Design of Active Battery Management System for Electric Vehicle Battery

A Dissertation submitted in fulfillment of the requirements for the Degree of

Masters of Engineering
in
Power systems

Submitted by

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Declaration

I hereby certify that the work which is presented in dissertation entitled, "Design of Active Battery Management System for Electric Vehicle Battery" in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical Instrumentation Engineering Department of Thapar Institute of Engineering Technology is as authentic record of my own work carried under the supervision of Dr. Mukesh Singh. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

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It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

Mukesh

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My sincere gratitude is to my advisor, Dr. Mukesh Singh. I was fortunate to have an advisor who let me explore on my own while also assisting me when my feet faltered. His encouragement and tolerance helped me finish this dissertation.For their constant support, I'd like to thank my family and friends, as well as the one who stands above us all, the all-powerful God. Finally, I'd want to thank the THAPAR family for their support.

DEDICATION

To the four pillars of my life: God, my family, my friends and my teachers.

ABSTRACT

In the literature, according to the special properties of li-ion cell physics, li-ion based battery technology must be used with caution in electrical vehicles. A balancing battery pack is one that has been regularly maintained. When all of the cells in the battery system are charged to the same level of charge, the balancing process takes place. The voltage of the cell is frequently the basis for this level. Numerous periods of recharging, during which the state of charge of each battery starts to differ considerably, cause a li-ion based rechargeable battery to become unbalanced. Temperature, cell chemistry, and the use of a BMS are just a few of the many factors that might cause this unbalancing. In this topology, the battery management system (BMS) will be examined as a method for balancing. This study will concentrate on the BMS as a tool to balance the battery cells, it offers a way to increase battery efficiency and longevity. To develop a fresh strategy for an effective system, two concepts based on earlier designs will be used. This design circuit helps to examine battery with new stage of working for electrical vehicles.

A major advantage of balancing a lithium-based battery system is that it allows the system to run more efficiently. The capacity of the batteries decreases when they are charged and drained. Unbalanced cell discharging and charging shortens the time it takes for the cell capacity to be depleted until the system becomes useless or until the time it takes for the system to fail is shortened. The end user may obtain the most energy and life out of the battery system as a whole by evenly charging and discharging each single cell, which also saves money and resources. While the technology for using batteries as an energy source is currently behind, their power capacity, size, and impact on the environment are all constantly improving. As a result, it is impossible to overestimate the relevance of contemporary battery technology.

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1. Introduction

(BMS) Battery Management System is a approach that controls the charging and discharging of a lithium-ion or polymer battery. It safeguards the battery by monitoring battery capacity, computing secondary data, reporting/recording that data and assisting in its balance. A BMS guarantees the battery pack's safety by continuously monitoring and adjusting factors such as temperature, power while battery going to charge or discharge.

Benefits of using a battery Management System is to ensures dependable array operations, continuous array health monitoring to prevent explosions, extends the battery's life lifetime and indicates array level. The BMS evaluates the battery's SOC (State of Charge) and SOH (State of Health) to optimize safety and performance. It guards against overcharging or discharging the battery pack. By maintaining charge levels between the maximum and minimum permitted capabilities, it is possible to avoid unforeseen catastrophes (explosions). A BMS is therefore a crucial piece of equipment for maintaining the safety of the battery and the user. [1].

There are other advantages to adopting BMS, which we shall address later in this post. A BMS is a circuit board with numerous circuits and components on it. The alarm system disconnects the battery pack from the load or charger when the BMS detects an issue with operational parameters (voltage, temperature, etc.). Because batteries can spontaneously explode if there is a significant current flow through them, which quickly raises their temperature. At all costs, avoid using it. Because of this, the BMS continuously checks the battery's temperature and maintains it at the specified level. The benefit of this feature is that it will alert you to begin/stop charging or discharging if the temperature rises above the recommended level.

Battery Authentication- This feature prevents the BMS electronics from being connected to a third-party battery pack. For both charging and discharging, the BMS uses a single system, and the microprocessor continuously checks the cell voltage and current. Manufacturers generally divide cells with comparative SOC based on voltage while constructing non-linear and non packs. The battery's factors significantly alter, which causes voltage differences between the cells to appear. The charger determines whether a battery pack is fully charged by examining its voltage-guideline point. Repeated charge and discharge cycles degrade the overloaded cell's state and cause capacity degradation.The management system would seek to merge one of two cell equalization strategies to provide a high-powered solution for this problem that taking into account the RUL (remaining useful life) and operational statuses of the batteries.

Normally, there are two types of cell balancer one is passive another is active balancer. Firstly, bypass the extra power through resistor and hence cells are going to evaluate the energy transfer from one cell to another. But in active cell the charge is stored in capacitors or inductors which stabilize the circuit and maintain the voltage level for energy transfers in cells[2].

Storage Mode Voltage – 3.6V Full charge voltage – 4.2V. So, the cell required for for 12.6V is three cell battery pack. The high power cables are used to connect battery with power supply. While the thin wire are used in battery for cells connection and carry less power. At end the wire selection for system is according to gauge and wire calculation. A BMS has a capacity rating is referred to the capacity and gauges the available electric charge.

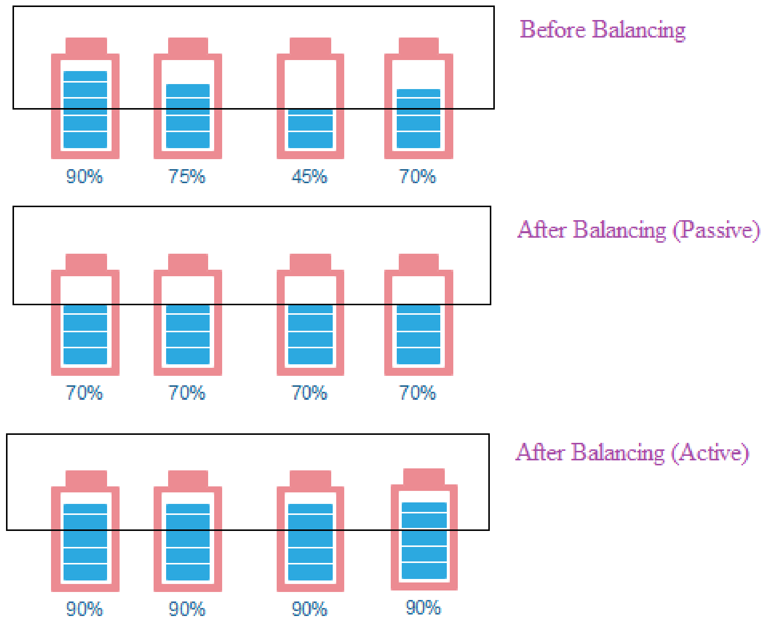

Figure 1: Balancing difference

Below listed functions are opted for designing of BMS -

Safety - Due to their higher density, lithium-ion battery packs have a greater risk of catching fire. As previously stated, it is critical to operate batteries at their rated capacity. This is done for you by a BMS. It protects the battery pack from overcharging and draining, extending its life. Short-circuit protection, charging and discharging over current protection, anti-reverse charging protection and other features are included. On current BMS, Bluetooth and USART communications are standard.

Optimum Battery Performance - For a battery to perform at its best, it must operate between the maximum and minimum rated values for current, voltage, temperature, and other factors. As was already said, a BMS aids batteries in maintaining these vital rated values. It aids in ensuring that the cells in battery packs are charged and discharged equally. As a result, the battery pack performs much better. A good battery management system increases performance while also extending the battery packs' life..

Health Observation and Diagnosis - When charging and discharging time of a battery is determined by its charge level. The charge available in the battery can be calculated and indicated using a BMS. By comparing the battery parameter to rated values, a BMS looks for anomalies. It's also capable of performing corrective actions to improve the battery's health. There are several different types of BMS available, ranging from 1S to 20S BMS. The letter "S" indicates for the number of cells in this case. As a result, an effective battery cell balancing system is a vital aspect of any BMS, as it keeps the cells' SOC at the same level.

Traditional passive balancing techniques, which are particularly helpful for small battery packs with low voltage, work by increasing the body temperature of an imbalanced cell to release its extra energy. Although this method is straightforward and reasonably priced, it can only be used on cells that are not seriously damaged by overcharging. An active circuit uses active element to transfer energy across cells as evenly as possible. Shunting, shuttling, and energy conversion techniques are all instances of active balancing techniques. In terms of energy flow, active balancing techniques encompass both dissipative and non-dissipative tactics. In non-dissipative systems, the extra energy is distributed across the string cells, resulting in a higher system efficiency. In dissipative systems, the extra energy is dissipated as heat across a resistor. One of the functions of a BMS is to balance the cells in a battery (Battery Management System). The capacity of an unbalanced battery may be quite low. After balancing, its capacity is the same as the cell with the lowest capacity.

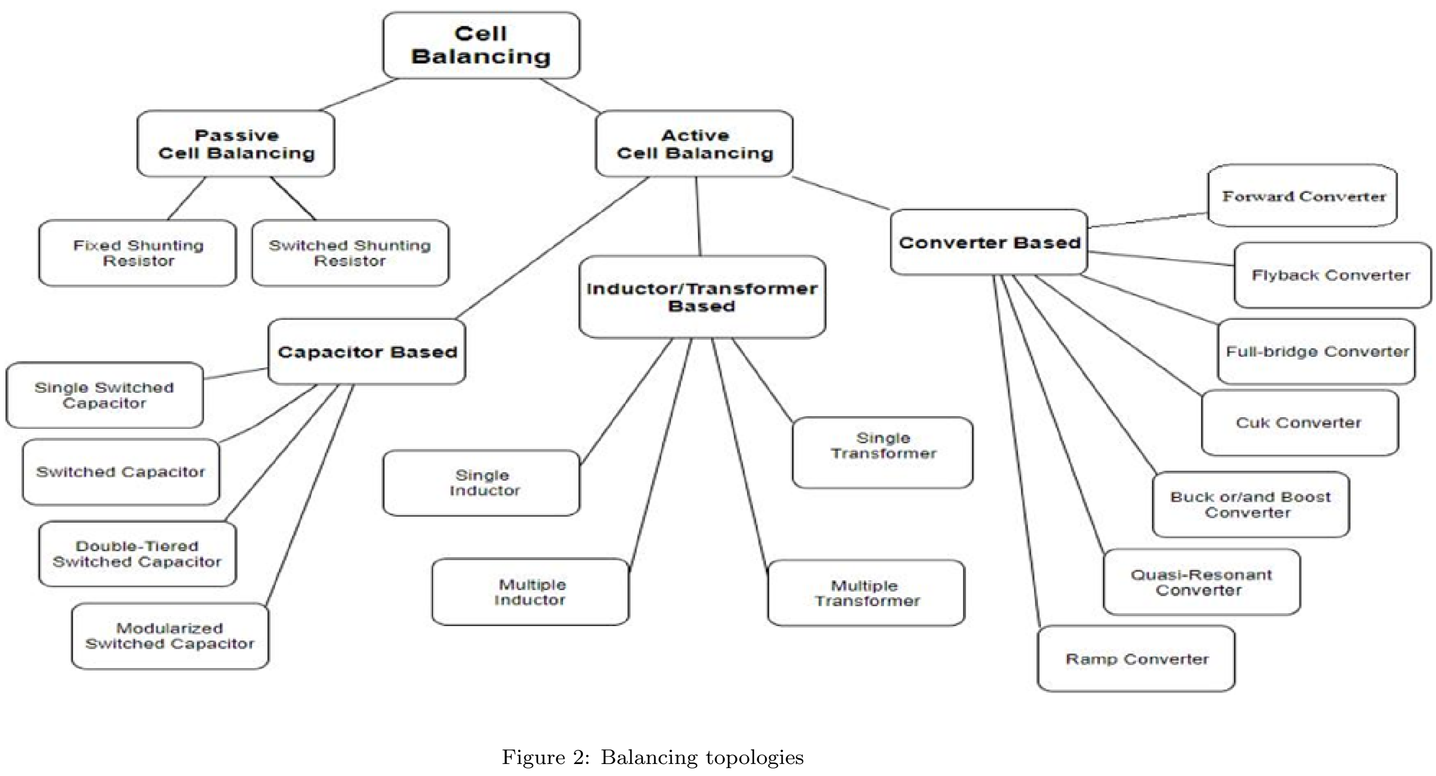

Figure 2: Balancing topologies

Passive Cell Balancing- In Passive BMS, the current enters the battery and fills the cells and charges the pack. When one cell is full the resistors take that energy and burn it off which finally converts it into heat, reducing the current flowing into that cell until all cells are balanced. Whereas in active BMS the current is directed towards the most less charged cells and it discharges to the other cells which are unfilled. Finally, fully charged cells are discharged to charge the lowest cells. In this situation instead of filling all cells at the same pace the current enters the battery and focuses on filling the empty cells until they reach the same level as the other cells. The current is equal once all cells are equal. Until all cells are fully charged the current is distributed evenly among them and fully balanced.

