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CELL STABILIZATION TOPOLOGY IN BATTERY MANAGEMENT SYSTEM: FLYBACK CONVERTER METHOD.

Yash Vilas Chavan[1], Shubham Amodkar[2], Devednya Kaginkar[3], Shruti Naik[4] and Prof. Pragya Jain[5]
Student [1][2][3][4] Professor [5]
Electrical Department [1][2][3][4][5],
Atharva College of Engineering, Mumbai, India [1][2][3][4][5]

Abstract: A worldwide movement to tackle greenhouse gas emissions has emerged including efforts such as the Paris Agreement in 2015. To reduce the plunder of greenhouse gas emissions, it's mandatory to drive down energy consumption with the assistance of environmentally familiar energy resources and consumer products. In the wake of climate change, many people are turning towards EVs as a sustainable alternative to internal combustion engine vehicles. EV (Electric Vehicle) and HEV (Hybrid Electric Vehicles) contribute heavily in narrowing the carbon footprint of transportation systems. EV's have brought about a revolution in the utilization of li-ion batteries. As ever-increasing demand brings competitiveness in the market to manufacture an Electric Vehicle that could have a maximum range on a single charge, the need for efficient battery systems rises. Also in all EV topologies, the battery acts as a critical component. The reliability and safety of the battery can be improved by the deployment of an independent control platform, known as BMS (Battery Management System). Cell State Monitoring and Charge Balancing tasks should be fed into the BMS to ensure smooth, safe and reliable operation of the battery. The entire system can be endangered by the faulty operating conditions of the battery. Typically, in a BMS (Battery Management system) in order to balance cell SOC (State of Charge) passive balancing methods were used, which involved parallel shuttling resistors, not only were they inefficient but were harmful as they could produce heat while balancing and would in itself limit power delivering capabilities. Hence, a need for more efficient techniques which is the active cell balancing techniques in which efficiencies could theoretically be increased up to 90%. This paper offers a review of the Battery Management System by observing and evaluating the active cell balancing technique using a flyback converter in MATLAB – SIMULINK simulation.

Keywords: BATTERY MANAGEMENT SYSTEM (BMS); Active Cell balancing techniques; Flyback converter; Matlab Simulink.

NOMENCLATURE

V	Output Voltage (V)
D	Duty Ratio
N	Number of windings/turns
Δ	Delta - small change
R	Resistance (Ohm)
C	Capacitance (F)
L	Inductance (H)
I	Output current (A)
f	Frequency (Hz)

Subscript

o	Output side
s	Source side
m	Mutual
L	Inductor related

I. INTRODUCTION

Battery packs may consist of a very large number of cells stacked in series for higher voltage and parallelly for higher capacity and higher output current. Each individual cell needs to be maintained to safely operate in an optimal range of temperature and voltage. For this, a significant role is played by the BMS. Not only that, it performs various other functions such as SOH (State of Health), SOC (State of Charge), Cell Balance, network and information storage and transfer, etc. It is a real-time system and most of the tasks are carried out simultaneously.

It is desired that in the battery pack all the cells must be of the same model manufacturer, must have the same terminal voltage, cell capacity, power output and same internal chemistry. However, it is not always fulfilled due to external factors. As soon as the battery charges – discharges, the cells inside the battery packs charge to imbalance and thus inconsistency increases. This improper balance if not corrected for consecutive load times, leads to reduced life and efficiency of a cell and thus the whole pack.

Batteries being one of the most critical and expensive components of any electrically-driven transportation vehicle, it becomes very important to take considerable care in order to ensure reliability and safety. The BMS used in the EV's is very sophisticated as it handles various critical tasks simultaneously and accurately. Amongst various functions performed, cell balancing is the most pivotal task of a BMS.

When anyone cell in the battery pack exceeds the Start Balancing voltage, the BMS will begin the balancing algorithm for all cells[8]. The BMS will look for the lowest cell, then place a load on all cells which are more than the maximum difference in voltage above the lowest cell [3].

The BMS has a feature to prevent over-discharging any cell during balancing in the event of a defective or dead cell[6]. The minimum balancing voltage threshold enables the programmer to specify a voltage limit above which BMS cannot remove energy from a cell [5]. This feature protects the cells from overcharging and helps prevent the possibility of BMS removing the charges from alternating cells.

