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Temperature Control of Battery Stack and Simulation of a Battery Management System

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A B S T R A C T

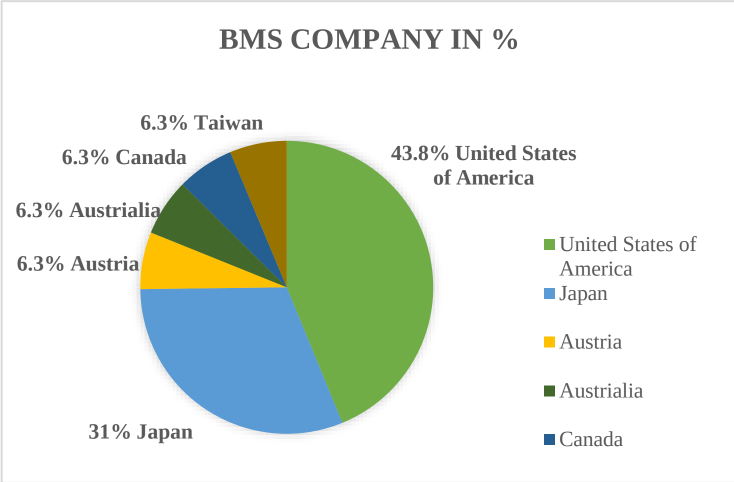
The battery is the most useable Component for the power source in electric vehicles and is most popular in modern technology of electric vehicles due to its advantage of storage capacity, compact nature, and reliability nature it is most prepared in electric vehicles. Moreover, one of the main Drawbacks of Electric vehicles is the Battery Life and the efficient use of the Battery. When a Battery is charged over several times battery efficiency decreases. The Battery depends upon various conditions like charge/discharge, overcharge/undercharged, and factors such as the battery materials like lithium, lead and chromium, phosphates, etc, and Cell to Cell Insulation for the battery for internal temperature change, State of charge like battery power for the vehicle, State of Health like degradation of the battery. These conditions and factors may be used for forecasting the Battery longevity in electric vehicles using the Modelling and Simulation of the BMS in Electric Vehicles. In combination with real-time Data on the usage of electric vehicles and fuel vehicles, Battery replacement cost, Vehicle type, comparison with Fuel vehicles, claimed Range and the Actual range of the Electric Vehicle, and Battery Cost. To Observe the factors affecting Battery longevity, the BMS Model was used to predict the issues and control them from several Methods to overcome those Factors like thermal runaway, temperature slowdown Self-discharge, State of Charge, and Cell balancing.

Keywords: *Thermal Runaway, Cell Balancing, Voltage controlling, Battery Management System, Temperature Cooling, State of charge, State of Health, Charge/Discharge cycles*

1. INTRODUCTION

This paper aims to describe the Battery Management System analysis based on the parameters of the state of charge, cell balancing, state of health, and the consciousness of the temperature rise or fall from outside and inside of the battery packs. Enrooting the Battery Capacity and efficient use of the battery. The cell balancing that is used in battery packs plays a vital role in equal charge distribution in the series and parallel set of 16 to 24 Cells in the Battery. And, again the battery is interconnected in a series and Parallel as per the design of the vehicle range and capacity of an energy storage system which are the battery packs and it impacts the physical dynamics and size of the battery. Cell balancing is done in two types active cell balancing and passive cell balancing. Where in active cell balancing which cell has more state of charge capacity like a type-1 cell with 65% and another type-2 cell with 50% that 15% charge is again 7.5% is equally transferred to both cells equal manner and cell balanced whereas in passive cell balancing that 15% from the type-1 cell is wasted in the form of heat from the semiconductor devices to equal the type-2 cell for equal state of charge and it is similar with the overall battery pack balancing. By eliminating the unequal charge distribution in the cells of the battery pack. And increases the efficiency of the battery storage system, and reduces battery life degradation, achieving a faster state of charge balancing, and temperature imbalance in the battery system during periods of high loads and surrounding outside temperature is High. To achieve maximum efficiency of the battery the temperature must be between 20˚ C to 40˚C and if it is below 10˚C the battery performance slows down and above 80˚C then thermal runaway takes place and the temperature rises and needs a cooling system for the battery cooling to maintain the ambient temperature of the battery packs. There are different modes of cooling techniques like Air cooling, liquid cooling, and thermoelectric modules. The temperature varies from the type of battery used as recommended by battery manufacturers. There are widely two types of batteries Lithium Iron Phosphate (LFP) and Lithium Nickel Manganese Cobalt (NMC). The NMC batteries have high energy density which means high charge storage and better range with acceleration performance than LFP batteries. At the same time, LFP batteries have a longer life and are safer than NMC batteries. The NMC battery can sustain up to 210˚ C and LFP batteries have 280˚ C.

The LFP batteries have longer life up to 2500 to 3000 charge/discharge cycles whereas NMC batteries with 1500 charge/discharge cycles. Every battery chemistry produces a different discharge signature, necessitating a customized model. Because they might take longer to charge, components like inductors and capacitors are not used in bigger battery packs. The state of health of the battery describes the battery life and rate of charge/discharge cycles. The average life of a Li-ion battery reduces to 12% after 3.2 years which Affects the range of Electric vehicles, the overall state of Charge capacity in the battery is also affected and again individual cells will get damaged. The state of health of the battery decides the overall performance of the battery. Here the BMS plays a major role in monitoring the condition of all these parameters like above mentioned state of charge, individual cell temperature imbalance from in/out of surrounding temperature, imbalance in cells charging, charge/discharge cycles, and the state of health of the battery to ensure



their safe use. BMS also controls all these parameters through a microcontroller which is specially designed for the BMS to increase the overall efficiency of the battery. Through BMS it is easy to manage battery modules and the performance rate of the electric vehicle also improves. The below-mentioned pie chart of the Global Distribution of Battery Management System (BMS) Manufacturers by Country.

