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Smart Battery Management System For Electric Vehicles With AI-Based Health Prediction

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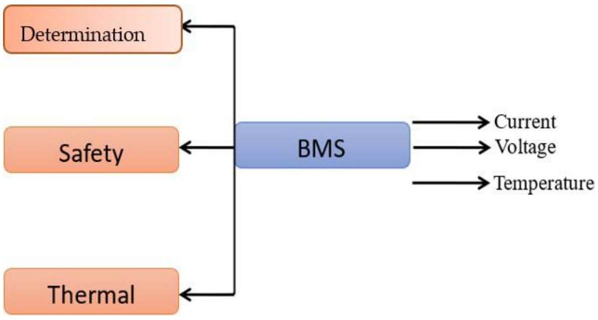
Abstract - The proposed system uses a Raspberry Pi 4B as the central control unit. It monitors key battery parameters, including voltage, current, temperature, charging time, discharging time, and total operating duration in real time..Continuous observation and analysis of these parameters help maintain safe operating conditions and extend battery lifespan. The collected battery data is processed to assess battery health and spot unusual operating conditions early. A data-based prediction method estimates battery condition and aids in timely preventive actions. The processed information is sent to a cloud platform and shown on a dashboard, allowing for remote monitoring of battery performance. Additionally, the Raspberry Pi controls the vehicle motor with an L293D motor driver while ensuring battery protection through an integrated management strategy. This system reduces unexpected downtime, boosts energy efficiency, and supports maintenance based on battery condition. This work advances the development of reliable and Battery management systems made for electric vehicle applications..

Index Terms - electric vehicles, battery management systems, artificial intelligence, predictive maintenance, state of health (SOH), state of charge (SoC), and simulation

I. Introduction

Electric Vehicles have become a vital solution to the global demand for sustainable and eco-friendly transportation. Their performance and reliability largely depend on the efficiency and lifespan of their systems, which serve as the main energy source. However, challenges such as battery degradation, overcharging, overheating, and unpredictable failures often limit their efficiency and safety. To address these challenges, an advanced and intelligent Battery Management System is required to continuously monitor and maintain *the health* of the battery pack. The Smart Battery Management System for Electric Vehicles with AI-Based Health Prediction introduces an innovative approach that integrates real-time monitoring, data analytics, and artificial intelligence [1]. Although the battery management system can handle many tasks, most research has mainly focused on estimating the state of charge and state of health. In contrast, the development of fault detection and diagnostic techniques has received less attention. attention until recent incidents involving battery systems in EVs. Additionally, if the acquisition sensor is faulty, other BMS activities that depend on data-gathering may be hampered,

Fig. 1. Block diagram of battery management system



Battery management systems rely on the data from current, voltage, and temperature sensors. These sensors give the necessary information to monitor battery performance and ensure safe operation. In electric vehicle battery packs, many sensors are installed to track the electrical and thermal condition of each cell. Since multiple sensors operate at the same time within the battery pack, the chance of failure for any single voltage or current sensor goes up. These failures can impact the accuracy of monitoring and may affect the overall reliability of the system. A sensor malfunction may lead to poor battery performance or possibly significant safety risks [2]. In electric vehicles, the battery management system consists of various electronic circuits and components. It includes power electronics, sensors, switching devices, capacitors, inductors, converters, and several safety elements. These parts work together and are managed using different control methods and programmed logic. Since the system is complex and must operate safely in different conditions, designing effective control algorithms for the BMS has gained a lot of interest from researchers. Model-based techniques and intelligent methods are the strategies used in BMSs the most often The system uses [3]. The Raspberry Pi 4B controller monitors key battery parameters, including voltage ,temperature, current, charging and discharging duration, and total usage time.. These data points are analyzed locally and sent to a cloud-based AI model for battery health prediction and performance assessment**.** The model uses prediction methods to determine the battery's State of Health, State of charge, and remaining life. The predicted results are displayed on a cloud dashboard, enabling remote monitoring and proactive maintenance. This not only ensures safe and efficient operation but also minimizes energy losses and enhances battery longevity [4]. Furthermore, the Raspberry Pi manages motor operations through an L293D motor driver IC, ensuring efficient power utilization and control of vehicle motion. The proposed system thus provides a compressive

