

## ADAPTABLE LITHIUM CELL BATTERY MANAGEMENT SYSTEM

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**ABSTRACT:** The advent of sophisticated battery technologies necessitates advanced management systems to ensure safety, efficiency, and longevity. This project introduces an innovative Smart Battery Management System (BMS), designed to optimize the performance and extend the lifespan of modern battery cells. Through a meticulous integration of real-time monitoring, predictive analytics, and adaptive control algorithms, the proposed BMS not only safeguards against common battery failures but also enhances the overall energy throughput. Employing a combination of voltage, current, and temperature sensors, alongside a robust microcontroller unit, the system meticulously governs the charging and discharging cycles, ensuring uniform cell usage and preventing overcharge scenarios. The project's novelty lies in its self-learning capability, which adapts to various battery types and usage patterns, promoting a greener footprint by maximizing battery reuse and reducing waste. The results demonstrate a significant improvement in battery health metrics, including state of charge (SoC) and state of health (SoH), validating the BMS as a pivotal tool in the realm of renewable energy solutions. This project not only contributes to the academic field but also holds significant promise for commercial applications, offering a scalable solution to the growing demands of renewable energy systems. As we advance towards an increasingly electrified future, the insights and methodologies from this project will serve as a cornerstone for the next generation of smart energy solutions, ensuring reliability, safety, and environmental harmony.

### INTRODUCTION:

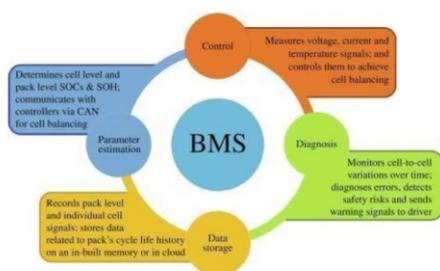
Electric Vehicles are the future of the automobiles and the recent technological advancements have proved to enhance the need for sophisticated systems which can monitor, control and operate the vehicles with improved performance. A significant component in electric vehicle is the energy storage system which comprises of electrochemical cells which are monitored using an electronic circuit called the battery management system. This BMS circuit plays a pivotal role in taking care of the battery, controlling the charging and discharging mechanisms, running periodic diagnostics of the battery pack and several other interim factors that ensure the proper functioning of the entire ESS system.

needs to be dissipated accordingly. Hence, the thermal analysis is needed along with the monitoring of the temperature of the battery pack. The electrochemical cell is capable of catching up fire or blast out because of abnormality in the function. This creates the need for safety and protection of the BMS.

Finally, all the data procured from the system is stored in the DAQ system for further analysis and understand the performance of the battery pack as a whole.

### ELECTRIC VEHICLES

Electric vehicles are attracting a lot of attention and many OEMs are shifting their industry landscape towards the creation of electric and hybrid electric vehicles. In order to improve the vehicle fuel economy, emissions, performance and reliability, more electric vehicles concept emphasizes the utilization of electric power systems instead of non-electric power transfer systems. In addition, the need for the improvement in comfort. Convenience, entertainment, safety, communications, maintainability, support-capability, perseverance and optimum operating costs necessitates more electric vehicular systems. As a result, these power systems have unique system architectures, properties, dynamics and stability issues which are not similar to those of conventional electric power systems. Solid-state power switching power converters are extensively used for generating, distributing, and utilizing electrical energy throughout the system. Electric vehicles (EVs) represent a transformative shift in the automotive industry, offering a cleaner and more sustainable alternative to traditional internal combustion engine vehicles. Powered by electric motors and equipped with



**Figure Overview of BMS**

The above Image Fig Overview of BMS Shows the first and foremost task of any BMS circuit is to provide an efficient means of charging and discharging for the battery back designed. Followed by this, cell balancing will be an important activity of the BMS followed by which there arises a need for estimating the battery state. Each cell undergoes a chemical reaction during charging as well as discharging and as a by-product there arises heat from the battery back which

rechargeable batteries, EVs produce zero tailpipe emissions, contributing to efforts to reduce air pollution and combat climate change. Lithium-ion batteries, with their high energy density, are the predominant technology, enabling longer driving ranges and enhanced performance.

