IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

Operation of Embedded Systems and Microcontroller-Based Control Units

Prof. Palve D. S., Aakanksha Kamlesh Gangurde, Vrushali Navnath Gavhane, Kirti Baban Wable
Department of Electronics and Telecommunication Engineering
Sau. Sundarbai Manik Adsul Polytechnic, Chas, Maharashtra

Abstract: *This internship report presents a comprehensive study of the operation of embedded systems and microcontroller-based control units used in electric vehicle systems at Kinetic Engineering Ltd., Ahilyanagar. The training focused on understanding the role of microcontrollers in major EV control units such as the Battery Management System (BMS), motor controller, and instrument cluster. The internship covered microcontroller architecture and peripherals including ADC, PWM, GPIO, CAN, timers, watchdog, and brown-out detection, along with firmware flashing, configuration, functional testing, communication, diagnostics, and system integration. Practical activities included firmware flashing using programming jigs, checksum and version verification, ADC and PWM testing, protection FET verification, CAN communication testing, live parameter monitoring, troubleshooting, and maintenance of testing equipment. Quality assurance practices such as Incoming Quality Control, End-of-Line validation, SPC, defect tracking, calibration, traceability through MES, and ESD safety were also studied. The internship provided valuable practical knowledge by connecting academic concepts of microcontrollers, embedded systems, digital communication, electronic measurements, and industrial safety with real-world EV manufacturing and testing processes.*

Keywords: Embedded Systems, Microcontroller, Battery Management System, Motor Controller, Electric Vehicle, Firmware Flashing, CAN Communication, ADC, PWM, Functional Testing, Quality Control, MES, ESD Safety

I. INTRODUCTION

Embedded systems have become an essential part of modern automotive and electric vehicle (EV) technologies because they provide dedicated control, monitoring, communication, and protection functions. An embedded system combines hardware and software to perform specific tasks with high reliability and real-time response. In EVs, microcontroller-based control units are used in important systems such as the Battery Management System (BMS), motor controller, instrument cluster, and charger. The uploaded internship report describes these control units as central elements for monitoring battery conditions, controlling motor operation, displaying vehicle information, and maintaining safe operation.

Microcontrollers provide the processing capability required to acquire sensor data, execute control algorithms, generate output signals, and communicate with other vehicle systems. Typical control units use peripherals such as Analog-to-Digital Converters (ADC), timers, Pulse Width Modulation (PWM), General-Purpose Input/Output (GPIO), CAN communication, watchdog timers, and brown-out detection. In a BMS, these peripherals support cell-voltage, temperature, and current monitoring, while in a motor controller they support Hall-sensor processing, inverter control, speed regulation, and regenerative braking. Recent research also emphasizes that BMS architecture is increasingly important for improving EV battery safety, reliability, performance, and lifespan. [1], [2]

The Battery Management System is one of the most important embedded systems in an electric vehicle because it continuously monitors and manages battery operating conditions. It performs functions such as cell-voltage monitoring, temperature monitoring, current measurement, cell balancing, State of Charge (SOC) and State of Health (SOH) estimation, and protection against abnormal operating conditions. Research has identified overcharging, over-

DOI: 10.48175/568

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

discharging, overheating, cell imbalance, and thermal runaway as important battery-related risks, making accurate monitoring and protection essential. [3], [4] The internship training similarly covered BMS protection functions such as over-voltage, under-voltage, over-current, and over-temperature detection.

Communication and diagnostic systems are also important for reliable operation of embedded automotive control units. The Controller Area Network (CAN) protocol enables different control units to exchange information such as battery voltage, current, SOC, temperature, motor speed, operating status, and fault information. The internship involved studying CAN message structures, communication timing, error frames, Diagnostic Trouble Codes (DTCs), and live parameter monitoring. Modern BMS research also highlights the increasing integration of communication interfaces, intelligent monitoring, diagnostics, and advanced algorithms to improve the capabilities of EV control systems. [5], [6]