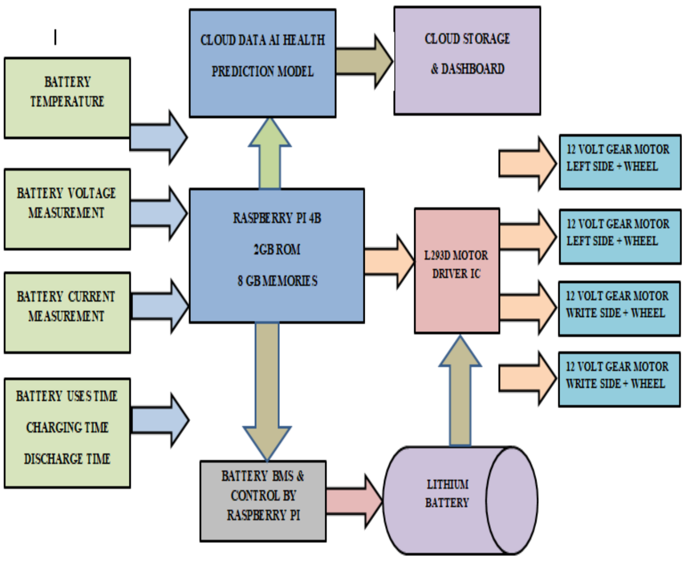
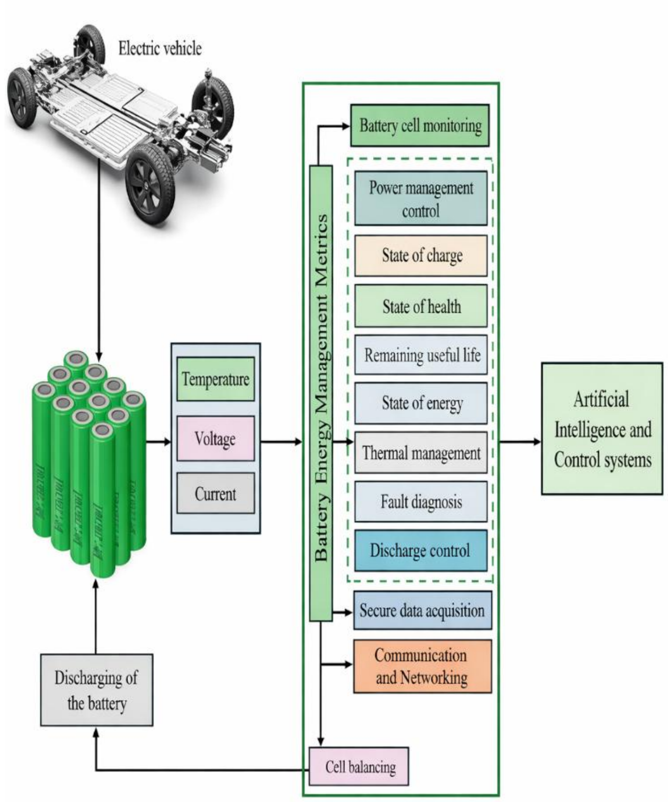


