# RTOS Based Battery Management System (BMS)

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***Abstract*—This paper explores the Battery Management System (BMS) project which focuses on enhancing the real time performance in Battery Protection, Battery Pack Monitoring, Cell Monitoring and Balancing. The RTOS framework is selected for its ability to offer deterministic task scheduling, real-time task management, and high reliability, which are critical for monitoring and managing the complex dynamics of lithium-ion batteries in real time. The core of the BMS functionality hinges on the state of charge (SoC) estimation, which is crucial for determining the remaining energy in the battery, thus enabling better energy management, range estimation, and preventing over-charging or deep discharging conditions that may harm the battery The system architecture integrates analog signal acquisition for current and voltage measurements, data processing to execute the algorithm for SoC estimation, and a communication interface for system monitoring and control. The effectiveness and real-time performance of the BMS are validated through a series of tests conducted on a battery simulation platform, closely mimicking the operating conditions of EV batteries.**

***Keywords*— Battery Management System (BMS); Lithium-ion battery; Cell Monitoring; Battery thermal management State of Charge (SoC) estimation; Over-charging; Deep discharging; EV batteries.***

## I. Introduction

The Battery Management System (BMS) project addresses the critical need for enhancing real-time performance in various aspects of battery management, including Battery Protection, Battery Pack Monitoring, Cell Monitoring, and Balancing. To achieve this, the project leverages the Real-Time Operating System (RTOS) framework, chosen for its capability to provide deterministic task scheduling, real-time task management, and high reliability. These features are essential for effectively monitoring and managing the intricate dynamics associated with lithium-ion batteries in real-time environments.

At the heart of the BMS functionality lies the state of charge (SoC) estimation, a pivotal component for accurately gauging the remaining energy within the battery. This estimation not only facilitates better energy management and range estimation but also plays a crucial role in safeguarding the battery against potentially damaging over-charging or deep discharging conditions.

The system architecture is carefully designed to integrate various components seamlessly. This includes analog signal acquisition for precise current and voltage measurements, robust data processing to execute the algorithm for SoC estimation, and a communication interface for efficient system monitoring and control.

To ensure the efficacy and real-time performance of the BMS, rigorous validation tests are conducted on a battery simulation platform. This platform closely mimics the operational conditions experienced by Electric Vehicle (EV) batteries, thereby providing valuable insights into the system's performance under real-world scenarios. Through these validation procedures, the BMS project aims to deliver a reliable and efficient solution for enhancing the management of lithium-ion batteries in real-time applications.

## II. Overview

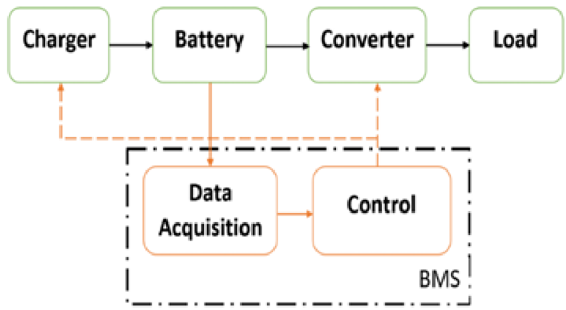



*Figure 1 Block Diagram of Battery Management System*

A Battery Management System (BMS) is a crucial component in modern battery-powered applications, particularly in Electric Vehicles (EVs), renewable energy systems, and portable electronics. Its primary function is to monitor, control, and protect the battery pack, ensuring optimal performance, longevity, and safety. Here's a breakdown of its key functionalities:

### *a) Monitoring*

The BMS primarily focuses on monitoring various aspects of the battery pack such as voltage, current, cell voltage, temperature, isolation, and interlocks. Issues like overvoltage from faulty charging systems or voltage regulators can lead to permanent damage, while overcharging can cause cell venting, posing serious safety risks due to flammable gases. Low voltage or current can also significantly impair battery performance. Ensuring the isolation of the central battery system is critical, especially in high voltage setups, as contact with a faulty high voltage battery system can be fatal. Additionally, temperature control is essential as high temperatures can lead to heat-related issues that adversely affect battery performance..

