# Review for Algorithm Model of Switched Shunt Resistor Passive Balancing Technique for Battery Management System

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***Abstract*- The lithium-ion batteries are specially designed for high power and high energy applications. Battery packs consists of lithium-ion cells connected in series. Lithium-ion cells are not identical due to manufacturing process and environmental factors. Cell unbalancing is the most common reason behind the working failure of battery packs at their possible maximum efficiency. In order to make theses battery packs more efficient and reliable for applications, it is necessary to balance them more frequently. The battery pack management system (BMS) is comprises of cell balancing techniques. This article presents methods to execute algorithm based on theory that continuously monitor state of charge (SOC), cell terminal voltage and available power. This article reviews algorithm for passive cell balancing using switched shunt resistor method.**

***Index terms*- battery management system (BMS), lithium ion batteries, passive cell balancing**

## I.INTRODUCTION

The commercially available lithium-ion cells are rated at 4.2V and 2.2Ah capacity but applications such as electric vehicles, hybrid electric vehicles, power banks, and portable electronic devices etc. demands higher voltage than its nominal voltage. In order to achieve required voltage level, designers connects number of cells (usually in series) to form a battery pack. This arrangement brings many issues and thus battery pack does not work on their possible efficiency.

Cell imbalance is the combined result of many factors broadly classified as internal factors and external factors. Internal factors such as, Due to manufacturing variance, cells in the same battery packs have slightly different capacities (tolerance ranging from 1% to 10%) and operate at may be different level of state of charge (SOC), different columbic efficiency. Alongside external factors such as change in temperature and variation in internal resistance causes a battery pack unbalancing. The above reason shows that it is highly impossible and far fetch to prevent cell from unbalancing during operation.

An unbalanced battery pack can result in severe issues such as thermal runaway, cell degradation, and incomplete charging of a battery pack. These disadvantage makes it mandatory to implement cell balancing process in order to maintain efficiency and safety.

Cell balancing is not required in battery pack consisting a cells connected in parallel as they are self-balancing. Practically battery packs used in real time applications consists of cell strings connected in both series and parallel so cell balancing becomes a primary part of BMS.

Cell balancing is the process of maintaining terminal voltage of each cell in the battery pack at same value to achieve maximum efficiency of the battery pack. Cell balancing techniques are broadly classified as:

1 Passive cell balancing.

2 Active cell balancing.

These cell balancing techniques are further divided into different categories as shown below. (figure.1)

The passive cell balancing topology drains energy from cell having more charge and transfer it to the cell having lower charge through a passive component such as resistors in the form of heat so that all cells could charge to their maximum SOC.

The active cell balancing topology removes charge from higher energy cell and deliver it to the cell with lower charge. During this process, energy is stored in active element such as capacitors, inductors, DC-DC converters.

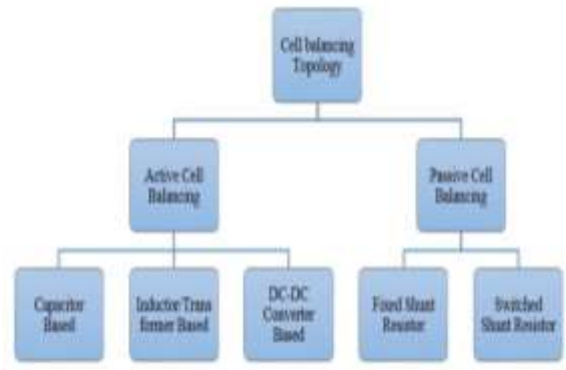


Figure.1 Classification of Cell Balancing Methodology

The ultimate goal of this article is to presents battery management system (BMS) algorithms based on switched shunt resistor circuit (passive balancing system) and hybrid pulse power characterization (HPPC) power limits estimation.

## II. BATTERY MANAGEMENT SYSTEM OVERVIEW

Depending upon the task to be performed different BMS configurations has been proposed till date, but the basic idea behind BMS is same. The basic task of a Battery Management System (BMS) is to ensure that best possible use is made of the energy inside the battery pack and the risk of damage to the battery is prevented. This is achieved by monitoring and controlling the battery's charging and discharging cycle.

