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IMPLEMENTATION OF INTEGRATED BATTERY MANAGEMENT SYSTEM FOR ENHANCED PERFORMANCE OF ELECTRIC VEHICLES

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ABSTRACT

This paper presents BMS works in electric vehicles, its role in maintaining safety and performance, and how it communicates with other vehicle systems. As technology advances, future improvements in BMS, such as using artificial intelligence, will make electric vehicles even more reliable and efficient, helping to make sustainable transportation a more widespread choice. Additionally, the BMS ensures the overall safety of the Electric vehicles maintain battery health by avoiding excessive charging and deep discharging and also over current. In electric vehicles, the BMS plays a main role in maximizing the lifespan of the battery by real time data for forecasting maintenance and energy usage patterns. This paper also discusses various techniques used to improve the accuracy of SOC and SOH estimation, as well as the importance of communication protocols for information sharing between the BMS and other car control systems. By focusing on the BMS interaction with the car's powertrain, regenerative braking system, and charging infrastructure, the research highlights how the BMS enhances the general reliability and effectiveness of electric cars. This paper practical guide for the systematic design, simulation, and performance analysis of electric vehicles and provides insightful information for the future advancements in EV technology.

1. INTRODUCTION

Battery management systems is encompass various estimations, such as SOC, SOH, SOE, SOP, SOL, and SOC are the states of charge, health, energy, and power, respectively. Among these, SOC and SOH monitoring are vital for improving reliability and safety. A typical BMS includes functional units such as Communication interfaces, temperature tracking, current sensing, and cell voltage balancing [1]. By maintaining a constant voltage across each cell in a battery pack, cell voltage balancing improves performance and prolongs longevity. Temperature monitoring prevents overheating and regulates thermal conditions. Accurate observation of the electric current flowing in and out the battery is made achievable via sensing of current. Communication of interfaces is enable data exchange between external systems and the BMS, like a car is using control unit or BM network. Additionally, the battery to protect from dangerous situations, the BM system integrates safety features inbuild like under-voltage, over-voltage, and over-current protection.[2] Additionally, The charge and discharge from the battery is controlled by the BMS, which makes sure they take place within ideal and safe bounds.

A BMS is crucial for safeguarding individual battery cells and enhancing their lifespan and cycle count. This is particularly vital for lithium-ion batteries, which require protection against overcharging and excessive temperatures to prevent cell damage. The following are a BMS's main duties:

- **Monitoring:** Continuously tracks variables including temperature, voltage, current, and charge level (SOC) of each cell.
- **Protection:** Prevents unsafe such as thermal runaway, deep discharge, and overcharging.
- **Balancing:** ensures that all cells receive the same amount of charge to optimize performance and longevity.
- **State Estimation:** Assesses the health status (SOH) and SOC to predict battery behavior and lifespan.
- **Communication:** Interfaces with external systems for diagnostics and performance analysis.

Lithium-ion batteries, while efficient, are susceptible to safety risks if not properly managed. A BMS addresses these concerns by:

- **Thermal Management**: Employing passive or active cooling systems to keep the working temperatures at ideal levels.

- **Overcurrent Protection**: Detecting and mitigating excessive current flow to avoid possible dangers including overheating.
- **State of Charge Management**: Preventing Battery life can be shortened by deep draining and overcharging and performance.

BMS in EVs can include a variety of actuators, controls, and sensors. They are cooperative in nature, providing a safe and diverse choice of actuators, controllers, and sensors for use with BMS. Accurate monitoring of battery parameters by BMS is also done to gain important data for assessing battery health, estimating state of charge, and improving overall battery performance [3]. The proposed BMS designs utilize greater number of sensors in contrast to the safety circuits that are currently in use, providing for enhancements like axact alerts and controls to stop overcharging, over discharge, and overheating. Sensors are necessary to track and measure battery parameters such as temperature, current, and cell voltage. The practical applicability of these measures is compromised by space constraints and device cost. Therefore, To improve state tracking capabilities in practical applications, accurate voltage, temperature, and current data are essential. Accordingly, State, SOC, and SOH estimates were acquired. Additionally, the thermal property is achieved by sensing the surface temperature, regarding the connection between battery life of SOC and SOH and temperature was discovered. [4].