Active Cell/Power Transfer Balancing- The additional charge on a battery is shifted to a battery with a lesser charge than it in this procedure. This re-allocation of charges is carried out in two methods, each of which has a different name. Energy flow direction The battery pack can, first and foremost, by transmitting power from the supercharged cell, the system will be restored. From the battery bank to the main battery, and from the main battery to the battery bank cell with less charge Second, primary energy transmission is possible. To another less charged cell from an overcharged cell. The Cell-to-cell balance is the second type cell-to-cell communication. Therefore, an external balancing device is required as well as custom circuits a circuit for balancing one cell is used[5].

Each cell in a battery system needs to be checked frequently and separately for a safe and protected operation. As applying sensors to each cell is complex, especially in large battery packs, the method described here indirectly measures each battery's voltage by using a buffer and adjusting its voltage per cell.

Inductive Converter

Inductor and switching circuit are used in active cell balancing. The switching circuit in this circuit is an inductor-based circuit. The charge of a high voltage cell is pushed into the capacitor and subsequently dissipated as energy into a lower voltage cell using a buck boost converter.

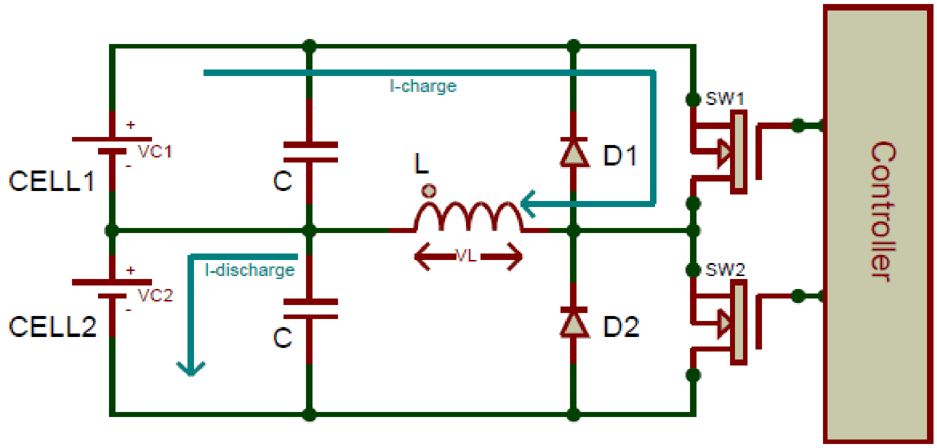

Figure 3: Basic working of Inductive Converter

Basic diagram of inductive converter- It eliminates the energy loss of the passive technique by using capacities or inductive charge storage and shuttling to provide energy where it is most needed while minimizing energy loss. It is simple to transfer energy between cells by connecting a capacitor first to a cell with a higher voltage and then to a cell with a lower voltage. More complicated systems allow connections between cells that are farther apart in the stack and neighboring cells for faster equilibration. The disadvantages of passive balancing are obvious; with high balancing currents, the heat that results may damage the cells and is not environmentally friendly. Active balancing appears to be superior at first glance because it does not waste energy. Active balancing does, has significant drawbacks there are more components to active balancing than passive balancing-higher cost, weaker reliability and more occupied volume. The amount of power squandered in stand-by current may result in higher losses than passive balancing.

Technique - The most popular and easily understood algorithm is the coulomb counting method. It is because the SOC value is based on the ratio of the total charge input to the battery's maximum capacity. Here is the equation for it[6].

$$SOC = \frac{TotalChargeInput}{MaximumCapacity} \tag{1}$$

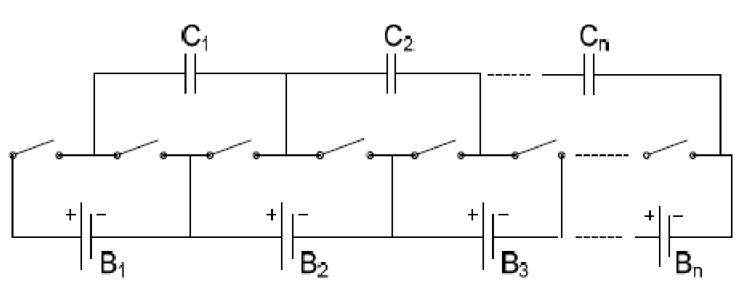

Figure 4: Basic circuit for charging

Although the data sheet will state the battery's maximum capacity, estimating the total charge input will require a modeling method. Because current fluctuates over time, we must use the current integration method to determine the total charge input, which is just the product of current and time. The input is total charge value is obtained by integrating the discrete current values that are measured at regular intervals. To reduce energy loss and improve cell performance, no-dissipative equalisation techniques (active balancing scheme) must be used.

S.No.	Active cell balancing	Passive cell balancing
1.	Extra energy is not wasted	Extra energy is dissipated
2.	High complexity	Easy implementation
3.	Lesser power losses	Higher power losses
4.	Expensive	Less expensive

Table 1: Difference between Active and Passive balancing

The four fundamental layers of active cell balancing. The circuit layout that is employed can also categorise active cell balancing [5]. The variations between figure-3 lists passive and active cell balancing. The active balancing technique and pack to cell type transfer are used in in addition to the switched transformer method of cell balancing. The pack voltage is put into the transformer's main winding, and the auxiliary distributes that power to other cells. A switched transformer is used in place of a capacitor or an inductor to avoid power dissipation and other problems. Furthermore, it transmits power more efficiently and balances faster.

2. Literature Review

In the literature, dissipative balancing is extensively explored. Additionally, resistive shunt balancing is made possible by the specific integrated circuit for voltage monitoring mentioned in Section, which requires just a small number of external components (such as Linear Technology) (2013). the underlying framework of energy transfer between cells. An active voltage-sharing device's fundamental idea[7].

The equalising currents Ieq supplement the primary charging current I. The equalising currents' magnitude and direction are controlled by the local voltages existing across the relevant device, can be used to realise the equalising current sources. This procedure is repeated until the voltages are equalised [8]. Cao et al (2008) present a variety of distinct approaches for scatter balancing systems. In order to stabilize the CC mode. According to the voltage of the cells, one method is to control all switches with the same signal only when the battery is charging, with the cell with the highest voltage receiving the least amount of charging current. Another possibility is to use only transistors in the alternate current channel, with no resistances. When the peak current voltage is reached, a circuit controls the transistors and correspondingly bypasses current through the cell because this adjustment prevents the BMS from controlling the balancing procedure, it is a dynamic balancing solution. So, this research try to make a dynamic type balancing System. The goal of this concept is to build a system that balances the cells to manage the voltage and SOC (state of charge) of the battery pack. Balancing is frequently done here [9].

When a cell's voltage reaches a certain level during the charging procedure the maximum voltage is reached. This method works well for charging because a portion of the energy in a battery is lost Balance algorithms for active cell balancing are commonly used based on an approach for voltage balancing. The approach for balancing consists of monitoring and comparing the voltages of all cells with the use of a threshold voltage. If a cell's voltage surpasses and if the battery's energy level falls below a certain threshold voltage, the battery's energy will be depleted. Disposing of with the use of a resistor and an internal circuit MOSFET resistance and prohibits from the cell overvoltage. If a cell's voltage is less than the threshold. When the voltage rises, the charging process accelerates.

2.1. Scope-

According to the special properties of li-ion cell physics, li-ion based battery technology must be used with caution in electrical vehicles. A balancing battery pack is one that has been regularly maintained. When all of the cells in the battery system are charged to the same level of charge, the balancing process takes place. The voltage of the cell is frequently the basis for this level. Numerous periods of recharging, during which the state of charge of each battery starts to differ considerably, cause a li-ion based rechargeable battery to become unbalanced. Temperature, cell chemistry, and the use of a BMS are just a few of the many factors that might cause this unbalancing. In this topology, the battery management system (BMS) will be examined as a method for balancing.This study will concentrate on the BMS as a tool to balance the battery cells, it offers a way to increase battery efficiency and longevity. To develop a fresh strategy for an effective system, two concepts based on earlier designs will be used [10]. This design circuit helps to examine battery with new stage of working for electrical vehicles.

2.2. Research Methodology-

A major advantage of balancing a lithium-based battery system is that it allows the system to run more efficiently [11]. The capacity of the batteries decreases when they are charged and drained. Unbalanced cell discharging and charging shortens the time it takes for the cell capacity to be depleted until the system becomes useless or until the time it takes for the system to fail is shortened. The end user may obtain the most energy and life out of the battery system as a whole by evenly charging and discharging each single cell, which also saves money and resources. While the technology for using batteries as an energy source is currently behind, their power capacity, size, and impact on the environment are all constantly improving. As a result, it is impossible to overestimate the relevance of contemporary battery technology.

3. Modelling and Simulation

Modelling of active cell balancer - A series battery pack is used as an illustration of the circuit equalisation theory. Whereas if difference between single cell balancing as well as the other array reaches the equalisation requirements, the balancing sub-circuit is activated. If the two fluctuation components meet the operating requirements of the balancing sub-circuit, the circuit is operational. The process of equalisation is finished when neither function.

Single cell equalization principle- Equalization principles for the charging process or the post-charging suspended state. The balancing approaches for the charging phase and the halted phase after charging are the same, and they require determining the greater cell voltage first and then regulating the balancing sub-circuits. Assume that the cell voltage of Cell 1 during charging or in the suspended condition after setting is higher than those other batteries. The balancing concept can then be divided into two steps after that.

