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Design and Development of Battery Management System for Electric Vehicle based on SoC

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Abstract: *The battery management system (BMS) is used in electric vehicles to monitor and control the charging and discharging of rechargeable batteries, making operations more efficient. The BMS ensures the safety, reliability, and longevity of the battery. Various monitoring methods are employed to track the battery's voltage, current, and ambient temperature, utilizing analog/digital sensors with microcontrollers. This paper discusses the state of charge, state of health, state of life, and maximum capacity of the battery. By examining these methods, future challenges and potential solutions can be identified. The battery has become a crucial energy storage device due to the rapid advancements in smart grid and electric vehicle technology. To make the battery a safe, reliable, and cost-effective option, it is imperative to enhance its performance. The unique features and requirements of the smart grid and electric vehicles, such as accurate estimation of state-of-charge (SOC) and health (SOH) and deep charge/discharge protection, further emphasize the need for an improved BMS. The BMS should incorporate precise calculations to assess and determine the functional status of the battery while also being equipped with advanced components to safeguard the battery from detrimental and inefficient operating conditions.*
Keywords: *Battery Management System, State-Of-Charge (SOC), State-Of-Health (SOH)*

1. INTRODUCTION:

In real-time scenarios, we typically see two types of vehicles: IC Engine vehicles and electric vehicles. IC Engine vehicles come with various problems, such as increasing fuel costs, pollution, and high maintenance costs. On the other hand, electric vehicles have lower running costs, are eco-friendly, and have lower maintenance costs and pollution compared to IC Engine vehicles. In off-grid electric vehicles, the motor is powered by a battery composed of multiple small cells connected in series and parallel.
However, when a battery is connected to a charger, the cells may not charge and discharge uniformly, creating an imbalance condition that can damage the cells, create high temperatures, and result in burning. This problem is solved by a battery management system (BMS). A BMS is a system control unit specifically designed to ensure the operational safety of the battery pack. Its primary function is to safeguard the battery and supervise each cell for safety, cell balancing, and aging issues. Additionally, the BMS takes corrective measures against any abnormal conditions in the overall system infrastructure. It also regulates the system temperature, which affects the power consumption profile. An electric vehicle (EV) is a vehicle that uses one or more electric motors or traction motors for propulsion. It can be powered by electricity from off-vehicle sources through a collector system or be self-contained with a battery, solar panels, fuel cells, or an electric generator. Rechargeable batteries that can be charged using common household electricity have powered the electric motor in an EV. The main components of an electric vehicle include the electric motor as the drive system,

electrical energy sources, control systems as a central control, and power converter as a device that converts the electrical energy source to meet the variable needs of the electric vehicle. Usually, batteries serve as the main energy source in electric vehicles.

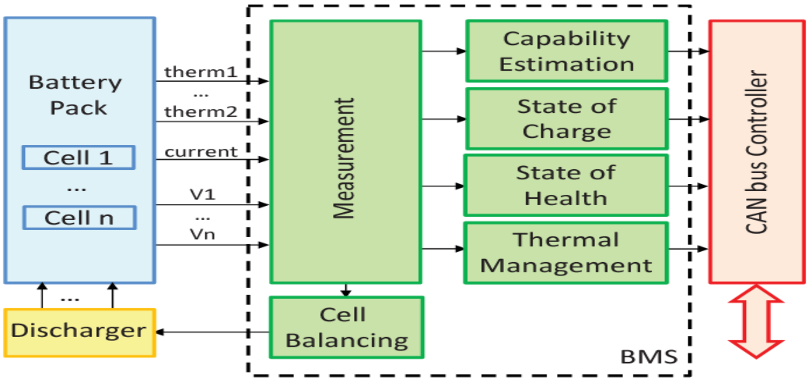
A BMS, or battery management system, is an essential element for the safe and efficient operation of an electric vehicle. In general, a Battery Management System (BMS) is a management scheme that monitors, controls, and optimizes the performance of an individual battery module or multiple battery modules in an energy storage system. The BMS can disconnect a module from the system in the event of abnormal conditions to improve battery performance and ensure safety. In power system applications, the BMS is introduced to monitor and control the delivery of the battery's power at maximum efficiency, taking battery life into consideration. In automobile applications, the BMS is used for energy management and to ensure system safety. There are several commercial BMSs available in the market. The BMS is dedicated to overseeing a battery pack, which consists of battery cells arranged in a specific configuration to deliver the desired voltage and current against expected load scenarios. The BMS provides oversight by monitoring the battery, protecting it, estimating its operational state, optimizing its performance, and reporting the operational status to external devices. It also allows users to monitor individual cells within the battery pack. The BMS is crucial for maintaining battery safety and reliability, monitoring the battery state, controlling the state of charge, balancing cells, controlling operating temperature, and managing regenerative energy.