The operation of embedded systems in an industrial environment also requires systematic programming, testing, validation, quality control, and safety practices. During the internship, activities included firmware flashing, configuration, checksum verification, ADC and PWM testing, GPIO and protection testing, CAN communication testing, troubleshooting, and MES-based traceability. Functional testing and quality gates are particularly important because failures in embedded control units can affect vehicle safety and performance. Therefore, the study of embedded systems and microcontroller-based control units provides practical knowledge of how electronic hardware, firmware, communication, testing, and quality-management practices work together in real EV manufacturing environments. [7]–[11]

Motivation

The motivation for studying Operation of Embedded Systems and Microcontroller-Based Control Units comes from the growing use of embedded technologies in electric vehicles and modern automotive systems. Microcontrollers play an important role in monitoring, controlling, protecting, and communicating between different vehicle systems. The internship provided an opportunity to understand how theoretical concepts related to microcontrollers, embedded systems, communication, testing, and electronic measurements are applied in an industrial environment. The practical exposure to BMS, motor controllers, firmware flashing, CAN communication, functional testing, troubleshooting, and quality-control procedures helped develop a better understanding of real-world EV control systems.

Objectives

1. To understand the operation and applications of embedded systems and microcontroller-based control units used in electric vehicles.
2. To study microcontroller architecture and important peripherals such as ADC, PWM, GPIO, timers, CAN, watchdog, and brown-out detection.
3. To learn firmware flashing, configuration, version verification, checksum verification, and programming methods used for control units.
4. To understand functional testing, CAN communication, diagnostic procedures, troubleshooting, system integration, and validation of BMS and motor controller units.
5. To gain practical knowledge of industrial quality control, ESD safety, MES-based traceability, maintenance, and testing practices used in embedded-system manufacturing.

II. LITERATURE SURVEY

[1] ―Battery Management System for Electric Vehicles: Comprehensive Review of Circuitry Configuration and Algorithms‖ – Andrey Kurkin, Alexander Chivenkov, Dmitriy Aleshin, Ivan Trofimov, Andrey Shalukho, and Danil Vilkov (2025). This paper presents a comprehensive review of Battery Management Systems (BMS) used in electric vehicles, with emphasis on circuit configurations and control algorithms. The authors discuss important BMS functions such as battery parameter monitoring, protection, cell balancing, state estimation, charging and discharging management, communication, and data logging. The study also reviews the application of artificial intelligence in next-generation BMS

DOI: 10.48175/568

ISSN: 2581-9429 Volume 6, Issue 2, August 2026 Impact Factor: 8.2

technologies. The work is highly relevant to microcontroller-based EV control units because these functions require real-time sensing, processing, protection logic, and communication implemented through embedded hardware and software.

[2] ―Applications and Challenges of Embedded Systems in New Energy Vehicles‖ – Ruzhe Lin (2025). This study reviews the applications of embedded systems in New Energy Vehicles, particularly in battery management, energy optimization, fault diagnosis, and communication integration. The author explains that embedded systems support accurate State of Charge (SOC) and State of Health (SOH) estimation, real-time fault detection, and efficient energy management. The paper also identifies challenges such as computational inefficiency, scalability, and integration of data from multiple sensors. These findings support the importance of microcontroller-based control units in EVs and directly relate to the embedded-system architecture and monitoring activities studied during the internship.

[3] ―Review of Electric Vehicle Traction Motors, Control Systems, and Various Implementation Cards‖ – Meriem Megrini, Ahmed Gaga, and Youness Mehdaoui (2025). This review investigates electric traction motors, their control strategies, and embedded-system implementation for electric vehicles. The authors identify induction motors and permanent-magnet synchronous motors as suitable propulsion technologies and discuss Field-Oriented Control (FOC) for simultaneous torque and speed control with reduced ripple and noise. The study also highlights model-based design and identifies platforms such as STM32 and DSP controllers for implementing EV control strategies. This work is relevant to the study of motor-controller microcontrollers, PWM generation, Hall-sensor processing, and embedded control systems used in EV applications.

