Design and Implementing V2G System With Battery Management System (BMS) For Electric Vehicles

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Abstract - *With the rising shift toward electric mobility, the need for smarter and more reliable energy management in electric vehicles has become increasingly important. This work introduces a combined approach that integrates a Battery Management System (BMS) with a Vehicle-to-Grid (V2G) framework. The primary function of the BMS is to supervise key battery conditions such as voltage levels, current flow, temperature variations, and the State of Charge (SOC), ensuring safe performance while minimizing risks like excessive charging, deep depletion, and overheating.*

The integration of V2G functionality permits bidirectional power exchange between the vehicle and the grid, thereby improving overall energy utilization efficiency. The entire system is developed using a microcontroller-based embedded platform capable of handling real-time data acquisition, maintaining uniform cell performance through balancing, and regulating power exchange intelligently.

By combining these features, the system not only improves battery durability and operational efficiency but also supports grid reliability and encourages the adoption of sustainable energy practices in transportation.

Key words — Battery Management System, Vehicle-to-Grid, Electric Vehicles, State of Charge, Bidirectional Energy Flow, Cell Balancing, Smart Grid, LiFePO4 Battery, Embedded Platform, Sustainable Energy.

1. INTRODUCTION

The adoption of electric vehicles (EVs) has increased significantly, transforming the modern transportation landscape significant attention as an alternative to conventional transportation, leading to major changes in the automotive sector. This transition has increased the importance of efficient energy management and reliable power systems within EVs. An essential role in managing battery performance is performed by the Battery Management System (BMS), as it regularly monitors important factors like voltage levels, current flow, temperature, and State of Charge (SOC). . By doing so, it helps in maintaining safe operation and protects the battery from conditions like overcharging, excessive discharge, and thermal stress.

At the same time, the development of Vehicle-to-Grid (V2G) technology has introduced a new dimension to energy usage in electric vehicles. Unlike traditional systems where vehicles only draw power, V2G allows energy to be transferred in both directions. This means that EVs can return stored energy back to the power grid when required, especially during high-demand periods. Such capability not only improves overall energy efficiency but also plays a role in stabilizing the grid and supporting the integration of renewable energy sources.

This project aims to develop an intelligent system that combines BMS and V2G functionalities into a single platform. The design approach involves the use of embedded systems, power electronic circuits, and basic data processing techniques to manage energy effectively. The outcome is expected to contribute toward smarter energy handling and support the advancement of sustainable electric mobility solutions.

2. LITERATURE SURVEY

Existing research has broadly explored battery management and grid integration for electric vehicles. Piller et al.

[1] provided foundational methods for State-of-Charge (SOC) determination applicable across various battery chemistries, establishing the basis for modern BMS design. Muta et al.

[2]demonstrated hybrid vehicle energy system architectures that influenced bidirectional energy management strategies in EVs.In the domain of V2G integration, Kester et al.

[3] reviewed enabling technologies for vehicle-to-grid systems, highlighting communication protocols and power electronics requirements.Hannan et al.

[4] presented a comprehensive review on lithium- ion battery charge and discharge management for vehicle applications, addressing SOC estimation accuracy and cell balancing strategies.Communication and control aspects for V2G-enabled plug-in hybrid EVs were addressed by Markel et al.

[5], who demonstrated that standard communication protocols combined with intelligent control algorithms enable effective demand- response participation.

3. RESEARCH OBJECTIVES

1.Design and implement a microcontroller-based Battery Management System (BMS) for real-time monitoring of voltage, current, temperature, and SOC.

2.Develop a bidirectional Vehicle-to-Grid (V2G) power flow control system enabling energy exchange between EVs and the grid.

3.Implement active and passive cell balancing algorithms to ensure uniform battery cell performance.
4.Integrate communication protocols for seamless interaction between the BMS, V2G system, and smart grid infrastructure.
5.Validate system performance through real-time testing of charging (G2V) and discharging (V2G) modes under various load conditions.
6.Develop a cost-effective and scalable hardware prototype using lithium-ion battery pack, BLDC motor, bidirectional charger, and embedded controller.