Fig: -1 BMS Country Shares Percentages Pie Chart

The BMS manufacturers like Ewert Energy Systems, STAFL Systems, Sensata Technologies, and Nuvation Energy. The top two BMS manufacturing countries are the United States of America which holds about 43.8% and Japan about 31.3%.

2. LITERATURE REVIEW

Authors in [1], A battery management system (BMS) is suggested here to resolve the important issues, according to Battery Management System for Electric Vehicle Application. A communication unit, a data collecting unit, and a battery state estimate model are some of the common modules that make up the system. Here, two more management units are created to enhance the safety of transportation tools: one is heat management, and the other is high voltage management. The power supply of it is the battery. However, this method has a drawback in that it is not fully efficient because the battery's temperature is not properly cooled. In [2], describes A battery system consisting of many battery cells or modules that may have different characteristics. The battery management system (BMS) must monitor the dynamics of each individual cell as well as the state of charge (SOC), state of health (SOH), failure status, and life expectancy projection in order to achieve dependable, efficient, and prolonged battery system utilization. Voltage sensors at the cell or module level are used in current battery technology; these sensors and their packaging are expensive, and there are significant reliability problems. This research presents new techniques that estimate the voltage and current of a single cell using battery string terminal voltage/current measurements by utilizing existing cell balancing circuits. This is accomplished by actively managing balancing circuits to give battery cell subsystems partial observability. But, this method of estimating SoC is inaccurate. In [3][4], The article provides a detailed overview of state-of-the-health of EV batteries and management technologies, emphasizing energy density, fast charging, and safety. The article reviews advancements and challenges in EV batteries and battery management, highlighting trends like lithium-ion, lithium-metal, and post-lithium battery technologies. In [5][6], Accurate battery SOC estimation is vital for efficient battery system operation. An enhanced EKF with adaptive battery parameters significantly improves SOC estimation accuracy over conventional methods, achieving better results under various conditions. In [7], describes Power module packaging technologies, particularly double-sided cooling, are evolving to enhance power density. Double-sided cooling significantly improves heat removal and semiconductor utilization in automotive Si and Sic power modules, with increasing.

3. METHODOLOGY

3.1 PASSIVE CELL BALANCING:

A battery pack requires cell balancing due to unequal voltages in lithium-ion cells because of uneven internal chemical properties. A battery pack may contain quite well-matched cells at first. However, as we age and experience charge/discharge cycles as well as high temperatures, the cell matching deteriorates. A poor battery cell becomes the limiting element in a system's runtime since it will charge and discharge more quickly than a stronger or larger capacity cell. Active balancing and passive balance are the two forms of balancing that are typically employed. Whereas passive balancing employs resistors in place of capacitors, active balancing uses capacitors to store energy [8]. The passive cell balancing method is used for balancing the unbalanced lithium-ion cells in a battery pack. Initially, the cells are charged still the threshold value of 4.12 volts reached in lithium-ion cells. When the same current passes through the other cells in the pack, the weakest cell often achieves the maximum voltage threshold value of 4.12 volts first.

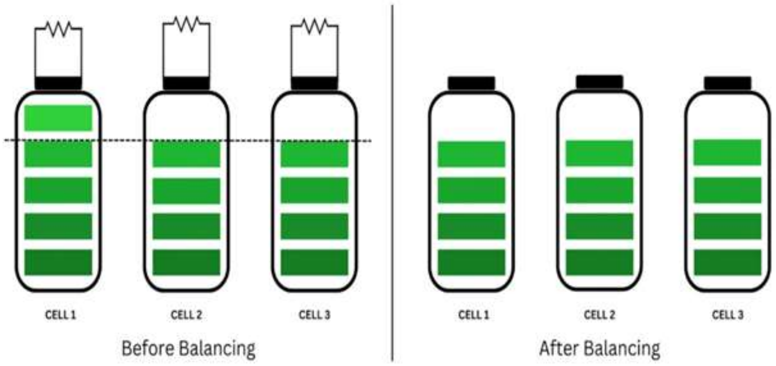


Fig 3.1: Passive cell Balancing

Here the passive cell balancing is done by using diodes and resistors to dissipate the energy of the cell with the highest voltage in a series pack of battery cells. To avoid overvoltage in battery cells. The access amount of voltage is bypassed through the diodes and resistors by the BD-140 transistor. The BD-140 transistor consists of an emitter, base, and collector terminals. When it reaches the threshold value of 4.12 volts then from the transistor emitter terminal the current passes to TL-341 Zenner diode through the base terminal of a transistor. From the transistor collector terminal, the current bypasses the IN-4007 diode the overvoltage is again given to a resistive load, and finally, the green LED glows. When the BD-140 transistor switch is activated, the cell is permitted to discharge through the resistor, also known as a bleeding resistor, when the voltage of the cell surpasses the SOA (safe operating area). For the cell voltage and SoC to drop to a safe level. Until all of the cells have attained the same voltage, this procedure is repeated.