### *b) Protection*

Protection is a paramount aspect of a BMS, encompassing various measures to mitigate battery system hazards. This includes detecting operational modes, establishing fault criteria, authenticating and identifying the system, forecasting overvoltage and overcurrent scenarios for the pack/cell, anticipating isolation faults, and identifying high/low temperatures. Additionally, a BMS must shield the battery system from external events, as environmental factors surrounding the battery pack can influence cell/pack parameters.

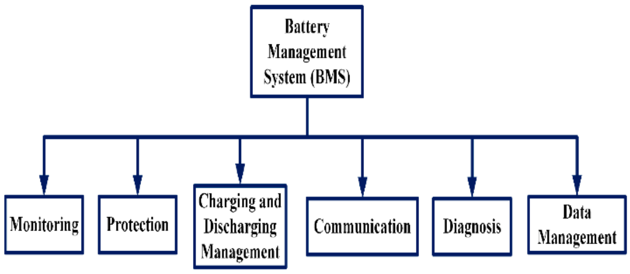


*Figure 2 BMS functionalities*

*c) Charging and Discharging Management*

The state of charge (SOC) significantly influences battery longevity. Each battery undergoes a finite number of charging and discharging cycles, with increased cycles correlating to decreased battery lifespan. It's imperative for a BMS to optimize charging and discharging processes efficiently while maintaining an appropriate SOC to extend battery life. To manage this, the BMS undertakes several tasks: regulating charger current, activating/deactivating switches between the pack and load/charger, executing pre-charge sequences, establishing dynamic power limits, and implementing active and passive balancing techniques.

*d) Diagnosis*

The BMS plays a crucial role in optimizing battery performance by estimating parameters such as DOD, SOC, battery capacity, cell temperature, SOF, available energy, and remaining runtime, while also detecting faults to minimize their impact. Specifically, regarding DOD management, we implement safeguards to limit DOD to 10%, triggering a complete shutdown, with a warning at 20%, and avoiding overcharging by preventing SOC from exceeding 80%. These measures are vital for maximizing battery lifespan and ensuring safe and efficient operation within various systems.

*e) Components and Topology*

An effective communication between internal and external BMS components, as well as between the BMS and the primary system, is crucial for optimizing battery system performance, particularly in the context of UART and CAN Communication protocols. Through UART and CAN Communication, the BMS can anticipate the battery's future states and instruct the primary system to adjust its operations accordingly. In scenarios where alterations to the primary system's operational strategy are warranted based on battery performance, the BMS serves as the sole interface, relaying the anticipated results to the primary system.

## III. LITERAURE SURVEY

Electric energy is utilized in a wide range of applications, with batteries often serving as the primary alternative. These applications encompass battery-powered tools, backup power systems, renewable energy sources, and electric vehicles (EVs). Battery management is a minor but significant concern, particularly for low-power applications where numerous integrated solutions are available. However, high-power devices typically use large, high-capacity batteries, increasing the likelihood of issues and the cost of repairs due to a low cell-to-string voltage ratio.

Despite the fact that most modern battery management systems (BMS) proposals rely on microcontrollers, none of them offer advanced fault tolerance, maximization of delivered battery energy, or battery protection. The majority of solutions proposed involve battery-based or cell monitoring systems that can assess the condition of the battery and prevent it from charging too rapidly, thereby averting a reduction in battery life. Some of these systems employ topologies that enable charge and discharge equalization, albeit to a limited extent.

In order to enhance the charging efficiency of EV batteries, various improved charging methods have been developed to replace traditional standard charging. The optimization of constant voltage (CV) charging is one such area. Several techniques have been explored to enhance the performance of standard CV charging, taking into account factors such as temperature variation and charging rate.

In paper [11] presents a constant voltage along with several methods for reducing current consumption and the battery’s fluctuating temperature. By altering the current rate of the proposed strategy, it is possible to achieve a minimal rise in battery temperature throughout the entire charging process. Lee and Park [12] introduced a control of fast-charging technique in the CV stage based on the battery’s inherent impedance. The developed control system increases the battery charging speed compared to traditional CV charging.