While the BMS is balancing, the balancing will pause every often so as to allow cell voltages to settle and to re-evaluate the balance of the cells in the pack. This is a normal part of the balancing algorithm and happens at set intervals. If the BMS unit itself is at an elevated temperature, the BMS will pause for a longer period of time to prevent overheating. To prevent a burn hazard, the BMS will not balance at all when the heatsink temperature is above 50°C.

1.1 There are two possible methods for cell balancing:

1. 1.1 Passive cell balancing.

This technique involves dissipation of the additional charge of a cell which is overcharged in a battery pack via a resistor. Although this technique is relatively easy to implement but is very inefficient as the extra charge in a cell is simply wasted. Moreover, this charge when passed through a resistor generates heat which is not desired as this may be hazardous and may affect the health of a cell pack in the long run.

1.1.2 Active cell balancing.

In this technique, the additional charge of an overcharged cell is passed on to the cells which are relatively undercharged. Due to this the energy is theoretically not dissipated at all making it much more efficient than the Passive Cell Balancing technique. As no energy is dissipated, heat produced is less which enables higher power charge transfer which in fact makes the process of Cell Balancing much faster. But with a catch, it is relatively complex and difficult to implement, making it an expensive option.

In this paper, we have attempted to accomplish active cell balancing by proposing a flyback converter circuit and lithium-ion batteries, the compilation results of which are demonstrated via Matlab Simulink.

Active Cell Balancing consists of the following main balancing categorizing components: 1. Cell to Pack, 2. Pack to Cell, 3. Cell to Cell, 4. Cell By-Pass. It can be further sub-categorized depending upon circuit – components used. Parallel shunting methods and modifications are primarily used to transfer charge from cell to cell. Changes in the equilibrium cycle can be determined through algorithms. Application and specifications of the battery pack is taken into consideration when specifying voltage specifications in the system. Components such as Capacitors and Inductors may extend the charging time and hence are ignored for utilization in larger battery packs. Generally, it is preferable to use a DC to DC converter to transfer higher values of voltage. The converters used for EV's are desired to be efficient, reliable, faster, cheaper and with minimal interactional working.

2. MATERIALS AND METHODS

2.1 Literature review

- SIMULATED SOLAR Assistance BATTERY Control System with Configuration Temperatures Control with Flybacks Converters Actives Cell Balance Circuits Coulombs Countings SoC Calculator Usings Matlabs Simulinks IEEE 2020 The book describes and introduces many other functions of BMS and SOC calculation and explains the probability of active cell balance for solar panels' battery storage. [1]
- Enhance Switching Patterns to ImprovesCells Balancing Performances in Actives Cells Balancing Circuits using Multi-Winding TRANSFORMERS 2020 IEEE. The manuscript explains the importance of BMS, battery model, cell balance and many other methods of cell balance. [2]
- Active cell balance for the lithium 2s ions battery packs using flyback converters and push-pulls converter. Kuzhivila Pannikottu Nivya, S K Deepa 2021 The book describes the active 2 cell balancing methods in detail, which helps us to understand and compare cell balance using a flyback converter in MatLab Simulink.[3]

II. METHODOLOGY

Active cell balancing using flyback converter method.

2.2.1 Flyback converter:

Flyback converter belongs to the family of buck-boost type DC to DC isolated converters which utilize a coupled inductor pair unlike that of a general AC transformer. Due to the reality that, unlike an AC transformer which directly transfers energy continuously, the flyback converter stores energy for a moment in its core which makes it practicable for low power applications (usually below 100W). By providing tapping out on the secondary side of inductors of a flyback converter, we can provide multiple outputs.

2.2.2 Principle of operation of a flyback converter:

Assuming position 1 is when the switch is closed i.e. MOSFET is ON and position 2 is when the switch is open i.e. MOSFET is OFF.When the switch is in position 1 (Fig. 2.2a), the primary side of the Flyback Converter is connected to a voltage source. MMF (Magnetic Field Flux) in the primary coil rises, storing electrostatic energy in the converter core. The voltage induced on the secondary side is of reversed polarity (i.e. of opposite nature - negative). Due to this, the diode is reversed biased (i.e. in a blocked state – no current passing through it). The secondary side filter capacitor transfers energy to the load if in case the capacitor is already charged. When the switch is in position 2 (Fig. 2.2b), the primary MMF which was stored in the transformer core flushes to the secondary side. Secondary Voltage is now of the positive polarity, which makes the diode forward biased and allows current to flow in the secondary circuit recharging capacitor and supplying the load.