Digital Voltmeter is used to monitor the individual cell's voltages are used to monitor the voltage. Balancing only takes place when there is a battery cell difference in voltages when it attains the threshold voltage of 4.12 volts first during charging and discharges the remaining overvoltage through diodes and resistors. The lithium-ion battery used in cell balancing consists of a series of connected 3 cells when the first cell, has 4.2 volts, and the remaining two cells are balanced until it is fully charged. And the lithium-ion battery cells are protected by overcurrent through an LM-317 regulator which regulates the overcurrent during the initial time of charging. Depicts the plan for using the shunt resistor approach to indicate the overvoltage protection. When the switch is turned on, current passes from the anode to the cathode led by a glowing green colour. However, when it is turned on, current passes via the resistors. It suppresses the current flowing inside it and dissipates it in the form of heat and turns some of the current is waste in the form of heat.

It offers a rather inexpensive way to balance the cells, but because of the discharge resistor, energy is wasted throughout the process. The battery cell voltage is now being maintained balanced. It is continuously monitored by the digital voltmeter to estimate the exact threshold voltage. The state of charge of each battery cell in the stack is used to assess its overall health. It estimates the ratio of the cell's capacity to its remaining charge. To calculate the amount of charge left in the battery, SoC also as measurements of the voltage, integrated charge and discharge currents, and temperature. To enhance battery stack performance, precisely the precise single-chip and multichip battery management systems (BMS) integrate passive or active cell balancing with battery monitoring, including SoC and temperature measurements.

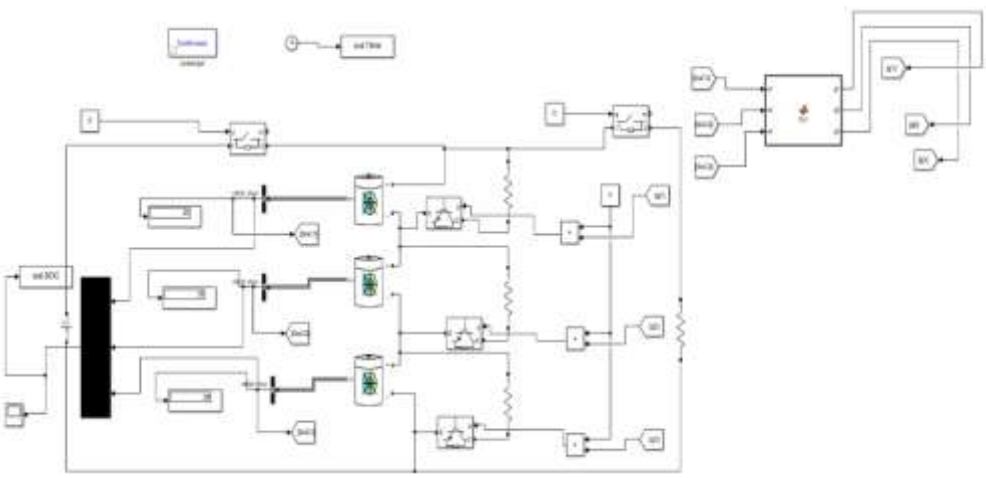


Fig 3.2: Simulation block diagram of passive Cell Balancing

3.2 SOC ESTIMATION:

OPEN CIRCUIT VOLTAGE METHOD

A more straightforward method of estimating battery conditions is to gauge the cell's open circuit voltage (OCV). Research has demonstrated a strong correlation between OCV as well as SOC of the battery. This voltage-based technique uses the battery's OCV vs SOC discharge curve to determine the equivalent SOC value of the supplied voltage value [9]. the Li-ion battery cell's actual SOC curve, and by looking at these curves, we can see that the predicted values are erratic and that can be explained by the fact that the diffusion voltage and hysteresis are not taken into account by this voltage-based technique. The battery SOH has also been estimated using OCV. It is simple to estimate internal resistance which can mostly be observed by the SOC/OCV relationship. The battery SOH was estimated by Mathew, Janhunen, Rashid, Long, & Fowler, 2018 using a mix of OCV and Coulomb counting techniques. Others, on the other hand, thought that the voltage-based approach was inappropriate for calculating SOH, listed various drawbacks associated with this approach, and attempted to remove the OCV from the equations to make the calculation of the battery SOH simpler. The easiest way to measure state-of-charge is by voltage, yet this method is not always precise. Different cell types produce different voltage profiles due to their different chemical compositions. Temperature is another factor. The open-circuit voltage increases with increasing temperature and decreases with decreasing temperature; this phenomenon applies to all chemical properties of the battery to different degrees. When a charger discharges the battery, causing the most obvious fault in voltage-based SoC.