[4] ―Implementation of Automotive Embedded System‖ – B. Balan, Thangapandi M, Nithish Kumar N, and Rakshith T (2026). This recent work presents an automotive embedded system based on an STM32F103 ARM Cortex-M3 microcontroller and FreeRTOS. The proposed architecture integrates important EV functions, including motor control, steer-by-wire, and Battery Management System operations, into a centralized Vehicle Control Unit. Each subsystem is implemented as an independent real-time task with priority-based scheduling. The authors also use sensors for real-time feedback, battery modelling for SOC estimation, PCB design, and hardware validation. The study demonstrates the practical importance of microcontrollers, real-time operating systems, sensor interfaces, and control algorithms in modern EV control units.

[5] ―A Lightweight FPGA-based IDS-ECU Architecture for Automotive CAN‖ – Shashwat Khandelwal and Shreejith Shanker (2024). This paper focuses on improving the security of automotive electronic control units communicating through the Controller Area Network (CAN). The authors propose an integrated ECU architecture with an intrusion-detection system capable of identifying attacks such as denial-of-service, fuzzing, and spoofing. The proposed embedded architecture achieves low message-processing latency and reduced power consumption while maintaining CAN communication performance. This research is significant for microcontroller-based automotive systems because modern EV control units depend heavily on communication networks, making communication reliability and cybersecurity important considerations alongside functional control and diagnostics.

Summary of Literature Survey

The reviewed studies demonstrate that embedded systems and microcontroller-based control units are fundamental to modern electric vehicles. Recent research focuses on BMS monitoring and protection, real-time embedded control, motor-control algorithms, communication, diagnostics, cybersecurity, and intelligent energy management. The literature also shows a movement toward centralized control architectures, advanced microcontrollers, real-time operating systems, and intelligent algorithms. These research developments support the practical study of MCU architecture, firmware flashing, ADC/PWM testing, CAN communication, BMS operation, motor-controller operation, functional testing, and troubleshooting carried out during the internship. The uploaded internship report similarly covers these areas through practical work with BMS and motor-controller control units.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

III. PROPOSED SYSTEM

A. Embedded Control Unit Initialization

The proposed system begins with the initialization of the microcontroller-based control unit. The control board is inspected for physical defects, proper connections, power-supply conditions, and component integrity. The microcontroller initializes its clock, ADC, GPIO, timers, communication interfaces, watchdog, and other required peripherals. This stage ensures that the control unit is ready for firmware programming and functional operation.

B. Firmware Programming and Configuration

In this section, the appropriate firmware is loaded into the microcontroller using programming methods such as SWD/JTAG or CAN bootloader. The board identification and firmware variant are verified before programming. Required parameters such as protection thresholds and CAN identifiers are configured, followed by read-back and checksum verification to ensure firmware integrity. MES-based traceability records the MCU serial number, firmware version, timestamp, and test information.

C. Functional Testing and Validation

After programming, the control unit undergoes functional and parametric testing. ADC channels are checked for accurate voltage, temperature, and current measurements, while PWM outputs, GPIO signals, protection FET operation, watchdog behavior, and CAN communication are verified. Power supplies, electronic loads, oscilloscopes, CAN analysers, and diagnostic tools are used to validate the control unit under defined operating conditions.

D. System Integration and Communication

After successful functional testing, the control unit is integrated into the appropriate EV subsystem. The BMS controller is connected with the battery pack, the motor controller is integrated with the powertrain, and the instrument cluster is connected to the vehicle communication system. CAN communication is then checked between the BMS, motor controller, charger, and cluster to confirm correct exchange of voltage, current, SOC, temperature, speed, status, and fault information.

E. Quality Control, Safety and Traceability

The final stage focuses on quality assurance, safety, and production traceability. Quality gates are applied after firmware flashing, functional testing, system integration, and final End-of-Line validation. Defects such as flash failure, ADC errors, CAN communication failure, and protection faults are identified and corrected through systematic troubleshooting. ESD protection, proper grounding, safe equipment handling, firmware access control, and MES-based traceability are maintained throughout the process to ensure reliable and safe operation of the microcontroller-based control unit.