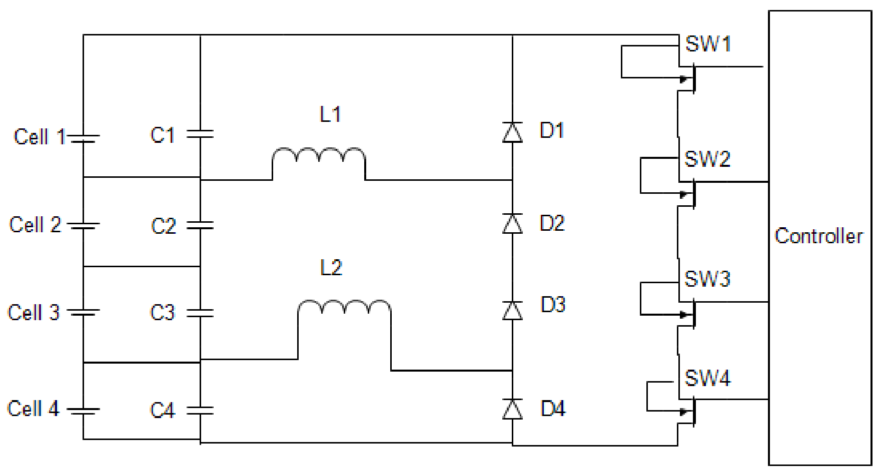

Figure 5: Working diagram for converter

L1 charges are the first stage- The equalisation approach is shown schematically in Figure, supposing that Cell 1's voltage is higher than another cells' voltages whether during recharging or while the cells are in a static situation after charging. When switch SW1 is closed, cell 1 charges inductor L1 and stores energy. A portion of the electrical energy is transformed into electric charges when the inductor's current I grows constantly. The closing time tonne of switch SW1 determines the maximum Imax of the inductor current. Ron, which includes the line resistance in printed board the DC internal resistance of inductor L1 and the turn-on resistance of switch SW1, is the overall circuit resistance when switching SW1 is closed. L stands for the L1 inductance, I for the current flowing through the inductor, and tonne for the switch SW2 closing time. In this operation, the inductor L1 conserves energy, and the regulating post lowers the battery voltage of cell 2 by receiving it[13].

L1 discharges are the second stage- The L1 discharge process is depicted schematically in Figure 5. Inductor L1 charges the remaining cells through switch D1 flywheel diode when switch SW1 is turned off at tonne, allowing energy to be transferred from cell 1 to the other cells. where Vd represents the voltage drop across body diode D2.

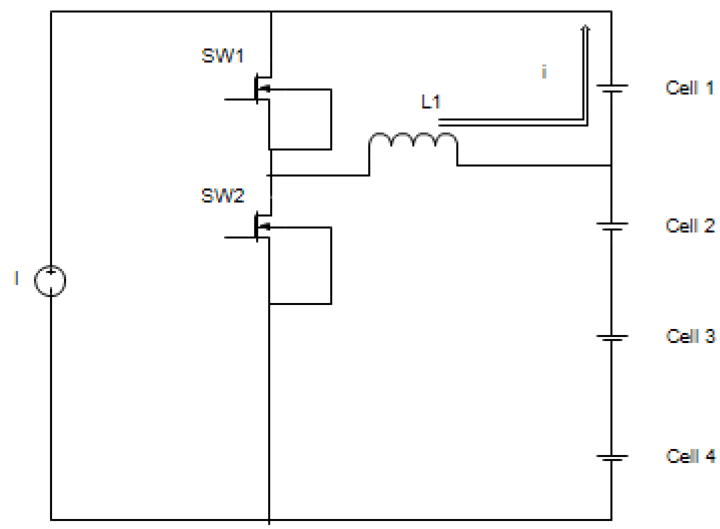

Figure 6: L1 Charging

Roff is the discharge loop's overall resistance. The circuit is first-order complete response, where Vb represents the combined voltage drop across cells 2, 3, and 4, and td represents the discharge time[14]. As a result, the formula below can be written as: To boost the charging currents of cells 2, 3 and 4, inductor L1 charges cells 2, 3 and 4 through the DC - link of MOSFET D2[15].

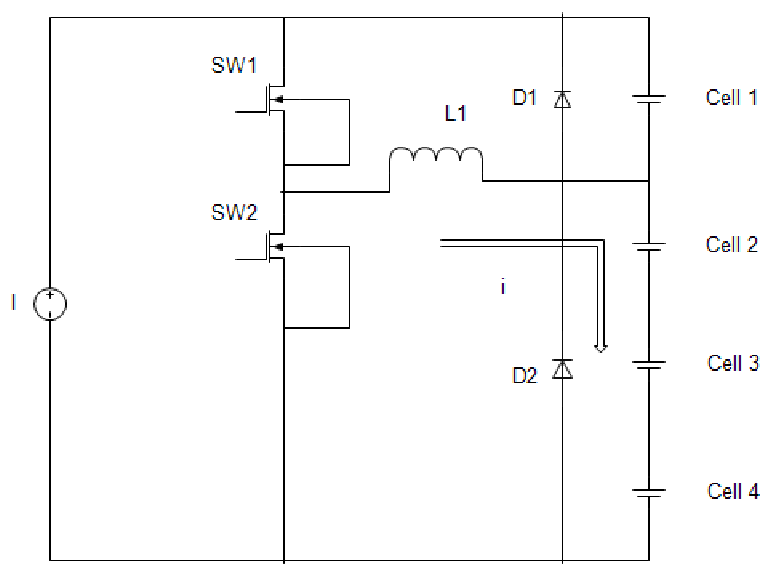

Figure 7: L1 Discharging

Equalization concept for the discharge procedure or the post-discharge suspended state. When draining or in the stalled condition after discharged, the equalisation notion can be divided into two phases. In order to use the Equalization for the Two Fluctuating Battery Parts principle, let's assume that cell 3 has a lower voltage than the others. Assume that the voltage in the upper half of the battery pack is higher than that in the lower half, both while charging and even in the suspension condition after recharging, and that the bus voltages meet the requirements of the balancing sub-circuit. Therefore, discharge equalize is needed for the battery's top half, which is split into two steps as shown in Figure 3[16].

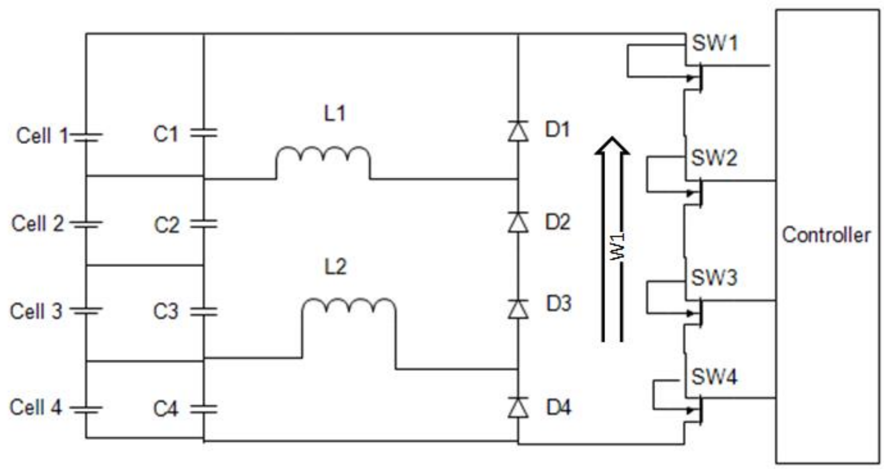

Figure 8: Discharging converter

As illustrated in Figure 4, when switch SW1 is turned on, cells 1 and 2 charge the inductor L. As illustrated in Figure 5, when switch SW2 is removed, inductor L charges cells 3 and 4 through the body diode of D2. In the end, energy is moved from cells 1 and 2 to cells 3 and 4. Assume that the voltage in the upper half of the battery pack is lower than that in the lower half either during discharging, but that the battery voltage meet the requirements of the rebalancing post. The next step is charge equalisation, which can be divided into two steps, for the upper half.

3.1. ***MATLAB Simulink-***

The charge and discharge cycles can be controlled by the BMS to avoid heat impact and power overload that might affect the surroundings. By taking these steps, power plants and utility networks can produce less pollutants, which will reduce air pollution and have positive effects on human health.

1.Charging- Simulink diagram for charging of BMS The cell has a predetermined number of charging and discharging cycles, and the battery life shortens as the number of cycles rises. BMS shall certify the charging / discharging processes. To optimize battery lifetime, a BMS must also keep the appropriate voltage. To assure management throughout this area, BMS manages the battery flow, activates/deactivates active switches between the pack and load/charger, executes the pre-charge sequence, establishes effective power constraints, and performs effective balance. The Charging of battery is in constant current [15]. Single cell BMS construction- This shows single cell charging diagram of BMS for 3.7V battery. There is a SOC, current and voltage battery monitoring output is connected with display and ideal switch is a combination of transistor and inductor which turn on the elementary circuit to balancing the cells.

Inductors based topology with inductors and capacitors, this equaliser spreads energy across numerous cells. Balancing a single cell is a buck-boost technique where energy transfers the battery power from a higher charge to a lower charged battery. To achieve voltage, monitoring of multiple cells is required for every storm. In BMS, the controller is maximize to control the PWM pulse of the switch in MATLAB as a gate pulse generator generates a pulse to gate signal. As a result, an exponentially growing duty cycle was chosen, which ramps current balance exponentially as a cell's voltage discrepancy rises. During the hardware testing phase, a simple exponential mapping was employed to translate voltage variations to duty cycles and hardware to avoid fluctuations in the duty cycle applied and the resulting balance current. To avoid cell damage, the mapping function additionally accounts for simple limiting, in which the duty cycle is set to zero when a cell is entirely dead [16].