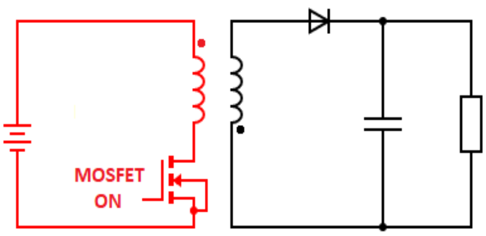

Fig 2.2 a) when MOSFET is ON

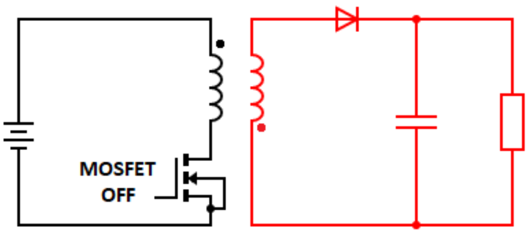

Fig 2.2 b) When MOSFET is OFF

2.2.3 Considerations when designing the flyback converter:

The turn ratio influences the peak primary and secondary currents as well as the duty cycle. Current in the primary winding will increase when the turn ratio rate is low and the duty cycle is shorter.

The transformers are usually custom-made since it is not possible to get a perfect turn ratio in the market. When it is difficult to obtain a perfect transformer with the required transformer turns ratio, the best thing is to start by looking for the available transformers and choosing what is closer to the desired ratings. The other component is chosen considering the slight difference that the transformer may introduce between the required voltage and the transformer.

2.2.4 Flyback Converter Design and Simulation:

A flyback converter can be made to work as a DC to DC converter or as an AC to DC converter. High switching speed and resemblance to a buck-boost converter are required in a converter (fig 2.4a).

The converter is simply a transformer with a few modifications such that the primary winding and the secondary winding do not store charge simultaneously at any given moment.

This balancing technique makes sure there is always electrical isolation between the primary side of the circuit and the secondary side of the circuit. The duty ratio in terms of Input, output voltages and the primary-secondary winding ratio is given (Equation: 2.4a).

$V_o = V_s * (D/ 1-D)*(N2/N1)$ …(Equation: 2.4a)

The capacitance can be obtained from (Equation 2..4b) with a fixed voltage ripple ratio.

Similarly, with a fixed current ripple ratio, the inductance (L) of the converter can be calculated from (Equation 3.4c).

$(\Delta V_o / V_o) = (D / R *C*f)$ …(Equation: 2.4b)

$L_m = (V_s * D) / (\Delta I_L)*f$ …(Equation: 2.4c)

In order to calculate the efficiency of the circuit, the above equations can be used along with assuming the following parameters such as Voltage Ripple = 5%, Current Ripple = 1%.

$\%Efficiency = (V_o*I_o /V_s*I_s) *100$ (Equation: 2.4d)

The flyback transformer is like two magnetically coupled inductors and therefore greatly different from the conventional transformer. The flyback is modified to store energy while the conventional transformer does not store energy. Hence, it is necessary that the primary and secondary inductor coils are magnetically coupled with necessary dot conventions. In addition, it works at high frequencies of around 50 kHz. Its core is generally made of ferrite and includes an air gap across which the energy is stored. The MOSFET is turned on and off by using a PWM signal.