In terms of scholarly research on electric vehicles, there has been a significant increase in recent years. This study aims to fill the gap in comprehensive integration and synthesis of these findings. It provides a comprehensive review of the Battery Management System of electric vehicles, highlighting existing research gaps in theories, modeling approaches, solution algorithms, and applications. This paper provides a comprehensive review of the technical background of BMS (Battery Management System) technology for electric vehicles and its various applications. It explains key concepts commonly used in this field and presents both the theoretical principles and practical systems involved in the development of BMS for electric vehicle design. Additionally, it identifies potential areas for future research in electric vehicle and BMS technology and its applications. By reading this review, readers will not only gain a thorough understanding of the technical aspects of BMS technology for electric vehicles but also attain a broader perspective of the research field as a whole the right to do the final formatting of your paper.

2. BATTERY MANAGEMENT SYSTEM AND CELL BALANCING:

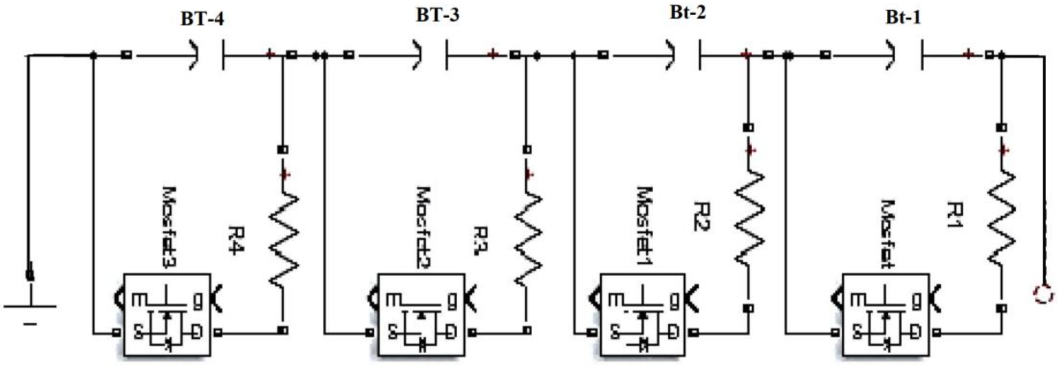
A model analysis of the drive train configurations in electric vehicles is illustrated here. Components such as the battery and the battery charger are included. The aim is to describe different alternatives, possibilities and bottlenecks associated with such components and configurations. The power train of a Battery Electric Vehicle (BEV) consists of an electric drive system with a battery serving as an energy buffer. Often there is only one electric machine, typically of three phase AC type, connected to the wheel shaft via a gearbox and a differential. However, some applications may utilize several electric machines, e.g., hub wheel motors. The energy is stored chemically in a battery, which is electrically connected to the machine via a DC/AC power electronic converter accompanied by a control system. The control system controls the frequency and magnitude of the three-phase voltage that is applied to the electric machine, and these are depending on the driver’s present request, which is communicated via the acceleration and/or brake pedal.

Fig. 1. Block Diagram of BMS



Cell balancing is a crucial aspect of battery management systems (BMS) that aims to ensure the optimal performance, longevity, and safety of battery packs. Battery cells within a pack often exhibit variations in capacity, voltage, and state of charge, leading to imbalances that can degrade overall efficiency and capacity. Cell balancing techniques are employed to address these imbalances and maintain consistent performance across all cells. Passive balancing uses resistors or dissipative elements to equalize voltage levels, while active balancing employs active circuitry to transfer energy between cells. Hybrid balancing combines both passive and active methods for a more efficient approach.