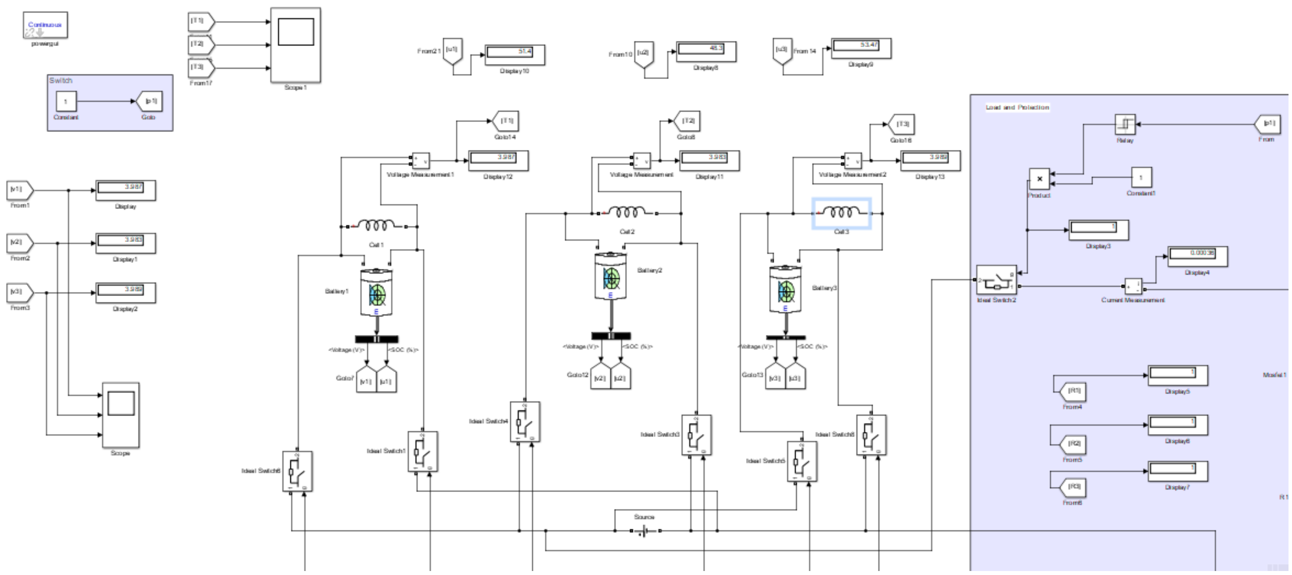

Figure 9: Inductor based active cell Balancing

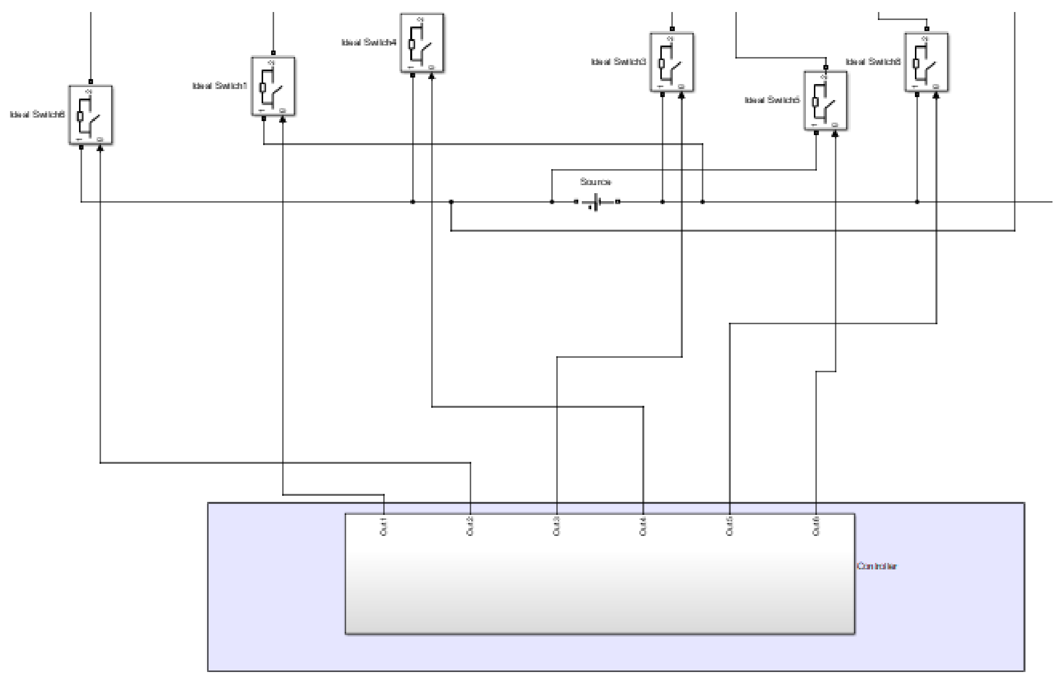

Figure 10: Controller 1

Another controller is used to balance the output difference of pulse for the switch and control the load side protection. As the Mosfet also requires some gate signal while discharging, it enables gate signal to MOSFET while discharging the battery.

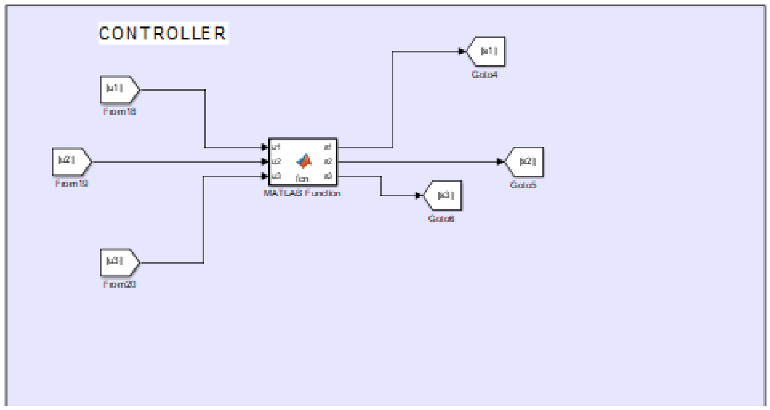

Figure 11: controller 2

Electronic test instruments called pulse gen emit pulses, often rectangular pulses. While pulse oscillators have several uses, testing method is where they are most frequently employed. Operation mode can be excited by pulses produced by pulsing synthesizers. It is necessary to make significant adjustments to the length, latency, repetition rate, and other aspects of the right sorts of pulses. Many of the tasks carried out by a signal generator are also accomplished by function generators and oscilloscope generators.

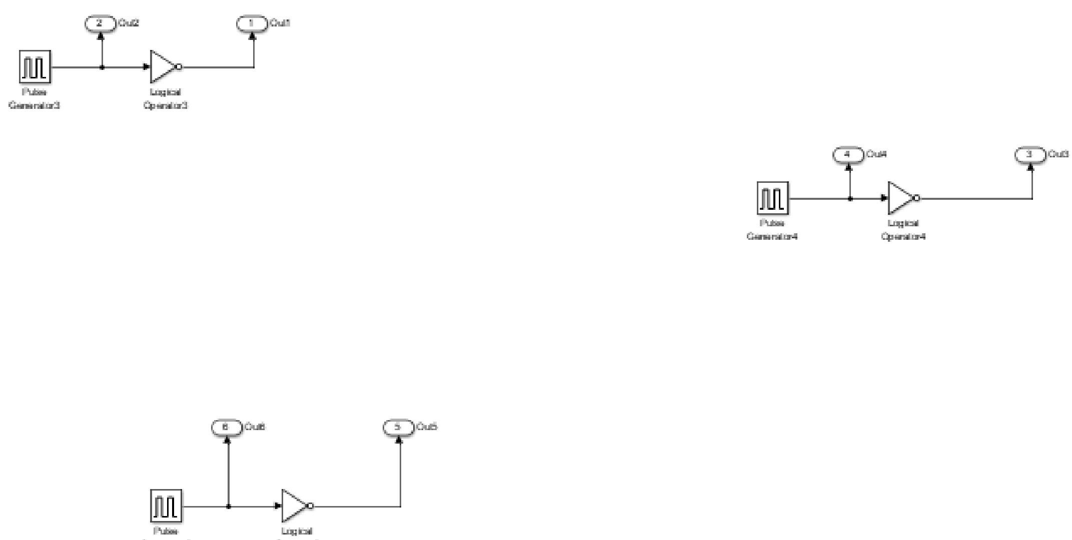

Figure 12: Pulse generator

A single cell in the battery pack has a voltage that exceeds the permissible voltage. The battery is only permitted to deplete for the sake of protection, and the charging relay is turned off. The BMS will usually set certain warning voltages within the permitted voltage range. The BMS will make a request to limit the charging current when the battery reaches this voltage. It's important to understand the difference between overvoltage and overcharge protection. The battery will not be overcharged if overvoltage protection is properly applied. Safety incidents such as thermal runaways can be prevented if overcharge protection is effective. When the controller activates the active overcurrent protection device, it may be set to separate the string from the battery system.

2. Discharging- When a lithium ion cell or battery discharges, it sends current to a circuit outside of the cell. An oxidation process inside the anode releases lithium ions, which pass to the cathode. The electrons that have been produced by the ions move in the opposite direction, into the electrical or electronic circuit that is being energised. At the cathode, the ions and electrons recombine. This process converts chemical energy into electrical energy, which is then released from the cell. During the charge mode, the responses happen in the reverse direction, with lithium ions travelling through the electrolyte from the cathode to the anode. Electrons from the external circuit mix with the lithium ions to produce the electrical energy that is stored [17].

Over-current protection- OC protection limits overloading of battery which protect the battery from explosion and fire hazards, as resistance and MOSFET circuit is used in protection circuit, so the while discharging MOSFET as a switch regulates the discharging current and control in under holding condition because we normally observe the battery is exposed to over current drawn from the battery, so this circuit draws current according to the temperature of battery which is controlled by the microcontroller.

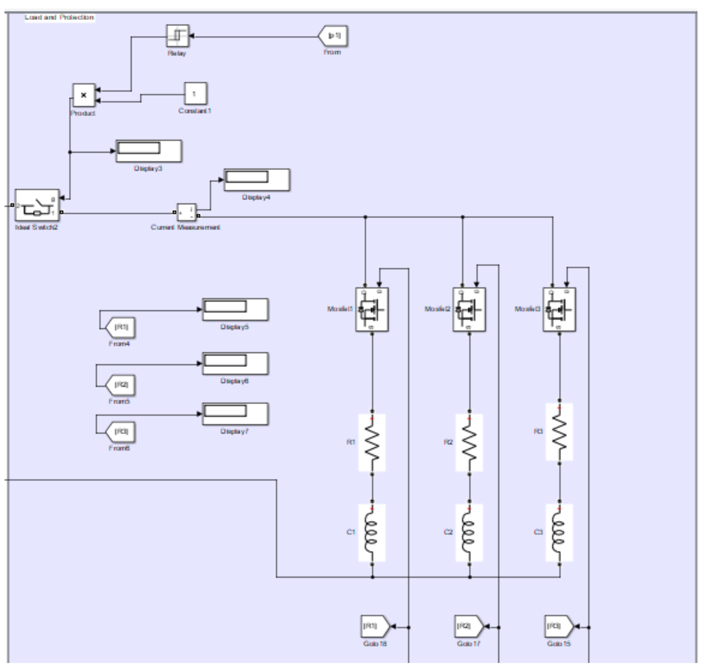

Figure 13: Load protection

Under Voltage- When the battery voltage falls below a predetermined level. The default setting for most BMS will be around 2.7V/cell. BMS systems will disconnect the load. Over voltage- When the battery voltage exceeds a defined parameter, this is known as an over voltage condition. The default setting for most BMS is roughly 4.2V/cell.

(Parameters)*Switch Reading*- This switch is combination of transistor and zener circuit which turn on when the battery is fully charge it's starts bypass the power from battery to resistor. But next parameter is considered is resistors. In a circuit with a voltage drop across them will dissipate electrical energy. Furthermore, this electrical energy is converted to heat energy. Another type of rechargeable battery is one in which lithium ions go from the negatively charged electrode to the positive electrode through an electrode at discharging and back again to recharging mode. The negative electrode of a lithium-ion battery is typically constructed of graphite, whereas the positive electrode is formed of an intercalated lithium polymer. It is 3.7V, 2Ah battery.

MATLAB Function- MATLAB Function blocks allow you to use the MATLAB language to define custom functionality in Simulink models. They are the quickest and most convenient way to import MATLAB code into Simulink. Simulink coder generates C/C++ code, which is supported by MATLAB function blocks. The code of MATLAB function is explain below, which is based on SOC.

Mosfet Parameters- When turned on, a MOSFET can conduct in both ways because it is simply a resistive channel that is opened or closed.(It opens with a minor resistance, closes with a large resistance, or has a small gradation in between, just like a tap). Both MOSFETs are now connected with their gates to an independent I/O pin in the case of battery protection, because when the battery is empty, it can be charged, and when it is full, it can be discharged. So the chip only turns on the MOSFET whose diode blocks the allowed directions, and if the battery is at one extreme of its use-case, its body diode will at least allow current to flow in the opposite direction, even if the over or under voltage situation persists for some time after current begins to flow. Whether or not this causes problems with MOSFET heating when a battery behaves strangely is a different question that has yet to be answered [18]. The body diode usually only conducts for a fraction of a second before the over/under voltage vanishes and both MOSFETs re-energize.