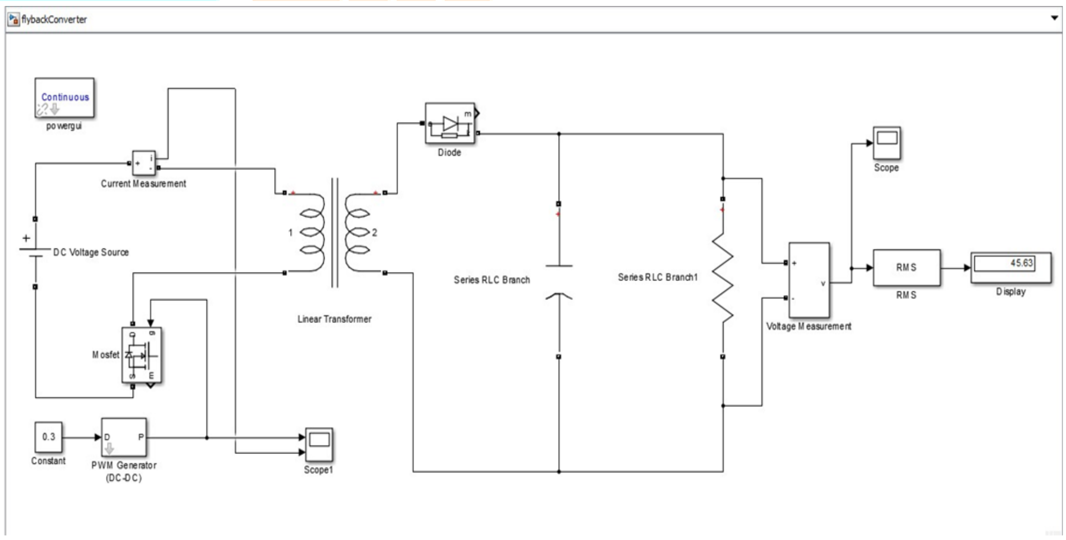

Fig 2.4.1 Flyback converter design simulation

The obligation cycle(D) of the converter is tracked down utilizing the main condition with the known essential and optional voltage. The voltage swell considered is 5% in condition 2.4b and this wave considered is 1% in condition 2.4c for polarizing inductance computation. To ascertain the proficiency of the converter these boundaries can be utilized.

