AI-Based Battery Management System for Predictive Maintenance and Operational Efficiency in Electric Vehicles

Aditya Appa Devkule[1], Prof. Mallad H M[2]
[1,2]*Electrical Engineering Department, Fabtech Technical Campus, Pandharpur, Solapur, Maharashtra, India*

***Abstract*—The Battery Management System (BMS) is a core part of electric vehicles (EVs) because it keeps the battery running safely and reliably. In this paper, we present a monitoring and fire prevention system that tracks key parameters like state of charge (SOC), voltage, current, and temperature. Our setup aims to stop overcharging, deep discharging, and overheating—issues that shorten battery life and cause dangerous hazards. By connecting the system to the Internet of Things (IoT), we can log battery data in real time and catch faults early. We also included a predictive maintenance model using basic machine learning to estimate SOC and battery health, helping us spot potential failures before they happen. If the battery gets too hot, the hardware instantly cuts off the power and triggers an alarm. As more people switch to EVs, building smarter, connected BMS solutions is becoming incredibly important for everyday safety.**

***Index Terms*—Artificial intelligence, Battery management system, Electric vehicles, Internet of things, State of charge, Temperature monitoring.**

I. INTRODUCTION

With the rapid growth of electric mobility, keeping battery systems safe has become more important than ever. In an electric vehicle, the battery is arguably the most critical and expensive part, and its lifespan depends heavily on how it is used and the temperatures it handles [1]. A battery produces energy through chemical reactions, and lithium-ion cells have become the standard for EVs because they hold a lot of power in a small space [2]. However, to keep them healthy, we have to constantly watch their voltage, current, and temperature.

This is exactly where a Battery Management System comes in—it acts as the brain behind the battery to keep everything running smoothly.

II. LITERATURE REVIEW

Adding Internet of Things (IoT) connectivity to battery systems has completely changed how we handle maintenance [3]. Older setups showed that if you send battery data over a network to a central server, you can easily track performance and diagnose problems from afar [4]. Now, a user or a mechanic can just open a web dashboard and see exactly how the battery is doing. This saves time and helps catch small issues before they ruin the battery [5]. Our work builds on this idea by bringing AI into the mix, so the system doesn't just show the data, but actually learns from it to predict future health.

III. AIM AND SCOPE

Our main goal for this project is to build an EV battery monitor that physically protects the cells while using machine learning to predict when things might go wrong. We want to make lithium-ion packs safer and less likely to catch fire or fail suddenly. As more drivers switch to electric cars, we desperately need smarter BMS solutions that take the guesswork out of battery maintenance and extend the life of the vehicle [6].

IV. OBJECTIVES

We set out to achieve a few specific things with this system:

- Track real-time parameters like state of charge (SOC), state of health (SOH), voltage, current, and temperature.

- Use AI models to analyze this data and give accurate predictions on how much life the battery has left.
- Create a physical safety net that cuts the power instantly if the battery gets too hot, keeping the car and passengers safe.

V. HARDWARE AND SYSTEM DESCRIPTION

For our hardware setup, we used an ESP32 microcontroller as the main brain, connected to temperature, voltage, and current sensors. We also added an LCD screen, a buzzer for alerts, and a relay switch. Power stability is maintained through a Regulated Power Supply (RPS) circuit, which steps down the AC voltage via a transformer, rectifies it using a bridge rectifier, and utilizes an LM7805 voltage regulator to supply a constant 5V output for the microcontroller and sensor modules.

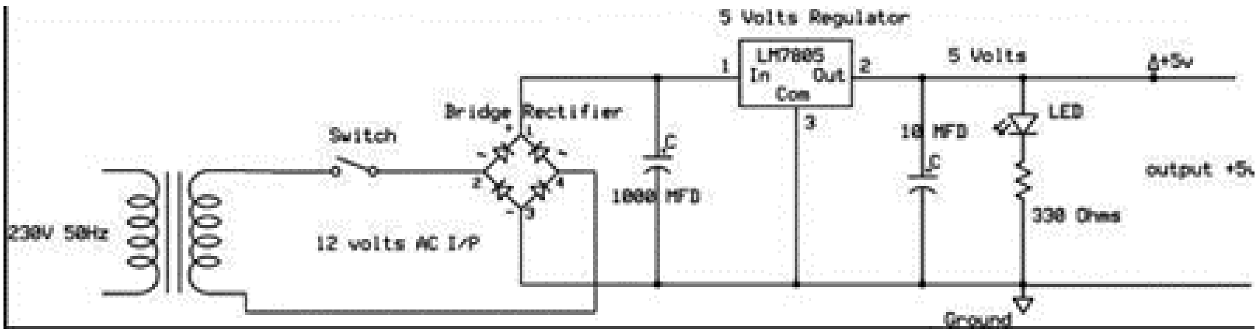

Fig. 1. Circuit diagram of Regulated Power Supply (RPS) with LED connection.