2. LITERATURE SURVEY

EV and Hybrid EV's have become increasingly used as substitutes for engines powered by internal combustion automobiles have a number of benefits, such as decrease emissions of reduced pollution of air, decreased greenhouse gas emissions, and improved efficiency of energy. EVs and HEVs are battery-driven, They are characterised by long-term functionality, low environmental impact, and high energy density. The increased EV use is reliant on battery technological developments. Work is starting to riseenergy storage capacity, decrease charging time, and decrease the price. Since lithium-ion (Li-ion) batteries have so many advantages, they are currently the most widely used battery type in electric vehicles (EVs). However, researchers are also looking into other battery chemistries. The idea opens up EVs to actively communicate with the electrical grid and act as energy storage devices in addition to being energy consumers. Global battery industry's rapid growth, forecasting a crossing of 2500 GWh in the coming decade [4]. demonstrates the growing Battery requirement across different regions and uses, The development of the modern battery business is mostly being driven by electric mobility. The demand for Smart mobility is made possible by electric and alternative fuel cars, which are driving research and development in battery materials and automotive technology.

China aspires to fulfil the global goal of carbon neutrality by reaching its peak emissions by 2030. The Li-ion Batteries are expected to achieve an energy density objective of roughly 500 Wh kg−1 of EVs, putting them on level with fossil fuel vehicles usage. Many electric car models have widely employed batteries made of lithium-ion and (Ni-MH) battery [5]. The increased dependability, power density, energy density, and efficiency of Li-ion batteries are the main reasons for their appeal [6].

Li-ion batteries have also become widely commercialised, allowing for their application in a variety of industries, thanks in large part to their declining manufacturing costs. Safe operation, improved driving range, better power management strategies, longer battery life, and reduced costs all depend on effective battery management. Particular consideration must be given to batteries in electric vehicle applications. Batteries can be seriously harmed by overcharging, over discharging, or other misuse, which can also accelerate ageing and increase the risk of fire or explosion [7].

3. METHODOLOGY

The methodology for the layout, simulation, and performance evaluation of the integrated battery control system for enhance performance of electrical vehicles.

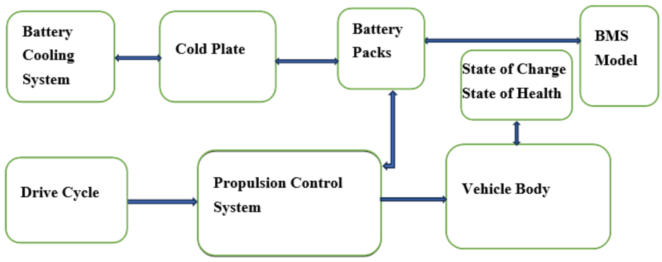

Figure 1: Block Diagram of BMS electric vehicle

a) BATTERY THERMAL MODEL

Lithium-ion batteries exhibit optimal performance within specific temperature and voltage ranges. Operating outside these parameters may result in decreased effectiveness, capacity loss, and possible risks to safety. Operating temperature is important for performance and longevity of batteries made of lithium-ion. While these batteries can function within a wide temperature range, their efficiency and lifespan are optimized within a specific window [8].

The following formula can be used to represent the thermal model:

$$\frac{d}{dt}Qaccu = {}_{\rho}Cp\,\frac{dT}{dt} = \frac{d}{dt}Qgen - \frac{d}{dt}Qdis$$

In this formula, Cell density, heat capacity, time, and temperature are denoted by the letter ρ,Cp, t, and T, respectively. Additionally, Qgen, Qaccu, and Q dis represent the heat that has accumulated, created, and dispersed, respectively.

b) STATE OF CHARGE (SOC):

Battery charging to go smoothly and effectively, careful thought and practical steps are needed. The SOC, which shows the charge level in relation to the battery capacity, is an essential component of battery operation. SOC shows the amount of energy left in a battery to power an EV, much as a fuel gauge in a car that runs on petrol. SOC has a significant impact on a number of important performance factors, including range and fuel efficiency. SOC, which is widely used to indicate a battery's present condition while it is operating, is usually given as a percentage (0% = empty; 100% = full).