3.2. ***Simulink Results***

Results of Simulation :- The display shows a reading of the cell balancing system. With the duty cycle set to 100 percent,this simulation was expected to run for hundreds of seconds. To explore the behavior of cells with and without balancing, the duty signal is only applied to half of the cells, every other cell in the stack. This simulation was also used to confirm that the total power dissipation within all components did not exceed the specified parts ratings over time. Every detail was checked to ensure that it was within the features restrictions, and energy transfer was visible. The voltages of the cells with the balancing system turned off grew while the voltages of the cells with balancing active cell. Energy is transferred from a cell or batch of cells to the next array of cells using power conversion cell level up processes that use inductors or transformers.

Identification of the high voltage cell causes the extra energy to be wasted across the resistor until the voltage of the high voltage cell matches that of the weak cells in the passive system. Energy-transferring components are used in the active topology to remove excess cell energy and transfer it to undercharged cells.

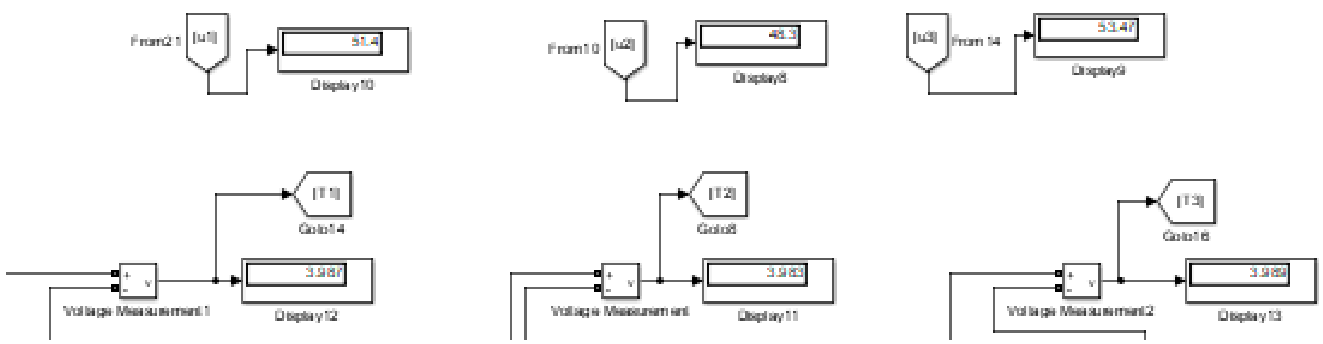

Figure 14: Display readings

Full-scale testing of the inductance began once the various system components had been validated and calibrated, and the balancing state machine had been unit tested. Even if the pack is balanced, voltage variations will occur during charge and discharge cycling. The MCU's functionality PWM module, unit testing of the serial data input and output functions, unit testing of the LED controls, and unit testing of the analogue input module were all carried out on the MCU, which provide to be fully operational after such minor HAL level changes. This results show the simulation data of 3 different cells.

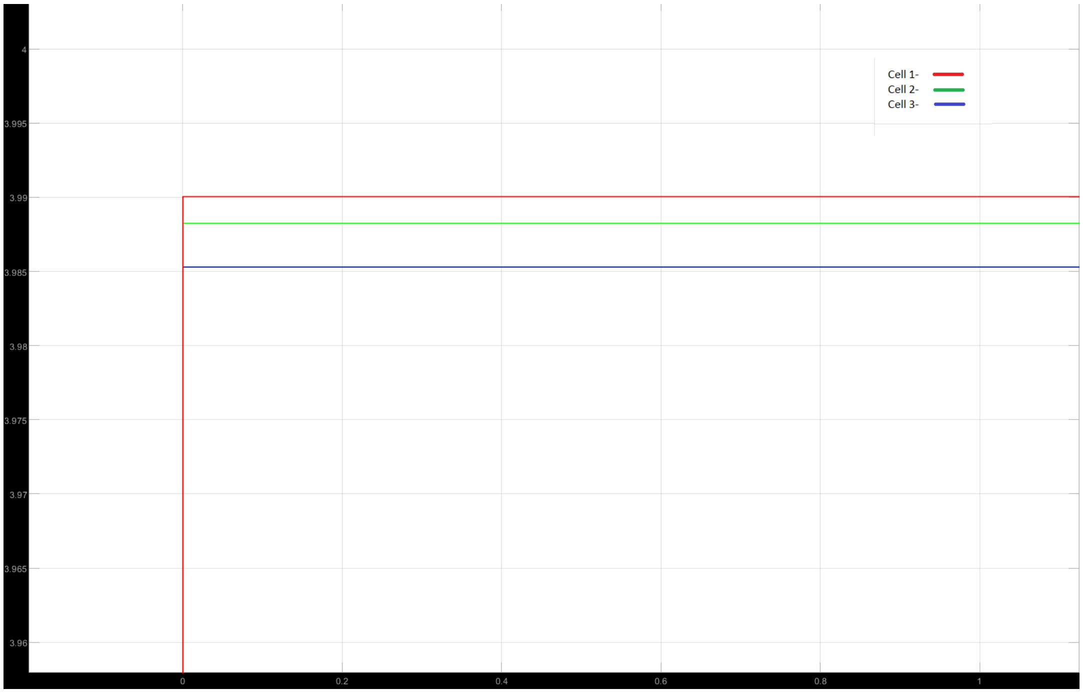

Figure 15: Cell balancing

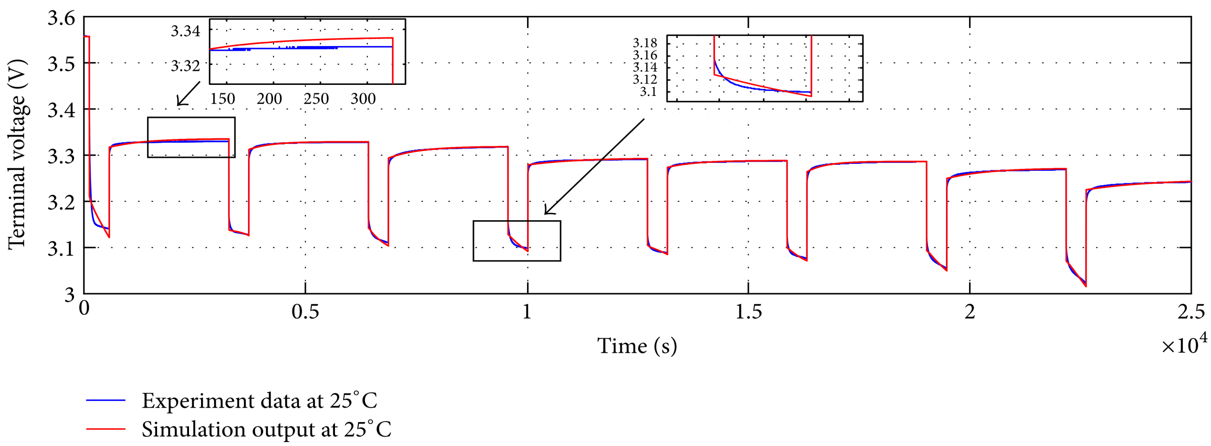

Figure 16: Cell output

This results show the simulation data of 3 different cells-

Figure 17: Different cell balanced

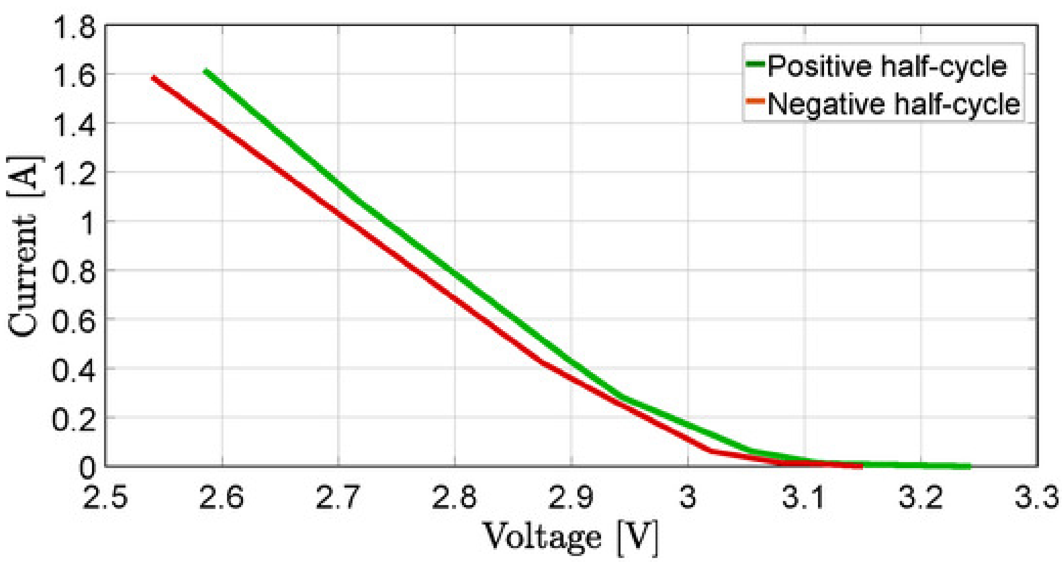

Figure 18: Charging

4. Hardware Design

Software - For construction of finalization of circuit Easy EDA software provides the hardware assembling function and also simulates the hardware designed make PCB prints which cope the system with manufacturing the circuits. The suggested lipo battery balancing charger circuit can be quickly built utilising a couple of integrated circuit stages as shown in the picture below [19].

The working of circuit-

Step 1: In this circuit there are 2 DC power supply. The first is a constant 12.6V for the integrated circuit and equip relay drivers board, and in second stage its uses to charge upto 4V the li-ion cells via the help of relay connections. The preset also feeds this 4.2V to the non-inverting pin of Arduino which is 3 of the operational amplifier.

Step 2: When the supply is turned ON, a high value signal is provided from 4017 which switches on a relay board via a transistor BC547. The battery going to charge in 4.2V and when battery is in discharging phase then it reaches between 3 to 3.7V.

Step 3: The Optional amplifier is connected with 2 port as a result of this decline in voltage the output of op drops as a there is no effect in port 14 where it connected with 4017.

Step 4: This circumstance permits the linked li-ion cell to begin to charge as it drop some amount of charge pin 3 potential rises over pin 2 potential, as set by the preset. This toggles port 14 of 4017 it hold the latch with pulse generator, instantaneously turning the Op amp's output high. The IC 4017's existing output pin HIGH is shifted to the following pin out as a result of the activity.

Cell balancer circuit Setting:-

Step 1: Cell 1 now starts charging, lowering the supply power in end part of battery then op amp's reset port 3 and battery holds to 3.5V or c1 is suppose to be discharge. During this time, the Op amp's port 3 has a low volatge compare to port 3 which effect in signal system the it trigger 4017 and port 6 and port 14 make a low pulse to system.

Step 2: In li-ion cell 1 charges the voltage across the cell gradually rises until it hold 4.2V. As when it fully charged the operational amplifier is exposed port 3 voltage, compelling its output in port 6 to generate high pulse which caused by 4017 the signal shifted to port 3 logic pulse which also goes high in phase, its next pin now starts trigger the driver stage of the pin.

Step 3: The mentioned stage initiates the charging of 2nd li-ion battery in such a way that the 1 cell was charged. The procedure now proceeds and continuous in loop in phases, which continuous scan cell power for charging.