The temperature sensor is strapped to the battery, constantly checking for heat buildup. If the heat crosses our safety threshold, the buzzer goes off and the relay physically cuts the battery connection so it can cool down. Meanwhile, the ESP32 logs all this data and uploads it to our IoT web page so we can check on the system from anywhere.

VI. SOFTWARE AND METHODOLOGY

Our approach mixes standard embedded C programming for the physical sensors with a machine learning model for the data analysis. The ESP32 does the heavy lifting on the hardware side, gathering the sensor readings and pushing them to the cloud [7]. To actually make sense of that data, we built an Artificial Neural Network (ANN) in MATLAB [8]. We trained this AI model to look at the voltage, current, and temperature, and accurately guess the State of Charge (SOC) and State of Health (SOH). This two-part approach means the hardware handles the immediate safety shutoffs, while the AI software handles the long-term health tracking.

VII. STATE OF CHARGE ESTIMATION

State of charge is basically the battery's fuel gauge—it tells you what percentage of power is left. It is probably the most important number for any EV driver. By feeding our sensor data into the AI model, we get a much more accurate SOC reading than older methods, which helps us prevent the battery from draining too much and taking damage [8].

VIII. ADVANTAGES AND APPLICATIONS

A smart BMS like this extends the life of the battery and practically eliminates the risk of overheating fires [9]. It makes everything more efficient, and since it sends data to the cloud, you do not have to physically inspect the battery as often. While we designed this with electric cars in mind, the same setup would work perfectly for home solar batteries or industrial backup power systems.

IX. CONCLUSION

Our proposed Battery Management System provides a straightforward and practical way to make EV batteries safer. By pairing standard hardware sensors with an IoT platform and machine learning, our system catches warning signs early—before they turn into catastrophic failures. It reacts instantly to overheating, keeps the user informed remotely, and uses AI to predict long-term health, making it a solid foundation for the next generation of smart vehicles.

X. FUTURE WORK

Moving forward, we want to take the AI algorithm we built in MATLAB and run it directly on the ESP32 microcontroller. This would allow the system to do the predictive math locally without needing an internet connection. We also plan to test the setup under extreme weather and driving conditions to gather more data, which will help us train the neural network to be even more accurate in the real world.

REFERENCES

[1] M. A. Hannan, M. M. Hoque, A. Hussain, Y. Yusof, and P. J. Ker, “State-of-the-Art and Energy Management System of Lithium-Ion Batteries in Electric Vehicle Applications: Issues and Recommendations,” *IEEE Access*, vol. 6, pp. 19362–19378, 2018.

[2] L. Lu, X. Han, J. Li, J. Hua, and M. Ouyang, “A Review on the Key Issues for Lithium-Ion Battery Management in Electric Vehicles,” Journal of Power Sources, vol. 226, pp. 272–288, 2013.

[3] R. Xiong, L. Li, and J. Tian, “Towards a Smarter Battery Management System: A Critical Review on Battery State of Health Monitoring Methods,” Journal of Power Sources, vol. 405, pp. 18–29, 2018.

[4] K. W. E. Cheng et al., “Battery Management System (BMS) and SOC Development for Electrical Vehicles,” IEEE Transactions on Vehicular Technology, vol. 60, no. 1, pp. 76–88, 2011.

[5] Y. Wang, J. Tian, Z. Sun, and L. Wang, “A Comprehensive Review of Battery Modeling and State Estimation Approaches for Advanced Battery Management Systems,” Renewable and Sustainable Energy Reviews, vol. 43, pp. 54–62, 2015.

[6] J. Meng, G. Luo, and M. Ricco, “Lithium-Ion Battery State-of-Health Estimation with Short-Term Current Pulse Test and Support Vector Machine,” Microelectronics Reliability, vol. 88, pp. 1216–1220, 2018.

[7] D. N. T. How, M. A. Hannan, M. S. Hossain, and S. M. A. Motakabber, “Energy Management System of Li-Ion Battery Based on Artificial Intelligence: A Review,” IEEE Access, vol. 7, pp. 126955–126977, 2019.

[8] S. Shen, M. Sadoughi, X. Chen, M. Hong, and C. Hu, “A Deep Learning Method for Online Capacity Estimation of Lithium-Ion Batteries,” Journal of Energy Storage, vol. 25, Art. no. 100817, 2019.

[9] H. Rahimi-Eichi, U. Ojha, F. Baronti, and M. Chow, “Battery Management System: An Overview of Its Application in the Smart Grid and Electric Vehicles,” *IEEE Industrial Electronics Magazine*, vol. 7, no. 2, pp. 4–16, Jun. 2013.