$$SOC\% = \frac{Q0+Q}{Qmax} \times 100$$

The calculation of SOC can be done by Equation, where Q0 (mAh) the original charge of the battery. Q (mAh) is the quantity of power transmitted by or provided to the battery. It is detrimental, when discharging and favourable during charging. Q max (mAh) and the highest a charge that is kept of battery.

c) BATTERY PACK ESTIMATION OF SOC:

The performance of individual cells and the non-uniform features within the pack differ [9]. While discharge testing is a means of determining a single cell's capacity and state of charge, it is not possible to apply these measurements directly to battery packs.

d) STATE OF HEALTH (SOH):

The extreme of importance is to separate two concepts: battery condition and estimated remaining usable life. The maximum number of cycles that a battery can withstand depending on its kind is known as its cycle life design, and the usage as defined by the manufacturer. The SOH compares an old battery's implementation and condition to that of a brand-new identical battery. [10]. SOH is determined by calculating the difference between the battery's nominal capacity (Qn) and real capacity (QC), as indicated.

$$\text{SOH} = 1 - \frac{Cbof}{0.2 \times Cbof} \times 100$$

where Cbof is the initial life of battery capacity. The battery's current capacity is denoted by C. $0 < \text{SOH} \leq 1$; if SOH = 1, the battery is new, and vice versa.
(SOH) is a qualitative assessment by considering numerous quantitative battery performance metrics, including temperature, stress, strain, self-discharge rate, voltage, resistance, and current has been defined variously in a number of studies. Even though SOH is determined by the performance and condition of an old battery in comparison to a new battery of the same kind. Temperature is also an important factor in battery performance. The optimal operating temperature range for a cell's cycle life is between 15°C and 45°C. Upon falling less then a certain temperature threshold, the cycle life slowly diminishes less then -15°C or above 45°C. Increased Thermal runaway causes temperature to drastically reduce cycle life [11].

e) BATTERY CHARGING AND DISCHARGING:

The discharge process should be halted when a battery's energy is exhausted, its state of charge reduces to 20% or less, or its terminal voltage falls below the cut-off voltage. After that, the battery needs to be recharged. The effectiveness of charging different kinds of batteries is demonstrated. It is imperative to avert wrong operations like over discharging, over-charging, or wrong charging since they can greatly hasten battery deterioration. Although Li-ion batteries usually possess stable operation, they possess a short life of cycle at temperatures that are too high and should detect the charging status, and upon detecting a fully charged battery, end the charging process.
BESS cells are used to obtain the needed power. integrated either in series or parallel structures. In recent decades, a variety of cell-balancing topologies have been proposed, which could be generally classified Both active and passive balancing fall within this category. The utilisation of energy storage elements and energy balancing techniques form the basis of these two groups.

f) BATTERY THERMAL MANAGEMENT :

A battery pack's batteries can't overheat thanks to a variety of components, including software and hardware, function together well. Among them, the BTMS is essential in keeping batteries and battery modules at a constant temperature. The battery's longevity and thermal safety are directly impacted by the BTMS's performance. Because batteries are used in many different settings and for a variety of purposes, the BTMS will have to be made flexible to accommodate various operating and ambient conditions.
But ineffective design of heating/cooling methods can cause temperature fluctuations and battery pack irregularities, deterioration of stability of temperature, security, and battery life. Properly designed BTMS also allows for temperature spreading within the battery pack system, while maintaining other elements like weight, portability, dependability, affordability, and suitability for usage in automobiles.

g) HEAT AT LOW TEMPERATURES IN EV THERMAL MANAGEMENT

For electric vehicles in cold areas, the best battery performance and economy are even more crucial. The capacity of batteries, internal resistance, and overall energy generation can all be negatively impacted by cold conditions. To mitigate these issues, EV makers and researchers have looked into different low temperature heat transfer methods used in thermal management:

1) PRE-HEATING OF BATTERY : When driving in cold conditions, preheating improves performance and efficiency. Manufacturers can increase the battery's temperature to the proper level before the car is driven by using resistive heating components included into the battery pack.

