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"Analysis Of Cell Balancing Techniques in BMS For Electric vehicle"

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Abstract

This paper explains how the Battery Management System (BMS) in an Electric Vehicle uses cell balancing techniques to balance the li-ion cells in lithium-ion battery pack. Cell balancing is done to ensure that all li-ion cells in a battery pack are charged and drained together. There are two types of cells balancing techniques: Passive cell balancing and active cell balancing. Passive cell balancing is accomplished by discharging the excess charge to a bleeding resistor but active cell balancing is accomplished by transferring the charge from higher charged cell to lower charged cell. Moreover, the charge is squandered in passive cell balancing, therefore in this technique cell balancing efficiency is harmed. However, when it comes to active cell balancing, charge transfer is accomplished via a transformer, inductor and capacitor so this balancing technique gives high efficiency compared to passive one. The simulation results of all methods of cell balancing are presented in this paper.

Keywords—Electric Vehicle, BMS, Cell Balancing, Active cell balancing, Passive cell balancing.

INTRODUCTION

As we are rapidly burning fossil fuels to power our vehicles, the negative impact on the environment cannot be overlooked. Vehicles emit CO_2 and some unburned carbon when they burn fossil fuels, and these are the principal contributions to greenhouse gas emission. Electric vehicles are in high demand due to advancements in battery technology, as they are more environmentally friendly than combustion engines vehicles. Lithium-ion batteries are the first choice for battery-powered vehicles because of their low self-discharge current, high power density, and high charge density [1]. But, despite all of these benefits, the lithium-ion battery has some drawbacks, such as being highly reactive and more sensitive to temperature change, i.e., if we operate it outside of its operating temperature range, its power output is severely impacted and its active material rapidly changes. So, to manage the lithium-ion battery in the best possible way, a battery management system (BMS) [2] is used. Battery management systems provide functions such as charging control, battery thermal management, state of charge estimation, state of health estimation, and most importantly, cell balancing [3],[4]. We will investigate cell balancing techniques in this paper. To achieve the desired current and voltage, lithium-ion batteries use series/parallel connections of lithium-ion cells. Even if we use similar cells, when we connect them in series, but due to many circumstances occurring in cell just for an example Like differences in internal characteristics such as internal resistance and capacitance cause a problem of cell imbalance. The cell with lower internal resistance gets fully charged faster than the cell with slightly higher internal resistance during the charging cycle, leading the charger to believe the battery pack is fully charged when, in fact, only the cell with lower internal resistance is fully charged and the others still need to be charged, resulting in the battery pack not being fully charged. When the battery pack is connected to a load, the same thing happens; this time, the cell that is charged quickly is also discharged quickly, resulting in a false battery charging alarm. As a result, the battery's full potential is not being utilized. As a result, a cell balancer is required to bring the SoC [4], Voltage of each cell to the same level. SoC stands for State of Charge, and it refers to the amount of capacity left in the battery when compared to when it was fully charged. SoC can be expressed as follows:

$$SoC_t = \frac{Q_t}{Q_n}$$

Where Q_t is current battery capacity and Q_n is the nominal capacity of battery. When the SoC of a battery reaches 0%, it is considered fully drained, and when it reaches 100%, it is considered fully charged.

Cell Balancing is done in two ways:

1) Passive Cell Balancing
2) Active Cell Balancing.

This paper is structured as follows: The passive cell balancing is explained in the second section of the paper, including how it is done, simulation, and the final result of balancing the eight cells. The third section discusses about active cell balancing, including various methodologies for active cell balancing, each of which is explained through simulation and results. The conclusion is in the fourth section of the paper.

II. PASSIVE CELL BALANCING.

Passive Cell balancing is charge draining way to balance the cells in battery pack. In this technique each cell is connected with a switch and bleeding resistor [5]-[7]. The simple circuit diagram for balancing two cells is shown in Figure 1. This circuit can also be scaled, to balance a larger number of cells. As a bleeding resistor is connected across each cell in the battery pack for charge dissipation, the passive cell balancing method is also called as shunting cell balancing. Here switch 1 is connected across cell 1 and switch 2 is connected across cell 2. Pulse controls switching by comparing the SoC of one cell to the SoC of other cells connected in series. If the SoC of Cell 1 is greater than the SoC of Cell 2 the Switch 1 will be triggered, and the cell 1 will discharge to bleeding resistor until the SoC of cell 1 equals the SoC of cell 2. This technique may cause thermal breakdown because the charge is wasted as heat energy, and the efficiency is low [6].