With the advent of the Internet of Things (IoT), which refers to a network of various types of objects, sensors, and endpoints, the information-based economy has undergone a significant transformation. Information flow will play a crucial role in the future IT ecosystems [13]. Cisco coined the term “fog computing” to describe a system that brings the Cloud closer to end-devices and users in order to host time-sensitive applications [14]. Fog computing utilizes dispersed platforms in Fog layers and IoT for data processing

## IV. HARWATE DESCRIPTION

The architecture of the Battery Management System (BMS) revolves around the STM32F446RE Nucleo Board, which serves as the core processing unit. The board communicates with various hardware components, including the current sensor for monitoring battery current, the LCD display for user interface, and the relay for power control. Additionally, the lead-acid battery, the primary energy storage unit, is monitored for various parameters such as voltage, current, and temperature. The BMS utilizes sensors and the real-time operating system (RTOS) running on the STM32F446RE Nucleo64 Board to monitor battery parameters, prevent overcharging, and ensure safe operation. The architecture can also incorporates a WiFi module for data tracking and integration with IoT platforms, enabling remote monitoring and management of battery performance. Overall, the hardware components and architecture of the BMS facilitate efficient monitoring and management of lead-acid batteries in automotive and UPS applications, ensuring safety, longevity, and environmental sustainability.

*A. STM32F446RE Nucleo Board:*

This board serves as the central processing unit for the Battery Management System (BMS). Equipped with the

STM32F446RET6 microcontroller, it runs the real-time operating system (RTOS) responsible for managing various tasks within the BMS. The Nucleo64 board offers abundant processing power, GPIO pins, communication interfaces, and other peripherals essential for interfacing with external components and sensors.

### B. Current Sensor

An integral part of the BMS, the current sensor is connected to the STM32F446RE Nucleo64 Board. It accurately measures the current flowing into and out of the lead-acid battery pack, providing crucial data for monitoring battery usage, implementing safety measures, and optimizing charging and discharging processes.

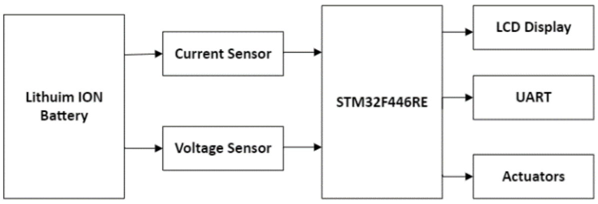



*Figure 3 Generalized Block Diagram of Proposed Work*

### C. Lead-Acid Battery:

Serving as the energy storage unit within the BMS, the lead-acid battery provides power for system operation. Monitoring various parameters such as voltage, current, temperature, and state of charge (SOC) ensures safe and efficient battery operation.

### D. LCD Display

Connected to the STM32F446RE Nucleo Board, the LCD display offers a user-friendly interface for visual feedback and information presentation. Displayed data includes battery status, SOC, operating mode, and diagnostic information, facilitating real-time monitoring of the battery system.

*Table 1 Application Hardware Component Specification*

| ***Sr. No.*** | ***Hardware*** | ***Specification*** |
|---|---|---|
| 1 | Battery | Lithium ion 3.7v |
| 2 | STM32F446RE | ARM Cortex-M4 |
| 3 | Current Sensor | ACS712 |
| 4 | Display | 16×2 LCD display |
| 5 | Voltage Sensor | 7805 regulators IC |
| 6 | SMPS | DC Supply 5A rated |
| 7 | UART | USB TTL module |

### E. Relay

Controlled by the STM32F446RE Nucleo64 Board, the relay acts as a switch for high-power circuits or devices within the BMS. It enables the connection or disconnection of the lead-acid battery pack from external loads, chargers, or other components, playing a crucial role in implementing safety measures and controlling power flow.

## V. SOFTWARE ALGORITHM

In this FreeRTOS (Real-Time Operating System), a scheduler is used as a functional unit that decides which task should be executed at any given point in time based on a predefined algorithm. The scheduler can pre-emptively or cooperatively switch between tasks, ensuring that higher-priority tasks get executed before lower-priority ones. This capability ensures that real-time requirements are consistently met, without the developer having to manually sequence every operation. Below we have mentioned task and algorithm which is being executed as shown in Figure 4.