Charging infrastructure is a key element in the widespread adoption of EVs, with home charging, public charging stations, and rapid DC fast charging networks becoming increasingly prevalent. Governments worldwide are incentivizing the adoption of EVs through tax credits, rebates, and other initiatives, fostering a growing market for electric vehicles. Advancements in battery technology, regenerative braking, and autonomous features are further enhancing the appeal and practicality of EVs. Despite challenges such as charging infrastructure expansion and concerns about battery production sustainability, electric vehicles are poised to play a pivotal role in the future of transportation, offering a sustainable and environmentally friendly solution to meet the evolving needs of a rapidly changing world. Many governments provide incentives and rebates to encourage the adoption of electric vehicles. These incentives may include tax credits, rebates, reduced registration fees, and access to carpool lanes.

EVs produce zero tailpipe emissions, reducing air pollution and greenhouse gas emissions. They contribute to efforts to combat climate change and improve air quality, particularly in urban areas. They are highly efficient in converting electrical energy from batteries to mechanical energy for vehicle propulsion. This efficiency is generally higher than internal combustion engines, especially in stop- and-go traffic.

A variety of converters like choppers, inverters, converters and rectifiers are used in source, load and distribution subsystems to provide power at different voltage levels and in both DC and AC natures. Most of the loads are also in the form of power electronic converters and electric motor drives. Therefore, in these vehicles, different converters are integrated together to form complex and extensively interconnected multi-converter systems.

**BLOCK DIAGRAM AND DESCRIPTION**

The proposed BMS system which its system description components which will solve the objective of establishing a common battery management system for a variety of cell chemistries. Specifically, creating stacks of multiple cells cannot be done each cell chemistry has a different cell specification and chemistry which was discussed in detail in the previous chapters. The project idea emphasizes the creation of the BMS common for different cell chemistries which means that a cell stack completely comprising of a particular cell chemistry is created and a similar cell stack of a different cell chemistry is created. The cell balancing circuit created with this purpose is kept common and the analysis is done using the two cell stacks created.

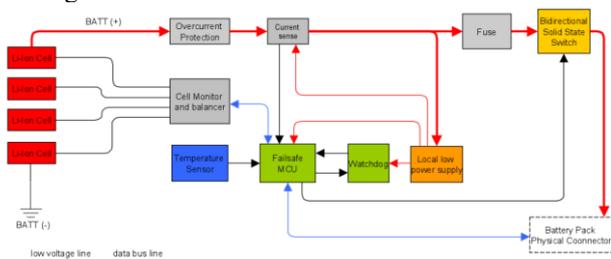


Figure Block Diagram of Battery Management System

The block diagram Figure shows the proposed system comprises of the components for the measurement, cell balancing, cell stack, CAN communication interface block. There exists a wired communication between the cell stack and the MCU of the BMS which monitors and controls the individual cell components Each individual cell usually remains at a particular SoC which is expected to decrease during discharging and increase while charging Eventually, in a battery pack all the cells are interconnected with each other. Hence, the mismatch in the SoC of one cell must be compensated by the remaining cells in the stack and finally all the cells need to be balanced and maintained at a particular percentage of SoC. The proposed system components create a space to replace the cell stack along with the availability of the remaining components in the same place.

The battery pack is the main power source of the system and is responsible for storing and supplying energy. It consists of multiple individual battery cells connected in series or parallel configurations. The battery management unit (BMU) is the central control unit that monitors and manages the battery pack. It collects data from various sensors and communicates with other modules to ensure the safe and efficient operation of the battery.

The communication interface allows the BMU to exchange information with external devices or systems. It can be wired or wireless, depending on the application. This interface enables the system to communicate with a host controller, user interface, or other external devices for data logging, diagnostics, or control purposes.

Sensors play a crucial role in the Smart Battery Management System by providing real-time data about the battery pack's state and environment. These sensors can measure parameters such as voltage, current, temperature, and state of charge. The data collected by the sensors is used by the BMU to make decisions and control the battery pack's operation.

**ARCHITECTURE OF BMS**

The below Figure 2.2 shows the basic architecture of a Battery Management System (BMS) typically comprises several key components that work together to monitor, control, and protect a lithium-ion battery pack. The architecture in figure 3 is of the fox BMS which is created using FPGA (Field Programmable Gate Array). In this layout, there exists one master BMS and multiple slave BMSs which is dedicated for one series of cells in the battery pack. This framework also comprises of pre-charge contactors, current and voltage sensors, galvanic isolation monitoring, fuses and service disconnect, display interface and so on. The primary components of a basic BMS architecture are as follows:

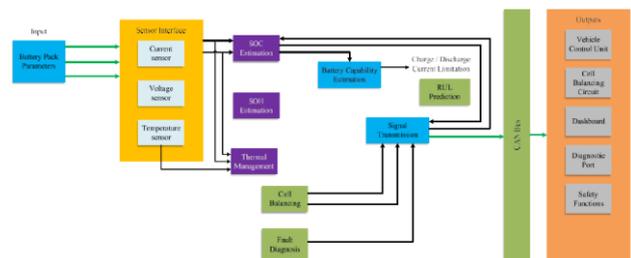


Figure BMS Architecture

The battery pack consists of multiple individual battery cells connected in series or parallel to provide the desired voltage and capacity. The BMS manages and monitors the health of each cell within the pack.