Fig. 2. Block diagram of Smart battery management system

Effective battery monitoring and control are essential for keeping electric vehicles safe and performing well. Modern battery management approaches focus on improving accuracy, adaptability, and reliability compared to conventional estimation methods. Figure 2 illustrates an overall framework for battery energy management in electric vehicles, integrating monitoring, control, and decision-support functions. Key input parameters such as battery temperature, voltage, and current are continuously measured to assess operating conditions and ensure safety. Core Figure 2. Structure of the Battery Management and functions of the system include battery cell monitoring, power regulation, estimation of the state of charge and state of health, and evaluation of the remaining useful life. Additional features such as thermal management, fault detection, discharge control, secure data acquisition, and cell balancing contribute to enhanced system reliability and efficiency[5]. Communication and networking modules enable smooth data exchange between system components. By utilizing real-time operational data and control algorithms, the proposed framework supports effective energy management, performance optimastion and safe battery operation in electric vehicles. Advanced battery management approaches provide real-time monitoring and predictive capabilities that are essential for handling the complex operating behavior of electric vehicle batteries. By utilizing historical operating data and real-time sensor



measurements, the system can estimate key parameters such as the state of charge and state of health with improved accuracy compared to conventional techniques. These estimation methods account for variations in temperature, load conditions, and battery ageing effects. Mathematical modeling and data-driven estimation techniques are effective in representing the non-linear characteristics of battery behavior, supporting accurate thermal regulation and early fault identification. Adaptive control strategies further enhance system performance by enabling optimized energy distribution, efficient power utilization, and improved regenerative operation under varying driving conditions. This approach ensures reliable, safe, and efficient battery operation throughout the vehicle's lifespan.[6]

Figure 3. Structure of the Battery Management and Control System in Electric Vehicles.

Recent technological developments have introduced real-time monitoring and prediction features that are important for managing the complex behavior of EV batteries. By using models trained with both historical and live data, the system can estimate the State of Charge and State of Health more accurately than traditional methods. These methods account for factors like temperature changes, varying load conditions, and battery aging to improve prediction accuracy.

II. AI-Driven Innovations in BMSs

A Battery Management System is a combined hardware and software architecture developed to maintain safe, reliable, and efficient operation of battery systems. A conventional BMS consists of several functional components, including cell voltage monitoring units, voltage balancing circuits, fuel gauge modules, cut-off switching elements, temperature sensing devices, state control logic, and timing units. Depending on the application, these components may be arranged in different configurations, ranging from simple analogue front-end circuits integrated with microcontrollers for monitoring and balancing tasks to advanced, self-contained BMS solutions capable of independent operation.[7]

Figure 5 shows a cloud-based framework for managing data and controlling electric vehicle battery systems. Operational information collected from various electric vehicles is sent to local servers. These servers then connect with a central cloud computing platform for more processing and analysis. This framework supports essential functions such as secure data collection, dependable data transmission, centralized data storage, and performance analysis for decision support. The cloud infrastructure enables effective coordination between monitoring units and control systems, contributing to improved system reliability, operational safety, and performance optimization. This distributed architecture allows real-time supervision and scalable management of battery systems, supporting efficient operation of electric vehicles under varying conditions.