2) PRE-HEATING OF BATTERY IN PUMP SYSTEMS :
Systems using heat pumps are used by some EVs, which have the ability to draw heat coming from the outside surroundings, even during extremely cold temperatures, and reroute it to the battery and cabin. For maintaining the right temperatures, this approach works well and uses less energy.

4. SIMULATION ANALYSIS AND RESULTS

Battery management system is the very important system in electric vehicle since batteries employed in electric. A drive cycle for electric vehicles (EVs) is a standardized series of speed and acceleration data points over time used to simulate real-world driving conditions and test EV performance and energy consumption, helping to determine factors like range and efficiency.

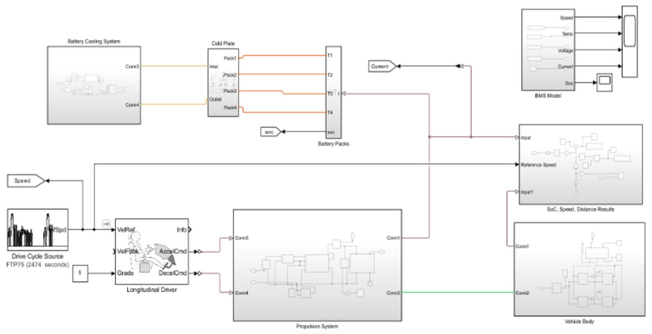

Figure.2: EV battery management system simulation.

Field Type	Permanent Magnet
No-load speed	10,000 rpm
Rated speed (at rated load)	3796 rpm
Rated load (Mechanical power)	84 KW
Rated DC supply voltage	320 V
Output voltage amplitude	310 V
PWM- Frequency	400 Hz
Vehicle Mass (Kg)	1470 Kg
Air density	1.225 kg/m^3
Drag frontal area	2.91 m^2
Drag co-efficiency	0.15, Tesla car-0.23

Drive cycles is defined by a a sequence of data points that plot vehicle speed against time, representing different driving scenarios. These data points are used to simulate the vehicle's behavior on a computer model, allowing engineers to predict its performance and energy consumption.

PROPULSION CONTROL SYSTEM:
Systems for propulsion control are necessary for the safe and effective operation of various vehicles, contributing to their maneuverability, speed, and overall performance. Monitor and control the operation of engines, gears, propellers, and other propulsion components. Optimize engine performance for fuel efficiency and power output. Ensure safe operation within predefined parameters and respond to potential issues.

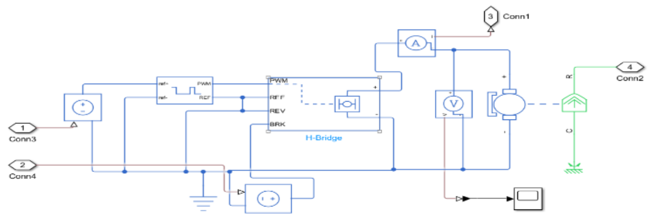

Figure.3: Propulsion control system.

DC MOTOR:

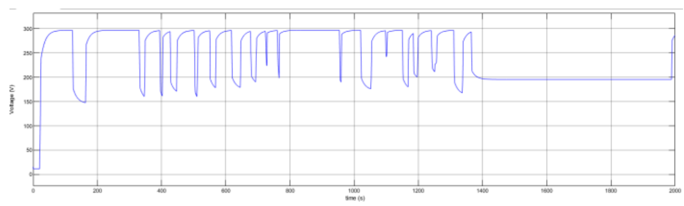

Figure.4. dc motor output voltage

A DC motor that uses 85kW of power and 310 volts will draw about 274.19 amps. The following formula is used to determine this: Current (I) = Power (P) / Voltage (V). Power is expressed in kilowatts (kW), so it is multiplied by 1000 to convert it to watts (W) (85kW = 85000W). I = 85000W / 310V = 274.19A as a result.