Each battery cell is equipped with monitoring circuitry that measures its individual voltage and sometimes temperature. These measurements are crucial for the BMS to assess the state of each cell accurately

The central control unit acts as the brain of the BMS. It processes data from the cell monitoring circuitry, executes control algorithms, and manages the overall operation of the BMS. The control unit makes decisions based on the real-time data received from the cells.

The BMS uses data from the cell monitoring circuitry to estimate the SOC and SOH of the battery pack. SOC indicates the remaining charge in the battery, while SOH reflects the overall health and capacity of the battery.

Cell balancing is essential to equalize the charge among individual cells within the battery pack. Balancing ensures that all cells have similar voltage levels.

### **SIGNIFICANCE OF BLOCK DIAGRAM:**

The significance further continues towards the improvement in the robustness of the system for a variety of cell chemistries as it makes it obvious to incorporate the features and functionalities of multiple battery technologies into the system and use it for the proper functioning of the system. In electric vehicle applications, battery packs variant can be provided as a marketing option for the customers by the manufacturers as the feasibility of using this as a product is quite extensive and a variety of choices is provided to the customer.

Different sensors, one with analogy output multiplexed in order to drive an A/D converter and another with digital output capable of communicating with the microcontroller through one of the commonly used interfaces. The BMS module must be able to measure the battery current. This allows the system to identify if there is any leakage current flowing in the circuit in the battery string and also helps in estimating the state of the battery. Since practically, the compromise is made between sensor accuracy and its power dissipation only one accurate sensor in the master module is used for the sensing purpose. The cell voltages and the current sensor outputs drive a resistors network, which weights the values respectively. The multiplexer selects each signal sequentially and drives an instrumentation amplifier feeding the A/D converter input. The microcontroller controls the equalizer and scans all the sensors sequentially. Since, only simple access to the battery cell interconnections is allowed, each cell must be measured indirectly.

Any BMS procured from the battery market is configured and designed for a particular cell chemistry. This means that it is not possible to use the BMS of lithium-ion battery for a lithium ferro-phosphate battery. By introducing the proposed project ideology, it becomes possible to use the same existing BMS for a lithium-ion and a lithium ferro-phosphate cell chemistry variants.

The importance of this system is that it can help us avoid the purchase of multiple BMS in order to handle each different cell chemistry that we make use of in our practical day-to-day applications.

In the circuit diagram for the Smart Battery Management System (BMS) represents a sophisticated and integral component in the realm of advanced energy storage solutions. Through its intricate network of sensors, microcontrollers, and communication modules, the Smart BMS ensures the optimal performance, safety, and longevity of lithium-ion batteries.

The inclusion of features such as cell balancing, overcharge protection, and temperature monitoring reflects a commitment to maximizing energy efficiency and safeguarding the battery

pack. As technology continues to evolve, the Smart BMS circuit serves as a pivotal interface between cutting-edge battery technology and the broader landscape of smart and sustainable energy solutions. It not only exemplifies the progress in energy storage systems but also sets the stage for further innovations in the quest for efficient and eco-friendly power management.

### **CIRCUIT DIAGRAM AND DESCRIPTION**

Battery Management System (BMS) is technology dedicated to the oversight of a battery pack, which is an assembly of battery cells, electrically organized in a row x column matrix configuration to enable delivery of targeted range of voltage and current for a duration of time against expected load scenarios.

In the intricate realm of Battery Management Systems (BMS), where precision and reliability are paramount, the circuit diagram serves as the blueprint for orchestrating the orchestration of various components. The design of a BMS circuit is a meticulous process, crucial for ensuring the seamless integration and efficient functioning of the battery system. This intricate web of electronic components and connections plays a pivotal role in monitoring, protecting, and optimizing the performance of rechargeable batteries.