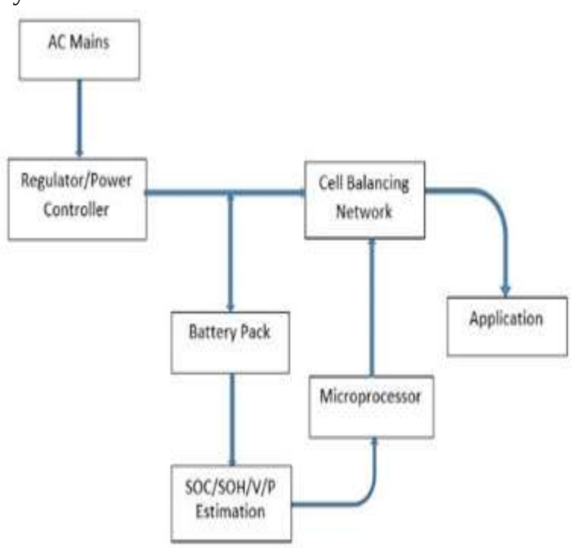


Figure.2 Block Diagram of General BMS

BMS controls the battery operation by cell balancing and limits estimation. Balancing or equalizing is the process of modifying the level of charge in cells on a cell-to-cell basis. Different criterions are used to balance a battery pack.

Two methodologies are extensively used to enable balancing activity:

1 SOC measurement: The pack is considered to be balanced when SOC is within ΔSOC of each other.
2 Voltage measurement: The pack is assumed to be balanced when voltage level of each cell is within ΔV of each other.
3 Total available energy: If cell holds same total or available energy then pack is decided as balanced.

The next important task is to determine when to balance a battery pack. Three possibilities of balance activity are listed below:

1 On charge: Irrespective of the pack condition, it dissipates charge in cell whenever plugged in.
2 Continuous charge: This technique is used for fast balancing and to maximize the pack power.
3 Predictive charge: It balances the pack when balancing is needed, depending upon the trigger points of ΔSOC, ΔV and available energy level.

On charging balancing is simpler and cost efficient as compared to other balancing modes. Predictive charging could be more efficient but equally complex and costly.

## III. ALGORITHM TO SIMULATE BATTERY PACK OF ESC CELL MODEL

The ultimate aim for designing this code is to examine the battery packs having random cell characteristics. The sole purpose is to see how frequently we might expect the battery pack become unbalanced after multiple charging-discharging cycles. This is most important task of the BMS in order to determine how quickly a pack needs to be balanced. Certain parameters such as temperature, capacity, resistance, self-discharge, coulombic efficiency and leakage current.

1. Temperature:
- Uniform: It takes the temperature of all cells in the battery pack at $25^0$C.
- Random: It takes the temperature of all cells in battery pack within $25^0$C to $27.5^0$C.

2. Capacity:
- Standard: It takes nominal capacity value from ESC cell model for respective cell model.
- Random: It modifies by adding -0.25 Ah to +0.25 Ah to nominal capacity of each ESC cell model.

3. Resistance:
- Standard: It takes the value of resistance from ESC cell model for corresponding temperature.
- Random: It takes uniform random values between -0.5mΩ and 1mΩ to resistance from ESC cell model.

4. Self-Discharge:
- On: Discharge resistance is calculated as-

$$Rsd = \{[(-20+0.4T_{sd})\times SOC] + (35- 0.5\times T_{sd}) \times 10^3\Omega$$

Where,

Self-Discharge Temperature $(T_{sd}) = T+T_{random}$
($T_{random}$ is distributed between $-5^0$C to $+5^0$C)

5. Coulombic Efficiency:
- Ideal: It takes coulombic efficiency to be 100%
- Random: It takes coulombic efficiency of each cell to be uniformly distributed between 99.7% to 99.9%

6. Leakage Current:
- Uniform: It places 10mA load on each cell.
- Random: It places Uniformly distributed load between 10mA to 12mA

The following flowchart (Figure.3) explains the code designed to estimate battery pack condition and SOC spread within the given charge-discharge cycles