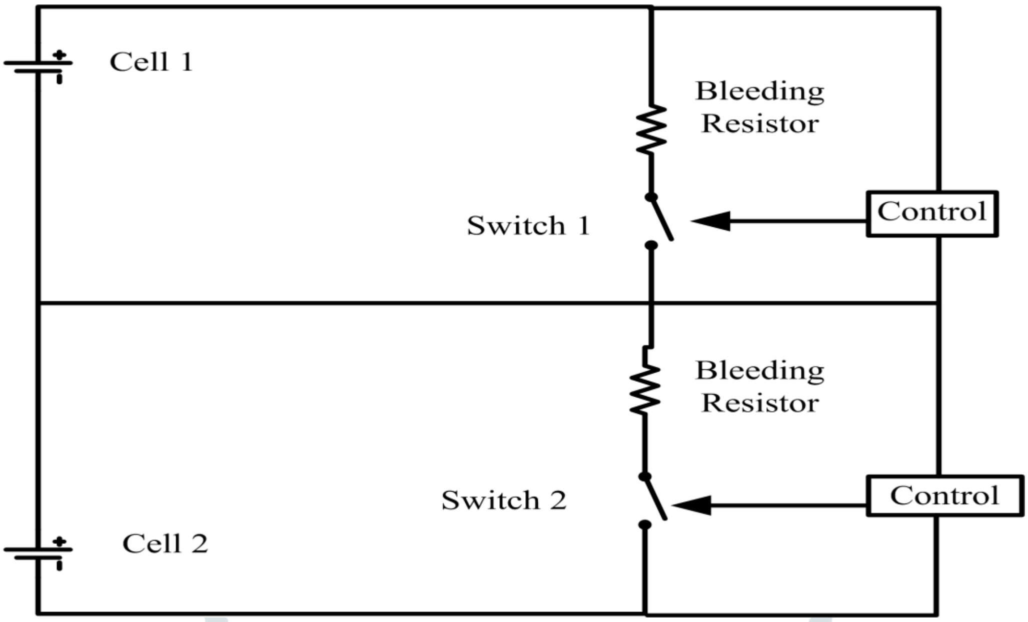


Fig. 1. Circuit of passive Cell Balancing

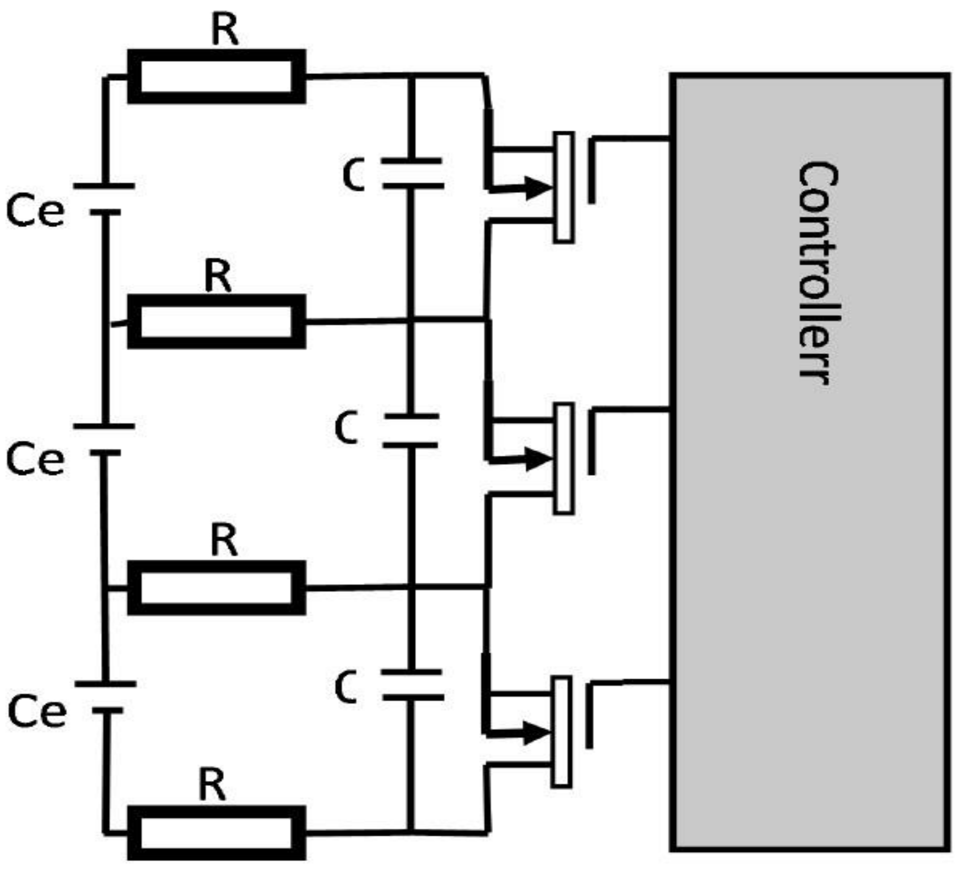


Fig. 2. Passive Cell Balancing Simulation of 8 Cells

Here eight cells of rating 3.7 Volts and 3.4 Ah having SoC level as 75%, 55%, 76%,50%,67%,96%,89% and 65% respectively are connected in series. A bleeding resistance of 0.25Ω is connected in parallel with each cell. The excess charge from the cell with a higher

SoC value is discharged through this resistor. The value of the bleeding resistor is kept low to balance the cell in less time.

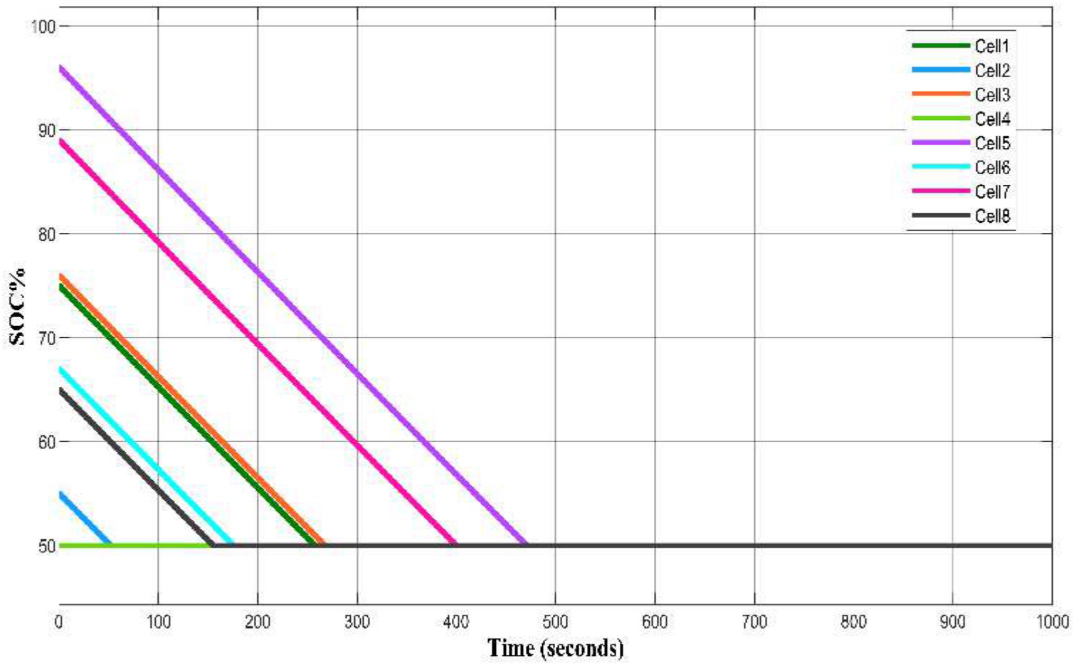


Fig. 3. Simulation Results of Passive Cell Balancing of 8 Cells

Figure 3 illustrates the simulation result, which demonstrates that the SoC of each cell is 50% at the end of the simulation i.e., cell having higher SoC are discharged till it matches the SoC of least charged Cell.