At its essence, the circuit diagram for a BMS encapsulates the intelligence behind safeguarding and enhancing battery life. It delineates the pathways through which signals flow, voltages are measured, and decisions are made to balance and protect individual cells within a battery pack. The circuit design involves a careful consideration of sensor placements, control logic, communication interfaces, and safety features, all working in harmony to create a robust and efficient battery management ecosystem.

The circuit diagram not only provides a visual representation of the BMS architecture but also serves as a guide for engineers and technicians during the manufacturing and assembly phases. It details the arrangement of components such as voltage and temperature sensors, protection circuits, balancing resistors, microcontrollers, and communication modules, outlining how they collaborate to ensure optimal battery performance.

As the demand for advanced battery technologies continues to rise in applications ranging from electric vehicles to renewable energy storage, the importance of a well-crafted BMS circuit diagram cannot be overstated. It is the cornerstone of innovation, paving the way for the development of energy-efficient, durable, and safe battery systems. In this landscape of evolving energy solutions, the design of BMS circuit diagrams represents a fusion of creativity and engineering precision, guiding us towards a future where energy storage is smarter and more sustainable.

The main goal of BMS is to keep the battery within the safety operation region in terms of voltage, current, and temperature during the charge, the discharge, and in certain cases at open circuit.

The circuit diagram for a Smart Battery Management System (BMS) is a meticulously designed arrangement of electronic components aimed at elevating the capabilities of rechargeable batteries. At its core lie strategically placed voltage and temperature sensors that continuously monitor individual cell parameters, furnishing real-time data for comprehensive analysis.

The Microcontroller Unit (MCU) acts as the brain, processing this information and executing control algorithms to make informed decisions regarding balancing, state of charge, and temperature conditions.

An active balancing circuit, comprising balancing resistors and control switches, prevents capacity imbalances, optimizing overall battery life and efficiency. Protection circuits, including safeguards against overcharge, over-discharge, and overcurrent, enhance safety by disconnecting the battery during emergencies. Communication interfaces such as Bluetooth, Wi-Fi, or CAN bus facilitate connectivity, empowering users to remotely monitor and control the BMS through dedicated applications. The circuit also encompasses energy storage control mechanisms, a fuse, and disconnect switch for added safety, and a stable power supply to ensure continuous BMS operation. This sophisticated integration of components collectively ensures the Smart BMS's ability to deliver optimal performance, longevity, and safety in diverse battery-powered applications. As technology advances, these circuit designs continue to evolve, promising even smarter and more efficient energy storage solutions.

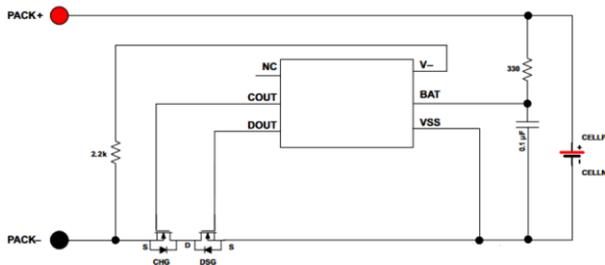


Figure Circuit diagram of battery manager

The above Figure shows the circuit diagram for a Smart Battery Manager incorporates a set of essential components to effectively oversee the operation of rechargeable batteries. Voltage and temperature sensors play a crucial role by continuously monitoring individual battery cell parameters, offering vital data for the BMS to gauge the state of charge and identify potential issues. At the heart of the system lies the Microcontroller Unit (MCU), serving as the central processing unit responsible for interpreting sensor data, executing control algorithms, and managing overall BMS functionality.

A Battery Management System (BMS) is a critical component in systems that use rechargeable batteries, such as electric vehicles, solar power systems, and portable electronic devices. The primary function of a BMS is to monitor and manage the state of individual cells within a battery pack. This includes tasks such as balancing cell voltages, temperature monitoring, overcharge protection, and over-discharge protection. The circuit diagram starts with the power input section, where the battery pack is connected to the BMS. This section includes protection components such as fuses and transient voltage suppressors to safeguard the BMS from voltage spikes.

### TECHNOLOGY USED FOR SMART BMS

Smart Battery Management Systems (BMS) leverage cutting-edge technologies to streamline operations, optimize energy usage, and enhance building performance. These systems are designed to monitor and control various building subsystems, such as HVAC, lighting, security, and energy management. The technologies used in smart BMS include:

1. Internet of Things (IoT): IoT solutions are integrated into smart BMS to enable the collection of data from intelligent sensors placed around the building. This data is then used for real-time monitoring and control of building parameters, promoting energy efficiency and sustainability

2. Intelligent Sensors: These sensors play a crucial role in collecting data on parameters such as temperature, humidity, energy consumption, and battery health, providing real-time information to the BMS for monitoring and control purposes.