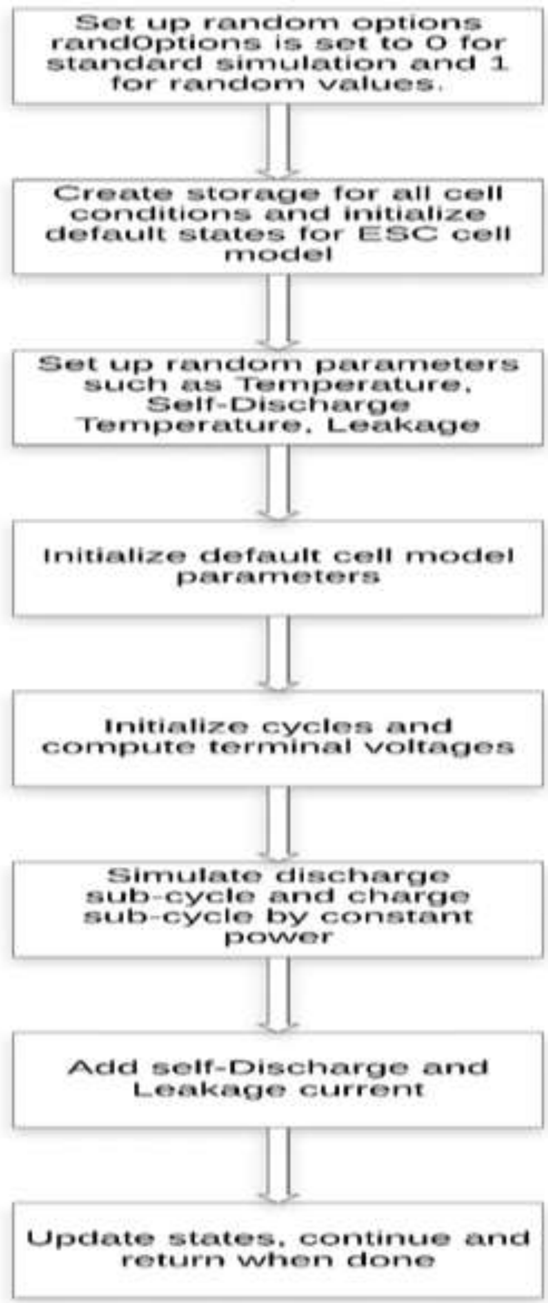


Figure.1 Algorithm Flow Chart for Simulation of Battery Pack with ESC Cell Model

## IV. SIMULATION RESULT

In this section of article, a simulation result of battery pack performance is represented using proposed algorithm. This code plots histogram of relative frequency of end-of-charge frequency after the completion of multiple discharge-charge cycle. This output can be used to visualize SOC and its overall distribution.

Four (4) battery packs consisting twenty five (25) lithium ion cells having a capacity of 4.2V and 2.2Ah each, are simulated for 400 discharging-charging cycles at 'Random' temperature, capacity, self-discharge, coulombic efficiency and leakage current. The simulation output is as shown below (figure.4). From simulation result for the assumed scenario, it can be concluded that $SOC_{min}$=60% and $SOC_{max}$=99.7% giving a SOC spread of 39.7%. Same code can be simulated to determine SOC spread for different number of cycles and under different circumstances.

The SOC estimation error is assumed to be 0.3% during the charging process and 1.4% during discharging process based on the pack model.

It is very difficult or almost impossible to determine the internal parameters such as SOC, SOH, etc. during running span of battery pack, because these internal

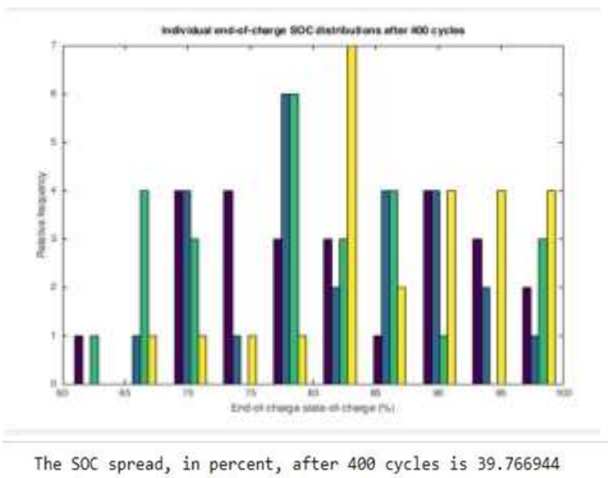


Figure.4 Output Result of Algorithm for ESC Cell Model Simulation

## V. PASSIVE CELL BALANCING USING SWITCHED SHUNT RESISTOR

Passive cell balancing is simpler low cost and most commonly used balancing topology as compared to active cell balancing method. This method works on a principle in which, cells with higher energy level are discharged through passive electronic components such as resistor as heat until charge matches with cells of lower energy level. The major drawback of passive cell balancing is, energy is not distributed across the cells in battery pack rather it's being wasted in the form of heat.

