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Simulation of battery management system for enhanced electric vehicle performance

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Abstract - *In electric vehicles, the battery management system (BMS) is used to track and regulate battery charging and discharging. Additionally, it keeps an eye on metrics like state of charge (SOC) and offers the services required to guarantee the battery operates safely. Battery management systems improve battery efficiency and make operations safer, more dependable, and more cost-effective. Thus, BMS is essential to guaranteeing the best possible battery performance. The suggested BMS enhances vehicle range by prolonging battery life and streamlining charging cycles. Various monitoring systems are employed to maintain the battery's status as well as the ambient temperature, voltage, and current. Various analog and digital sensors with microcontrollers are utilized for monitoring. This essay discusses a battery's maximum capacity as well as its charge, health, and life states. It is feasible to identify potential future problems and their solutions by going over all of these approaches. Because BMS is a crucial component of any electric car, there is constant research being done in this area to create more advanced battery management systems. The simulation is conducted using software tool like MATLAB Simulink providing a various BMS functionalities.*

Keywords**: charging state, discharging state, Battery performance and Charging Cycle**

1.INTRODUCTION

World's population growth, economic expansion, expanding car usage, and urbanization are all contributing to an increased vehicle and E-motor vehicle (1). EVs have several benefits, such as being more economical to run and maintain and being healthier for both the environment and people (2) . The study's objective is to determine the best approach to use batteries, DC-DC converters, and motors from the standpoint of an EV application by surveying actual electric vehicles (3). Because of its substantial advantages over other energy storage technologies— such as their high energy and power density, extended lifespan, and low self discharge performance factors under improper temperatures— batteries are used in many everyday applications (4). Because of the aforementioned benefits, batteries have drawn a lot of attention lately and have shown potential as an energy storage source in electric vehicles (EVs)(5). PHEV batteries can be used efficiently to supply services to ISO workers, the automotive sector, and microgrid systems (6). The overall hardware and software system used to increase the safety and efficiency of batteries is known as the battery management system (BMS) (7). By monitoring crucial parameters including the battery cells' temperature, voltage, and current, the system controls the charging and discharging operations (8). Consequently, there are applications in the literature-based research that may be applied in real-time and theoretical research that aims to increase efficiency (9). In order to monitor batteries more effectively and safely, BMSs are frequently employed with battery-operated industrial, commercial devices and systems (10). They put out a novel approach to creating a dependable and universal BMS that explains current BMS methodologies (11).

2.Literature

For electric and hybrid cars, batteries serve as the primary energy source, and how well they work has an impact on how well the cars function. Numerous factors need to be taken into account when choosing a battery, including low internal resistance, no memory effect, fast charging, high level safety, high energy density, high power density, long life, high charge-discharge efficiency, high reliability in cyclical use, low cost, and the capacity to undergo recycling procedures (12). outlined a few viable strategies for EV viability improvement to increase its acceptability over a larger range. This includes the use of EV components that aren't used frequently, such used load batteries. Similarly, the stationary energy storage capacity of these batteries must also be taken into account in order to increase the overall economic efficiency of vehicles (13). Several studies have provided an overview of the analysis of restoring and reusing expired EV batteries for reduced energy-demanding applications (14). NREL provides reports on the economic and technological feasibility of reusing electric vehicle batteries (15). Cready as well as others suggested utilising used EV batteries for static purposes in order to lower the cost of electricity regulation (16). If an old EV battery cannot provide 80% of the maximum power needed for the vehicle's acceleration, it is no longer useful for electrical mobility in comparison to a new battery (17). Non-rechargeable batteries were used in sequence in this instance, and it was discovered that their discharge was irregular. Here, a "weakest-link" phenomena was noted. An integrated building block system has been proposed for the management of retired battery packs consisting of many battery cells from transportation applications. Additionally, a control method for managing spent batteries is suggested (18). Here, each cell is monitored, controlled, and protected by a separate modular converter. Each cell can be arranged separately using this way of integrating various building pieces. No extra equalizers or centralized converters are required for the management of old batteries. Additionally, it offers a more robust protection system, simplicity of reconfiguration, and customization. In addition, it provides power reduction, temperature regulation, and the ability to lessen voltage strain on power electronics components. A two-level control strategy was suggested for used batteries to operate at their best. Several equalization methods based on parallel, series, or series-parallel architectures have been discussed (19). According to automakers that employ Li-ion batteries, typical old EV batteries are retired after around five calendar years, or 1500 life cycles (20).