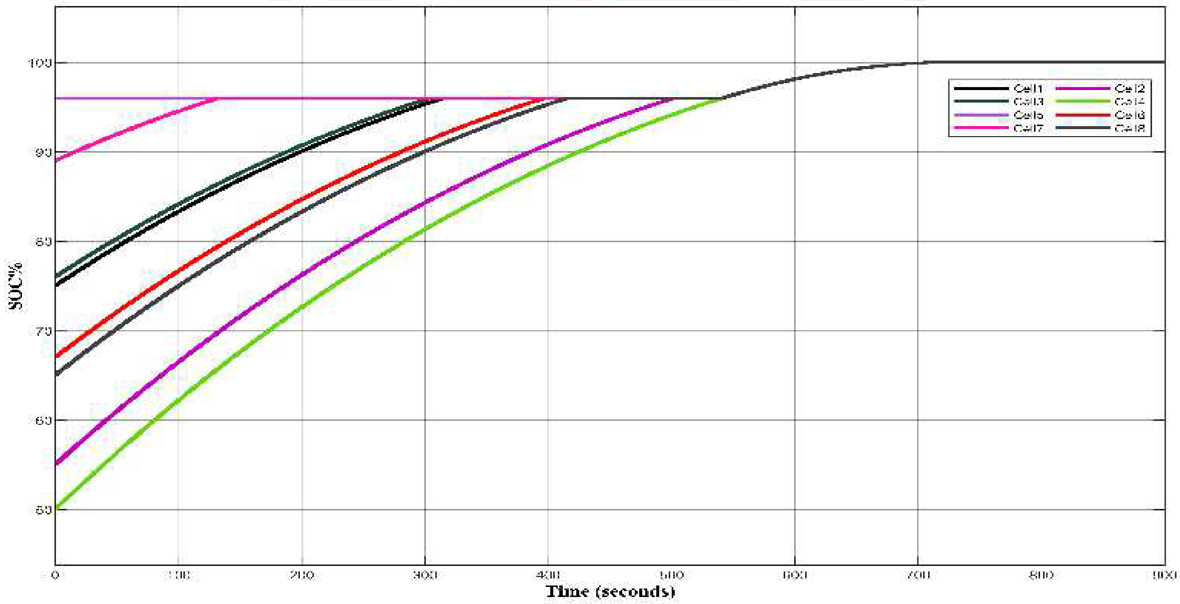


Fig. 4. Cell Balancing During Charging

Figure 4 depicts the simulation result obtained while charging with a DC Source of 40Volts. The maximum charged cell is chosen first, after which each cell in the string is charged up to that level, and finally all cells in the string are charged together until all are fully charged.

III. ACTIVE CELL BALANCING

The Active Cell Balancing Method [8] solves the problem of Charge Wasting in the Passive Cell Balancing Method. Instead of wasting charge through a resistor, here charge is transferred from a cell with more charge to a cell with less charge using a capacitor, an inductor, and a multi-winding transformer.

A. *Flyback Converter based Active Cell Balancing.*

As in passive cell balancing the charge is wasted through bleeding resistor so the cell balancing efficiency is low. Therefore, in this flyback converter [9],[10] based active cell balancing, multi-winding transformer is used to reduce the charge wastage. The primary winding of a multi-winding transformer is fed with the complete sum of voltage from both cells, and this voltage is spread evenly between both cells on the secondary side.

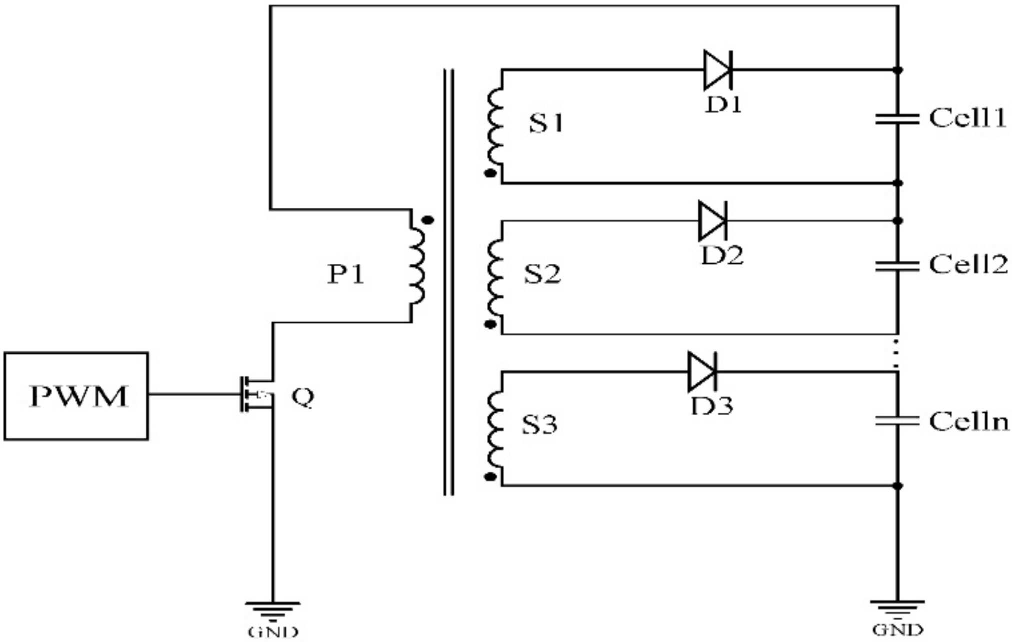


Fig. 5. Cell Balancing Flyback Converter

Figure 5 shows the simulation of Flyback converter-based method of active cell balancing. A transformer with a rating of 250VA is used in this simulation, which run at a frequency of 50hz. The voltages at the terminals are 73.5V:31.5V:31.5V. As a result, the turns ratio is 2:1:1, distributing an equal charge to both cells connected to the output terminal.

The cells connected to the output terminal have an initial voltage of 3.6V and 3.8V, respectively.

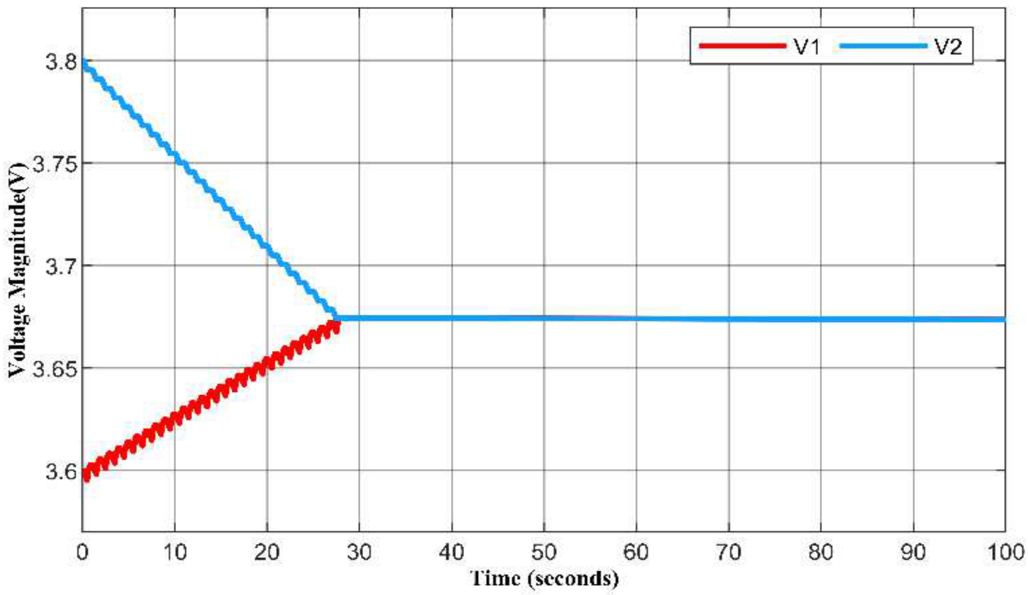


Fig. 6. Simulation Result of Flyback converter-based method.