4. PROPOSED METHODOLOGY

4.1 System Architecture

The proposed system consists of five integrated modules working together to deliver safe and efficient energy management. The architecture enables bidirectional power flow between the electric vehicle battery and the smart grid, coordinated through a central microcontroller-based decision engine as shown in Fig. 1.

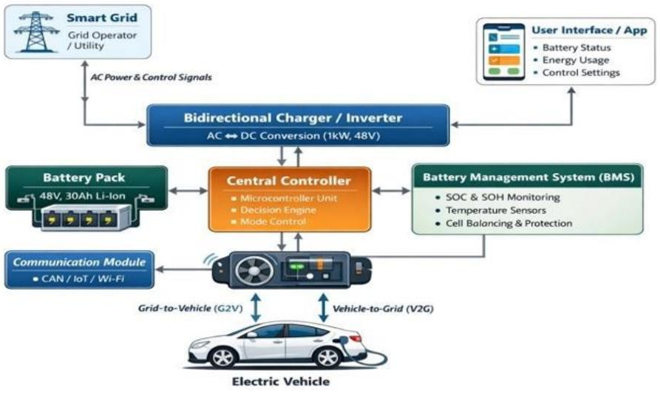

Figure 1:*V2G-BMS System Architecture Diagram*

Battery Pack: A 48V, 30Ah lithium-ion battery pack serves as the primary energy storage unit. The BMS interfaces directly with the battery to monitor individual cell parameters. Battery Management System (BMS): Monitors and controls voltage, current, temperature, SOC, and State of Health (SOH), enforcing protection thresholds and managing cell balancing via CAN bus.
Bidirectional Charger/Inverter: Converts AC power from the grid to DC for charging (G2V mode) and converts DC from battery back to AC for grid supply (V2G mode), rated at 48V and 1kW. The Motor Drive System uses a 48V BLDC motor for vehicle propulsion and regenerative braking energy recovery.

4.2 BMS Monitoring Module

The BMS continuously monitors cell voltage and temperature. It calculates State of Charge (SOC) using Coulomb counting combined with voltage-based correction as given below:

$$SOC(t) = SOC(t_0) - (1/C) \times \int I(t)dt$$

Where C is battery capacity in Ah and I(t) is instantaneous current. SOH is estimated by comparing current maximum capacity against rated capacity. Protection thresholds prevent overcharging (above 3.65V/cell), deep discharging (below 2.8V/cell), and overheating (above 60°C).

4.3 V2G Power Flow Control

The V2G module uses a repurposed home UPS inverter as a cost- effective bidirectional power converter. The EV battery (LiFePO4) connects to the DC input. In V2G mode, the module converts DC battery power to 230V AC to supply household loads or grid-connected infrastructure.
A voltage booster module bridges the charging voltage mismatch
— the UPS charges at 13.4V while LiFePO4 requires 14.6V. Mode switching between G2V and V2G is controlled via relay and microcontroller. In cases of deep discharge, a backup external charger activates automatically.

4.4 Cell Balancing Strategy

The system incorporates hybrid cell balancing strategies, including passive dissipation of surplus energy through resistive elements and active redistribution of charge between cells via DC-DC conversion, ensuring uniform cell performance. The balancing algorithm activates when voltage deviation across cells exceeds 50mV.

5. HARDWARE SPECIFICATIONS

Table 1: presents the hardware components used in the prototype implementation. The design prioritizes cost-effectiveness and scalability

Component	**Specifications**	**Qty.**
Battery Pack(LiFePO4)	3.2V/cell, 6S	16
V2G Module	48V DC → 220V AC, 1kW	1
Charge	48V DC charger	1
Transformer	12-0-12, 1KVA, 48V, 1kW	1
BLDC Motor	1kW, 48V	1
Microcontroller	MCU (Arduino/STM32)	1
Voltage Booster	DC-DC boost converter	1

5. RESULTS AND DISCUSSION

5.1 BMS Monitoring Performance

The BMS was tested under varied charge and discharge conditions. Real-time monitoring of voltage, current, and temperature was validated against reference measurements.

SOC estimation accuracy was within ±3% across multiple charge cycles.

Table2: Presents performance results across key operational parameters.