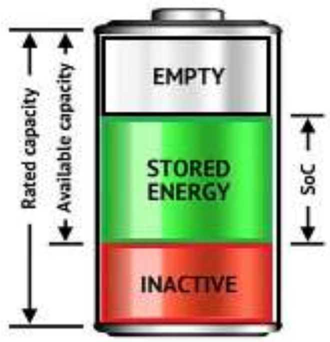


Fig:3.3: Battery Soc Capacity

The voltage is distorted by this agitation and is no longer indicative of the actual state of charge. In an open circuit, a rested0cell suggests an SoC of about 1 percent. A large percentage of the stored energy is retained in the highly flat discharge voltage profiles of +i-manganese, +i-phosphate, and 2MC. This feature helps applications that need a constant voltage, but it makes fuel gauging difficult. Only complete charge is indicated by the voltage method. low cost and inaccurately estimates the huge middle part. When measuring SoC by voltage, it is important to take into account the varied plate compositions of bead acid. A maintenance-free addition called calcium increases the voltage by thirteen percent. The open-circuit voltage is also influenced by temperature; heat causes it to rise, while cold causes it to fall. Surface charge deceives SoC estimates even more by exhibiting an increased voltage just after charging; however, a quick discharge before measurement corrects the inaccuracy. When determining the state of charge using open circuit voltage, the battery voltage needs to be completely "floating" with no load. Installed in an automobile, the parasitic load creates a Closed-circuit Voltage (CCV) state that will cause the measurements to be manipulated. When measuring the SoC in the CC/state, adjustments must be made by taking the load into account. Using this method, the battery's voltage is monitored without any load or charge source connected.

Based on the relationship between the OCV and the battery's SoC, the SoC can be estimated using the OCV. The fact that OCV measures the SoC directly and doesn't require integration or comparison to preset curves is one benefit of utilizing it to estimate SoC. Furthermore, OCV is unaffected by the amount of current entering or leaving the battery, meaning that it is unaffected by the battery aging.

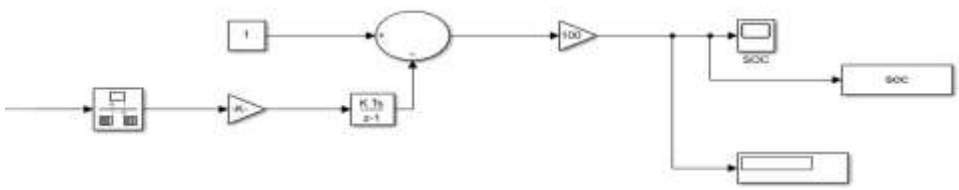


Fig 3.4: Simulation Block diagram of SOC Estimation

3.3 COOLING METHODS

A cooling system in battery cells is essential for several reasons, primarily to maintain the ambient temperature conditions and extend the lifespan of the battery cells. Batteries generate heat during charging and discharging processes due to charging and chemical changes inside the cells. If this heat is not dissipated effectively, it can lead to various issues, including reduced performance by accelerating the rate of discharge, state of health degradation, and even worse conditions leads to explosions sometimes.

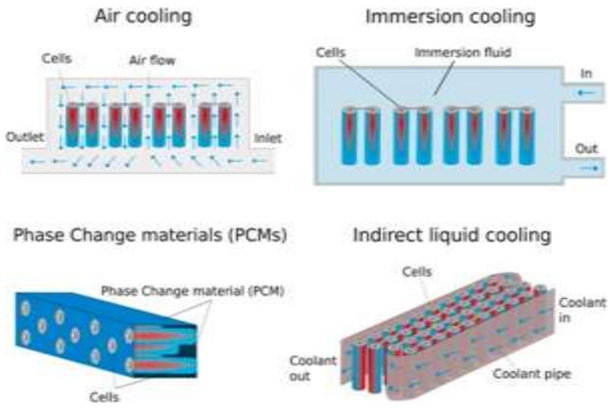


Fig 3.5: Different Cooling Techniques

This cooling technique is the most straightforward and economical. To move air around the batteries, fans or blowers are used. Firstly, excessive heat causes the battery cell to lose its charge more quickly and the lifespan of battery cells reduces. High temperatures accelerate chemical reactions inside the battery cells, leading to faster degradation of lithium-ion reaction with electrolytes vaporizing the electrolyte, and pressuring the cell casing. If the cell case breaks it releases the flammable and toxic gases. This degradation can result in decreased capacity, reduced efficiency, and ultimately shorter battery lifespan. By implementing a cooling system, excess heat can be removed, helping to mitigate these effects and prolong the battery's operational life [10]. Moreover, overheating poses safety risks to both the battery itself and the surrounding environment by releasing toxic gases like sulphur dioxide, nitrogen dioxide, hydrogen fluoride, hydrogen bromide, and hydrogen cyanide. Lithium-ion batteries have an ambient temperature to maintain the battery performance high between 20˚C to 40˚C. If it is below 10˚C then the battery performance reduces and if it is susceptible to thermal runaway when it reaches above 80˚C a phenomenon where increased temperature triggers a self-reinforcing reaction, leading to rapid heating, gas generation, and potentially even fire or explosion.

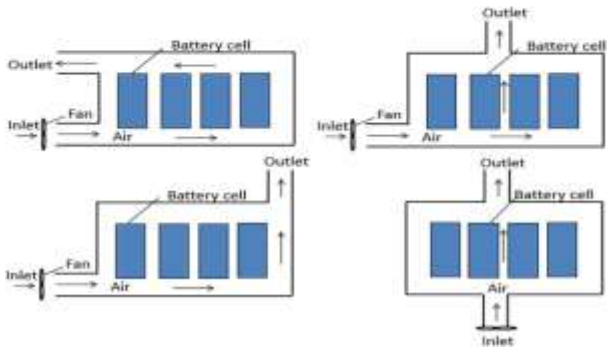


Fig 3.6: Different Air-Cooling Techniques.