The initial voltage across both cells is 7.4V. On the input side, this voltage is fed to the transformer. A MOSFET switch is connected to the transformer's primary terminal, and both cells are connected to the output terminal through the switch. The MATLAB function will compare the input voltages of both cells and gives output as 1 if they are not equal, and 0 if they are equal. The MATLAB Function's output is multiplied by the Pulse Generator's output. This signal is the pulse for the MOSFET connected to the transformer's primary terminal. When the anode voltage is greater than the cathode voltage at the output terminal, the diode conducts and charges the cell; when the voltages of both cells will at same level, the MATLAB Function provides 0 as an output, which turns off the MOSFET and opens the circuit at the primary side of the transformer.

Figure 6 shows the simulation result in which both cells have equal voltage of 3.67Volts

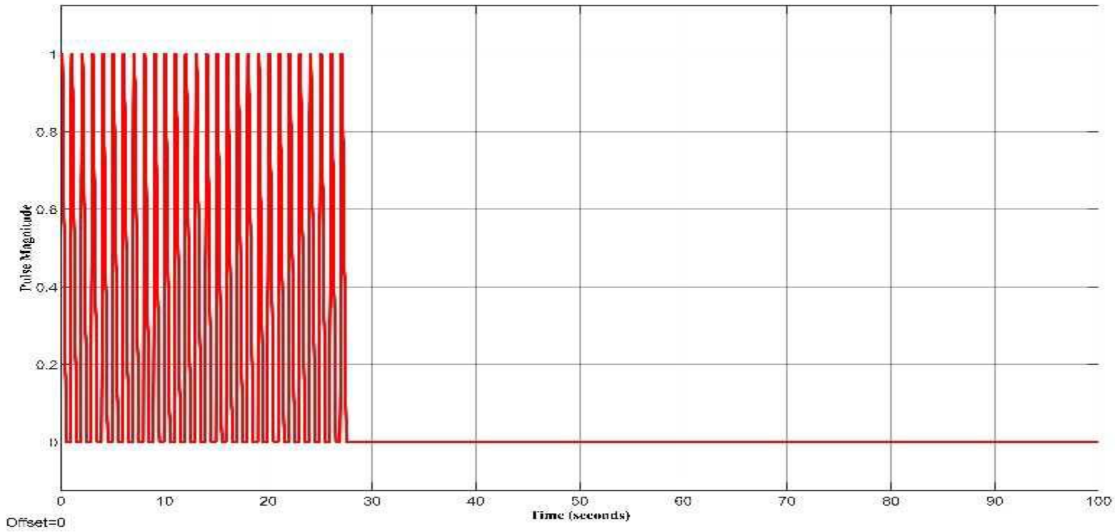


Fig. 7. Pulse given to MOSFET at Primary Winding

The pulse is high till the cell voltage of both cells are equal after that the pulse is low.

B. *Capacitor based Active Cell Balancing.*

This method requires n-1 capacitor and 2n switches for balancing where n is the number of cells that need to be balanced [11]. This method works both for charging and discharging condition.

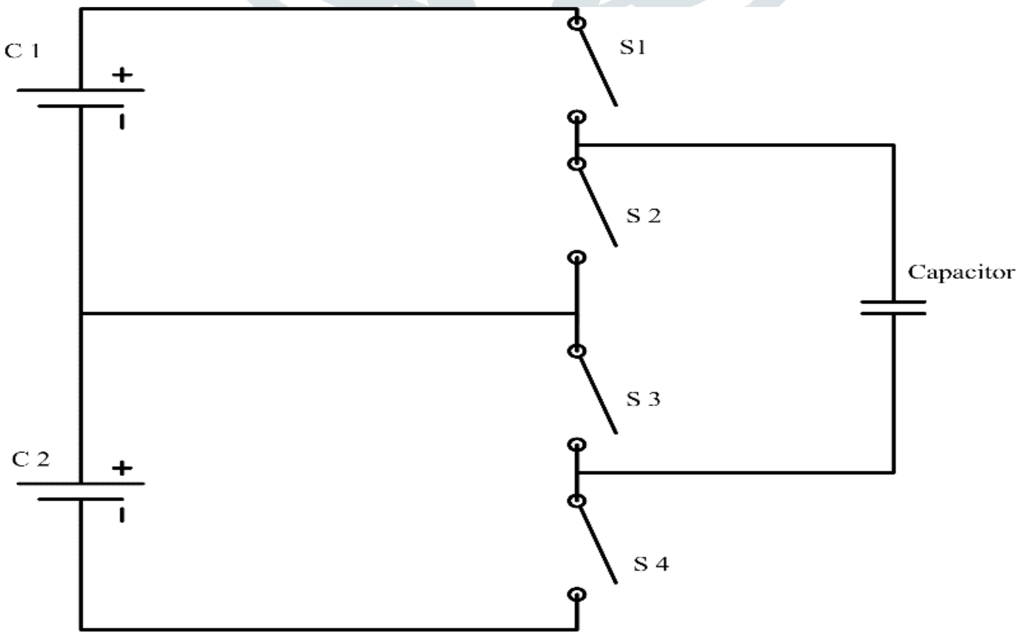


Fig. 8. Circuit diagram of switched capacitor balancing

As it operates in only two modes, it is a fairly easy technique for balancing the cell. that is in first mode switch S_1 and S_3 are closed and hence the capacitor is connected to cell C_1 and capacitor will charge until its potential becomes equal to cell C_1 after that some transition time is given and then switch S_2 and S_4 are turned on and now cell C_2 is connected across capacitor. Assuming that cell C_1 is highly charged as compared to cell C_2 then in this scenario the capacitor will charge the cell C_2 [8]. The main Problem in this balancing is it require very long time to balance the cell. This can be showed by taking an example. Suppose we are balancing two cells having voltage difference of 0.1V and the battery capacity of both cells are 10Ah. Now energy transfer in one cycle of switching is given by:

$$E = \frac{1}{2}C(V_{high}^2 - V_{low}^2) \tag{1}$$

$$E = \frac{1}{2}C(V_{high}^2 + V_{low}^2)(V_{high}^2 - V_{low}^2) \tag{2}$$

Also, the energy release in terms of SoC is given by:

$$E = SoC * Q * V_{nominal}$$

Suppose nominal voltage is the average of both V_{high} and V_{low}

Now comparing equation (1) & equation (2) we get

$$Soc = \frac{C}{Q}\Delta V.$$

Given battery is of 10Ah so Q=36000C.