IV. SYSTEM DESIGN

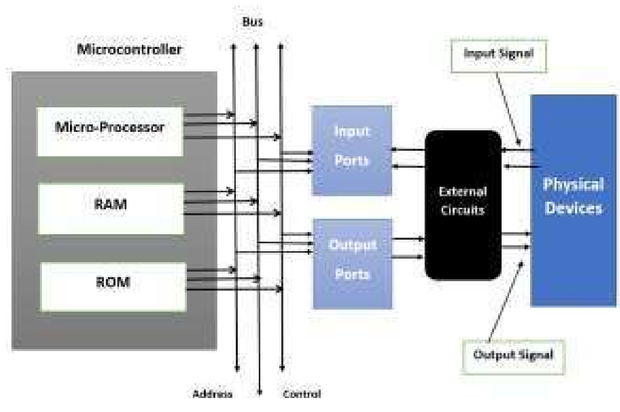

Fig. 1 Block Diagram

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

System Design

The given system design represents the basic working architecture of an embedded system based on a microcontroller. It shows how a microcontroller receives input signals from physical devices, processes them using its internal processing and memory units, and generates output signals to control external devices. The overall flow can be understood as Input → Processing → Output.

A. Microcontroller

The microcontroller is the main controlling unit of the system. It contains a microprocessor, RAM, ROM, input/output ports, and communication buses. The microprocessor executes the instructions stored in memory and controls the complete operation of the embedded system. In EV applications, microcontrollers are used in systems such as BMS, motor controllers, and instrument clusters. The internship report similarly describes microcontrollers using peripherals such as ADC, timers/PWM, GPIO, CAN, watchdog, and brown-out detection.

B. Microprocessor, RAM and ROM

Inside the microcontroller, the Micro-Processor performs the main computational operations. It receives data, executes program instructions, makes decisions, and controls the connected devices. ROM stores the permanent program or firmware required for system operation, while RAM temporarily stores data, variables, and intermediate results during execution. In the EV control units studied during the internship, firmware contains initialization, control logic, communication, diagnostics, and protection functions.

C. Bus – Address, Data and Control

The diagram shows three important buses: Address Bus, Data Bus, and Control Bus. The Address Bus specifies the location from which data needs to be accessed. The Data Bus transfers data between the processor, memory, and input/output sections. The Control Bus carries control signals that coordinate operations such as reading, writing, and device control. These buses allow the microprocessor to communicate efficiently with RAM, ROM, input ports, and output ports.

D. Input/Output Ports and External Circuits

The Input Ports receive information from external circuits and physical devices and transfer it to the microcontroller for processing. The Output Ports transfer processed signals from the microcontroller toward external circuits. External circuits act as an interface between the microcontroller and physical devices, allowing signals to be conditioned, converted, amplified, or controlled as required. In the internship's EV control-unit context, similar interfaces are used for sensor signals, protection devices, motor-control signals, and communication systems. For example, BMS controllers acquire cell voltage, temperature, and current information, while motor controllers receive Hall-sensor and throttle information.

E. Physical Devices and Input/Output Signals

The Physical Devices represent real-world sensors, actuators, motors, switches, displays, or other devices connected to the embedded system. An Input Signal travels from the physical device through the external circuit and input port to the microcontroller. The microprocessor processes this information according to the programmed firmware. It then produces an Output Signal, which passes through the output port and external circuit to operate or control the physical device.

Overall Working

The complete operation can therefore be represented as: Physical Device → Input Signal → External Circuit → Input Port → Microprocessor → RAM/ROM → Output Port → External Circuit → Output Signal → Physical Device

In an EV example, a sensor may provide a battery temperature or voltage signal to the microcontroller. The microcontroller processes the measured value and compares it with programmed protection conditions. If an unsafe condition is detected, it can generate an output to activate the appropriate protection mechanism. The BMS architecture described in the report uses ADC inputs for sensing and GPIO outputs for protection FET control, while CAN provides communication with other vehicle control units.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

Thus, the system design demonstrates how a microcontroller acts as the central decision-making unit between physical devices and control outputs, making it suitable for real-time embedded applications such as EV battery management, motor control, monitoring, and protection.

VI. OUTCOMES FROM THE SYSTEM

The proposed embedded-system architecture provides a structured method for sensing, processing, controlling, and communicating with physical devices. During the internship, the operation of microcontroller-based control units was studied through firmware programming, functional testing, communication testing, system integration, and troubleshooting. The outcomes demonstrate improved understanding of how microcontrollers and their peripherals are used in practical EV control systems.

