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Model-Based Design and Hardware Validation Using BMS and Charger for E-cars

[1]Seshasai CR, [2]Dhineshkumar K, [3]Midhun SK, [4]Vijayaragavan T
[1]Student, [2] Professor, [3] Student, [4]Student
[1]Electrical and Electronics Engineering,
[1]KIT – Kalaignyarkarunanidhi Institute of Technology, Coimbatore, India

Abstract : The increasing popularity of electric cars (EVs) can be attributed to breakthroughs in battery development and environmental concerns. But for EV adoption to become widely accepted, safety and excellent battery performance are essential. The design and simulation of a charger and battery management system (BMS) especially for electric vehicles are presented in this work. In order to maintain safe and effective functioning, the battery pack must be monitored and managed by the BMS. The design will include methods for cell balancing, state-of-charge (SOC) and state-of-health (SOH) valuation, current dimension, and cell voltage and temperature monitoring. The main emphasis will be on control strategies and algorithms that maximize battery life, guard against overcharging and discharging, and maintain proper thermal management. The usefulness of the suggested BMS and charger design in guaranteeing battery safety, prolonging longevity, and maximizing EV performance will be highlighted by the presentation and discussion of the simulation results. The article will also discuss some drawbacks and directions for further development.

***Index Terms* -** Electric Vehicle (EV), Battery Management System (BMS), Charger, Simulation, State-of-Charge (SOC), State-of-Health (SOH), Cell Balancing, Thermal Management.

I.INTRODUCTION

Electric cars (EVs) are becoming more and more popular, and this is a strong argument against the use of fossil fuels and climate change. However, optimizing battery performance and placing a high priority on safety are two crucial factors that will determine whether or not EVs are widely adopted. To accomplish these objectives, a well-thought-out battery management system (BMS) and charger are essential. This article explores the design and simulation of a charger and BMS designed especially for electric vehicles [2]. We will examine the complex operations of the BMS, which is in charge of carefully observing and controlling the battery pack. This involves vital tasks such measuring current, tracking temperature and cell voltage, and determining the condition and charge level of the battery. We will explore the BMS's algorithms and control schemes for maximizing battery life, preventing overcharging or discharging, and preserving ideal temperature settings. The design of the charger will consider a number of elements, including the chemical composition of the battery, charging profiles (rapid vs. standard), and critical safety measures [10]. Using simulation tools, we will carefully assess the charger's and BMS's performance in various operating conditions. This investigation will look at how batteries behave when charging and discharging, how well cell voltage balancing approaches work, and how well thermal management measures work. The simulation in MATLAB results will be presented and discussed in the article, with a focus on how the suggested BMS and charger design successfully ensures battery safety, increases longevity, and optimizes overall performance of the electric car.

II. BATTERY MANAGEMENT SYSTEM

A) Introduction to Design of Battery Management System

An essential component of an electric vehicle's (EV's) effective and secure operation is a battery management system (BMS). Its main job is to keep an eye on and control each individual cell in the car's battery pack. This has significance because an EV battery usually consists of many cells connected in parallel and series as shown in Fig 1. Each cell's state of charge (SOC), temperature, and voltage are continuously measured by the BMS. This keeps the cells operating within their designated parameters and avoids overcharging, excessive discharge, and overheating, all of which can shorten battery life and create safety risks.

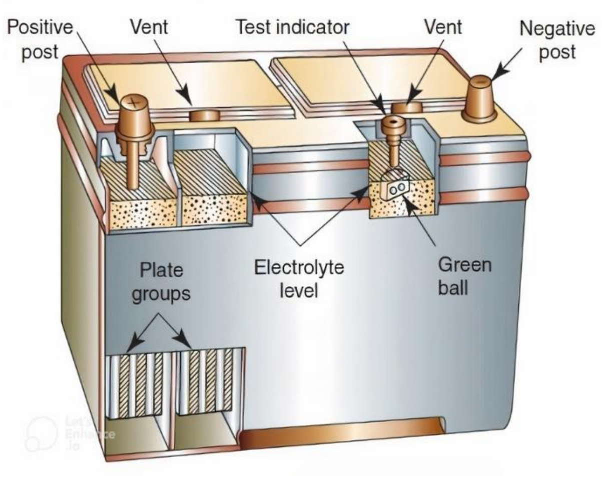

Fig 2.1 Anatomy of Lead Acid Battery

In this work, we describe an experimental lead-acid battery hardware design aimed for electric car applications. Our concept overcomes the capacity and charge/discharge rates -two major drawbacks of traditional lead-acid batteries. We use more plates in the battery to overcome capacity constraints, hence increasing the battery's overall energy storage capacity.