2.1 Proposed System

When using a BLDC motor in an electric vehicle (EV), the battery management system (BMS) should prioritize effective energy harvesting, optimal battery performance, and increased safety through real-time monitoring and control. Regenerative braking and sophisticated control algorithms may also be included.

BMS Components

2.1.1 Speed Control:

The efficiency of the system can be increased by precisely controlling the BLDC motor's speed using field-oriented control or other sophisticated control techniques. BLDC motors have been controlled using a wide variety of control methods. A power transistor acting as a linear voltage regulator regulates the motor voltage. When operating motors with more power, this is not feasible. PWM control is necessary for high-power motors, and a microcontroller is needed for starting and controlling

2.1.2 PWM(pulse with modulation):

A BLDC motor's speed can be managed using a technique called pulse width modulation, or PWM. To regulate the BLDC motor's speed and torque, it modifies the voltage applied to the motor's winding. Because it enables precise speed control of BLDC motors with minimal power loss, it is a useful technique. A brushless DC motor's speed can be adjusted by adjusting the input DC voltage and current. The speed increases as the voltage increases. BLDC motors have been controlled using a wide variety of control methods.

2.1.3 State of charge:

Soc is a crucial factor in battery system management, especially for electric cars (EVs). It serves as a digital fuel gauge by displaying the amount of energy left in a battery as a proportion of its overall useful capacity. For the battery pack to operate well, be safe, and last a long time, the SoC must be accurately determined. An inaccurate estimate may result in deep discharge, overcharging, or unplanned vehicle shutdowns, all of which could endanger safety or deteriorate battery health. SoC must be approximated using mathematical and data-driven models because it cannot be measured directly like temperature or voltage can

2.1.4 Voltage Measurement:

Plays a key part in performance optimization, safety, control, and monitoring in electric vehicles (EVs). Each battery cell in an EV pack can function safely and effectively within a certain voltage range. The BMS can assess the battery's state and charge level in real time by measuring the voltage of each individual cell as well as the pack voltage as a whole. In addition to regulating power delivery, cell balance, thermal behavior, and charging techniques, precise voltage readings are crucial for calculating the State of Charge (SoC) and State of Health (SoH).

2.1.5 Inverters:

An essential part of an electric vehicle (EV) is the inverter, which transforms the direct current (DC) from the battery into the alternating current (AC) required to power the electric motor. Since batteries store energy in DC form and the majority of high-performance electric motors, like AC induction or permanent magnet synchronous motors (PMSM), run on AC, this power conversion is crucial. The inverter not only handles this conversion but also controls the frequency and amplitude of the AC voltage, which in turn regulates the motor's speed and torque output Therefore, the vehicle's acceleration, efficiency, regenerative braking, and general driving dynamics are all directly impacted by the inverter.

2.1.6 Capacitor:

Capacitors improve performance, efficiency, and dependability in an electric vehicle (EV) by supporting the Battery Management System (BMS) and the overall power electronics architecture. Although an EV's battery pack serves as its main energy source, capacitors are incorporated into the BMS and powertrain circuits in a number of locations, particularly in DC-DC converters, inverters, and protection modules, to offer high-speed energy buffering, voltage stabilization, and transient suppression.

3.Methodology

In this project, a Battery Management System (BMS) is simulated in Simulink to compare the performance of different battery chemistries—i.e., Lead-Acid, Lithium-Ion, Nickel-Cadmium, and Nickel-Metal Hydride—when utilized to drive a BLDC motor. The simulation starts with the implementation of a BLDC motor, driven through a six-switch inverter topology. The switching signals (s1 to s6) are created to power the inverter, allowing DC power from the batteries to be converted into three-phase AC power needed by the motor. Every battery type is represented with its own electrical characteristics such as state of charge (SOC), terminal voltage, and current. The parameters are constantly monitored and displayed using individual scopes.