Passive cell balancing using switched shunt resistor circuit consists of a resistors connected in parallel to each cell, controlled by the parameters such as SOC, SOH, terminal voltage of cells, available power etc. Total number of balancing circuits depends on the total number of cells in the battery pack. For 'n' cells, 'n' number of balancing circuits are required. The schematic circuit diagram of switched shunt resistor is as shown in the below. (figure.5)

Variables are heavily dependent on discharging-charging cycles, temperature and other parameters. We don't have any sensors or IC's available commercially which can directly determine SOC, SOH, available power. As SOC has direct relation with terminal voltage of the cell, we can balance the battery pack depending upon voltage differences of cells. The output of this model can be used to trigger the balancing algorithm, depending upon the decrease in battery capacity for repetitive number of discharging-charging cycles under certain conditions, which can helps to predict the battery life as well. Integration of this algorithm with battery packs can eventually leads to the concept of smart battery as it offers the ability of self –monitoring.

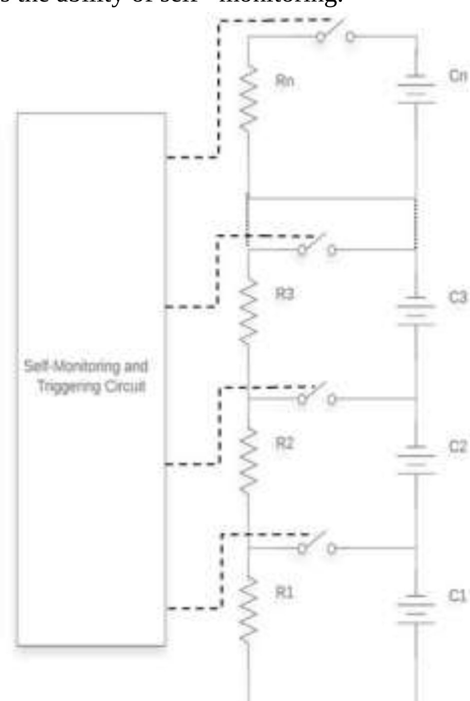


Figure.5 Passive Cell Balancing Using Switched Shunt Resistor Circuit

The value of resistor is chosen such that the leakage current flowing through them should be two to ten times bigger than leakage current through cell. The important factors which plays vital role to determine magnitude of bypass current to balance a cell.

a. SOC spread
b. Cell capacity
c. Desired balance time

The bypass current is then determined using the formula shown below:

$$I_{bypass} = \frac{SOC\ Spread \times Cell\ Capacity}{Desired\ Balancing\ Time}$$

Depending upon the magnitude of bypass current and battery pack power a compatible resistor is selected for balancing circuit.

$$R_{balance} = \frac{Cell\ Terminal\ Voltage}{By\ Pass\ Current}$$

Apart from this condition, the magnitude of balancing resistor should not exceed than maximum limits of cell balancing power or battery balancing power. This power limits are determined by either using terminal voltages, EKF (Extended Kalman Filter), SPKF (Sigma-Point Kalman Filter), HPPC (Hybrid Pulse Power Characterization). This methods are already explained and analyzed in other books, research papers and review papers. Power limit calculation is itself a vast topic for cell balancing and hence it does not comes under the scope of this article.

## VI. CELL BALANCING USING SWITCHED SHUNT RESISTOR ALGORITHM OVERVIEW

An important decision to be made during BMS and cell balancing is, when to switch ON the bypass switch. Different algorithms are studied and reviewed earlier out of them, SOC & cell terminal voltage based algorithms are simplest. Cell balancing algorithm can be made more complex by implementing feature of balancing on charge only and at high state of charge only. This optimizations are complicated to implement due to complex logic. This optimization can make the circuit costlier and might increase the simulation period due to complexity.

The flow chart of algorithm for switched resistor cell balancing is shown below. (figure.6)