A cooling system helps to regulate the temperature of the battery cells within safe limits, minimizing the risk of thermal runaway and ensuring the overall safety of the battery system. A cooling fan system for a battery using an LM35 temperature sensor an Arduino Uno controller and a customizable cooling fan for maintaining ambient temperature conditions, thereby enhancing battery performance and lifespan. The system operates by continuously monitoring the temperature of the battery and activating a cooling fan when necessary to dissipate excess heat. For small battery packs or devices running in well-ventilated areas, air cooling is appropriate [11]. Systems that utilize liquids to remove heat from batteries do so by using a liquid, such as coolant or water. The liquid is moved in close contact with the batteries through channels or plates, absorbing and removing heat. Since liquid cooling is more effective than air cooling, it is frequently utilized in settings with limited space or high-power battery systems. Materials that absorb and release heat during phase changes, such as melting and freezing, are known as phase change materials, or PCMs. PCMs can be positioned next to the batteries or incorporated inside the battery pack itself. The PCMs absorb the heat produced by the batteries and go through a phase shift to store the heat. As soon as the batteries discharge, the Heat pipes are hermetically sealed tubes with a working fluid and wick structure within.

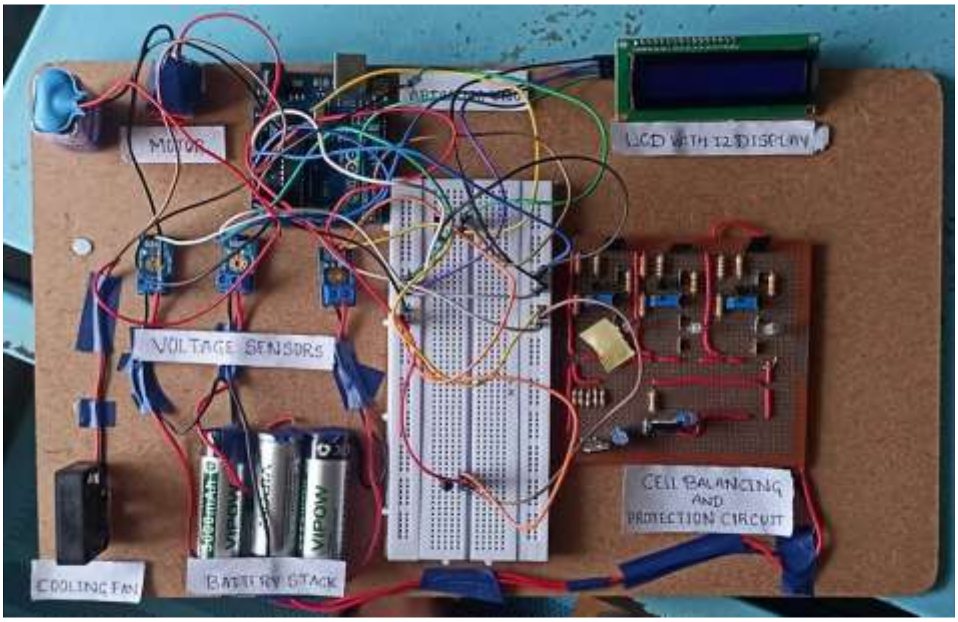


Fig 3.7: Hardware Connection Design

The working fluid in the heat pipe evaporates when heat is provided to one end, traveling to the colder end where it condenses and releases heat. Heat is successfully transferred away from the batteries by this mechanism, which establishes a continuous heat transfer loop.

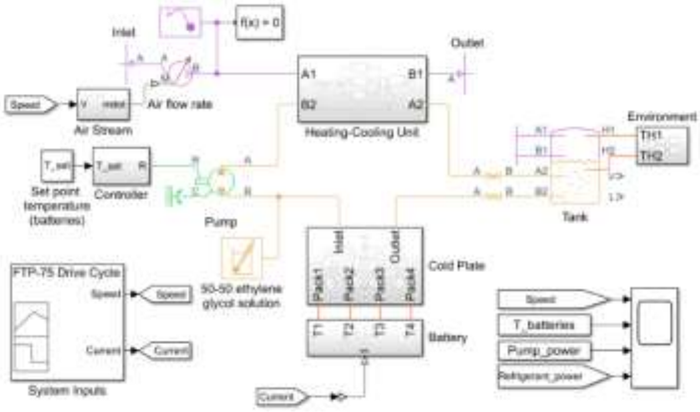


Fig 3.8: Simulation Block Diagram of Cooling Method

Real Time Graphs:

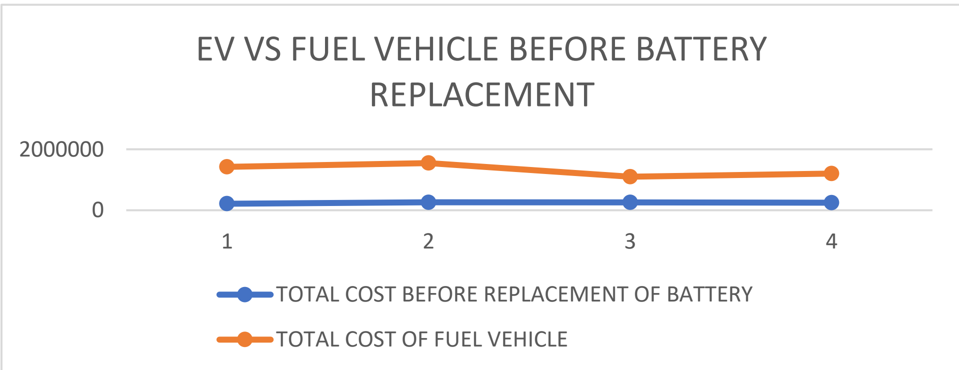


Fig 3.9: EV vs Fuel Vehicle Before Battery Replacement

This graph is about the comparison of total costs of electrical vehicle and fuel vehicle before replacement of battery of electrical vehicle. There is a huge difference in the total costs. The electrical vehicle has very less cost than fuel vehicle over a period of 3 years. By observing the graph, we can say that electrical vehicles are best and cost saving over a period of time.