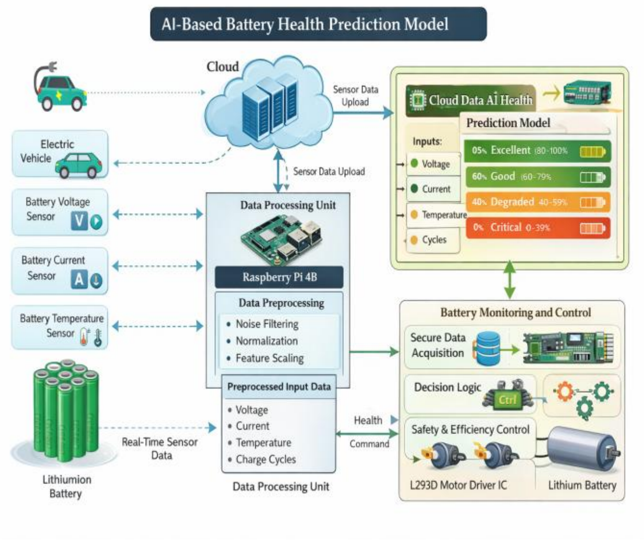


fig 4. AI-Driven Innovations in BMSs

The proposed system uses a data-driven model to estimate the battery health of an electric vehicle. It collects key battery parameters such as voltage, current, temperature, and usage cycles in real time through sensors. A Raspberry Pi processes this data. The measured information is filtered and normalized before being sent to a cloud platform[8] . A prediction model trained on historical battery data assesses the battery condition. It estimates the state of health based on operating patterns. The model's output categorizes the battery status as healthy, degraded, or critical. The Battery Management System then takes appropriate control actions based on this result to improve safety and operational efficiency. This approach allows for continuous monitoring and early fault detection. It also enhances battery use without needing complicated physical models, making it suitable for real-world electric vehicle applications.[9]

III. AI MODEL DEVELOPMENT AND WORKING METHODOLOGY

A. Data Acquisition

The system continuously measures key battery parameters, including voltage, current, temperature, and charge-discharge cycle count. These parameters show the electrical, thermal, and aging characteristics of the battery. The system collects sensor data in real time and sends it to the processing unit for further analysis.[10]

B. Data Pre-Processing

Before applying the AI model, the team cleans and standardizes the collected data. They remove noise and normalize the range to make sure that all input parameters stay within safe operating limits. This step improves the stability and accuracy of the prediction model.

C. AI Model Creation

A supervised learning regression model is used to estimate the battery State of Health. The model is trained with historical and experimental battery datasets that link operating conditions to health values. It uses voltage, current, temperature, and cycle count as input features, while SOH is the target output. A decision-tree-based approach is chosen because it has low computational complexity and is suitable for embedded platforms.

D. Model Training

The dataset is split into training and testing subsets to avoid overfitting. During training, the model learns how battery operating parameters relate to degradation behavior. The trained model identifies these patterns and saves them for real-time inference

E. Model Execution

In real-time operation, sensor data goes into the trained AI model. The model processes the input parameters and predicts the current SOH. Based on the estimated SOH, the system calculates the State of Charge and Remaining Useful Life using degradation trends and empirical relationships.

F. Decision-Making and Control Actions

The predicted SOH is checked against set threshold values. Based on the battery's condition, the system generates actions like normal operation, performance monitoring, load reduction, maintenance scheduling, or battery replacement alerts. These actions help improve battery safety and reliability.[11]

G. Output Visualization and Monitoring

The final outputs, including voltage, current, temperature, SOC, SOH, RUL, and recommended action, are shown on a local interface or sent to a cloud-based dashboard for remote monitoring. This allows for real-time observation and proactive maintenance planning. performing now let us discuss the action taking by the ai proactive maintenance planning. performing now let us discuss the action taking by the ai