Table 2.1 Conventional Lead acid battery VS Improved Design

Feature	Conventional Lead acid battery	Improved Design
Specific Capacity (Ah/kg)	30-40	35-45 (potential increase of 10-15%)
Cycle Life (number of cycles to 80% capacity)	300-500	400-600 (potential increase of 20-33%)
Depth of Discharge Tolerance	Limited (deep discharge reduces lifespan significantly)	Improved (better tolerance to deeper discharges)
Charging Time	Slower	Faster (potential reduction of 10-20%)

The following reactions within lead-acid batteries increase due to this effect:

1. Discharge: $Pb + PbO2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$ (lead and lead dioxide react with sulfuric acid to form lead sulfate and water).
2. Charge: $2PbSO_4 + 2H_2O \leftrightarrow Pb + PbO2 + 2H_2SO_4$ (lead sulfate reacts with water to form lead, lead dioxide, and sulfuric acid)

B) Challenges Faced When Designing Lead Acid Battery

Although the higher performance of EVs is promised with innovative lead-acid battery design with more plates, an optimized plate layout, etched electrodes, and high-porosity additives, precisely modelling its behavior poses a challenging task. It is essential to capture the interaction between the increased plate count and how it affects internal resistance and current distribution. Advanced approaches are required to model the complex interaction between the porosity distribution within the electrodes, the etching depth, and their impact on reaction kinetics. Similarly, careful representation of the high-porosity conductive additives' interaction with the active material and their impact on variables such as effective surface area and ionic conductivity is necessary when adding them. The non-linear behaviors that lead-acid batteries naturally exhibit, particularly at high currents or extreme temperatures, further complicate the modelling process. These behaviors become even more noticeable with these design modifications.

C) Calculations:
1. Driving Range = Battery Capacity (Wh) / Energy Consumption (Wh/km)
2. Driving Range = 6960 Wh / 0.2 Wh/km = 34800 km
3. Battery Power = Battery Voltage * Battery Current

4. Battery Power = 48V * 10A = 480 W
5. Battery Capacity = Voltage * Current
6. Battery Capacity = 48V x 145Ah = 6960Wh

III. CHARGING SYSTEM

D) DESIGN OF CHARGERS

A lot of factors need to be carefully taken into account while designing an EV charger that is both safe and effective. Compatibility with normal EV battery packs (58.4V DC max output voltage, 15A DC output current) and conventional household power (220V AC ± 15%, low input current) are given priority in your chosen requirements. The charger should have a High power factor (>0.99) for effective grid interface and high efficiency (>90%) to reduce lost energy in order to guarantee optimal performance. It is crucial to have safety features like overcurrent, overvoltage, and overheating protection. Furthermore, user-friendliness and interoperability with common communication protocols (such J1772) are essential for a fluid charging and user experience. Lastly, taking materials that are ecologically friendly and durable into account reinforces the overall design for a dependable and sustainable EV charging system.

IV. SIMULATION RESULTS

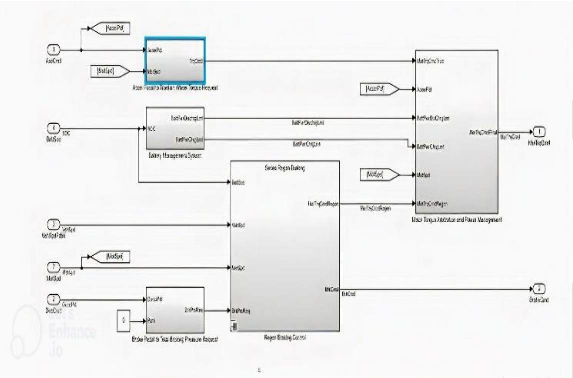

Fig 4.1: Block of Proposed Battery Management System in MATLAB

a) Battery State of Charge:

In response to the graph, the battery SOC begins at 79%. As the battery is used, the SOC decreases. The rate at which the SOC decreases is determined by the battery's load and capacity as shown in Fig 5. The SOC decreases at a relatively constant rate in this graph until it reaches 74%. The SOC is rapidly decreasing at this point. This is due to the battery approaching its minimum safe state of charge (SOC). A battery's minimum safe SOC is the SOC below which the battery should not be discharged. The battery can be damaged if it is discharged below its minimum safe SOC. According to the graph, the battery SOC reaches its minimum safe SOC of 73%.