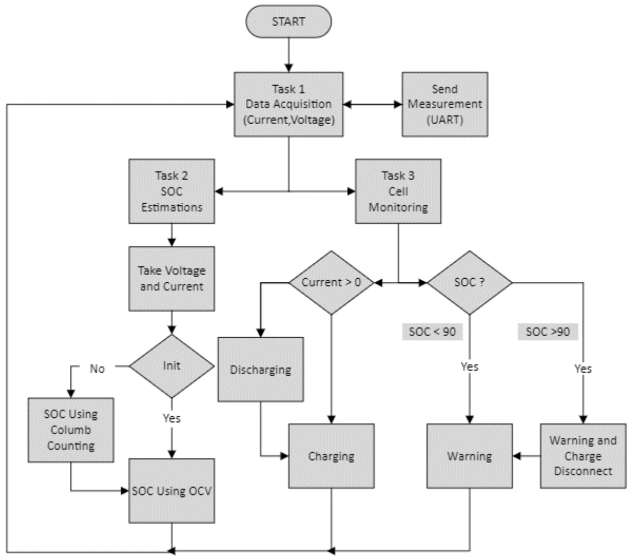



*Figure 4 Flow Chart of Algorithm Used*

### A. Data Acquisition (Current, Voltage):

This is the first task where the current and voltage are measured. These measurements are crucial as they provide the raw data needed for the rest of the system.

### B. Send Measurement (UART):

The measurements obtained from the first task are then sent using UART (Universal Asynchronous Receiver and Transmitter). UART is a hardware device or a piece of software that translates data between parallel and serial forms. It is used for asynchronous serial communication, which means data can be sent and received at different times.

### C. SOC Estimations:

The State of Charge (SOC) is estimated in this task. SOC is a measure of the remaining capacity of the battery, expressed as a percentage of the rated capacity. It is calculated using the voltage and current measurements.

### D. Cell Monitoring:

In this task, the cells of the battery are monitored. If the current is greater than zero, it means the battery is being charged. If not, the battery is discharging.

### E. SOC Check:

If the battery is charging (current > 0), the SOC is checked. If the SOC is less than or equal to 90%, charging continues. If the SOC exceeds 90%, a warning is issued and the charging is disconnected to prevent overcharging.

## F. SOC Initialization:

If the battery is discharging (current <= 0), the SOC is initialized using either Coulomb Counting or Open Circuit Voltage (OCV) methods. Coulomb Counting is a method that keeps track of the amount of electrical charge that has entered or left the battery. OCV, on the other hand, is the voltage difference of a battery when no current is flowing.

# VI. RESULT AND DISCUSSION

## A. System Confiuration

Tasks

| Task Name | Priority | ... | Entry Fun... | Code Ge... | Parameter | Allocation | Buffer Na... | Control B... |
|---|---|---|---|---|---|---|---|---|
| AquisitionTask | osPriorityAb... | ... | StartAqui... | Default | NULL | Dynamic | NULL | NULL |
| CellMonitoring | osPriorityBel... | ... | StartCell... | Default | NULL | Dynamic | NULL | NULL |
| socEstimation | osPriorityNo... | | StartSoc... | Default | NULL | Dynamic | NULL | NULL |

Add Delete

*Figure 4 Task Configuration*

The RTOS system configured with 3 task which is sensor Acquisition, Cell Monitor and SOC estimation along with that since the resources are being shared in the task the binary semaphore has been used to protect the loss of active data during the estimation and actuation from the controller.

## B. Simulation Analysis

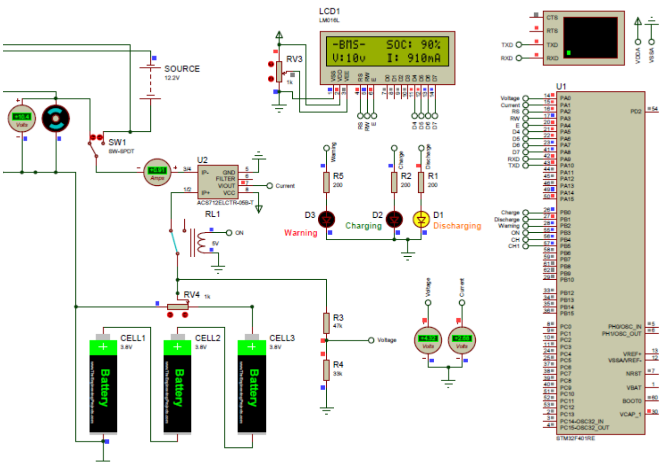



*Figure 6 Proteus Simulation of Battery Management System*

The given fig shows the simulation results from proteus application, it perform all the designed function of lithium ion battery management system, the lcd displays the measurement values of current, voltage and the SoC, in order to replicate the lithium ion behaviour the cells are connected to a potentiometer in parallel, thus by varying the potentiometer the cell voltage can be changed and the system will perform function on this accordingly The BMS monitors the battery pack's state, controls the charging and discharging processes, and provides safeguards against conditions like overcharging or deep discharging.