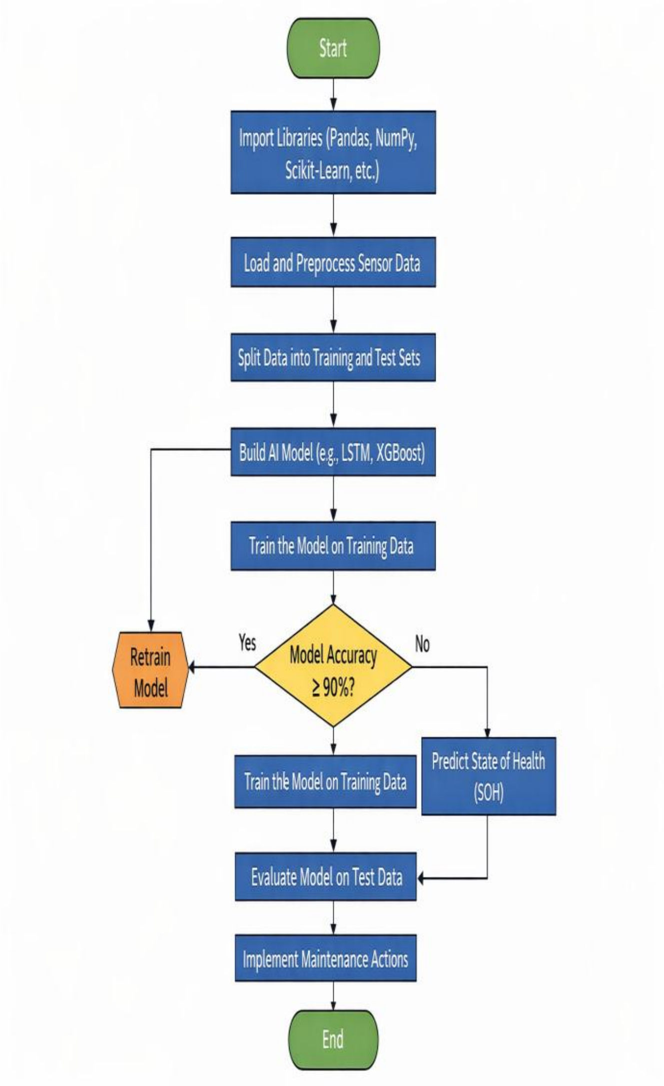


Figure 5. flow chart of AI model

TableI AI model Action

SOH	Action
>80%	No maintenance
60–80%	Monitoring
40–60%	Maintenance soon
20–40%	Reduce load
<20%	Replace battery

IV. CIRCUIT CREATION OF SMART BMS

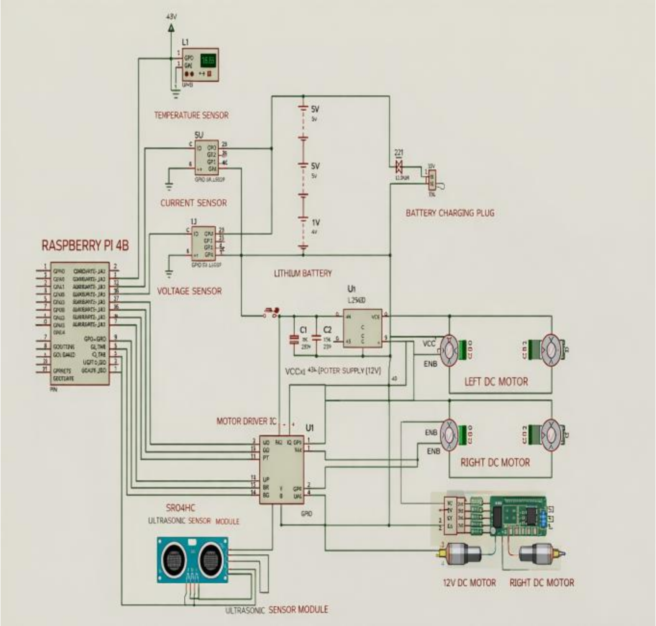


Figure 5 illustrates the hardware architecture of the proposed Smart Battery Management System (BMS) for electric vehicles integrated with AI-based battery health prediction. The system is centered around a Raspberry Pi 4B, which functions as the main control and processing unit. The lithium-ion battery pack is continuously monitored using voltage, current, and temperature sensors to acquire real-time operational data essential for estimating battery state parameters. The measured voltage and current values are used to evaluate the State of Charge, while temperature monitoring ensures protection against overheating and thermal runaway conditions. These sensor signals are conditioned and transmitted to the Raspberry Pi, where the data are logged and preprocessed for further analysis. A regulated power supply unit provides stable operating voltage to the controller and peripheral modules, while protective switching elements isolate the battery during abnormal operating conditions.[12] The system also interfaces with a motor driver circuit that controls DC motors representing electric vehicle loads, allowing dynamic load regulation based on battery condition. In addition, an ultrasonic sensor is integrated to demonstrate the capability of the controller to support safety and auxiliary functions in intelligent electric vehicle platforms. The collected battery parameters are supplied as inputs to an AI-based model for State of Health and Remaining Useful Life prediction, enabling early fault detection.[13]