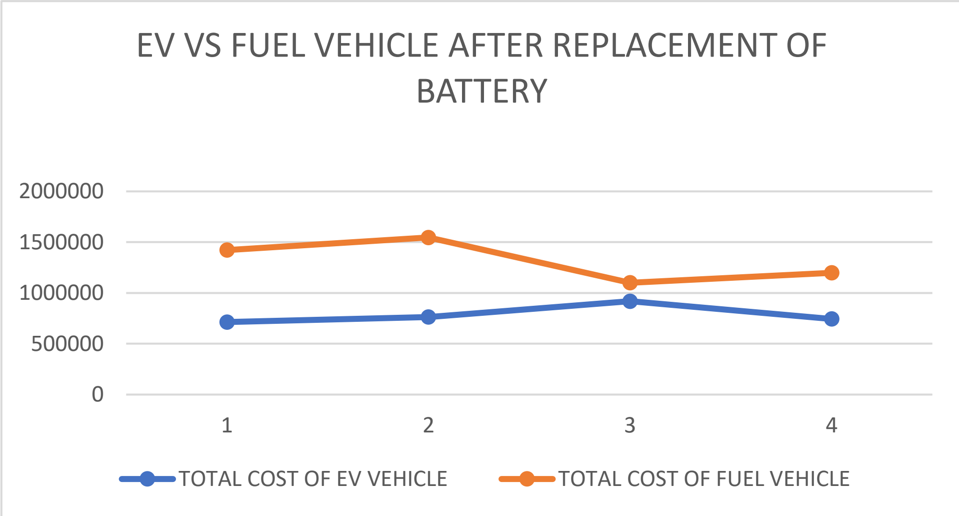


Fig 3.10: EV vs Fuel Vehicle After Battery Replacement

This graph is about the comparison of total costs of electrical vehicle and fuel vehicle after replacement of battery of electrical vehicle. There is a less difference in the total costs as compared to before replacement of battery graph. The Battery cost of each electrical vehicle is about 30% of cost of the electrical. The electrical vehicle has very less cost than fuel vehicle over a period of 8 years. By observing the graph, we can say that electrical vehicles are best and cost saving over a period of time.

Fuel Vehicle Advantages: -

- Have the advantage of less time taken for fuel refilling from fuel station.
- Suitable for long range without any refuel interruptions.
- Have more service station for any repair or maintenance problem.
- Less cost of vehicle when compared with an electric vehicle.

Drawbacks of Fuel Vehicles: -

- Daily cost for the fuel of a Vehicle is more.
- Cost is very high in fuel if chosen for Long Distance.
- More services or maintenance required for fuel vehicle.

Electric Vehicle Advantages: -

- No interruption as of fuel until the battery is fully charged.
- Continuous refueling is not required during driving.
- Fuel cost is less as lesser number of times are recharged for the battery.
- High savings for the cost of fuel and maintenance with an electric vehicle.
- Less number of times services are required when compared with a fuel vehicle.

Drawbacks of Electric Vehicles: -

- More Time taken for recharge of battery then the fuel vehicle.
- Very fewer charging stations or less amount of charge in battery interruption during driving.
- More cost of the vehicle when compared with fuel vehicles.