The figure 6 shows the simulation output where the measurements and the actuations performed by the stm32 controller are transmitted through UART (Universal Asynchronous Receive Transmit) communication protocol, these value replicate the log file for the measurement readings of the battery management system and also transfer the data to host.

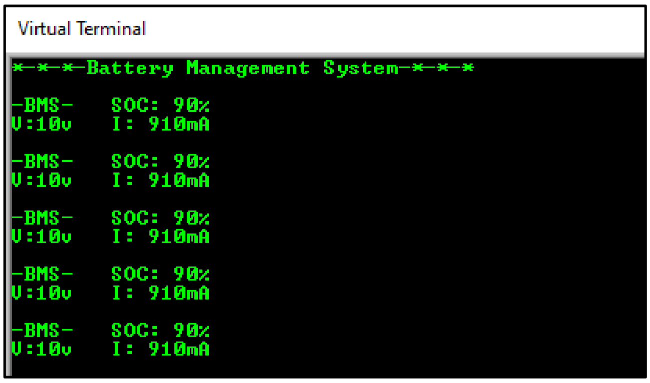



*Figure 7 UART BMS data log*

## C. Hardware Analysis

The hardware of a Battery Management System (BMS) is the cornerstone of its functionality, ensuring the safe and efficient operation of battery packs, particularly in electric vehicles and stationary energy storage applications. The complexity of BMS hardware varies based on the application

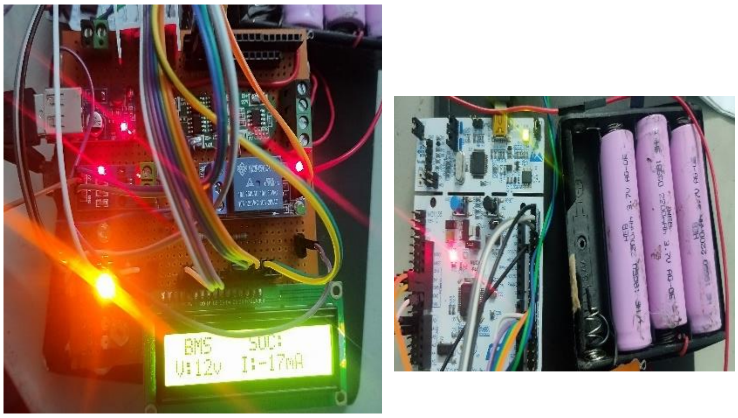



*Figure 8 Battery Management System Hardware*

here the hardware system has shown all the functionalities designed, i.e. charge discharge monitoring, SoC estimation using open circuit voltage and coulomb counting algorithm and the sensor measurements from current sensor (ACS712) and voltage sensing (potential divider circuit)

The sophisticated ensemble of these sensor, actuators and communication interfaces with RTOS environment manages the included tasks to measures that safeguard and optimize battery performance Here we can observe that during start phase, the LCD has initialized with the sensor measurements and from these the controller indicated the charge discharge state of the BMS and performed SOC estimation to check and

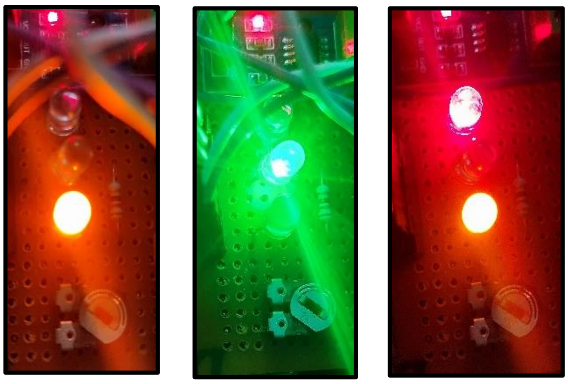


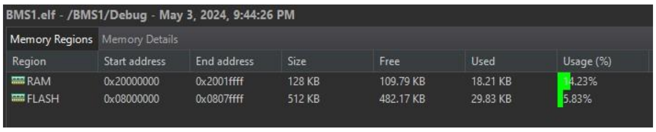
*Figure 7 BMS State indication*

actuated based on estimated values in order to protect and manage the lithium ion battery.