Fig.2. Schematic diagram of Cell balancing



3. EXPERIMENTAL SETUP:

Cell balancing hardware is an essential component of battery management systems (BMS) and is responsible for equalizing the voltages, state of charge (SoC), or capacity of individual cells within a battery pack. Fig.3. shows the real time image of the experimental setup. Three rechargeable Li-ion Batteries are used to validate the proposed work. Table I shows the summary of the ratings and features of the components used.

Fig.3. Hardware setup of proposed work

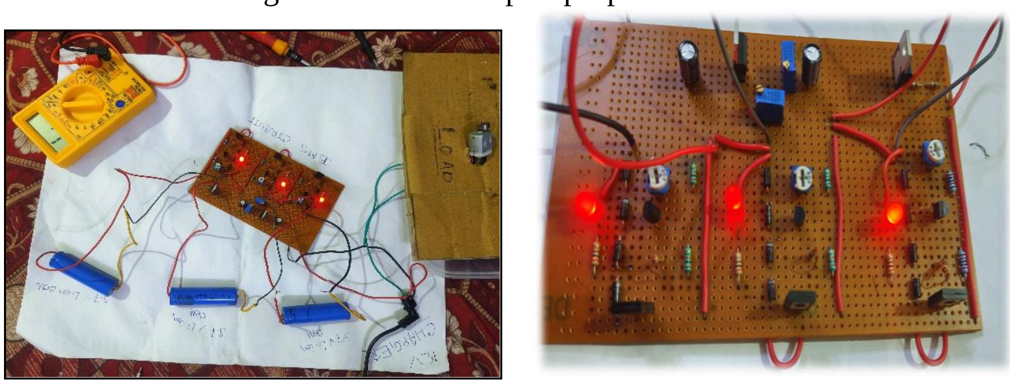


Fig.4. Simulink model for BMS in MATLAB environment

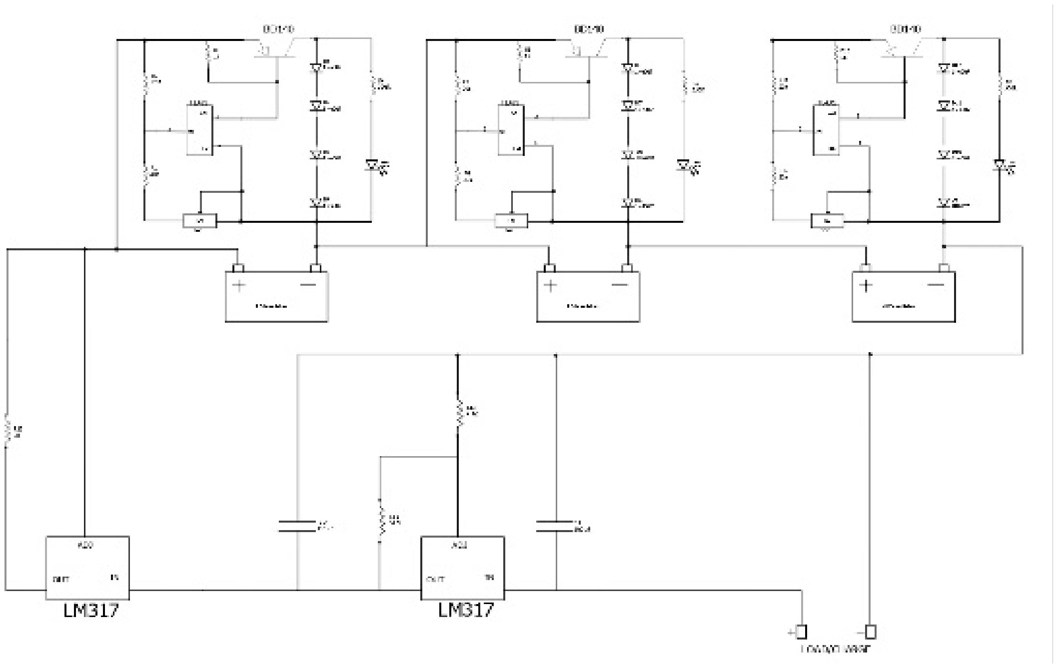


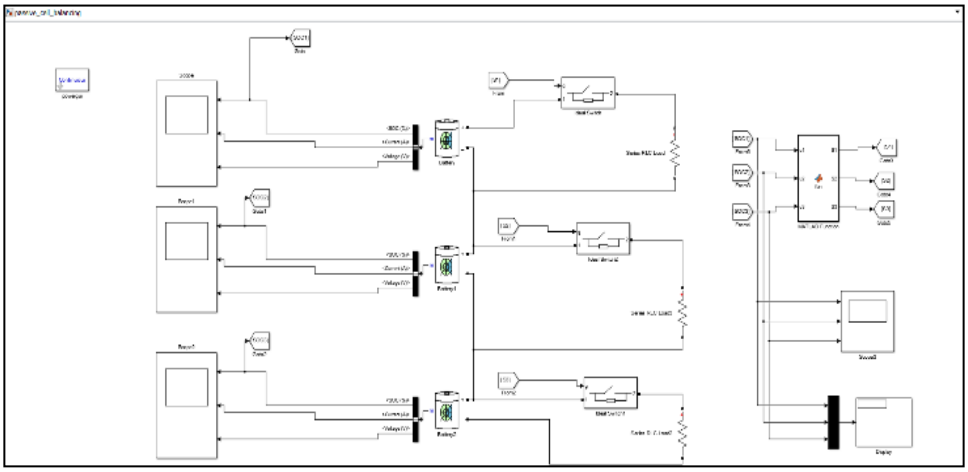
Table 1- Ratings and features of Different components

Item	Description
Resistance	Ceramic 20 Kohm,1Kohm, 4.7 Kohm and 500 ohm
Capacitor	Electrolytic 100 µF
1N4007 Diode	Maximum current capacity:1A, with peak withstand upto 30A. Reverse current: 5uA. Power dissipation: 3W
Li-ion Batteries	Charging temperature range: 5 to 45 °C (41 to 113 °F). Self-discharge rate: Typically, 1.5–2% per month. Charging below 0 °C or above 45 °C can lead to battery degradation
BD140 Transistor	DC current gain (hFE): 800 A Continuous collector current (Ic): 100mA Emitter-base voltage (VBE): 6V Base current (IB): 5mA
LM317 Voltage Regulator	Output current: >1.5 A, IL(MIN)= 3.5 mA typical, 12 mA Adjustable output voltage: 1.2 V to 37 V Operating junction temperature-0-125oC

4. SIMULATION OF CELL BALANCING:

Simulation of BMS has been done on MATLAB environment. Fig.4. shows the simulink model of battery management system. Simulation provides a flexible and efficient platform for modeling, analyzing, and optimizing battery management systems. By leveraging various toolboxes of MATLAB, engineers and researchers can explore different BMS architectures, algorithms, and control strategies, enabling them to design and implement robust and efficient BMS solutions for a wide range of applications.