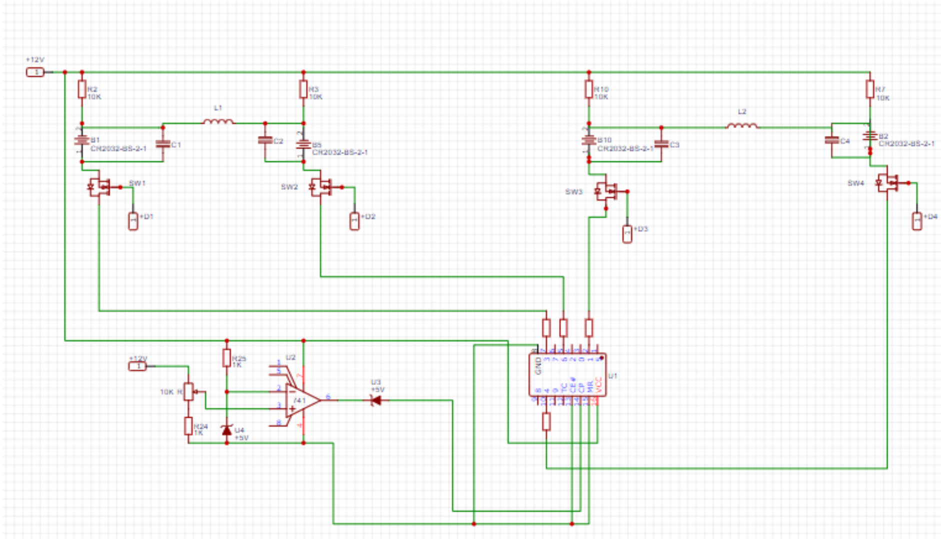

Figure 19: Balancer circuit

s the ned shift initiates the charging of the second lipo battery cell in the same way that the first cell was charged.The procedure now proceeds and repeats itself in phases, scanning and charging the cells.

Step 4: As circuit is connected to system for long duration the li-ion cells, the optimal charging level of the li-ion battery cells is maintained by the lipo, as mentioned above battery balance charger circuit.

Nowadays, there are many fake lithium and NiMH batteries on the market, which are advertised as having higher capacities than they actually have. As a result, distinguishing between a genuine and a counterfeit battery is quite difficult. Similarly, determining the capacity of rescued 18650 laptop batteries is challenging. As a result, a device to measure the true capacity of the batteries is necessary.

Circuit of the Power Supply- A supply of 9V and two filter capacitors, C1 and C2, make up the power supply circuit. The Arduino pin Vin is connected to the power output (Vin). I'm stepping down the voltage to 5V using Arduino's onboard voltage regulator.

Load Circuit with Constant Current- The Op amp LM358 is the circuit's main component, and it contains two operational amplifiers. A low-pass filter (R2 and C6) filters the PWM signal from Arduino pin D10 before feeding it to the second operational amplifier. In a voltage follower design, the output of dual Operational amplifier is connected to the first Operational amplifier. A decoupling capacitor C5 filters the power supply to the LM358. A constant current load circuit is created by the first Op amp, R1, and Q1. We can now change the PWM signal pulse width to adjust the current through the load resistor (R1).

Circuit for Measuring Battery Voltage- The Arduino analogue input pin A0 measures the battery voltage. The constant current load circuit generates noise that can decrease the ADC conversion performance, so two capacitors C3 and C4, are utilised to filter it out.

Circuit for the User Interface- Two pushbuttons and a 0.96" I2C OLED display make up the user interface circuit. Increase or decrease the PWM pulse width with the Up and Down push buttons. For the Up and Down push buttons, R3 and R4 are pull-up resistors. The push buttons are debounced using C7 and C8. Resetting the arduino is done with the third push button (RST).

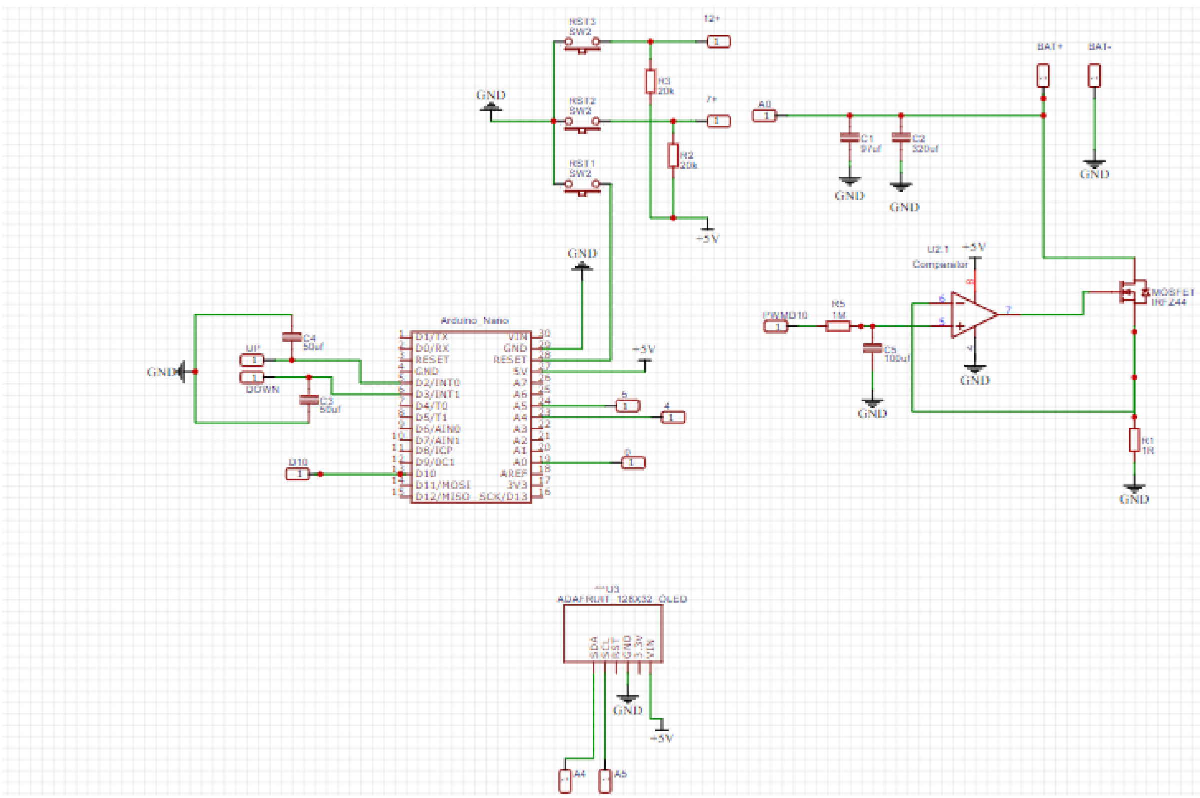

Figure 20: Display and voltage differentiator circuit

Instead of utilising a predetermined set of PWM values for each current step establish an array of recent intended deals that will be used to compute the necessary PWM values to get as near to those current values as feasible. This then calculated the actual current values that can be attained with the PWM values he determined.

4.1. PCB Design

For the construction of the circuit, a PCB board design must be completed first to produce and fabricate electronic models. For the developer to construct and analyze the models the electronic systems should be completed with detailed specific tools and with technical considerations. The following parameters need to be considered when designing the board tracks have a resistive effect. The length, thickness, and maximum current that the rails should carry must be considered while designing the circuit. To detect and determine the dimensions, software tools should be employed. The thermal effect is a phenomenon that occurs when heat is applied to a surface. The connections and thermal and electromagnetic interferences must be considered when locating the components. The capacitive and inductive effects are both present [20]. The BMS's power segment should be kept as far from the control section as possible.

The analogic plane must be segregated from the digital plane to prevent electromagnetic interference (EMI) and offer electrical protection. The integration using the Single European configuration, as shown in Fig. 17,18. Once it has been finished to create a working printed circuit assembly, or PCA or its also called PCB. Component leads are placed into holes during through-hole construction. Components used in copper pads construction are positioned the component required for physically and electrically secured to the metal soldiering which gives physically protection in both types of construction. Many different soldering methods are used to join components to a PCB. Although bulk wave soldering or reflow ovens are typically used for high volume production, competent technicians can solder extremely small items.

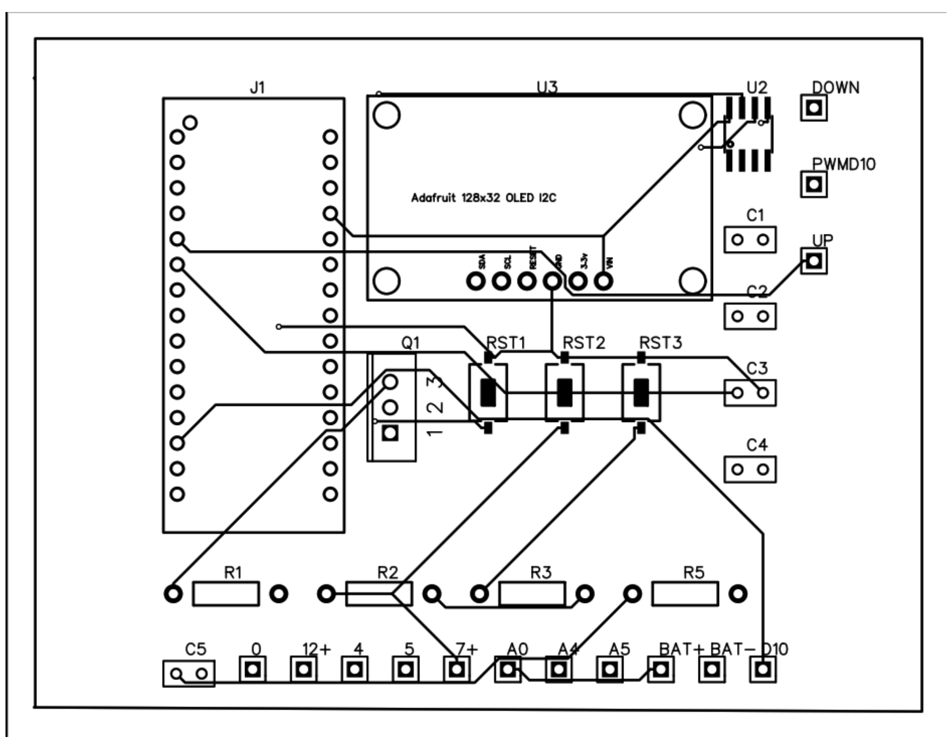

Figure 21: Controller

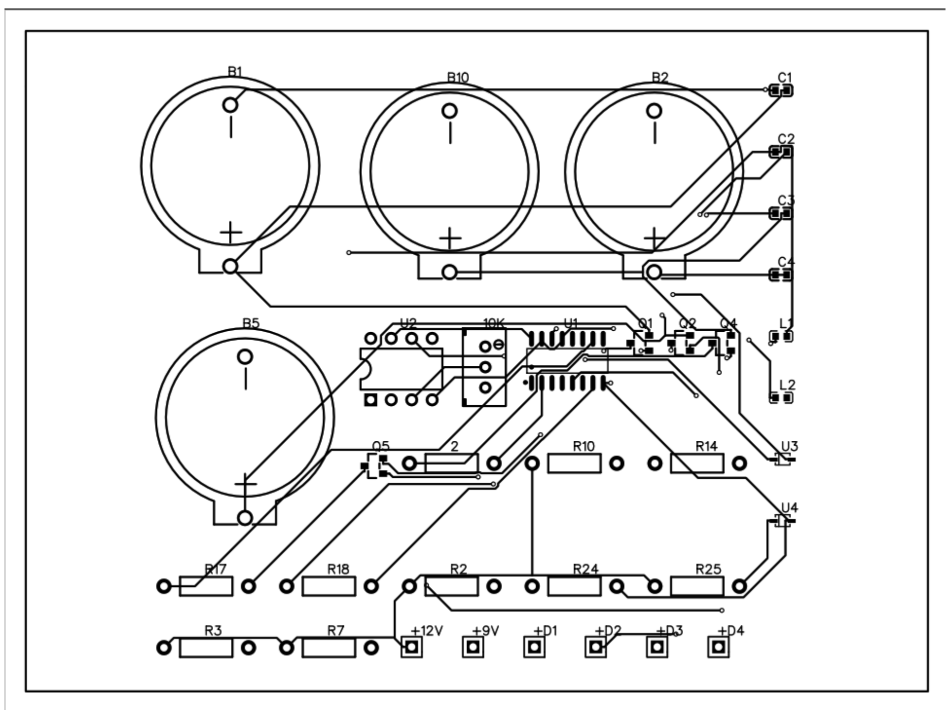

Figure 22: Active balancer

4.2. ***Hardware Fabrication and Assembly***

The fabrication of multi-layer PCBs are varying from 1-12 layers the custom builts boards are more flexible, So PCBs multiple RF interfaces.