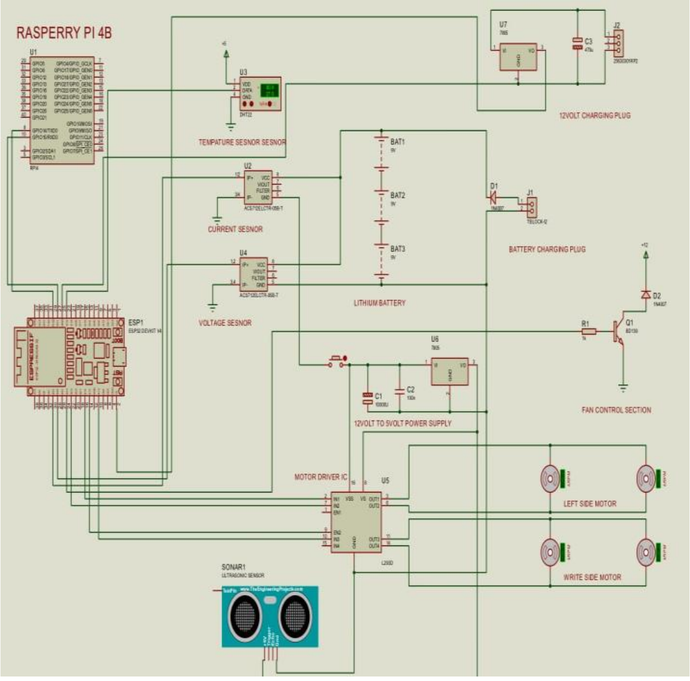


Figure 6. circuit diagram of BMS

RESULTS AND DISCUSSION

This section describes the simulation and experimental results from the proposed Smart Battery Management System for electric vehicles. It includes an AI-based method for predicting battery health.The results validate the effectiveness of the designed circuit and AI-based analysis monitoring

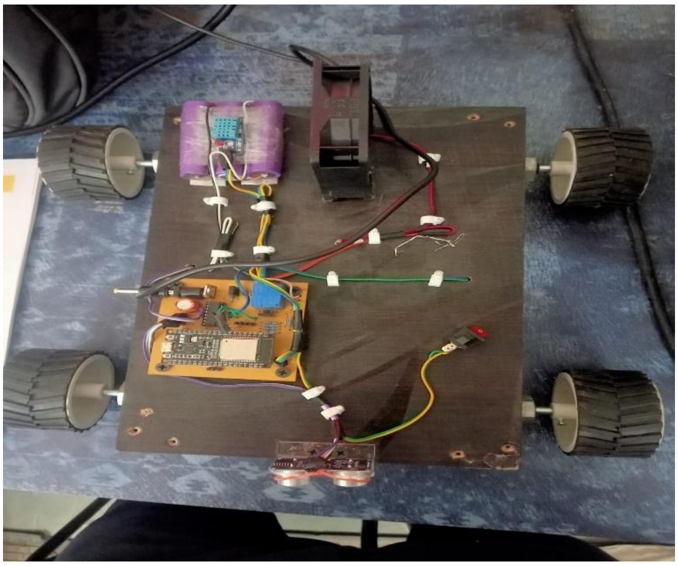
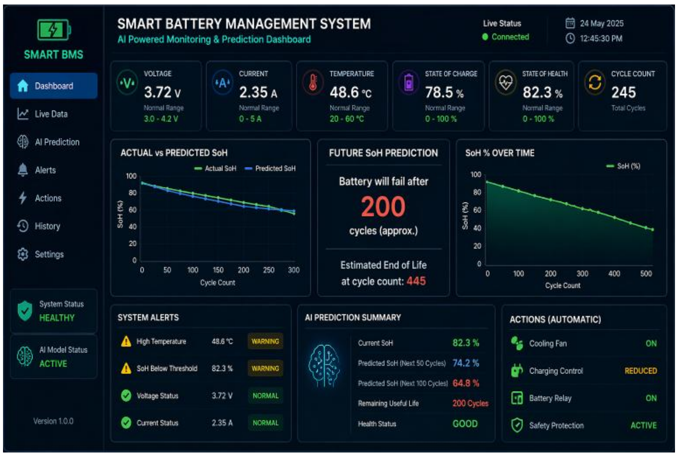