Fig.5. Simulink model for BMS in MATLAB environment



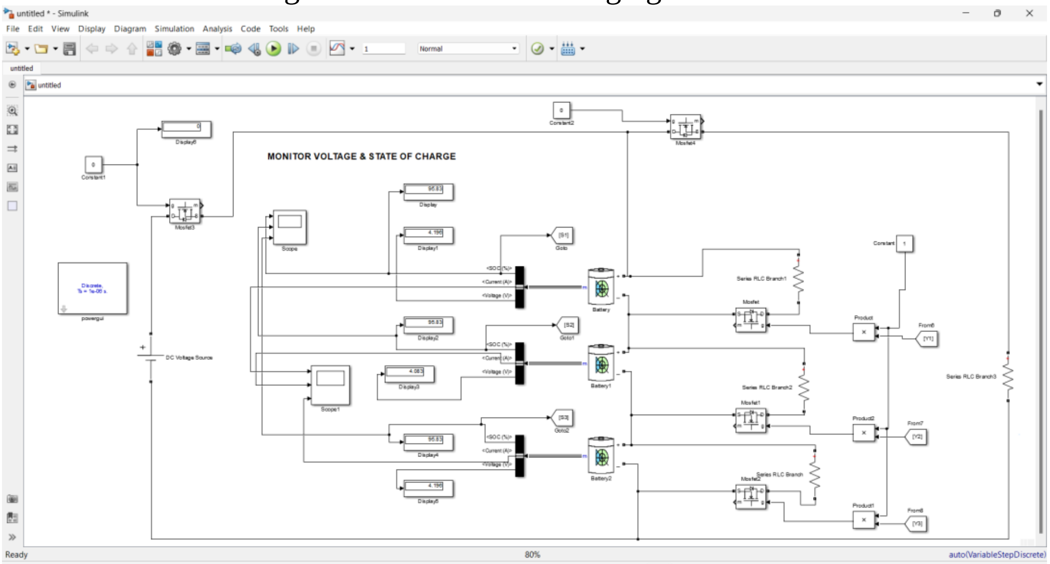
During discharge, lithium ions (Li+) carry the current within the battery from the negative to the positive electrode, passing through the non-aqueous electrolyte and separator diaphragm. During charging, the charging circuit, an external electrical power source, applies an over-voltage (higher voltage than the battery produces) of the same polarity, causing a charging current to flow within the battery from the positive to the negative electrode. This is the reverse direction of a discharge current under normal conditions. The lithium ions then migrate from the positive to the negative electrode, becoming embedded in the porous electrode material through a process called intercalation.

Energy losses resulting from electrical contact resistance at interfaces between electrode layers and contacts with current collectors can account for up to 20% of the entire energy flow of batteries under typical operating conditions. The charging procedures for single Li-ion cells and complete Li-ion batteries differ slightly- A single Li-ion cell is charged in two stages: A. Constant current (CC) B. Constant voltage (CV). A Li-ion battery (a set of Li-ion cells in series) is charged in three stages which are - 1. Constant current 2. Balance and 3. Constant voltage

During the constant current phase, the charger applies a consistent current to the battery while steadily increasing the voltage until the voltage limit per cell is reached. During the balance phase, the charger reduces the charging current or cycles the charging on and off to reduce the average current. This allows the state of charge of individual cells to reach the same level through a balancing circuit until the battery is balanced. Some fast chargers may skip this stage, and others achieve balance by charging each cell independently. During the constant voltage phase, the charger applies a voltage equal to the maximum cell voltage multiplied by the number of cells in series. This voltage is applied to the battery until the current decreases to a level below a set threshold of about 3% of the initial constant charge current. A periodic topping charge is recommended approximately once every 500 hours. It should be initiated when the voltage drops below 4.05 V/cell. Failure to follow the current and voltage limitations can lead to an explosion.

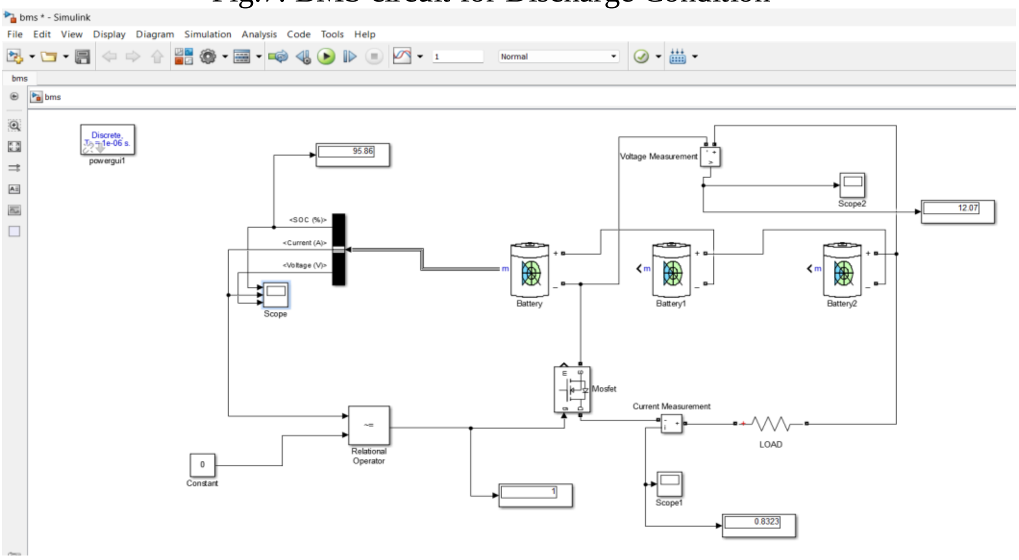
The charging temperature limits for Li-ion batteries are stricter than the operating limits. While lithium-ion chemistry performs well at higher temperatures, prolonged exposure to heat reduces battery life. Li-ion batteries perform best and allow for "fast-charging" within a temperature range of 5 to 45 °C (41 to 113 °F). Charging should be done within this temperature range. Charging is also possible at temperatures from 0 to 5 °C, but the charge current should be reduced. During a low-temperature charge, the slight temperature rises above ambient caused by the internal cell resistance is beneficial. Charging at high temperatures may lead to battery degradation, and charging above 45 °C will result in degraded battery performance. On the other hand, lower temperatures may increase the internal resistance of the battery, resulting in slower charging and longer charging times. Consumer-grade lithium-ion batteries should not be charged below 0 °C (32 °F). Even though a battery pack may appear to be charging normally, a subfreezing charge can cause electroplating of metallic lithium on the negative electrode, which can't be removed even through repeated cycling. Most devices with Li-ion batteries do not allow charging outside the range of 0–45 °C for safety reasons, except for mobile phones, which may allow some charging during emergency calls.