4. RESULTS

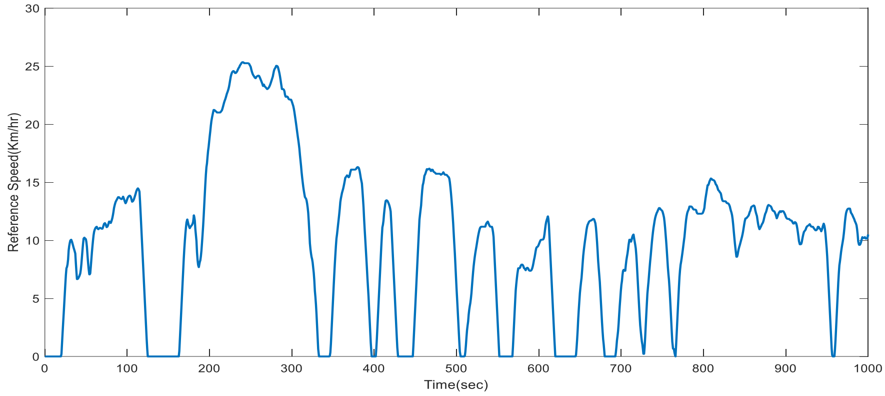


Fig4.1: Reference speed vs Time

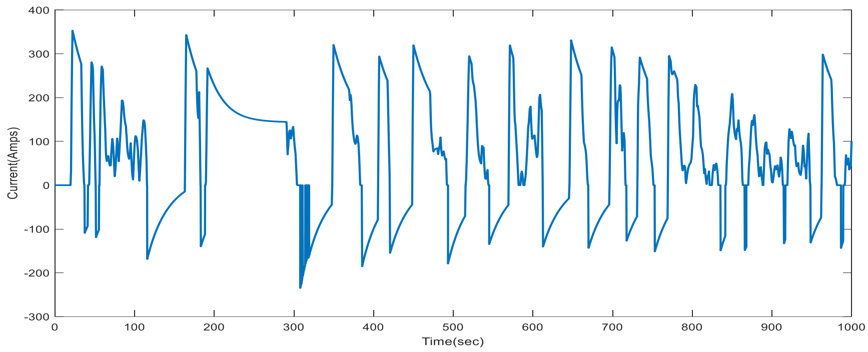


Fig 4.2:Voltage profile of battery in an urban area

The above figures show the voltage over time during charging and discharging conditions. By seeing the above figure, we can easily say that during discharging the voltage in the battery decreases, and during charging the voltage in the battery increases.

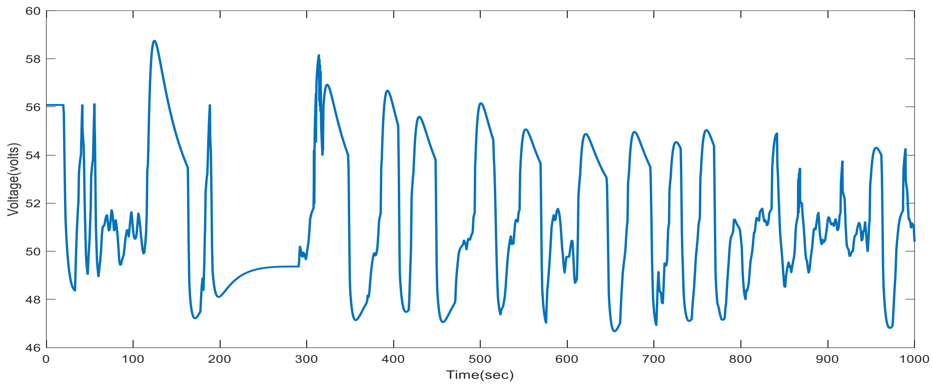


Fig 4.3: Current profile of battery

The above figure shows the current overtime during charging and discharging. When the vehicle is moving in upslope the current taken by the motor increases as the speed increases in a positive direction. When the vehicle is moving in a downward direction the motor will act as a generator due to regenerative braking and produces negative torque, so negative currents will flow into the battery.

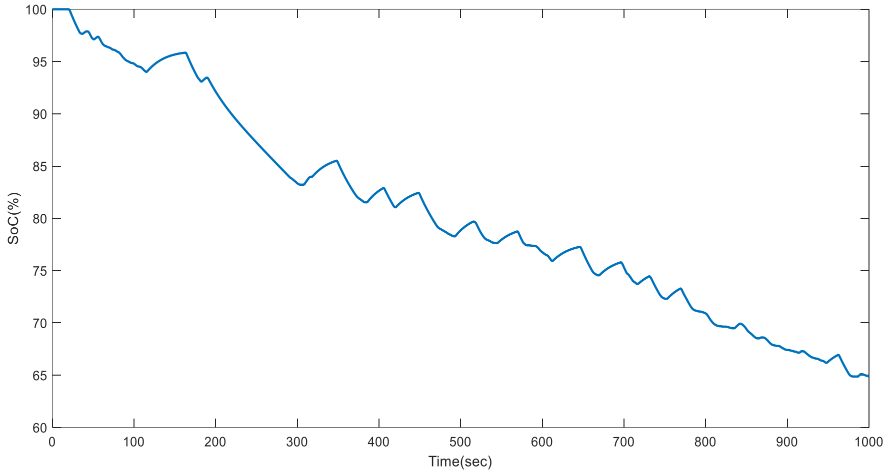


Fig 4.4: SoC at various instants

The above figure shows the State of Charge (SoC) over time during charging and discharging. During discharging the SoC of the battery decreases and during regenerative breaking the SoC of the battery increases.