Fig 7 Hardware Model



SMART BATTERY MANAGEMENT SYSTEM
AI Powered Monitoring & Prediction Dashboard

Live Status: Connected
24 May 2025
12:45:30 PM

VOLTAGE	CURRENT	TEMPERATURE	STATE OF CHARGE	STATE OF HEALTH	CYCLE COUNT
3.72 V	2.35 A	48.6 °C	78.5 %	82.3 %	245
Normal Range 3.0 - 4.2 V	Normal Range 0 - 5 A	Normal Range 20 - 60 °C	Normal Range 0 - 100 %	Normal Range 0 - 100 %	Total Cycles

FUTURE SoH PREDICTION
Battery will fail after
200
cycles (approx.)
Estimated End of Life
at cycle count: 445

System Status: HEALTHY
AI Model Status: ACTIVE

SYSTEM ALERTS

High Temperature	48.6 °C	WARNING
SoH Below Threshold	82.3 %	WARNING
Voltage Status	3.72 V	NORMAL
Current Status	2.35 A	NORMAL

AI PREDICTION SUMMARY

Current SoH	82.3 %
Predicted SoH (Next 50 Cycles)	74.2 %
Predicted SoH (Next 100 Cycles)	64.8 %
Remaining Useful Life	200 Cycles
Health Status	GOOD

ACTIONS (AUTOMATIC)

Cooling Fan	ON
Charging Control	REDUCED
Battery Relay	ON
Safety Protection	ACTIVE

Fig8 . Output Dashboard

and predicting battery performance. The Voltage vs State of Charge curve shows a nearly linear increase in SoC with rising battery voltage. As the voltage increases from 11.2 V to 12.6 V, the SoC increases from approximately 20% to 100%. This relationship confirms that battery voltage is a reliable indicator for SoC estimation and validates the effectiveness of the voltage monitoring approach used in the proposed smart battery management system

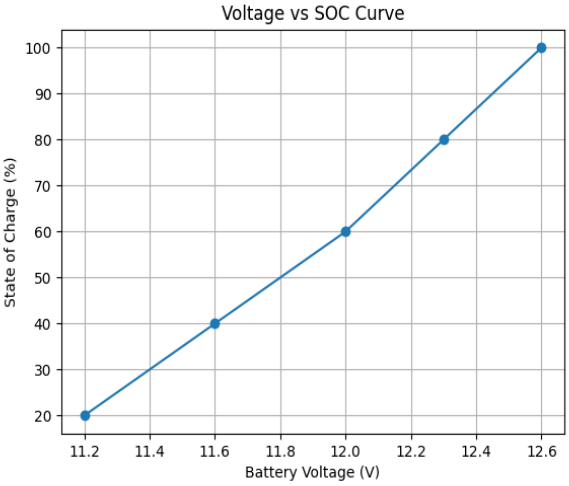


Fig. 7. Voltage versus State of Charge characteristic

The Charge Cycles vs State of Health curve shows a gradual decline in battery health with an increase in the number of charge discharge cycles. The decreases from approximately 95% at 50 cycles to around 40% at 500 cycles, indicating progressive battery degradation due to aging. This result highlights the importance of cycle-based health monitoring for accurate battery lifespan prediction in electric vehicle applications.[14]