Fig.6. BMS circuit for charging condition



Batteries gradually self-discharge, even when not connected or delivering current. Manufacturers typically state that Li-ion rechargeable batteries have a self-discharge rate of 1.5–2% per month. The rate of self-discharge in batteries is influenced by temperature and state of charge. A study conducted in 2004 found that for most cycling conditions, self-discharge was mainly dependent on time. However, after several months of being left on open circuit or float charge, the losses due to state of charge became significant. Interestingly, the self-discharge rate did not consistently increase with state of charge - it actually decreased somewhat at intermediate states of charge. As batteries age, the self-discharge rates may increase. In 1999, the monthly self-discharge rate was measured at 8% at 21 °C, 15% at 40 °C, and 31% at 60 °C. By 2007, the monthly self-discharge rate was estimated to be between 2% and 3%, and it remained at 2-3% as of 2016.

Fig.7. BMS circuit for Discharge Condition



5. RESULT AND DISCUSSION:

The charging and discharging processes of lithium-ion (Li-ion) batteries offer insights into how key parameters evolve over time.Fig.8. shows the block parameter of battery where SOC is 30% and 50% During charging, battery voltage gradually rises towards a maximum value, while charging current decreases. Simultaneously, the state of charge (SoC) increases from a low value to 100%. Conversely, during discharging, battery voltage declines steadily, discharging current flows out of the battery, and SoC decreases from 100% to a low value. Plots typically include voltage, current, and SoC versus time, aiding in analyzing battery behavior, estimating runtime, and optimizing operation strategies for Li-ion battery systems.