Parameter	Measured Range	Threshold
Cell Voltage	2.9V – 3.6V	< 2.8 / > 3.65V
Temperature	22°C – 48°C	> 60°C
SOC Error	±2.8%	-
Balancing	ΔV > 50mV trigger	ΔV < 20mV target

5.2 V2G Power Flow Evaluation

The V2G module was tested in G2V and V2G modes under household load conditions. The repurposed UPS inverter delivered stable 230V AC output from the 48V LiFePO4 battery pack. Mode switching achieved smooth transitions with no observable transient disruption to connected loads.

Table3: V2G Power Flow Test Results

Mode	Input	Output	Eff.
G2V	230V AC	48V DC,~20A	~88%
V2G	48V DC	230V AC,800W	~85%
Backup	48V Charger	LiFePO4 pack	~90%

5.3 System Performance Summary

A system performance summary gives a clear picture of how well a system is functioning over a specific period. It helps in understanding whether the system is meeting its expected goals and where improvements are needed.

Table4: System Performance Summary

Performance Metric	Result
SOC Estimation Accuracy	±2.8% error
V2G Output Voltage Stability	230V ±2%
Mode Transition Time	< 200ms
Cell Balancing Effectiveness	ΔV reduced to < 20mV
Thermal Protection Response	< 50ms trigger

6. Limitations

The current V2G implementation using a repurposed UPS is not grid-synchronized, limiting operation to off-grid or backup supply scenarios. The pricing model does not adapt dynamically to real-time grid tariff signals. Results are based on laboratory prototype testing; real-world deployment in a moving EV will introduce additional variability from vibration, thermal cycling, and load unpredictability.

-Renewable Energy Storage: Storing excess energy from solar/wind systems in EV batteries for supply during peak demand.

-Emergency Power Backup: Using V2G to supply power to buildings or critical infrastructure during outages

7. CONCLUSION

This study introduces a detailed design and implementation of the proposed system framework for a Battery Management System (BMS) integrated with a Vehicle-to-Grid (V2G) system for electric vehicles. The proposed system effectively addresses key challenges in EV energy management including accurate SOC estimation, cell balancing, thermal protection, and bidirectional power flow. The microcontroller-based embedded design provides a cost-effective and scalable solution that enhances battery lifespan and improves energy efficiency.By bridging EV energy storage with grid requirements using are purposed UPS as the V2G module, this system demonstrates a practical low-cost approach to bidirectional energy management. Future integration with AI, IoT, and blockchain technologies will further elevate the intelligence and capability of such systems.

8. FUTURE SCOPE

Future developments include integration of Artificial Intelligence (AI) and Machine Learning (ML) for predictive battery degradation analysis, fault detection, and optimized charging algorithms. IoT-based cloud connectivity will enable remote monitoring of battery health and large-scale data analytics. Blockchain technology can enable decentralized, secure peer-to- peer energy trading in V2G networks. The BMS can be adapted for emerging battery chemistries such as solid-state and lithium- sulfur batteries. Long-term vision includes integration with smart city infrastructure where EVs serve as distributed energy storage nodes within renewable energy ecosystems.

9. ADVANTAGES

-Enhanced Battery Safety: Continuous monitoring of voltage, current, temperature, and SOC prevents overcharging, deep discharging, and thermal runaway.

-Extended Battery Life: Proper charge/discharge cycle control with active and passive cell balancing maintains uniform performance across the battery pack.

-Vehicle-to-Grid Energy Exchange: EVs supply stored energy to the grid during peak demand, enabling load balancing and grid stabilization, with potential financial incentives for EV owners.

-Support for Renewable Energy: EVs act as mobile energy storage units, storing surplus solar or wind power and supplying it when needed.

-Smart Grid Integration: The system supports IoT-based remote monitoring, real-time data analytics, and predictive maintenance.

-Scalable Design: Microcontroller-based architecture is cost-effective and suitable for both small-scale and industrial EV applications.

10: APPLICATIONS

-Electric and Hybrid Vehicles (EVs/HEVs): Safe, efficient, and reliable battery operation and performance monitoring.-Smart Grid Integration: Load balancing, grid stability, and demand-side energy management through V2G technology.

11. REFERENCES

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