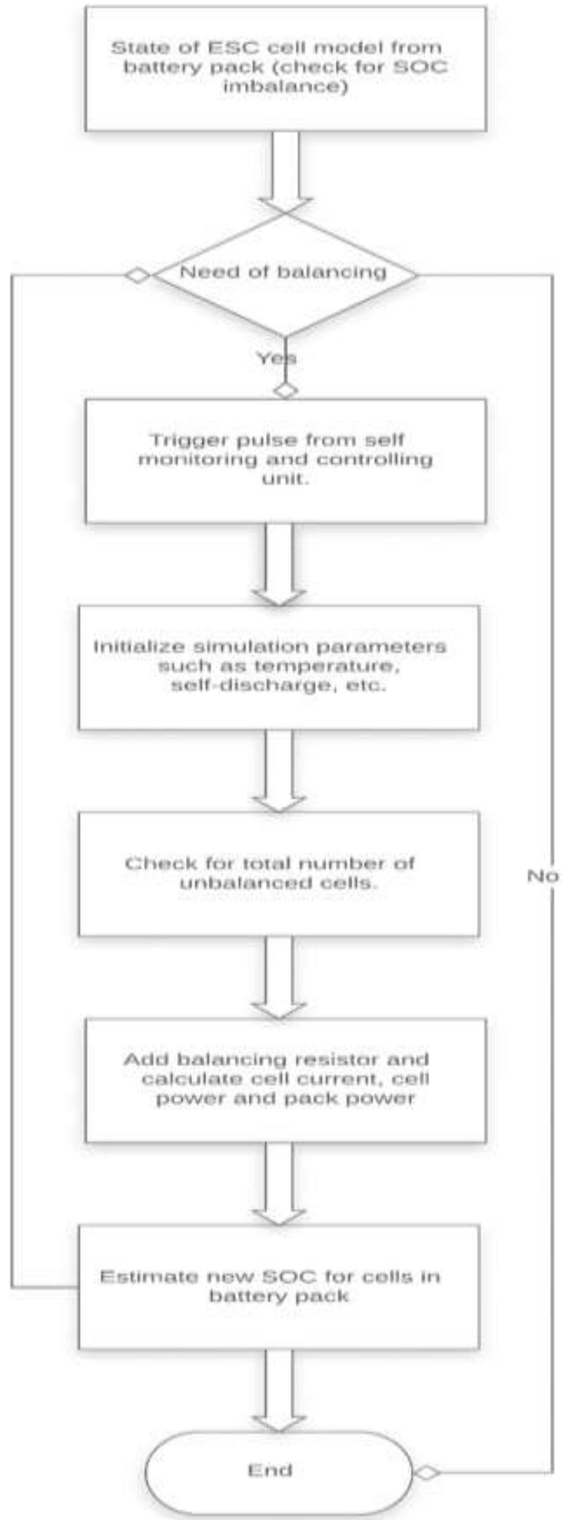


Figure.6 Flowchart of Algorithm for Passive Cell Balancing Using Shunt Switched Resistor

The input of passive cell balancing algorithm is driven out from output of the ESC cell model states simulation which was performed earlier. This simulation determines the total number of unbalanced cell through histogram of SOC spread of all cells in the battery pack. SOC spread and change in cell terminal voltage triggers the balancing circuit. Triggered pulse received from self-monitoring and controlling unit turns bypass switch on. This switching action causes completion of circuit by keeping balancing resistor in parallel to the cell. The value of balancing resistor is the most important factor of this algorithm. Balancing resistor determines the quality of cell balancing procedure. Now excess charge from cell with higher energy level starts dissipating through the balancing resistor and this excess energy is lost in the form of heat until all cells in a battery pack matches the identical energy level. Again, new SOC level is estimated to determine degree of imbalance, if all cells from battery pack attains equal energy level, self-monitoring and controlling unit passes another trigger pulse in order to turn OFF bypass switch.

## VII.SIMULATION RESULT

A simulation output for the battery pack balancing using proposed algorithm is represented in this section of the article.

Code plots the histogram of all cells in the battery pack to visualize SOC dispersion across the battery pack. As code proceeds it shows number of hours and completed and number of remaining cell to be balanced. The code also plots four different graphical visuals as listed below:

1 Total pack power Vs Time
2 Maximum cell balancing power Vs Time
3 Post balancing SOC spread
4 Cell terminal voltage during balancing.

A same battery pack which was modelled earlier, consisting of 100 cells (4 packs with 25 cells each) of capacity 4.2 V and 2.2Ah are simulated with above algorithm for 'Random' balancing parameters and balancing cell of 174.5 Ω. The value of balancing resistor is decided for keeping maximum pack power as 10W and individual cell power of 0.1W. The output is shown below

