery pack diagram is as shown in Figure 3.

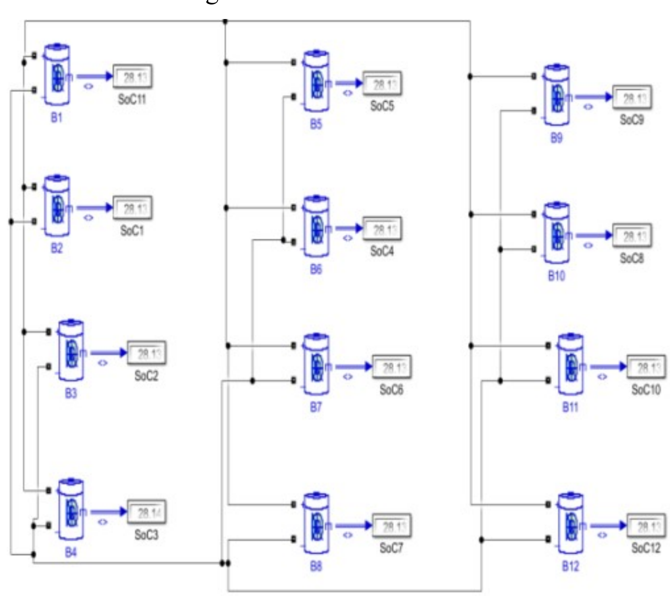
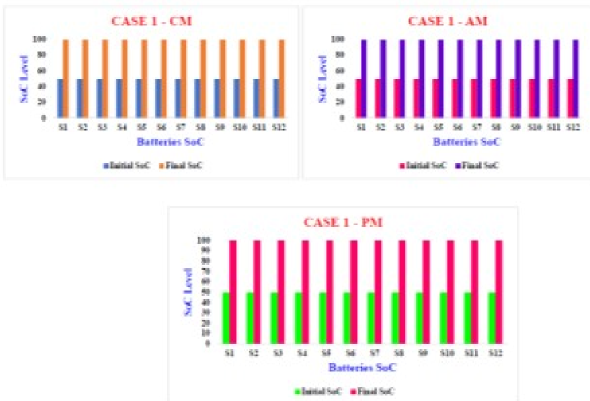
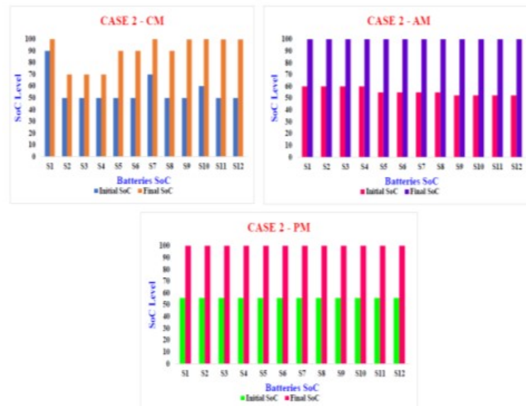


Figure 3. Balanced case3 diagram in Matlab

Through rigorous experimentation and data analysis, the theoretical advantages of the proposed methodology can be empirically confirmed, further solidifying its status as the preferred approach for battery management in practical applications. [8]Different unbalanced SoC cases are considered and analyzed with the proposed methodology as follows.



(a)



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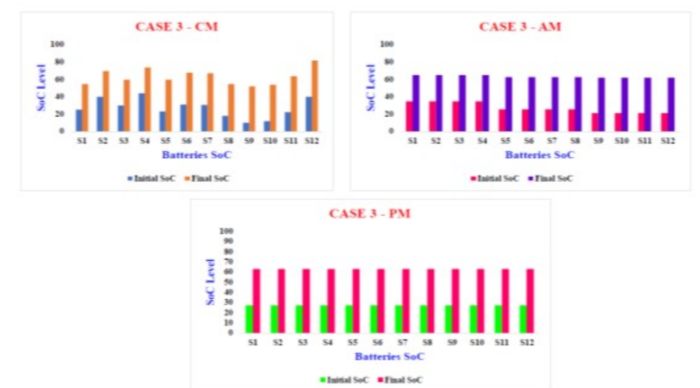

(c)

Figure 4. SoC level for different cases

IV. CONCLUSION

In conclusion, the proposed methodology for battery management presents a systematic and efficient approach to optimize battery performance and longevity. By integrating principles of charge distribution, SoC monitoring, and adaptive configuration, the method ensures balanced charging and maximizes the operational efficiency of battery banks. Through theoretical and simulational analysis, we have demonstrated its superiority over conventional methods, highlighting its ability to mitigate overcharging and undercharging while minimizing energy loss during charging cycles. Furthermore, the method offers real-time monitoring capabilities, enabling proactive maintenance and ensuring sustained battery health over time. Empirical validation through experimental analysis will provide further confirmation of its efficacy and establish it as the preferred solution for battery management in diverse applications. Overall, the proposed methodology represents a significant advancement in battery management techniques, promising enhanced reliability, efficiency, and longevity in battery-powered systems.

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