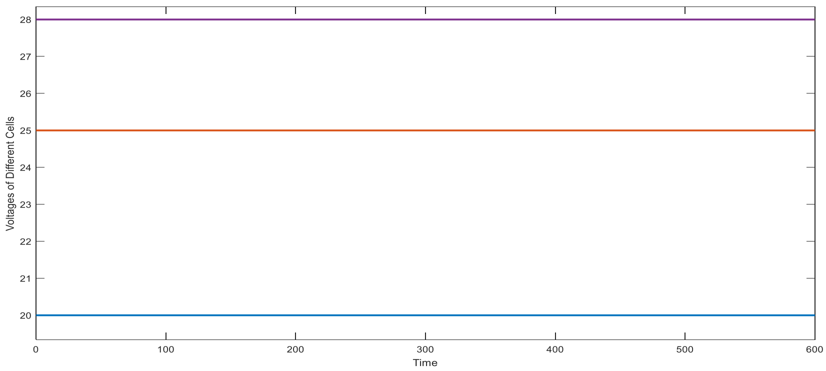


Fig 4.5: Before Cell Balancing voltages of different cells

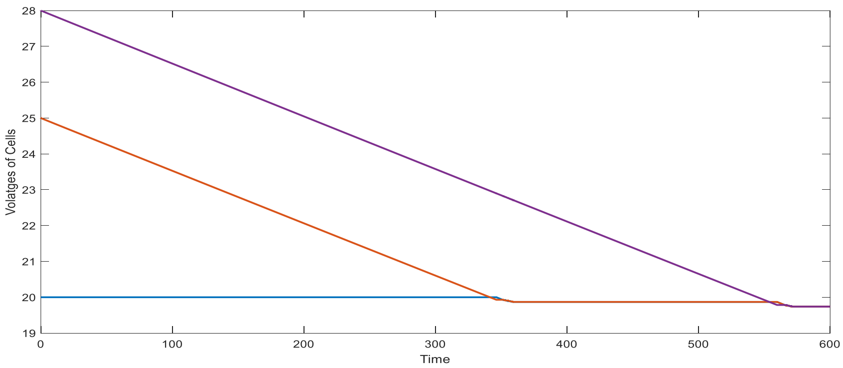


Fig 4.6: After Cell Balancing Voltages of Cells

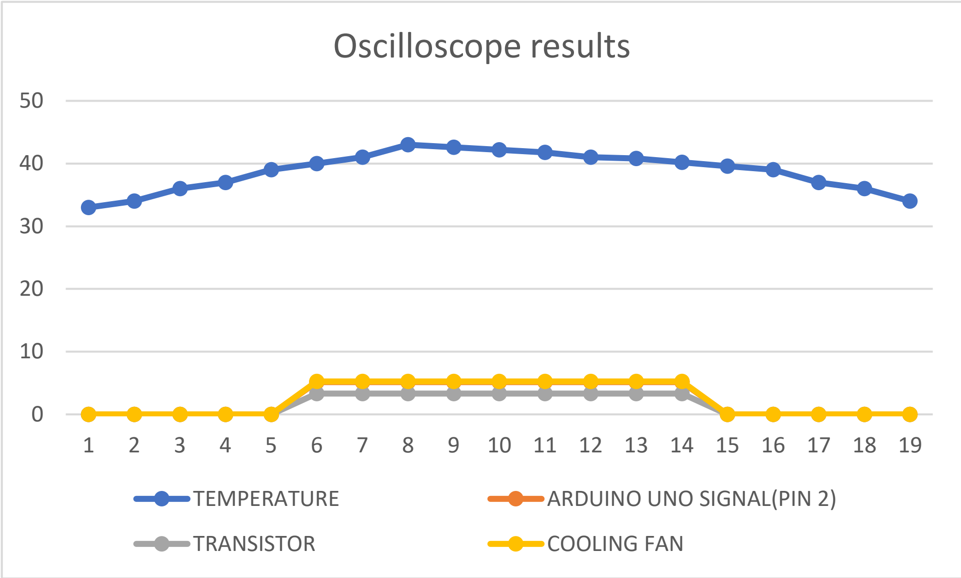


Fig 4.7: oscilloscope Results

The above graph represents a temperature-controlled system likely designed to regulate the cooling of a particular environment. The system appears to consist of several components including a temperature sensor, an Arduino Uno microcontroller, a transistor, and a cooling fan. Temperature records the temperature readings captured at regular intervals. These temperatures range from 33 to 50 degrees Celsius, indicating fluctuations in the environment's temperature over time. Arduino uno signal (PIN 2) seemingly records the output signal from the Arduino Uno microcontroller, specifically from pin 2. The signal values fluctuate between 0 and 5.15, indicating that the microcontroller may be actively monitoring and adjusting the system based on temperature readings. "TRANSISTOR" appears to track the behaviour of a transistor within the system. Transistors are often used to control the flow of current in electronic circuits. In this context, the transistor may be involved in regulating power to the cooling fan based on the signals received from the Arduino Uno. Cooling Fan registers the behaviour of the cooling fan. The values remain constant at 0 and 5.25, suggesting that the fan may be either turned off or operating at maximum speed throughout the observed time intervals. From the graph, it appears that the system activates the cooling fan when the temperature exceeds a certain threshold (40 degrees Celsius), as indicated by the non-zero values in the cooling fan during intervals where the temperature is higher. The Arduino Uno microcontroller likely plays a central role in this process by monitoring the temperature sensor and controlling the transistor to regulate the power supplied to the cooling fan accordingly. Overall, this system demonstrates a basic temperature-controlled cooling mechanism implemented using Arduino Uno and associated components.

5.CONCLUSION

Finally concluding by this paper on the crucial role of batteries in electric vehicles and the factors influencing their longevity. It discusses the impact of charge/discharge cycles, battery materials, and internal conditions (temperature, state of charge, state of health) on battery performance. The study emphasizes the use of hardware and simulation modelling to forecast battery longevity and control factors like thermal runaway, temperature slowdown, and cell balancing. It also compares electric and fuel vehicles in terms of battery life and cost, highlighting the importance of battery management systems (BMS) in electric vehicles. The paper reviews various methods for estimating battery state of charge and health, including voltage-based methods and the use of open circuit voltage (OCV). Additionally, it explores different cooling techniques for maintaining optimal battery temperature and prolonging battery life, such as air cooling, liquid cooling, and phase change materials. Finally provides valuable battery management by cell balancing and air-cooling techniques for the optimization of electric vehicles.

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