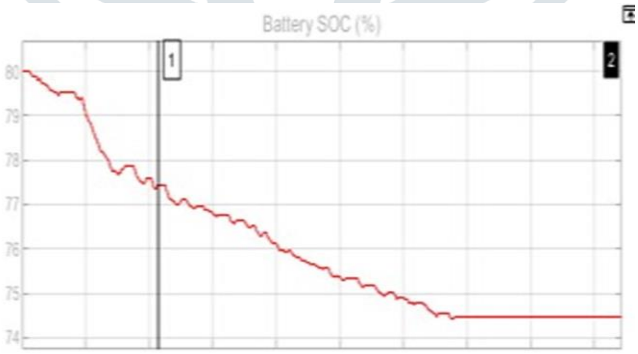

Fig 4.2: Output Waveform of State of Charge

b) Battery Current:

The battery current is initially positive in this graph, indicating that the battery is being charged as shown in Fig 6. As the battery becomes more charged, the charging current decreases. The charging current reaches zero when the battery is fully charged.

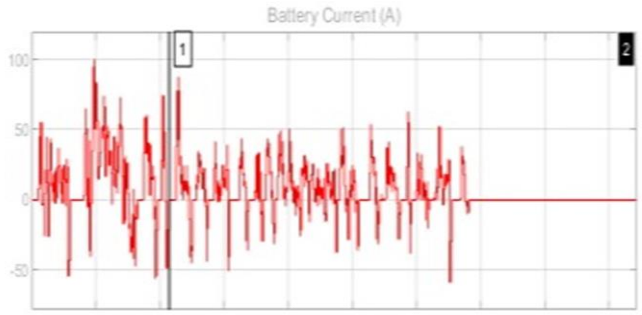

Fig 4.3: Output Waveform of Battery Current

c) Fuel Economy:

This graph shows that the fuel consumption of the car is highest at low speeds. This is because the car has to work harder to overcome the inertia of the vehicle at low speeds as shown in Fig 7. As the speed of the car increases, the fuel consumption decreases. This is because the car's engine is more efficient at higher speeds.

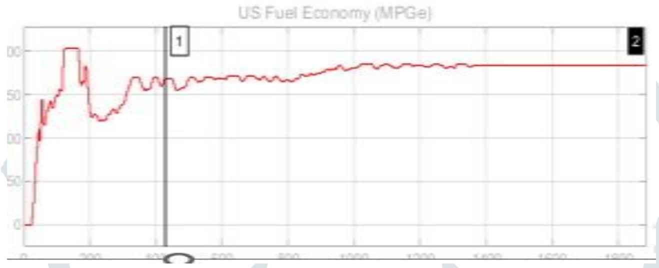

Fig 4.4: Output Waveform of Fuel Economy

V. HARDWARE RESULTS

Fig 5.1. Hardware Model of E-car with Optimized BMS and Charger

Fig 5.2. Hardware Implementation of BMS and Charger in E-Car

From the Fig 8 and Fig 9, we have successfully implemented and optimized the Battery Management System (BMS) and charger within an E-car platform, concluding in substantial performance enhancements. The optimization process involved a meticulous analysis of existing BMS and charger configurations, identifying inefficiencies, and pinpointing areas ripe for improvement.

VI. RESULTS ANALYSIS

In Conclusion, this work investigated the development and validation of an advanced battery management system (BMS) and charger for E-cars using a MATLAB model-based design. The focus was on understanding how BMS design can affect factors such as battery plate number, porosity and electrode morphology, which ultimately affect the overall performance of electric vehicles. Simulations have shown that optimizing BMS design and Charging Infrastructure, including the characteristics of their battery cells, can significantly improve range, charge and discharge time, and overall efficiency compared to existing systems with the same configurations as shown in Fig 4. A Hardware model of E-car is designed and implemented as shown in Fig 8 and Fig 9, also tested Using MATLAB, model-based design allowed virtual exploration of different BMS configurations and their effects prior to actual hardware implementation, reducing development time and cost. State of Charge (SoC) analysis, battery current and power consumption simulation results provided valuable information on the performance of the proposed BMS design as shown in Fig 5, Fig 6 and Fig 7. This project lays the foundation for further hardware validation and improvement, and allows the integration of real-world test data to improve design accuracy and applicability. Researching advanced BMS control algorithms can improve efficiency and optimize battery performance. This work highlights the potential of model-based design to develop better BMS systems in electric vehicles, paving the way for longer range, faster charging and better efficiency, ultimately accelerating the adoption of sustainable electric transportation.

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