3.1.1bldc Motor Modeling:

A BLDC motor was simulated with three-phase connections for real-world operation. Inputs like stator current, electromagnetic torque, and back EMF were set to measure motor performance. A rotor position feedback system was

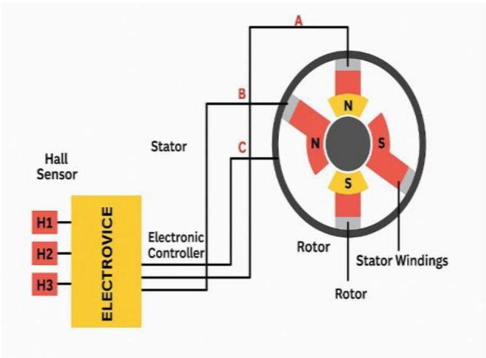

Fig-1: BLDC Motor

implemented to guarantee correct commutation, which is important for efficient and smooth motor control.

3.1.2 Inverter Design and Control

To power the motor, a six-switch inverter configuration was utilized with IGBT switches S1 to S6. These switches transform the DC voltage of the batteries to the three-phase AC signals used by the BLDC motor. The switching signals of the inverter were synchronized with the position of the rotor, ensuring proper and efficient switching during motor operation. The main task of the inverter is to transform the constant DC voltage into a three-phase AC supply, with regulated amplitude and frequency, appropriate for driving the motor effectively. The IGBT switching is controlled by gate signals derived from rotor position feedback.

3.1.3 Battery Modeling:

Four distinct battery chemistries—Lead-Acid, Lithium-Ion (Li-ion), Nickel-Cadmium (Ni-Cd), and Nickel-Metal Hydride (Ni-MH)—were simulated separately. Each battery was modeled to approximate its real electrical properties, e.g., internal resistance, nominal voltage, capacity, and SOC behavior. These models enabled realistic simulation of how each battery behaves under load condition.

3.1.4 Testing and Comparison:

Each battery was tested individually by attaching it to the inverter-motor system under the same conditions. This ensured a fair and equal comparison. Through the analysis of parameters like voltage stability, current output, and SOC depletion, the performance of each battery type was analyzed to ascertain its efficiency and viability for BLDC motor applications. The SOC depletion rate reflected the energy delivery capacity and life of each battery type. Voltage stability was tested by monitoring voltage sag or recovery during current spikes, especially during motor startup when current demand is maximum. Current output patterns were also studied to determine any inconsistency or limitation in the battery's capacity to deliver enough power.

4.Block Diagram

4.1 Battery

The system is powered by DC from the battery serves as a mechanism for energy storage, providing that the motor will always have power. frequently found in home appliances, industrial equipment, and electric cars. offers a steady DC voltage. Motor power rating (Voltage & Ah rating) determines capacity. It must be able to manage heavy power demands.

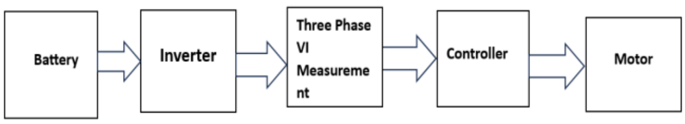

Fig- 2 Block Diagram

4.1.1 Inverter

Transforms the battery's DC (direct current) into AC (alternating current) for the BLDC motor. produces a three-phase voltage source with the appropriate amplitude and frequency. modifies the voltage and frequency of MOSFETs and IGBTs, which are switches that regulate power flow, to control the motor's speed and torque.

4.1.2 Three phase measurement

Determines each phase's voltage (V) and current (I). gives the controller feedback in real time. ensures that the motor receives the right amount of electricity. detects issues with undervoltage or overcurrent. aids in field-oriented control, or vector control (FOC). use current transformers, shunt resistors, or Hall sensors for measurement. makes sure the right voltage and current are reaching the motor. guards against power supply imbalanceoverload, and short circuits.