We can choose any capacitance value, but high capacitance also means high resistance, which slows down the equalization process even more. For instance, let's take capacitance value as 1F. Now change in SoC in one cycle is given by:

$$\Delta SoC = \frac{1}{36000} * 0.1 = 3 * 10^{-6}$$

So, for voltage difference of only 0.1V the rate of change of SoC is very low, if the voltage difference will be very large value, then cell equalization time will go in hours' time.

However, this method is being modified to reduce cell equalization time, but another issue with this method is that it is very expensive due to the large number of switches required. [8].

C. *Inductor based Active Cell Balancing.*

Instead of using capacitor here inductor [13],[14] is used to shuttle the charge from one cell to another cell. The reason for using an inductor instead of a capacitor is that it requires n switches for every n cell, whereas a capacitor requires 2n switches.

In this methodology there is two steps in first step the switch S_1 is turned on and in this way the cell C_1 will charge the inductor afterward the switch S_1 is turned off and switch S_2 is turned on and in this way the inductor will charge the low voltage valued cell C_2 considering the cell C_1 is high voltage valued cell. In this technique the equalization time is more because consider there are four cells connected in series C_1, C_2, C_3, C_4. The lowest Potential value cell is C_4 and highest potential valued cell is C_1. So, to balance all the cell this method will first transfer the excess charge from C_1 to C_2 after that C_2 to C_3 and finally C_3 to C_4 so basically this method is just comparing the two adjacent cells and then transferring the excess charge from one cell to another cell one by one and in this long time is taken by inductor to balance all the cell at equal voltage. Figure 9 shows the convention block diagram of inductor-based cell balancing method.

However, another inductor-based balancing technique is widely used and has a shorter equalization time than the others. The cells are divided into groups [15] [18] and then balanced groupwise in this technique, which in turn reduces the time required for equalization. Here N-1 switches is required for every N cells

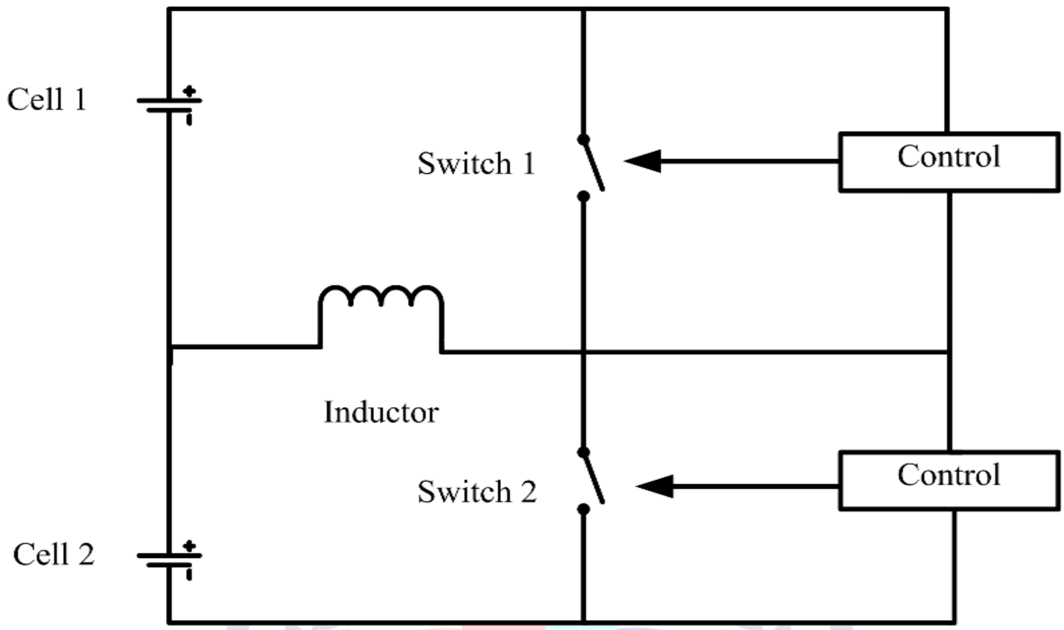


Fig. 9. Circuit diagram of Inductor based balancing

In this inductor-based balancing, cell is divided into groups like inductor L_1 will balance the cell1 and cell2 after that inductor L_5 will balance the group of cell1, cell2 and cell3, cell4 like on after that inductor L_7 will balance the upper half and lower half group of cells [10]-[12].