Fig.8. Block parameter of two batteries with different SoC

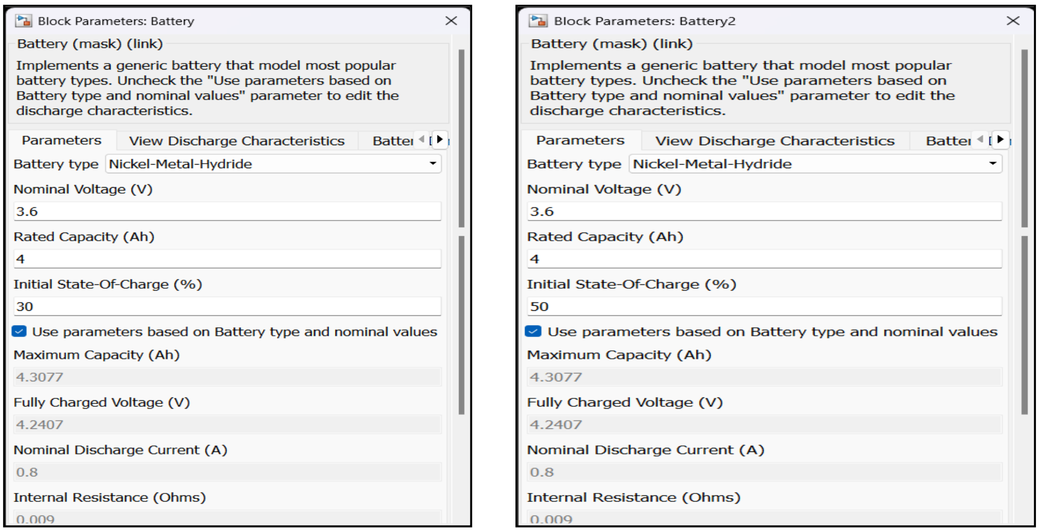


Fig.9. shows the output of scope for charging and discharging condition. It shows the charge current approaches almost 7.085 amp, 7.968 amp and 7.0855 amp and Fig.8. represents different parameters as SOC current and Voltage which has maximum value as 95.8%, 0.9milli-amp and 4.01volt. Table II and Table III represent charging and discharging values observed from hardware setup. Voltage level of three batteries are tabulated which shows similar characteristic as obtain from simulation model.