4.1.3 controller

Regulates the motor's efficiency, torque, and speed. accepts data from encoders, Hall sensors, or current sensors. modifies the PWM signals that are transmitted to the inverter in order to control motor operation. includes safeguards against overvoltage, overcurrent, and overheating.

4.1.4 Bldc Motor

produces mechanical energy (rotational motion) from electrical energy. uses three-phase windings on the stator and permanent magnets on the rotor. needs electronic commutation, which is not the case with brushed motors.

5.Results

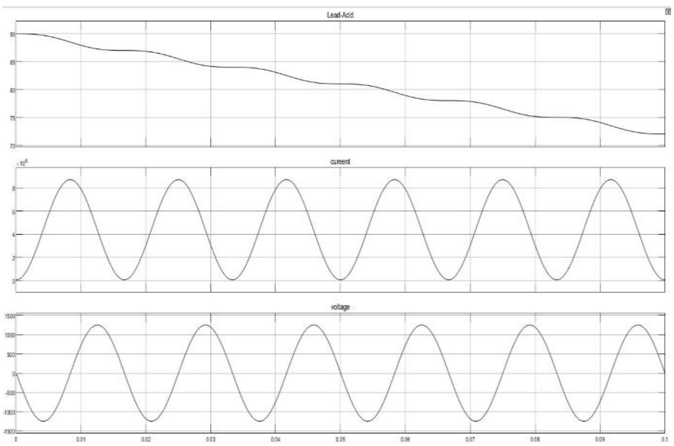

Fig-3 Lead Acid

Lead-Acid battery charged with alternating current (AC) for a brief period. The initial subplot at the top traces what is probably the efficiency or state of charge (SOC) of the battery, which tracks steadily from around 90% to 70%. This tells us that the battery is slowly discharging or losing efficiency as it delivers power.

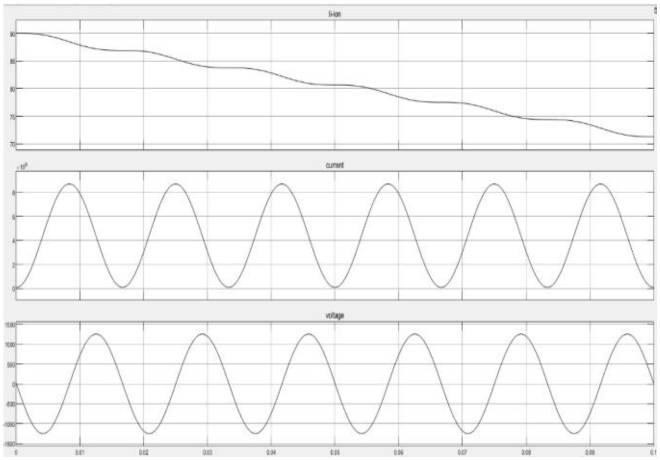

Fig-4 Lithium-ion

Li-Ion (Lithium-Ion) battery under an alternating current (AC) load for a short period of time. It consists of three subplots.the state of charge (SOC) or maybe battery efficiency, which begins at about 90% and decreases slowly to about 70%. This means the battery is draining slowly since power is being supplied to the load.