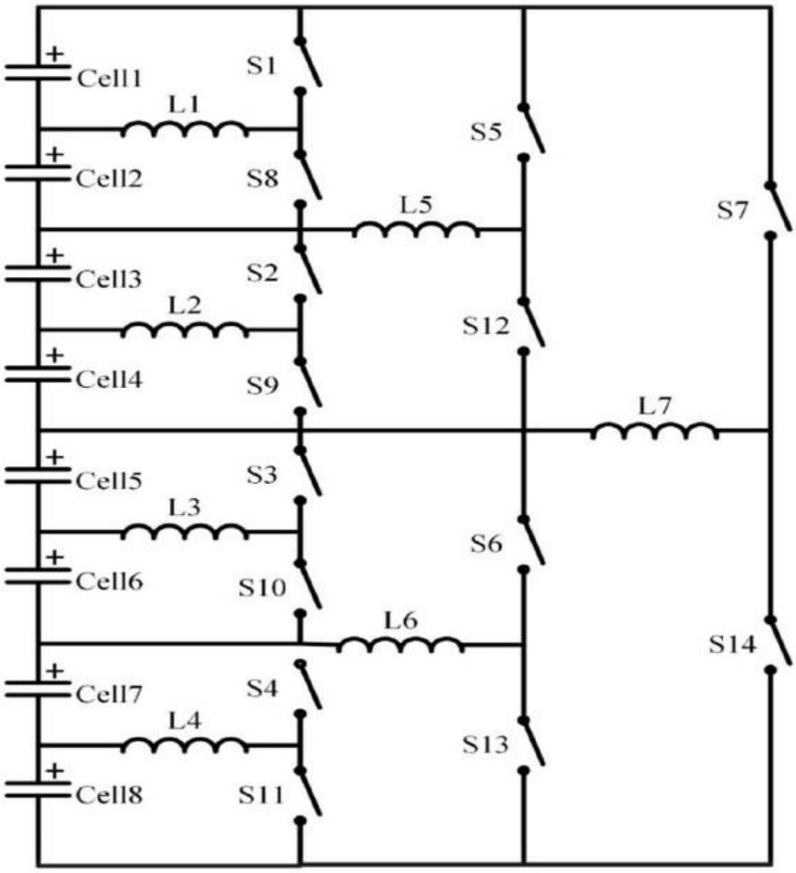


Fig. 10. Circuit Diagram of Balancing 8 Cells by Inductor

To balance the cells first switches $S_1, S_2, S_3, S_4, S_5, S_6, S_7$ are turned on to charge the inductor after that in next cycle switches $S_8, S_9, S_{10}, S_{11}, S_{12}, S_{13}, S_{14}, S_{15}$ are turned on to balance the adjacent cells.

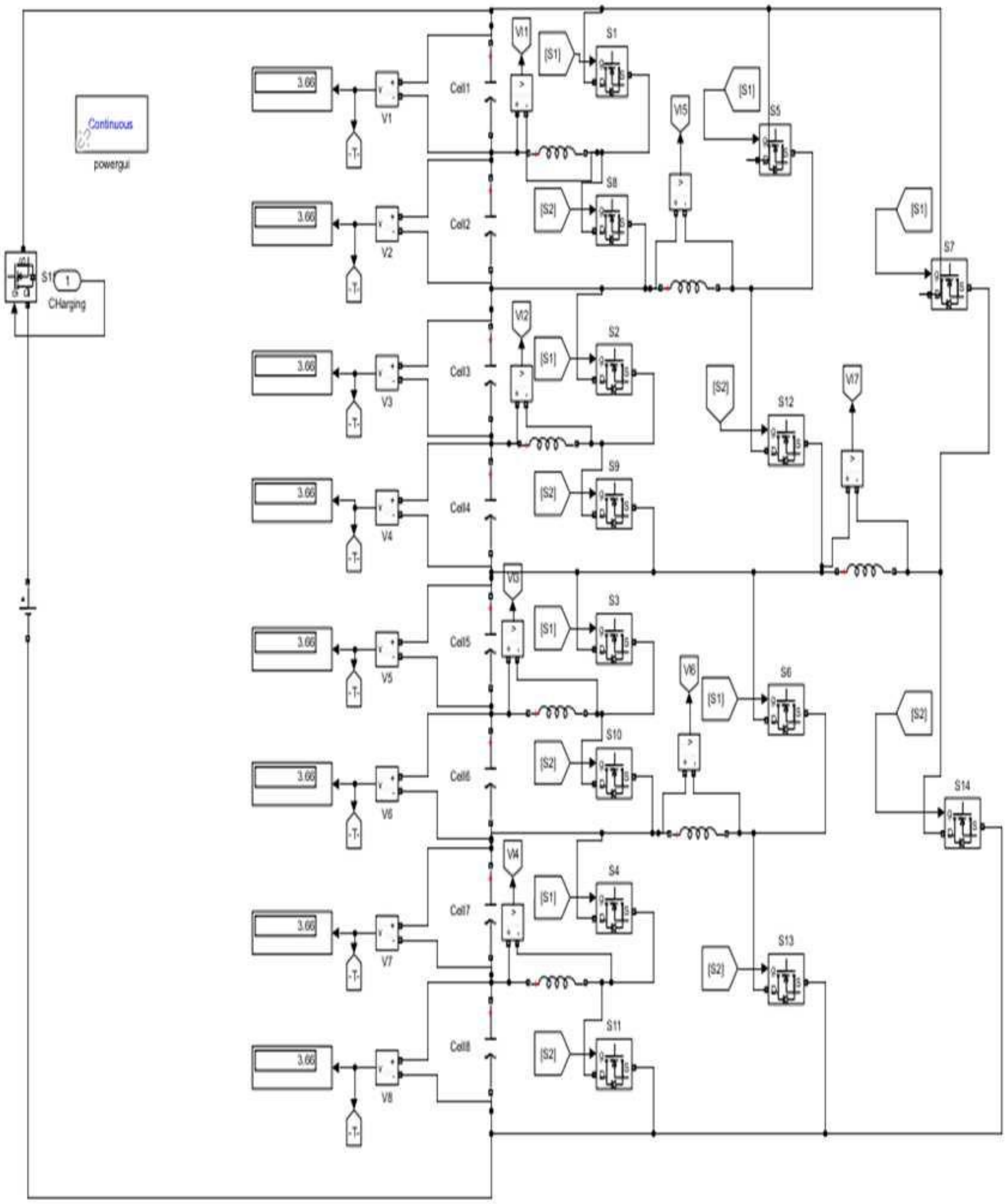


Fig. 11. Simulation to balance 8 cells

Here 8 capacitors [10] is connected which will behave as the cell [11] – [16] and the voltage of all are in the range of 3.0V to 4.2V. The value of each inductor connected is 10µH and the capacitance value is 50mF. A DC source of 30V is connected to charge the batteries.
Here MOSFET is used as switches and is operated at two frequencies of 50kHz and 250kHz with 50% duty ratio to see the losses while equalizing the cells.