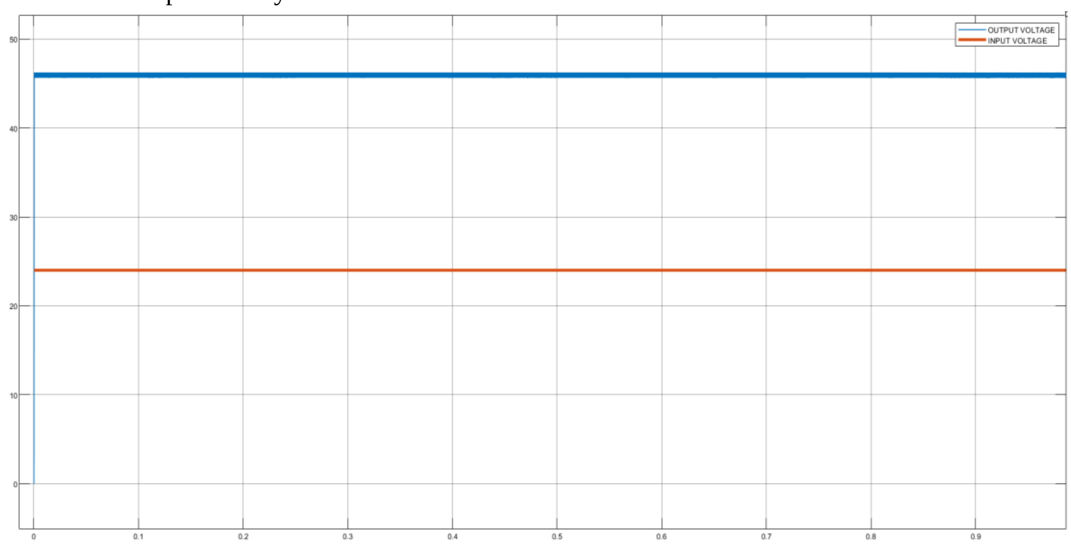

Fig 2.4.2 Output voltage and Input voltage

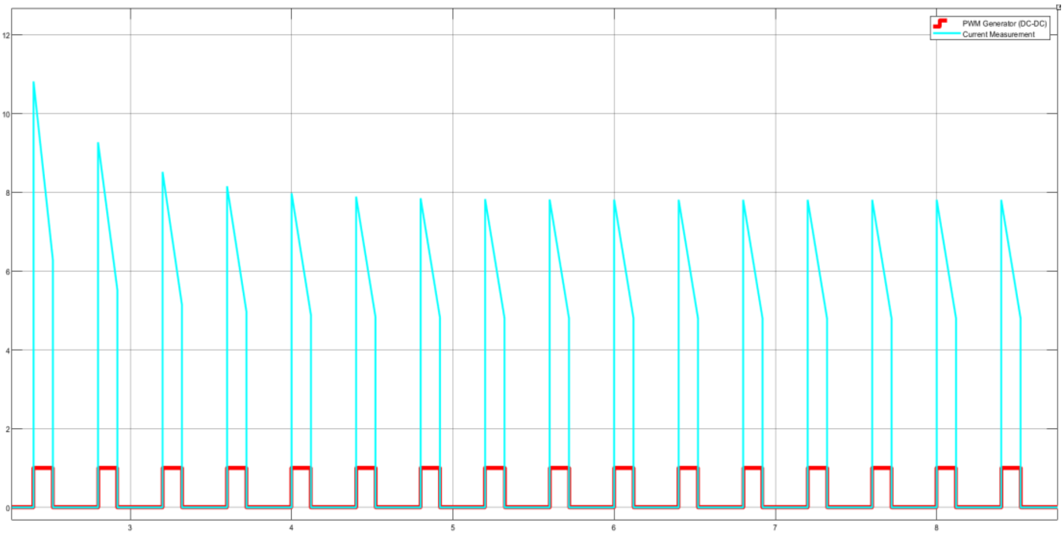

Fig 2.4.3 Output current and duty ratio

2.2.5 Advantages

- Output and Primary winding coil are isolated from each other
- Capable of supplying multiple output voltages, all isolated from the primary.
- Ability to regulate the multiple output voltages with a single control.
- For the Operation wide range of input voltages is used.
- A Flyback converter rarely uses any components when compared with different types of SMPSs.

2.3 Proposed Circuits

Considering the benefits, we have implemented an active cell balancing technique with the help of a flyback converter. The circuit diagram is displayed underneath.