1. This is a balancer board which is connected with battery and controller and in hardware there are two balancer boards.
2. The arduino uno R3 used at the place of controller with control MOSFET output signal with working with C code fig 20.

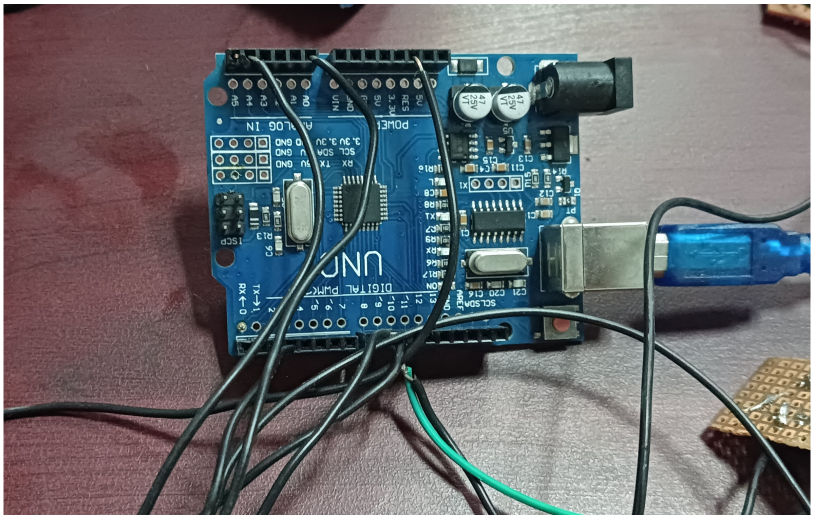

Figure 23: Arduino Uno

3. Comparator is used to compare different level of battery voltage and provides output to controller.

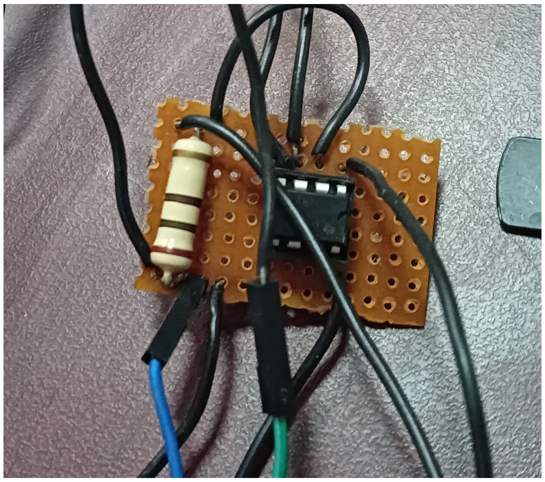

Figure 24: Comparator

4. The overall construction of circuit.

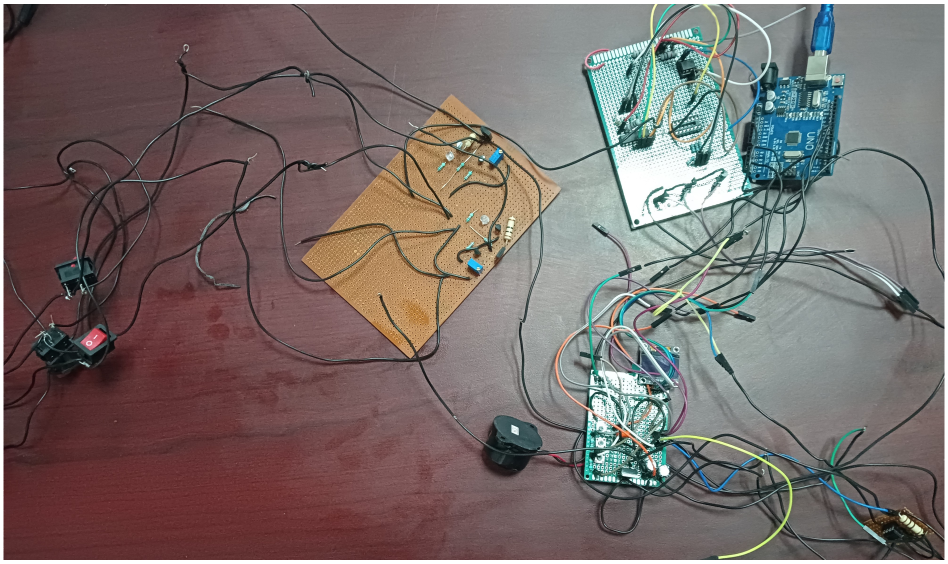

Figure 25: Hardware

5. The display shows the output reading of cell voltage, discharging current, capacity.

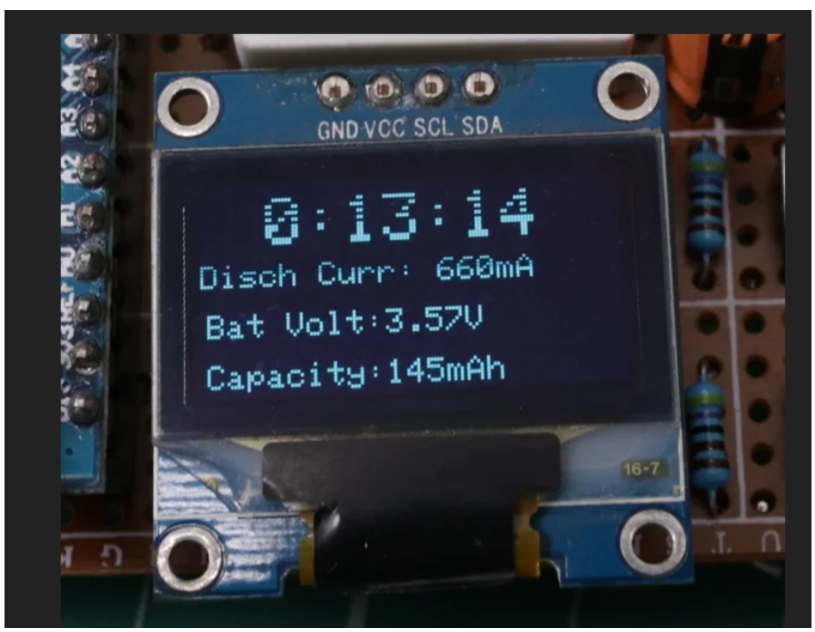

Figure 26: Display reading

4.3. ***Algorithm***

Charging Algorithm

Step 1 - Connect battery with charger.

Step 2 - Measuring the voltage of all the batteries.

Step 3 - Determine voltage and hold 4.25V.

Step 4 - If less then or =4.25 then start charging.

Step 5 - Charging is done in CV mode

Step 6 - Put forward to transfer the charge to other batteries for stabling

Step 7 - When balancing is done but it going to continues monitoring stage of battery.