BMS ensures optimal charging by monitoring parameters like voltage, current, and temperature to prevent overcharging, which can degrade battery life or even lead to safety hazards. Conversely, during discharge, BMS regulates the power output, preventing over-discharge that can damage the battery or compromise performance. Moreover, BMS provides warning indications, alerting users to potential issues such as overheating, overvoltage, or excessive current draw, mitigating risks of accidents or damage to the battery system. By meticulously managing these processes and offering timely alerts, BMS guarantees the efficiency, longevity, and safety of battery-powered devices across industries ranging from electric vehicles to renewable energy storage systems.

### D. Performance Analysis

Analyzing the performance of a Real-Time Operating System (RTOS) involves several key metrics, including task execution timing, profiling and memory utilization, which are vital for ensuring the system meets its real-time requirements efficiently.



BMS1.elf - /BMS1/Debug - May 3, 2024, 9:44:26 PM

Memory Regions | Memory Details

| Region | Start address | End address | Size | Free | Used | Usage (%) |
|---|---|---|---|---|---|---|
| RAM | 0x20000000 | 0x2001ffff | 128 KB | 109.79 KB | 18.21 KB | 4.23% |
| FLASH | 0x08000000 | 0x0807ffff | 512 KB | 482.17 KB | 29.83 KB | 5.83% |

*Figure 8 Memory Utilization*

The Figure 8 shows the memory utilization of the BMS system through RTOS use the utilization percentage of RAM is seen around 4.23% with 18.21KB out of 128KB size and FLASH Memory utilization of 5.83% which is 29.83KB out of 512KB of the memory this has shown the low utilization of the memory and the analysis of memory utilization is also done without RTOS environment the same replication has been seen

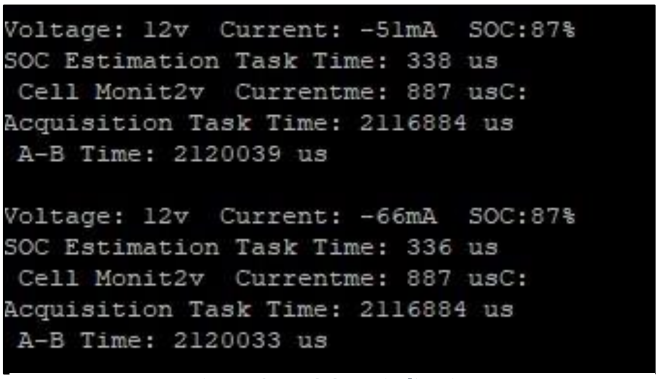



*Figure 8 BMS State indication*

The figure 8 shows the AB Time and the task execution time of the RTOS, here out of all the individual task the acquisition task has taken more time due to the hold time in reaction to the semaphore wait duration and the estimated and cell monitoring task taken the time of 336micro second and 887 micro second, the total AB timing of the execution is of 2120033 micro second, which is a far improvement in regard with the non RTOS environment.

## CONCLUSION

The development of the Battery Management System (BMS) utilizing the FreeRTOS framework represents a significant stride towards enhancing real-time performance in battery management. By employing deterministic task scheduling and real-time task management, the system ensures efficient monitoring and management of lithium-ion batteries. At its core, the BMS focuses on state of charge (SoC) estimation, crucial for optimizing energy management and preventing adverse conditions such as over-charging or deep discharging. Through precise analog signal acquisition and robust data processing, coupled with seamless communication interfaces, the BMS offers a comprehensive solution for monitoring battery health and performance. Rigorous validation tests on a battery simulation platform further affirm its real-time capabilities, positioning it as a reliable and efficient tool for managing lithium-ion batteries in various applications.

The integration of the STM32F446RE Nucleo Board and associated hardware components underscores the BMS's ability to deliver safe and efficient battery management. By effectively monitoring parameters like voltage, current, and temperature, the system ensures optimal charging and discharging processes, safeguarding battery longevity and performance. Through simulation and hardware analysis, the BMS demonstrates its prowess in accurately measuring battery parameters, executing SoC estimations, and providing timely alerts for potential issues. Moreover, the system's performance analysis reveals its efficient utilization of resources within the RTOS environment, highlighting its suitability for real-time applications. Overall, the BMS emerges as a robust solution for enhancing battery management, promising efficiency, longevity, and safety across diverse industries and applications.