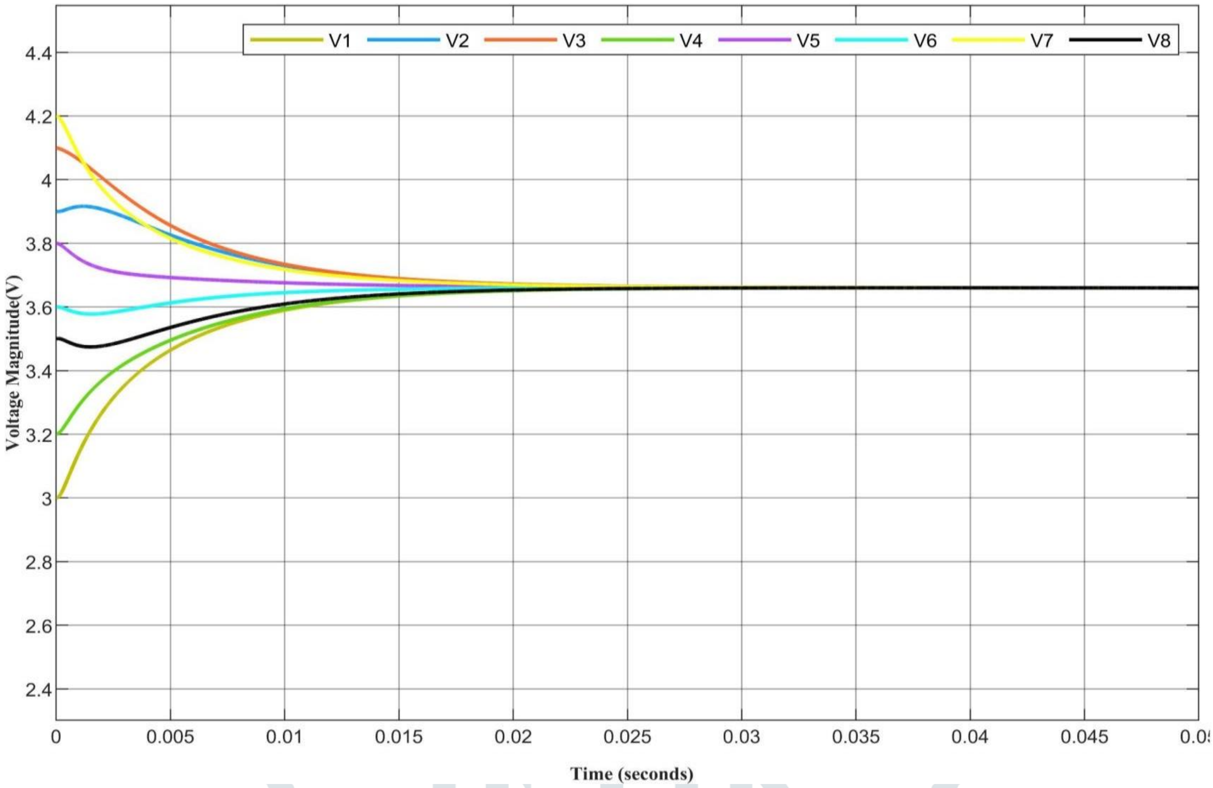


Fig. 12. When operated at 250kHz

When the battery pack is not connected to the DC Charging Source, the first simulation is conducted, and the voltage of the battery pack after balancing is the average of all cell voltages, which is 3.66V. After then, the simulation is repeated with a frequency of 50kHz.

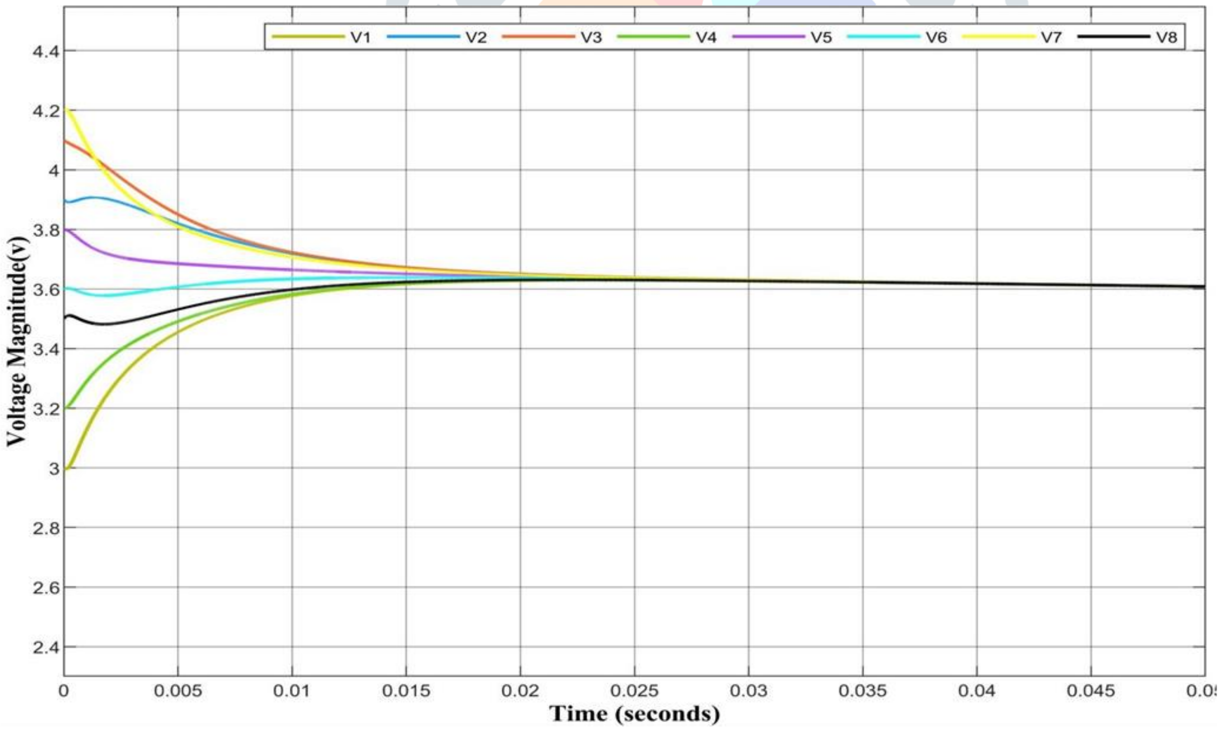
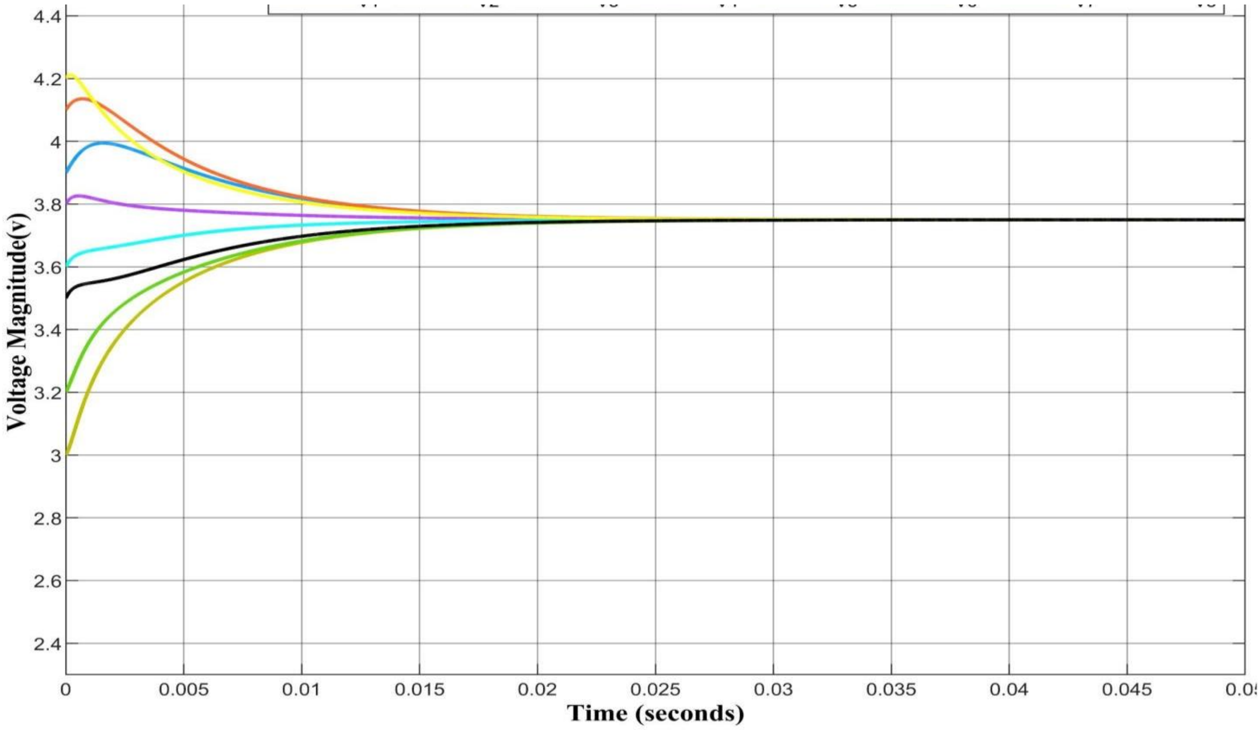