Fig.9.Graphical representation of Charging

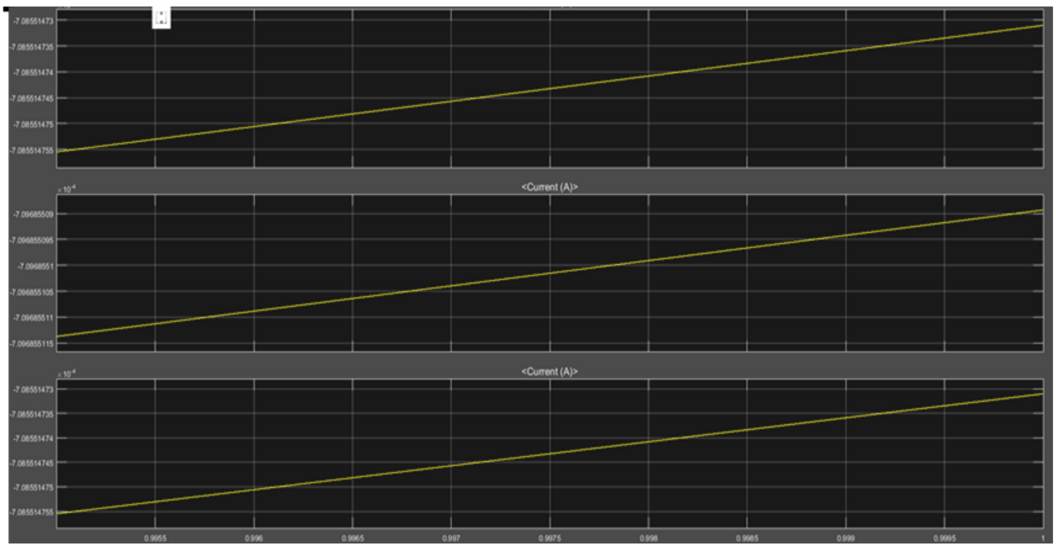


Fig.10.Graphical representation of Different Parameters

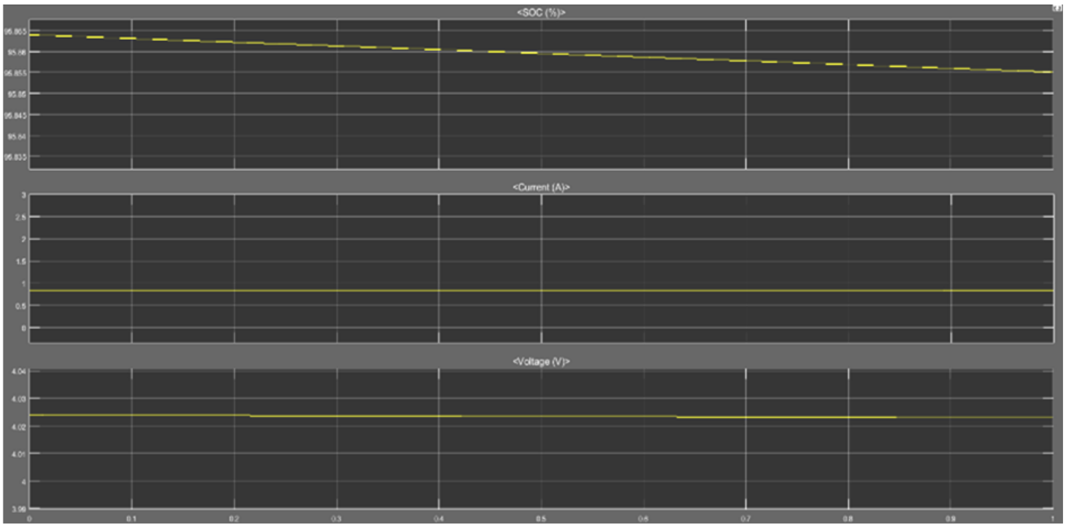


Table 2 - Battery Discharging Reading of Hardware Model

No. of Observation	Time(min)	Voltage in battery 1 (v)	Voltage in battery 2 (v)	Voltage in battery-3 (v)
1	0	3.86	3.86	3.85
2	1	3.83	3.85	3.85
3	3	3.80	3.79	3.82
4	5	3.80	3.79	3.81
5	7	3.80	3.78	3.81
6	12	3.80	3.76	3.78
7	17	3.76	3.75	3.71
8	24	3.70	3.71	3.78
9	29	3.66	3.60	3.69
10	32	3.61	3.60	3.64
11	39	3.59	3.55	3.57
12	47	3.52	3.52	3.50
13	50	3.3	3.32	3.35
14	54	2.23	2.20	2.15
15	57	1.73	1.92	1.84
16	60	1.1	1.23	1.19

Table 2 - Battery Charging Reading of Hardware Model

No. of observation	Time(min)	Voltage in battery 1 (v)	Voltage in battery 2 (v)	Voltage in battery-3 (v)
1	0	1.12	1.13	1.12
2	1	1.46	1.5	1.54
3	3	1.67	1.66	1.60
4	5	1.89	1.88	1.91
5	7	2.13	2.19	2.22
6	12	2.46	2.49	2.42
7	17	2.78	2.79	2.71

8	24	2.9	2.88	2.85
9	29	3.12	3.09	3.05
10	32	3.32	3.39	3.36
11	39	3.36	3.42	3.40
12	47	3.4	3.45	3.43
13	50	3.53	3.50	3.49
14	54	3.56	3.55	3.53
15	57	3.61	3.61	3.60
16	60	3.69	3.67	3.65

6. CONCLUSION:

This proposed work states the design and development of 3.3kw on-board charger for EV. Here PFC (Power Factor Correction) Boost Converter and FBPS (Full Bridge Phase Shift) Converter are used to build the On-Board Charger. To obtain the hardware setup and to perform the simulation in MATLAB we had to study Working/Operation, Connections of PFC Boost Converter and FBPS Converter. After that, required parameters are calculated to select proper hardware components to build the total hardware set up. At last, design the whole hardware set up and run it properly. Finally, the hardware results are analyzed and it satisfies the simulation study results.

The primary objective of this proposed endeavor is centered on the development and creation of a 3.3kw on-board charger tailored specifically for electric vehicles (EVs). This on-board charger is comprised of two essential components: a PFC (Power Factor Correction) Boost Converter and an FBPS (Full Bridge Phase Shift) Converter. To initiate the process, a detailed examination of the functionalities and interconnections of both the PFC Boost Converter and FBPS Converter was undertaken to facilitate the configuration of the hardware setup. This phase also involved the implementation of simulations using MATLAB to ensure the operational efficacy of the designed system. Subsequent to this analysis, a meticulous calculation of the requisite parameters was carried out to facilitate the selection of appropriate hardware components essential for the construction of the entire hardware configuration. Finally, the comprehensive hardware setup was meticulously designed and subjected to rigorous testing procedures. The outcomes derived from the hardware testing phase were then scrutinized and compared against the results obtained from the initial simulation study, revealing a strong correlation between the two sets of results.

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