VEHICLE BODY:

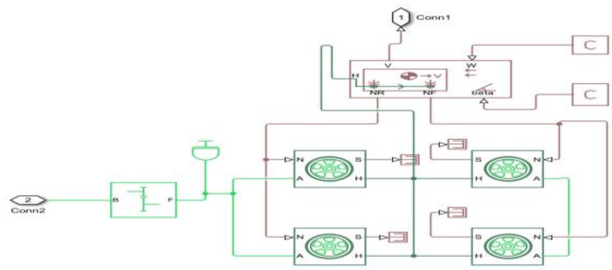

Figure.5: Structure of the vehicle body.

The vehicle body, or "space frame," is designed for strength, safety, and lightweight construction using materials like -aluminum and magnesium, and potentially composite plastics, to house the battery pack and other components.

BATTERY COOLING SYSTEM:

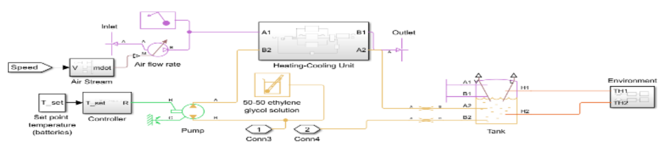

Figure.6: Battery pack cooling system.

The battery should be kept within its ideal temperature range ensures efficient energy transfer and maximizes driving range. Overheating can hasten battery deterioration, resulting in a shorter lifespan and lower capacity. Overheating can lead to thermal runaway, a hazardous circumstance in which the battery cells may ignite on their own.

BATTERY PACK:

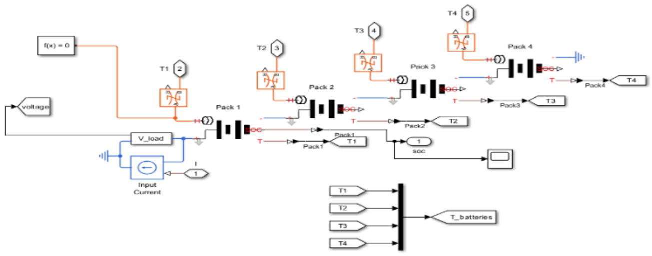

Figure.7: Battery pack system.

The battery pack, which is usually made up of several battery cells organised in series and parallel combinations, is an essential part of electric vehicles (EVs) that stores and provides the electric motor is powered by electricity. Since lithium-ion batteries have a high energy density and efficiency, they are frequently seen in EVs.
In electric vehicles (EVs), Batteries are connected in parallel and series to get the capacity and voltage that are needed. Parallel connections boost capacity, but series connections boost voltage (amp-hour rating).

BATTERY MANAGEMENT SYSTEM MODEL:

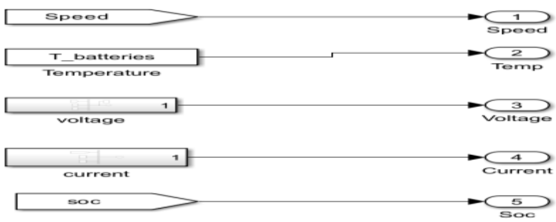

Figure.8: BMS Modelling system.

In electric vehicles a to ensure safe and effective operation, the battery pack's health and performance are the Battery Management System oversees and controls and keeping an eye on the state of charge (SOC), temperature, voltage, current, as well as balancing individual cells and managing charging/discharge.

Battery Monitoring:

Temperature (K)	Max- 40°C Min-25°C	(Set-T_set+19.5) (Set-T_set-4.5)
Voltage (V)	Max- 400 V Min- 20 V	(T_set+379.5) (T_set-0.1)
Current (A)	Max- 300 A Min- -150 A	(T_set+280) (T_set-171)

The BMS manages the energy generated during regenerative braking, directing it back into the battery pack for charging.
The Vehicle Distance plot shows the distance travelled by the EV within the given time frame. Ranging from 0 to 15.6 km, the plot gives useful insights like drivetrain efficiency, evaluate energy use per kilometers and determine driving scenarios that lead to higher or lower energy usage into the vehicle's movement habits and driving style (See fig. 12).