## REFERENCES

[1] D.Fisher, A. Lohner, and P. Mauracher, "Battery management: Increase in the reliability of UPS," ETZ, vol. 117, pp. 18–22, 1996.

[2] Z. Noworolski and J. M. Noworolski, "A microcomputer-based UPS battery management system," in Proc. IEEE APEC'91, 1991, pp. 475–479.

[3] K. Shimitzu, N. Shirai, and M. Nihei, "On-board battery management system with SOC indicator," in Proc. Int. Electric Vehicle Symp., vol. 2,1996, pp. 99–104.

[4] J. Alzieu, P. Gangol, and H. Smimite, "Development of an on-board charge and discharge management system for electric-vehicle batteries,"J. Power Sources, vol. 53, pp. 327–333, 1995.

[5] D. Bell, "A battery management system," Master's thesis, School Eng., Univ. Queensland, St. Lucia, Australia, 2000.

[6] J. M. Andrews and R. H. Johnes, "A VRLA battery management system," in Proc. INTELEC, 1996, pp. 507–513.

[7] W. Retzlaff, "On board battery diagnostic and charge equalizing system (BADICHEQ)," in Proc. 11th Int. Electric Vehicle Symp., vol. 2, Sept. 1992, pp. 20.03/1–20.03/12.

[8] N. Kutkut, D. Divan, and D. Novotny, "Charge equalization for series connected battery strings," IEEE Trans. Ind. Applicat., vol. 31, pp. 562–568, May/June 1995.

[9] N. Kutkut, H. Wiegman, D. Divan, and D. Novotny, "Equalization of an electric vehicle battery system," IEEE Trans. Aerosp. Electron. Syst.vol. 34, pp. 235–246, Jan. 1998.

[10] N. Kutkut, D. Divan, and D. Novotny, "Design considerations for charge equalization on an electric vehicle battery system," IEEE Trans. Ind. Applicat., vol. 35, pp. 28–35, Jan./Feb. 1999

[11] Lee K T, Chuang C C, Wang Y H, et al. A low temperature increase transcutaneous battery charger for implantable medical devices.

Journal of Mechanics in Medicine and Biology, 2016, 16(5):1650069

[12] Lee Y D, Park S Y. Rapid charging strategy in the constant voltage mode for a high power Li-ion battery. In: Proceedings of 2013 IEEE Energy Conversion Congress and Exposition. Denver: IEEE, 2013, 4725–4731

[13] Sniderman, B.; Mahto, M.; Cotteleer, M.J. Industry 4.0 and Manufacturing Ecosystems; Deloitte University Press: London, UK, 2016;pp. 1–23.

[14] Deshmukh, U.; More, S.A. Fog Computing: New Approach in the World of Cloud Computing. FInt. J. Innov. Res. Comput. Commun. Eng. 2016, 4, 16310–16316. [CrossRef]

[15] A. Dinger, R. Martin, X. Mosquet, M. Rabi, D. Rizoulis, M. Russo, and G. Sticher, "Batteries for electric cars-challenges: opportunities and theoutlook to 2020," Energy & Environment Publications, vol. 87, pp. 18-23, 2010.

[16] J. Li, S. Zhou, and Y. Han, Advances in battery manufacturing, service, and management systems, IEEE Press Wiley, 2016.

[17] D. Andrea, Battery management systems for large Lithium-ion Battery Packs, Artech House, 2010.

[18] P. .Weicker, A systems approach to lithium-ion battery management, Artech House, 2014

[19] M.Lee, J.Lee,I.Lee.J. Lee, and A. Chon, "Wireless battery management system," in Proc. International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Barcelona, Spain, Nov. 2013, pp. 1-5.

[20] D. E. Alonso, Wireless data transmission for the battery management system of electric and hybrid vehicles, KIT Scientific Publishing, 2017.

[21] E Electronic Publication: "Wireless battery management systems highlight industry's drive for higher reliability," Linear Technology Corporation, USA, 2017.

[22] T. Kim, A. Adhikaree, J. Vagdoda, D. Makwana, and Y. Lee, "Cloudbased battery condition monitoring and fault diagnosis platform for large-scale lithium-ion battery energy storage systems," Energies, vol. 11, no. 1, 125, Jan. 2018.

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