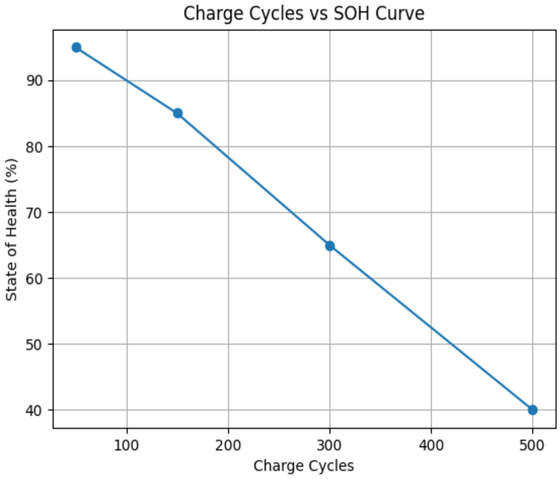


Fig. 8. Variation of battery State of Health with charge cycles.

The Temperature vs State of Health curve shows a significant decrease in battery health with increasing temperature. As the temperature down from 30 °C to 60 °C, the drops from approximately 95% to about 35%, indicating accelerated battery degradation at elevated temperatures. This result highlights the critical role of temperature monitoring and thermal management in smart battery management systems for electric vehicle applications.[15]

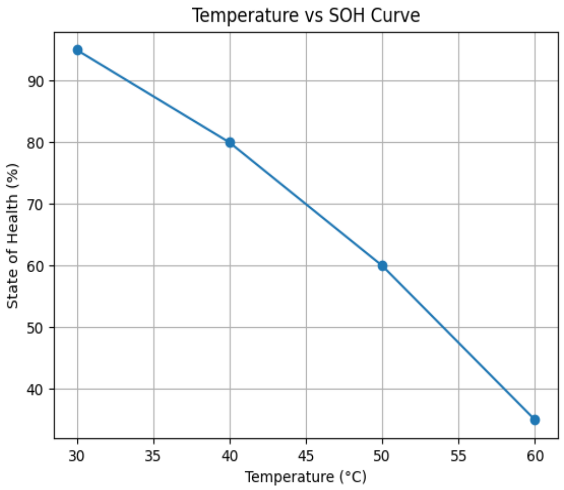


Fig. 9. Effect of battery temperature on State of Health.

The table summarizes the relationship between battery voltage, temperature, current, State of Charge, and State of Health (S under different operating conditions. At higher voltage and lower temperature, the battery exhibits high SoC and SOH indicating excellent performance. As temperature and current increase, a noticeable reduction in both SOC and SOH is observed, leading to degraded and critical battery states. These results demonstrate that elevated temperature and high discharge current significantly impact battery health, highlighting the effectiveness of the proposed smart BMS in identifying battery condition and enabling timely preventive action.

TableII AI-Based Battery Health Prediction Results

Voltage (V)	**Temperature (°C)**	**Current (A)**	**SOC (%)**	**SOH (%)**	**Battery Status**
12.6	30	1.8	100	95	Excellent
12.3	32	2.1	80	85	Good
11.8	40	3.2	60	65	Degraded
11.2	55	4.8	20	40	Critical

self-learning, and energy-efficient vehicles, contributing significantly to the future of sustainable electric transportation..

CONCLUSION

SBMS for Electric Vehicles with AI-Based Health Prediction provides an intelligent and efficient approach to monitoring and managing EV battery performance. By integrating sensors, a microcontroller, and artificial intelligence algorithms, the system ensures accurate estimation of battery parameters such as current, voltage, temperature, and state of charge . The AI-based prediction model helps forecast the battery's health and lifespan, enabling early detection of potential failures and preventing unexpected breakdowns. This smart system enhances safety, optimizes energy usage, and increases the overall lifespan of the battery, making electric vehicles more reliable and sustainable. In addition, by enabling remote monitoring and predictive maintenance through IoT integration, the project aligns with the future direction of smart and connected transportation systems. Overall, the proposed BMS offers a promising solution for advancing green mobility and supporting the global shift towards clear and energy-efficient electric vehicles.

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