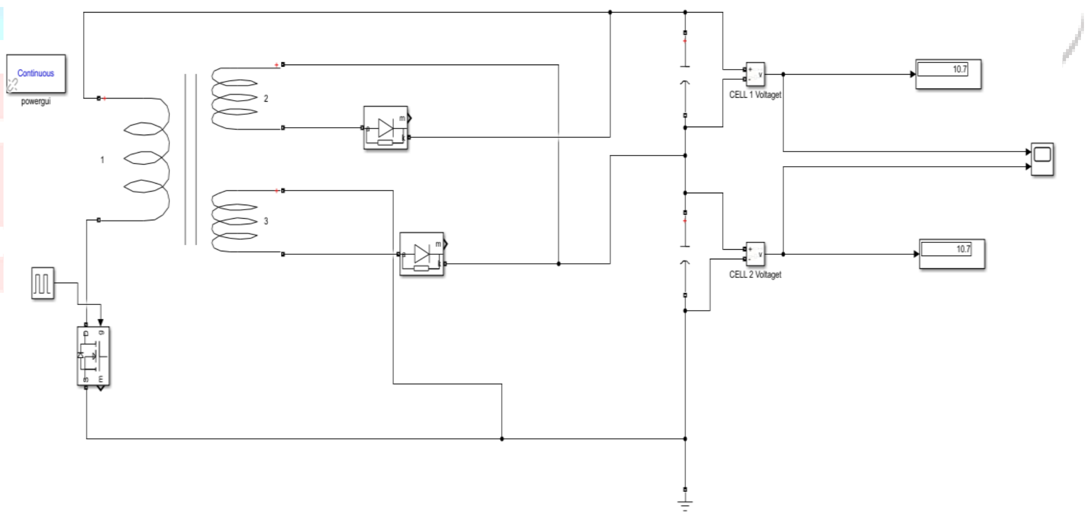

Fig 2.3.1 Capacitor voltage balancing

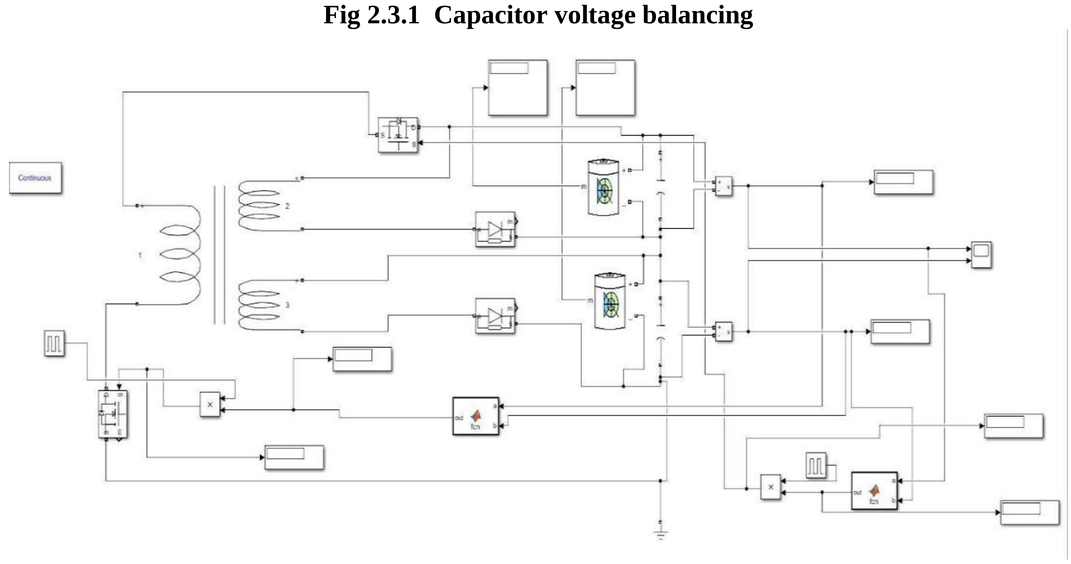

Fig2.3.2 Li-ion cell balancing

3. SIMULATION RESULTS AND DISCUSSION

Fig 2.4.1 demonstrates the working of a flyback converter, Fig 2.4.2 illustrates the input-output voltages and Fig 2.4.3 shows the output current and duty ratio. A change in the duty ratio can change the output voltage and current.

SOC determination: Cell voltage varies as a linear function of the state of charge (SOC) of a cell. Therefore, we consider cell voltages as measuring parameters for balancing.

Fig 2.3.1 shows the simulation of a multi-winding flyback converter used for balancing capacitors. The capacitors are assumed to be cells for faster charge transfer. And Fig 3.1 is the output graph. Hence the result presents the voltage equalization over time. Similarly, Fig 2.3.2 demonstrates the Matlab-Simulink simulation of the balancing circuit by connecting 2 li-ion cells in series with each other on the secondary side but with a parallel winding of the flyback converter connected via diode across each cell and Fig 3.2 concurs the corresponding output graphs. Results show voltage equalization over time. Hence it can be concluded that cells are balanced.

Discussion:

Although the simulation is performed for over two cells the balancing technique can be scaled to fit a large number of cells. Depending upon the cell voltages suitable flyback converter of a specific rating should be considered. Also by varying duty ratio voltages can be increased - decreased according to the need this feature is essentially important when balancing cells under different atmospheric conditions, for example, if the ambient temperature is low large current can be flown through the circuit safely without causing any harm, but if the ambient temperature is high, we need to limit the amount of current flowing through the circuit to prevent cell packages from being maintained at required temperatures. Besides balancing the SOC of cells, the capacitor can also be used as an additional energy source to provide traction power and reduce the working time of low SOH cells or high-temperature cells, increasing the amount of battery usable energy as well as extending the battery lifetime. The thermal efficiency of batteries should be taken into consideration. Also, before implementing this technique on large scale, the feasibility of using a flyback converter for cell balancing should be considered, as with large numbers of cells to balance the cost of components rises and so does the complexity of wiring.

Future scope: The cell equalization carried out on the voltage level of the cell is limited as it relies on large approximations given that the decimal values are being rounded off. Hence an improvised version should take several more parameters into account to measure the precise value of cell SOC (State Of Charge) such as the coulomb counting method. Moreover, a smart mechanism can be incorporated to change the duty ratio of the flyback converter in order to restrict the cell pack below critical temperatures when the ambient temperature is high. As the duty ratio remains low the current flowing through the circuit will be lower, as a result, balancing the temperature will not rise significantly.