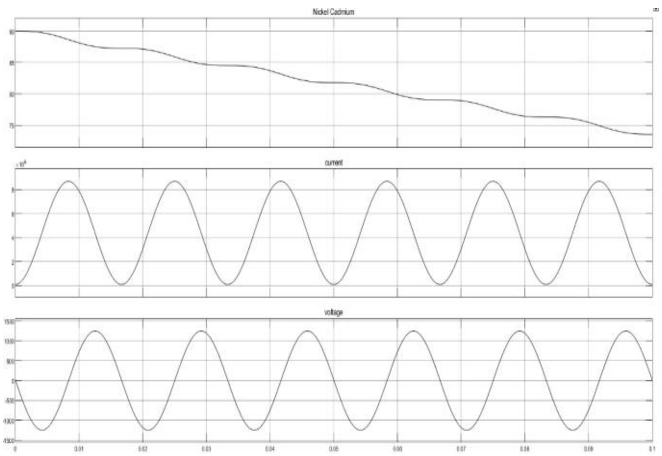

Fig-5 Nickel-Cadmium

The Nickel-Cadmium (NiCd) battery under an alternating current (AC) load for a brief duration. The upper subplot with the title "Nickel Cadmium" probably reflects the state of charge or terminal voltage of the battery, which exhibits a gradual reduction from around 90 to 74 units within the 0.1-second duration This indicates that the battery is discharging steadily, perhaps owing to continuous power supply to a load connected. The waveform is periodic and steady, which suggests that the load is significantly resistive or slightly reactive, consuming current at a steady frequency. The lower subplot shows the associated voltage waveform, also sinusoidal, but with amplitudes varying from ±1500 units. This is indicative of a steady AC voltage supply, either created or sustained by the battery system, perhaps through an inverter

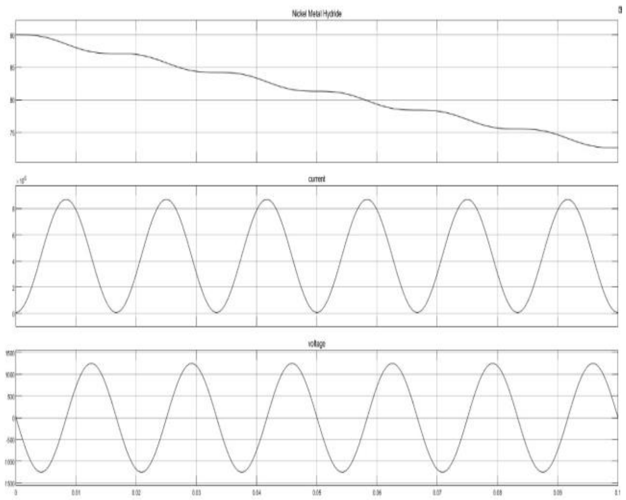

Fig-6 Nickel Metal Hydride

Nickel Metal Hydride (NiMH) battery under load for a brief time interval of 0.1 seconds, plotted in three subplots. The upper plot, titled "Nickel Metal Hydride," probably plots the state of charge (SoC) or voltage level of the battery, which drops steadily from approximately 90 to about 75 units.

6. CONCLUSIONS

In conclusion,The Battery Management System (BMS) is essential for maximizing efficiency, safety, and performance, particularly when combined with Brushless DC (BLDC) motors. To make sure the battery runs within safe and ideal bounds, the BMS continuously monitors and controls important battery characteristics like voltage, current and State of Charge (SoC). This makes it possible for the car to operate dependably and consistently in a variety of driving situations. Acceleration, torque control, regenerative braking, and overall drivetrain efficiency are all improved by the BMS's precise energy delivery to the BLDC motor through real-time data sent to the motor controller and inverter. In the end, a well-designed BMS and BLDC motor system work together to protect the battery from deterioration, ensure vehicle safety, and allow EVs to run as efficiently and effectively as possible. Improvements in BMS design, such as AI-based SoC estimate, active balancing, and predictive fault diagnostics, will reinforce its position as the foundation of intelligent electric propulsion systems as EV technology develops. he basic function of BMS is to regulate the temperature in case of overheating. This work showcases that lithium batteries are more significant as they carry a longer period as compared to lead-acid batteries. The simulation results of the Lithium battery cell – 1RC network, and 2RC network parameters have been analysed. These batteries are lighter and allow the chemical reaction to emit less heat thus minimizing the chain of chemical reaction problems.

7.Comparsion of Batteries Table

Batteries	Maximum Time	Minimum Time
Li-Ion	90	68.93
Lead Acid	90	69.77
Nickel Cadmium	90	71.46
Nickel Metal Hydride	90	70.44

Table-1 Comparsion of Batteries

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