3. Cutting-Edge Data Analysis: Smart BMS systems utilize advanced data analysis technology to achieve real-time monitoring of various parameters, such as battery health and status, enabling users to make informed decisions and take timely actions.

4. Battery Management System (BMS): In the context of energy storage systems, BMS software is used to monitor and manage the battery's health, status, and performance, ensuring efficient and reliable energy storage

### CELL MODULE DESCRIPTION

Cell module is connected directly to the cell, from which it takes own power supply. Cell module Microcontroller (Attiny84) receives the cell voltage, cell pole temperature, balancing resistance temperature signals and, using the logics contained in its software, performs the following functions:

- It communicates by I2C serial protocol with the Master Unit called "Control Unit"

- It sends to Control Unit the values of: cell voltage, cell pole temperature, balancing resistor temperature for battery pack management system

- It executes the cell balancing (by a mosfet) according to Control Unit command.

- The cell modules all communicate in parallel with the control unit via an isolated 4-wires I2c bus.

### TEST RESULTS AND DISCUSSION FOR SMART BMS

In the rapidly evolving landscape of energy storage systems, Smart Battery Management Systems (BMS) play a pivotal role in ensuring the optimal performance, safety, and longevity of battery packs. As the demand for efficient and intelligent energy solutions continues to rise, the thorough examination of smart BMS through comprehensive testing becomes imperative. This report presents a detailed exploration of the test results and subsequent analysis conducted on a state-of-the-art Smart BMS, shedding light on its capabilities, reliability, and adherence to performance benchmarks.

The primary objective of this evaluation is to scrutinize key aspects of the smart BMS, including its ability to accurately monitor individual cell parameters, implement effective balancing strategies, and safeguard against potential faults. Through a series of controlled tests and real-world scenarios, we aim to assess the BMS's performance under varying conditions, such as dynamic charging and discharging cycles, temperature fluctuations, and load variations.

This analysis delves into critical metrics, such as state-of-charge (SoC) accuracy, balancing efficiency, and response to abnormal conditions, to provide a comprehensive understanding of the smart BMS's operational characteristics. Additionally, we explore the effectiveness of communication protocols, the user interface, and any embedded intelligence in optimizing energy management and predictive maintenance.

The results presented herein serve not only to validate the manufacturer's specifications but also to offer insights into the real-world applicability and reliability of the smart BMS. Furthermore, this analysis aims to contribute valuable data to the broader discourse on advancing battery technologies, providing stakeholders, engineers, and researchers with a basis for informed decision-making in adopting and further developing smart BMS solutions.

As we embark on this exploration, it is our hope that the findings presented herein contribute to the ongoing evolution

of Smart BMS technology, fostering advancements that will propel the energy storage industry toward more sustainable, efficient, and intelligent solutions.

### ANALYSIS OF PROPOSED SYSTEM

The proposed BMS circuit comprises of the components as mentioned in the description diagram show in figure. The circuit comprises of an MCU which controls all the operations involved inside the BMS. The MCU always remains in connection with the NTC which is a Negative Temperature Coefficient Thermistor for monitoring the temperature of the battery pack. When detecting the state voltage and temperature of battery cells, usage of AFE is recommended. The AFE communicates with the MCU and learns the current state of the BMS system. Along with this, there exists an LCD display which is optional which is connected through a UART module. MCU needs a code on which it will function. For this purpose, PC software block is available for flashing of software onto the MCU. General Purpose I/O ports are available for the communication with one input and six outputs. Contactors are provided for the protection purpose and along with a DC fuse. A number of cells are stacked according to our requirement to achieve the intended voltage and capacity in series and parallel combinations. This circuit is capable of charging, discharging, balancing and controlling the operations of the battery pack created on.

#### Charging Circuit:

The variation of state of charge, current and voltage against time. When we look at the curve of SOC as shown in fig. below, we can see that as the time increases, the state of charge also increases and the curve is linear. using the lithium based electrochemical cells. The circuit can also be equipped with coolant systems if needed to reduce the system while the temperature crosses the limits.

The current in this case remains constant throughout the entire run. The voltage increases as the time increases to a certain point and then remains constant for the remaining time of the circuit.