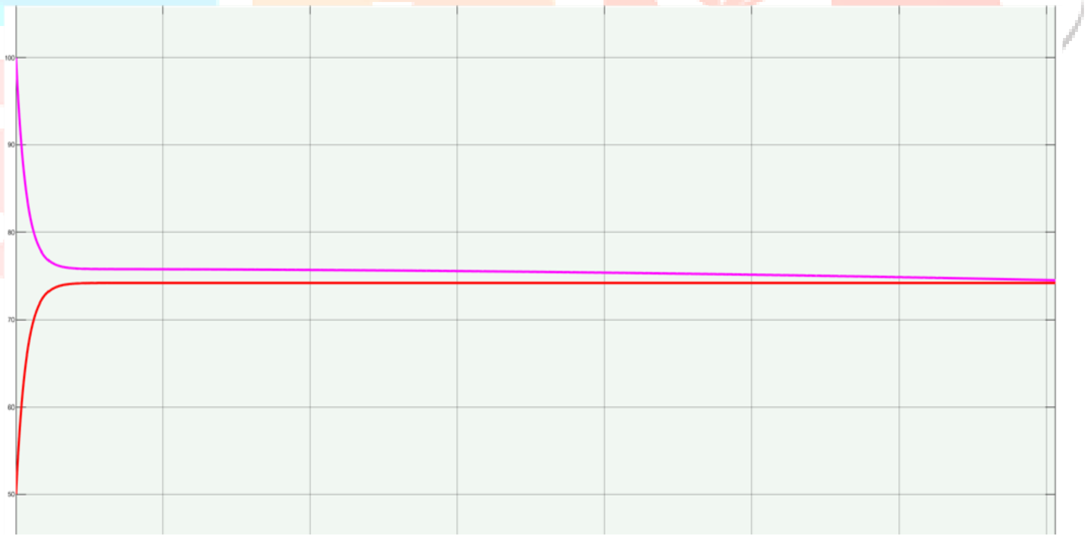

Fig.3.1. Scope Of Balanced capacitor Voltage

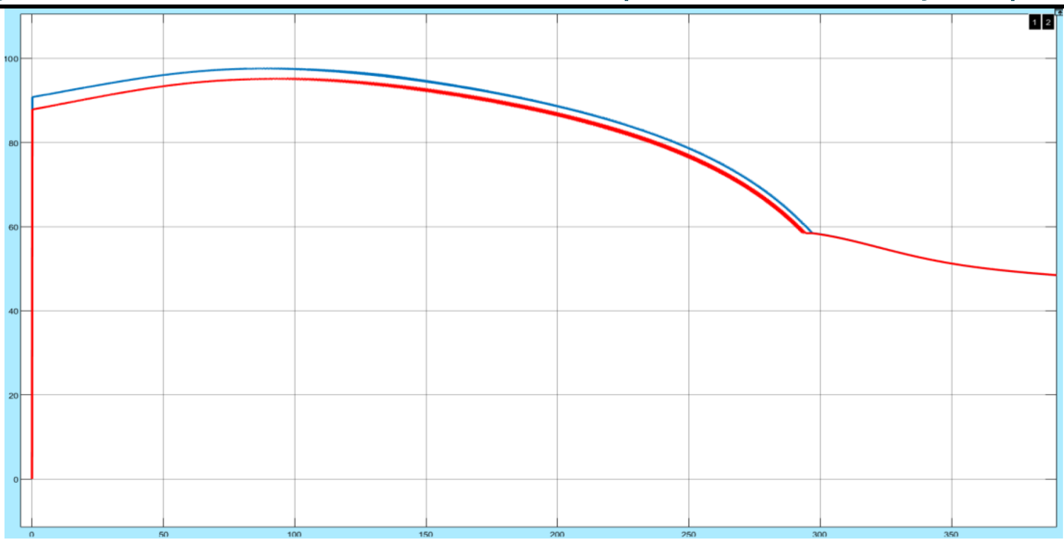

Fig. 3.2. Scope Of Balanced Li-ion cell Voltage

Table 1. Proposed circuit parameters

Parameter name	Value(unit)
Capacitance CELL1 CELL2 Frequency Duty ratio	1 microfarad 87% SOC 50% SOC 1kHz 0.5

CONCLUSION

The balancing performance of the suggested active balancing method using a flyback converter has been proven with the help of Matlab Simulink simulations. The improvement of battery efficiency by utilizing this new topology needs further confirmation with more experiments. What's more, the functions of this topology can be further developed when battery thermal performance and cell state of health (SOH) are taken into consideration.

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