A. Functional and Technical Outcomes

The system successfully demonstrated the major functions of microcontroller-based control units, including input sensing, data processing, output control, firmware execution, and communication. Practical testing included ADC measurements, PWM observation, GPIO/FET control, watchdog verification, and CAN communication. During hands-on testing, a 3.7 V input was checked through an ADC channel, PWM was observed at 1 kHz with 10% duty cycle, and CAN responses were verified within 100 ms.

Table 1: Functional Testing Outcomes

Sr. No.	Test Parameter	Observed/Specified Data	Outcome
1	Power-up current	Approximately 50 mA	Power-up operation verified
2	ADC input	3.7 V applied	Reading verified within 3.68–3.72 V
3	PWM output	1 kHz, 10% duty cycle	PWM operation observed
4	Protection FET	ON/OFF command	Gate-drive operation verified
5	CAN communication	Response within 100 ms	Communication verified
6	BMS temperature	Approximately 32°C	Live parameter successfully monitored
7	BMS SOC	Approximately 68%	SOC monitoring verified
8	Motor speed	Approximately 25 km/h	Motor-controller parameter monitored

B. Quality and System-Level Outcomes

The system also provided outcomes related to quality control, traceability, integration, and troubleshooting. Firmware version and checksum verification helped ensure correct programming, while functional and integration quality gates were used to identify defective control units. The manufacturing process targeted a functional first-pass yield above 98%, while flash success rate was monitored as an important production-quality parameter.

Table 2: Quality and Performance Outcomes

Sr. No	Parameter	Target/Result	Outcome
1	Functional first-pass yield	>98%	Improved production quality
2	Flash success rate	>99.5% target	Firmware quality monitored
3	Firmware verification	Version + checksum	Correct firmware ensured
4	System integration	CAN messages present	Communication verified
5	Protection testing	OV/UV/OC/O T	Safety functions validated
6	Traceability	MCU serial + firmware + test data	Production tracking achieved
7	CAN troubleshooting	Dry joint identified	Communication fault resolved
8	Maintenance	Programming jig/contact cleaning	Reliable testing supported

C. Overall Outcome

Overall, the system design helped establish a complete relationship between physical inputs, microcontroller processing, memory, output control, communication, and physical devices. The practical work strengthened knowledge of firmware flashing, ADC/PWM operation, CAN communication, protection logic, system integration, troubleshooting, quality control, and industrial safety. The internship therefore provided practical understanding of how embedded systems operate as real-time control units in EV applications.

VIII. CONCLUSION

The internship on Operation of Embedded Systems and Microcontroller-Based Control Units provided practical knowledge of how embedded control systems are used in electric vehicles. The training helped in understanding the complete operation of microcontroller-based units, starting from input sensing and data processing to output control, communication, testing, and system integration. The major areas studied included Battery Management Systems (BMS), motor controllers, and instrument clusters, which are important for the safe and efficient operation of EVs.

During the internship, practical knowledge was gained in firmware flashing, microcontroller configuration, ADC and PWM testing, GPIO control, CAN communication, watchdog operation, and diagnostic testing. The hands-on activities helped in understanding how sensor data is processed by the microcontroller and how appropriate control signals are generated for different vehicle functions. Troubleshooting activities also provided experience in identifying problems related to communication, power supply, connections, and electronic components.

The training also provided an understanding of industrial quality control and safety practices. Firmware version verification, checksum checking, functional testing, End-of-Line validation, MES-based traceability, calibration, ESD protection, and preventive maintenance were studied as important parts of the manufacturing and testing process. These practices help ensure that microcontroller-based control units are reliable, safe, and suitable for use in electric vehicles.

Overall, the internship successfully connected the theoretical knowledge of Microcontrollers, Embedded Systems, Digital Communication, Electronic Measurements, and Industrial Safety with practical industrial applications. It improved technical knowledge, troubleshooting skills, testing abilities, and understanding of professional manufacturing practices. The experience provided a strong foundation for further learning and career development in embedded systems, automotive electronics, microcontrollers, and electric vehicle technology.