#### Discharge Circuit:

The figure shows the variation of SOC current and voltage against time for battery 2 of 12V 6Ah. It is observed that the SOC of this battery decreases as time changes and the voltage and current decrease for the initial time but later remain constant for the entire time period. This figure also shows the variation of Battery 3 of 12V and 6Ah and channel lining against time.

The SOC of the battery as we can see is decreasing with respect to change in time and the voltage and current of the battery are reduced initially but later follow a constant path through the entire time interval. The channel lining is constant.

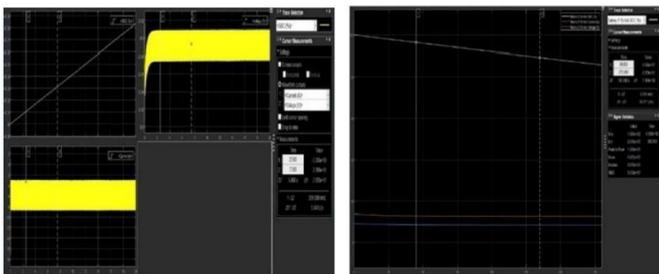


Figure Output Graph Of Charging And Discharging Circuits

### RESULTS AND ANALYSIS:

The obtained results are shown in figure and inference is that the BMS is capable enough of handling lithium-ion as well as lithium-ferro phosphate. Moreover, the flexibility was

achieved in the selection of the number of series or parallel combination of stack, the number of bms modules used, etc. This is the main advantage of the proposed system. The figure shows the practical demonstration of the experimental setup using lithium ferro-phosphate cells of 3.3V and 6 Ah capacity each.

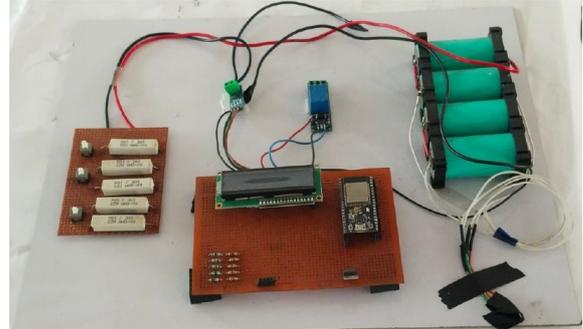


Figure Experimental hardware setup

The practical demonstration using the lithium-ion cell with four electrochemical cells of 3.7V and 2.6Ah is created. The hardware setup contains a Bluetooth module through which the data is obtained by the mobile application. The voltage of each cell and the mode of charging and discharging can also be controlled using the same mobile application. The smart BMS used also has another cell chemistry feature namely LTO (Lithium Titanate Oxide). In some practical applications, titanate variant of lithium is also used. Furthermore, the temperature of the cell stack is monitored by the NTC line which continuously provides data regarding the temperature. The application is equipped with an automatic cut-off feature if the temperature exceeds the permissible limits. The ambient temperature of the cells needs to be maintained in order to save the cells from adverse conditions and thermal runaway situations.

### CONCLUSION

In conclusion, the Smart Battery Management System (BMS) project embodies the pinnacle of innovation in energy management. By harnessing the power of artificial intelligence and predictive analytics, the project has successfully developed a system that not only monitors and protects battery cells but also intelligently adapts to their changing conditions. The BMS's ability to predict future performance and health of batteries represents a significant leap forward in extending their lifespan and reliability. This project has far-reaching implications, offering a blueprint for future advancements in renewable energy storage and management.

It stands as a beacon of progress, signaling a shift towards more sustainable and efficient use of energy resources. The success of this project is a harbinger of the transformative impact that smart technologies will have on our approach to energy conservation and environmental stewardship. As we move towards an era where energy demands are ever-increasing, the Smart BMS serves as a critical tool in our arsenal to achieve a greener, more resilient energy infrastructure. This project is not just a culmination of academic endeavor but a stepping stone towards a future where technology and sustainability converge to create a better world for all.

The need for a common battery management system for lithium-based cell chemistries is a revolutionary idea to exhibit a profound flexibility for the customers with respect to the usage of all the available cell chemistries in the market without worrying much about the electronic circuitry that handles the operation of the battery pack. Future BMS

architectures may become more modular and flexible, allowing for easier integration with various battery configurations and chemistries. This adaptability is essential as the energy storage landscape evolves with different types of batteries for diverse applications.

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