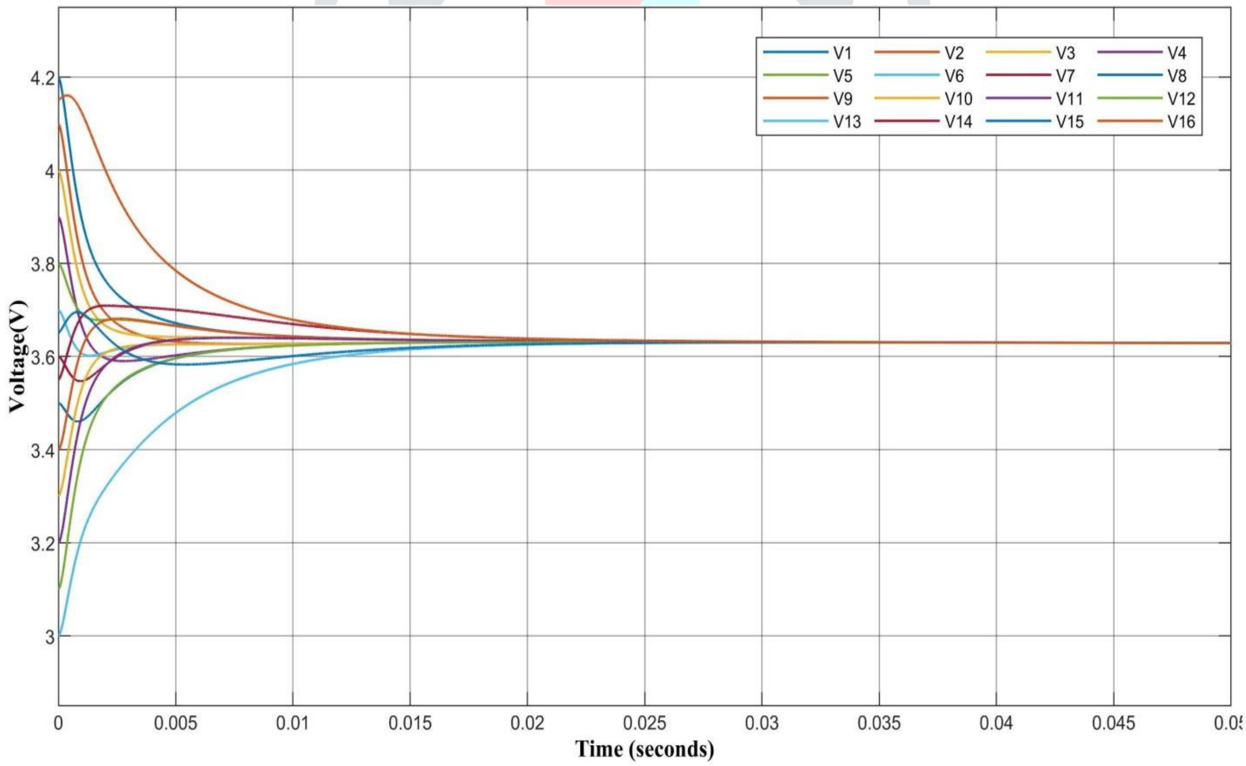
Fig. 13. Operated at 50kHz

As a result of the reduced switching frequency, we can detect a tiny drop in battery voltage. In the next simulation, a DC voltage source of 30 volts is connected to a circuit operating at 250 kHz, and the ultimate voltage value of the battery pack is found to be 3.75 volts.

Fig. 14. During Charging Mode

Fig.15. Simulation Result of 16 Cell balancing





The extended simulation result of 8 cell inductor-based balancing is shown in figure 15. With the help of inductor, here 16 cells are balanced in this simulation. The cell's voltage in the battery pack is in the range of 3.0V to 4.2V. The final voltage of each cell after the simulation is 3.629V, which is the average voltage.

IV. CONCLUSION

Different cell balancing techniques are examined and simulated in MATLAB in this paper. Each cell balancing techniques have their own set of benefits and drawbacks. Passive Cell balancing is the simplest and easiest to implement, but problem is the charge dissipation in the bleeding resistor in the form of I^2R losses, which will affect the circuit thermally. As a result, active cell balancing is used to minimize the charge loss during equalization. However, in Flyback converter based active cell balancing, there are losses such as core loss and copper loss, and in addition, to balance the larger number of cells, the amount of winding required increases, increasing the cost. Capacitor-based balancing is the next step, but the cost is high due to requirement of 2N switches for N cells and also the cell equalization time is very long. So, the next model is the inductor-based model, but the conventional one also requires long equalization time so to combat longer equalization time a new inductor-based cell balancing method is introduced, which divide the cell into group and then balances the cell group by group.

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