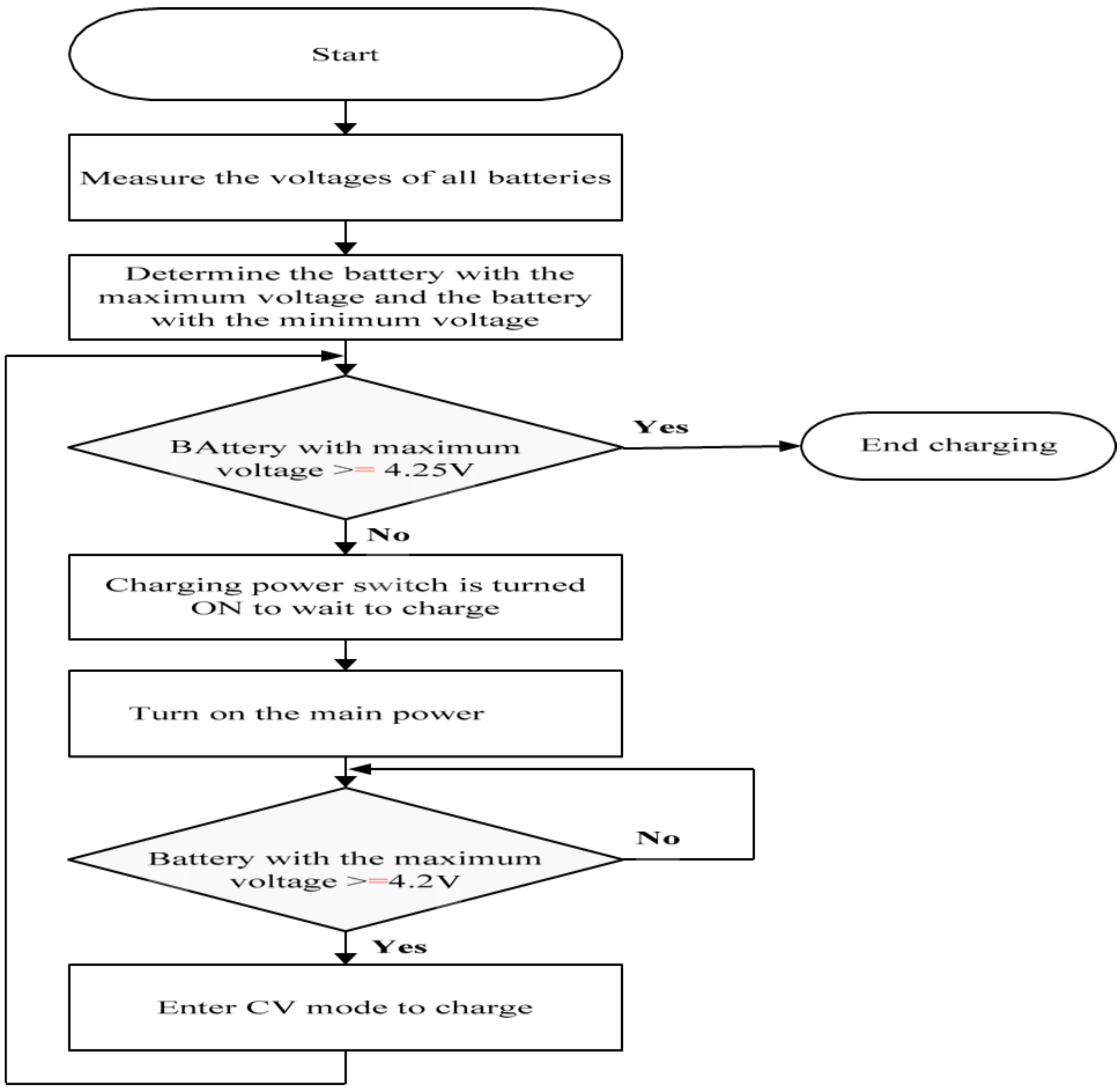

Figure 27: Charging with modes

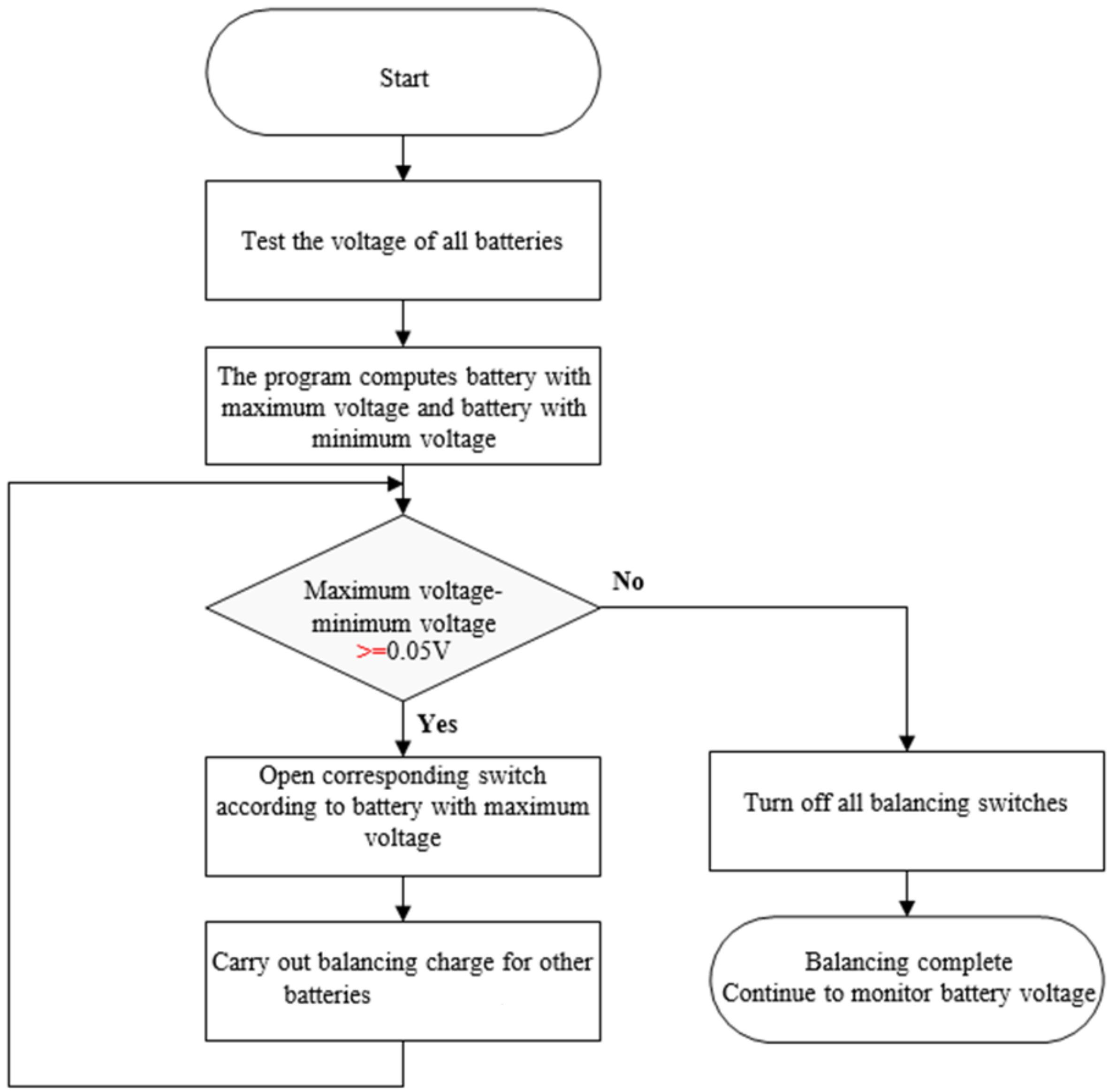

Figure 28: Testing of battery voltage

5. Battery Construction and Maintenance

Battery Management System specification is listed below on the table-

S.No.	BMS Specification
1.	Active BMS
2.	BMS Voltage 12.6V
3.	Balanced Type BMS
4.	Provide Short Circuit Protection
5.	4S series

Table 2: BMS Specification.

5.1. Cell Data

Cell (12V 4Ah) 3.7V 2Ah. The 18650 battery is a li-ion rechargeable battery with a capacity of 2Ah. This is not a conventional AA or AAA battery, but it is ideal for applications that require a constant high current or a high current in brief burst [21]. A single 18650 cell may be charged and drained 1000 times without losing much capacity. They are safe to use have a long battery life and are environmentally friendly. It has a high energy density and provides your device with good continuous power sources. It should be used in conjunction with a protection circuit board that protects the battery from overcharging, over discharging and over current draw.

Battery Type	18650 Battery
Normal Capacity	2 Ah
Normal Voltage	3.7V
Charging Voltage	4.20+/-0.05V
Discharge ending Voltage	2.75+/-0.05V
Standard Charge Current	0.5C
Standard Discharge Current	0.5C
Max charge current	2C
Max discharge current	2C
Operating Temperature	Charging: 0 to 45 °C, Discharging: -20 to 60°C

Figure 29: 18650 cell configuration

In the world of batteries, the C rating is a widely misunderstood notion. The time required for charging or discharging a battery determines the C rating. You can change the rate, which has an inverse influence on the amount of time further it measure the sampling time for charging or discharging the battery.

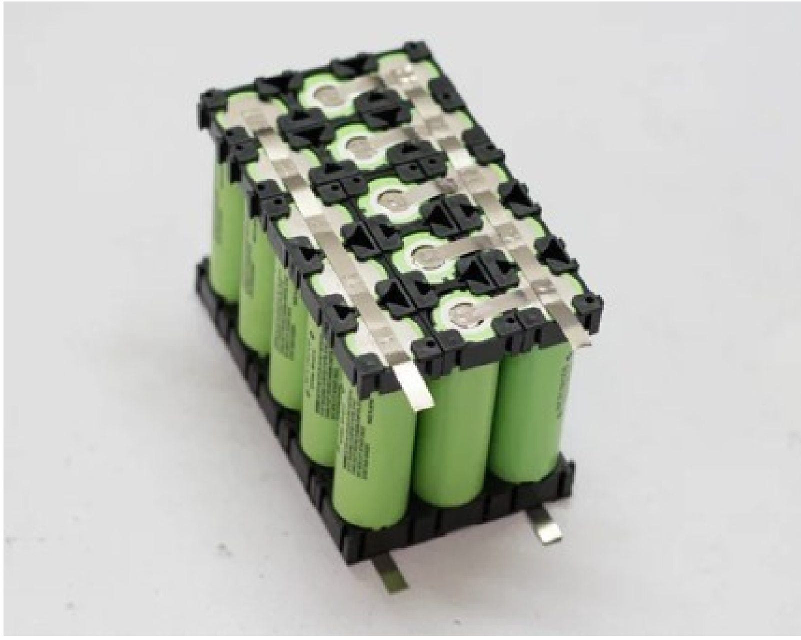

Figure 30: Battery

For instance, if a cell has a capacity of 2Ah and a 1C rate, charging or discharging the battery will take 60 minutes. The 1C rating is the starting point, which is always 1 hour or 60 minutes [22]. The charge or discharge time for the C rating varies proportionally with the rating. 1C rating is equal to 60 minutes, a 2C rating is equal to 0.5h or 30 minutes, and a 0.5C rating is equal to 2h or 120 minutes. The formula is straight forward. To view in hours or minutes, use t = 1/Cr or time =60 minutes / Cr (C rating).

5.2. *BOM*

Bill of materials - It's a list of run down of material with description , assemblies, different materials for manufacturing to achieved end of product. .

ID	Name	Designator	Footprint	Quantity
1	330	2,R14,R17,R18	RES-TH_BD2.	4
2	10K	R2,R3,R7,R10	RES-TH_BD2.	4
3	1K	R24,R25	RES-TH_BD2.	2
4	R	10K	RES-ADJ-TH_	1
5	Header-Male-:	+9V,+12V,+D1,+	HDR-1X1/2.5	6
6	CR2032-BS-2-1	B1,B2,B5,B10	BAT-TH_BS-2	4
7	0.1u	C1,C2,C3,C4	C0603	4
8	1m	L1,L2	L0603	2
9	2N7002	Q1,Q2,Q4,Q5	SOT-23_L2.9-	4
10	4017	U1	SOIC-16_L9.9	1
11	741	U2	DIP-8	1
12	+5V	U3,U4	SOD-323_L1.	2

Figure 31: BOM 1

ID	Name	Designator	Footprint	Quantity
1	Header-Male	0,4,5,7+,12+,A	HDR-1X1/2.54	14
2	100uf	C1,C3,C4,C5	RAD-0.1	4
3	220uf	C2	RAD-0.1	1
4	Arduino_Nan	J1	DIP-30_L43.18-	1
5	IRFZ44	Q1	TO-220AB	1
6	1R	R1	RES-TH_BD2.3-	1
7	20k	R2,R3	RES-TH_BD2.3-	2
8	1M	R5	RES-TH_BD2.3-	1
9	SW2	RST1,RST2,RS	SW1-SMD	3
10	ADAFRUIT_12	U3	ADAFRUIT_OLE	1
11	LM358M	U2	SOIC8	1

Figure 32: BOM 2

5.3. *Cell Maintenance*

The battery management must also take into account the variations in the speed of auto-discharge of single cells, which are brought on by design flaws and variations in temperature of the cell. The majority of the time, systems for balancing are either passive or active. Any switching circuit and resistor arrangement of power dissipation of a cell with a higher voltage, or a better SOC, during passive balancing. The weak cells receive this energy via active balancing. To handle this effectively, more switches, capacitors, or inductance's are needed, which increases the system's structure and cost of system. [23].

A simple safety procedure is concern caused by a about the cell connecting in series loop is to use a switch to totally bypass the cell. The bypass must then be able to carry the highest possible charge and discharge currents. This does not seem to be feasible for most applications because of the approximate range of the switching device that is needed and the cost that goes along with it. [24].

6. Conclusion

During charge, passive balancing solutions based on resistor dissipation have been utilized, however they are inefficient. One solution that has been proposed for second-generation batteries is active cell balancing. In order to make sure that no cell is functioning outside of its prescribed parameters, it involves monitoring each cell's potential, current, and temperature. The advantages include a improvement in RUL along with safety with a higher power capability for a relatively small cost increase. Increasing cycle and calendar lifetimes is crucial for lithium-ion chemistries in particular because, despite what they state, they can be easily blemish and constitute an explosion risk if handled incorrectly[25].

To achieve these objectives, mathematical models of each battery technology's behavior have been developed. Advanced BMS is thought to improve electric car efficiency and lengthen battery life. Improvements to this method should lessen the current societal acceptance problems since these two characteristics are essential for the mobility and economic viability of EVs. While charging, passive balancing methods based on resistor dissipation have been employed. They are ineffective, though. Active cell balancing causes it to be replaced by second-generation batteries which track data, temperature, and monitoring to make sure that no cell is operating beyond of its permitted boundaries. For a relatively little cost increase, its benefits were a cycle life, increased safety, and a higher power capability. For lithium-ion chemistry, it is essential.

7. Publication

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Development of Passive Battery Management System at TRL 4 (TEKNOMEKANIK)

Mukesh Singh, Rahul Kumar Kamboj (Author)

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