IX. FUTURE SCOPE

The future scope of Embedded Systems and Microcontroller-Based Control Units is extensive, particularly with the continuous development of electric vehicles and intelligent automotive technologies. Based on the areas identified during the internship, the following improvements and developments can be considered:

1. Advanced Battery Management Systems: Future BMS development can focus on more accurate SOC and SOH estimation, improved cell balancing, temperature compensation, and advanced battery-monitoring techniques to improve battery performance and life.
2. Advanced Motor Control: Motor controllers can be further improved using advanced FOC techniques, flux weakening, improved Hall-sensor processing, and better regenerative braking control to provide smoother and more efficient motor operation.

REFERENCES

1. Kurkin, A., Chivenkov, A., Aleshin, D., Trofimov, I., Shalukho, A., & Vilkov, D. (2025). “Battery Management System for Electric Vehicles: Comprehensive Review of Circuitry Configuration and Algorithms.” World Electric Vehicle Journal, 16(8),451. DOI: 10.3390/wevj16080451.
2. Lin, R. (2025). “Applications and Challenges of Embedded Systems in New Energy Vehicles.” Theoretical and Natural Science, 109, 166–172. DOI: 10.54254/2753-8818/2025.GL24073.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

3. Megrini, M., Gaga, A., & Mehdaoui, Y. (2024). "Review of Electric Vehicle Traction Motors, Control Systems, and Various Implementation Cards." Journal of Operation and Automation in Power Engineering. DOI: 10.22098/joape.2024.13967.2077.

4. Gowri Sankar, P. A., Shanmuga Priya, S. R., Karthikumar, K., & Suba, S. (2025). "Electric Vehicle Battery Management System: A Comprehensive Review." Proceedings/Conference Publication.

5. Singh, A. K., Kumar, K., Choudhury, U., Yadav, A. K., Ahmad, A., & Surender, K. (2024). "Applications of Artificial Intelligence and Cell Balancing Techniques for Battery Management System (BMS) in Electric Vehicles: A Comprehensive Review." Process Safety and Environmental Protection, 191, 2247–2265. DOI: 10.1016/j.psep.2024.09.105.

6. Ashraf, A., Ali, B., Alsunjury, M. S. A., Goren, H., Kilicoglu, H., Hardan, F., & Tricoli, P. (2024). "Review of Cell-Balancing Schemes for Electric Vehicle Battery Management Systems." Energies, 17(6), 1271. DOI: 10.3390/en17061271.

7. Liu et al. (2024). "Advances in Battery State Estimation of Battery Management System in Electric Vehicles." Journal of Power Sources, 612, 234781. DOI: 10.1016/j.jpowsour.2024.234781.

8. Hannan et al. (2025). "Driving the Future: A Comprehensive Review of Automotive Battery Management System Technologies, and Future Trends." Journal of Power Sources, 629, 235827. DOI: 10.1016/j.jpowsour.2024.235827.

9. Vishwakarma, V. K., Srivastava, S., & Mishra, V. (2025). "Strategies of Battery Management Systems in Electric Vehicles: A Review." International Journal of Modelling and Simulation. DOI: 10.1080/02286203.2025.2523065.

10. Jena, S., Pahadasingh, C., Pattanaik, A., Das, D., & Jena, S. (2024). "An Overview of BMS Technologies in Electric Vehicles." Journal of Electrical Engineering and Automation, 6(1), 32–48. DOI: 10.36548/jeea.2024.1.003.

11. Rajwade, S., & Yadaw, P. K. (2024). "Battery Management System for Electric Vehicles: A Comprehensive Review." Journal of Computational Analysis and Applications, 33(7), 3196–3204.

12. Challoob, A. F., Rahmat, N. A. B., Ramachandaramurthy, V. K. A., & Humaidi, A. J. (2024). "Energy and Battery Management Systems for Electrical Vehicles: A Comprehensive Review & Recommendations." Journal of Engineering and Applied Sciences/Engineering-related publication, 42(1). DOI: 10.1177/01445987231211943.