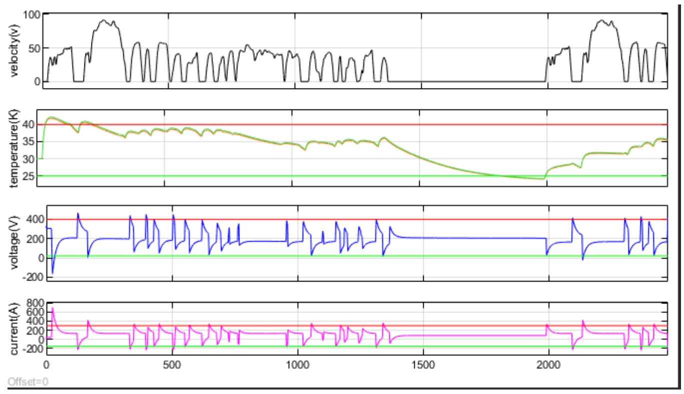

Figure.9: Reference speed, Temperature, Voltage and Current.

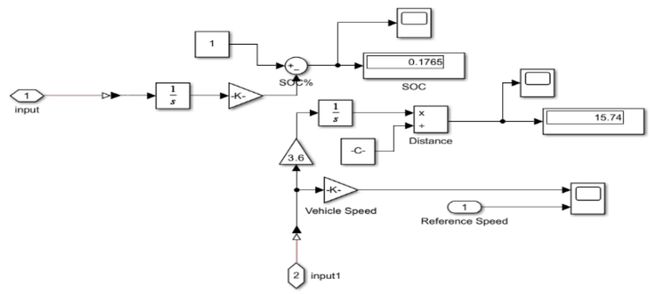

Figure.10: Distance and SOC simulation.

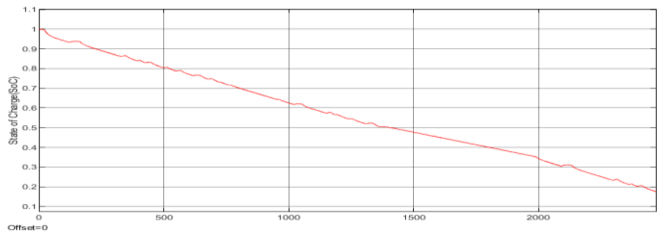

Figure.11: State Of Charge (SOC).

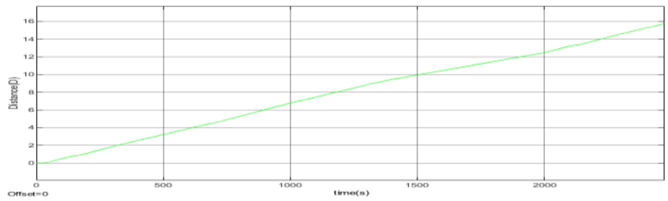

Figure.12: Vehicle traveling Distance.

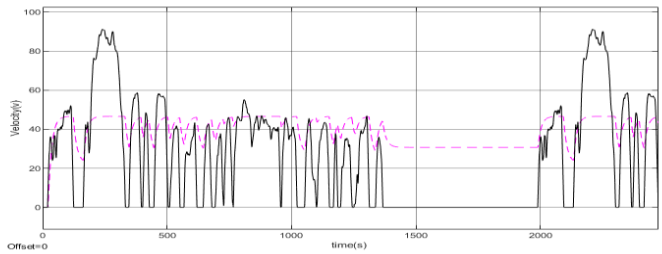

Figure.13: Reference speed versus Vehicle speed.

The Velocities graph illustrates fluctuations in the EV's velocity over time, V1 and V2 being different velocity measurements. From 0 to 100 V, this graph provides full parameters of the EV acceleration, decelerating, and cruising. (See Fig 13).

5. CONCLUSION

This paper's main goal was to model and create a four-wheeled electric vehicle (EV) using MATLAB/Simulink and to analyze its performance across different operational modes — The paper concludes by the prospective developments and future problems in BMS technologies, such as the use of advanced sensors, machine learning, and artificial intelligence to maximise the performance of batteries for next-generation electric vehicles.

The future generation of EVs depends on the BMS's incorporation of AI, ML, and sophisticated sensors. These innovations enhance battery performance while also promoting the general safety and sustainability of electric vehicles. Achieving broad acceptance and maximising the potential of electric vehicles will require tackling the present issues and investigating prospective developments in BMS as the EV market grows.

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