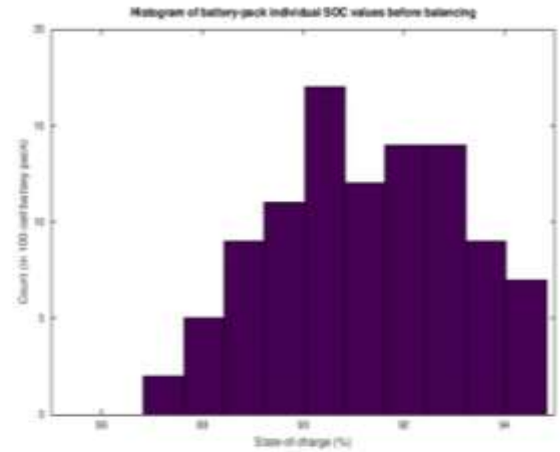


Figure.7 Graphical Output of Unbalanced Cell Data

```
Completed 1h balancing (98 "unbalanced" cells remain).
Completed 2h balancing (96 "unbalanced" cells remain).
Completed 3h balancing (94 "unbalanced" cells remain).
Completed 4h balancing (92 "unbalanced" cells remain).
Completed 5h balancing (89 "unbalanced" cells remain).
Completed 6h balancing (84 "unbalanced" cells remain).
Completed 7h balancing (80 "unbalanced" cells remain).
Completed 8h balancing (77 "unbalanced" cells remain).
Completed 9h balancing (70 "unbalanced" cells remain).
Completed 10h balancing (63 "unbalanced" cells remain).
Completed 11h balancing (58 "unbalanced" cells remain).
Completed 12h balancing (52 "unbalanced" cells remain).
Completed 13h balancing (48 "unbalanced" cells remain).
Completed 14h balancing (43 "unbalanced" cells remain).
Completed 15h balancing (37 "unbalanced" cells remain).
Completed 16h balancing (33 "unbalanced" cells remain).
Completed 17h balancing (29 "unbalanced" cells remain).
Completed 18h balancing (24 "unbalanced" cells remain).
Completed 19h balancing (18 "unbalanced" cells remain).
Completed 20h balancing (13 "unbalanced" cells remain).
Completed 21h balancing (10 "unbalanced" cells remain).
Completed 22h balancing (7 "unbalanced" cells remain).
Completed 23h balancing (4 "unbalanced" cells remain).
Completed 24h balancing (3 "unbalanced" cells remain).
Completed 25h balancing (2 "unbalanced" cells remain).
During balancing, maximum pack balancing power was 9.452889W (should be less than 10W)
During balancing, maximum cell balancing power was 0.096641W (should be less than 0.1W)
Time to balance was 25.474444h (should be less than 29.5h)
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Figure.8 Algorithm Output of Time Estimation for Battery Pack Balancing

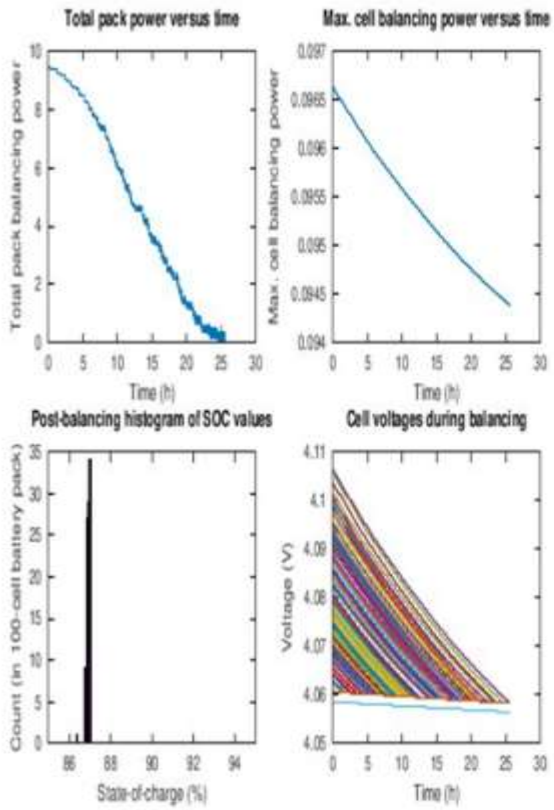


Figure.9 Graphical Output of and Post Balancing Battery Pack Parameters

## VIII. CONCLUSION

Battery cell balancing is the key factor of BMS in order to improve the pack life, minimize maintenance and to extract maximum efficiency out of it. This article reviews the algorithm for passive cell balancing using controlled shunt resistor topology using SOC spread estimation. Different types of algorithms for cell balancing are analyzed and reviewed earlier but many of those cell balancing algorithm were unable to identify the number of unbalanced cells and degree of imbalance across the cells in a battery pack. Though this proposed algorithm takes large time to simulate but the degree of imbalance was successfully simulated using this algorithm through graphic visual. A graphical data is summarized at the end to summarize whole cell balancing procedure and analyze post balancing scenario of battery pack. This algorithm approach provides flexibility to create a battery pack as per requirement.

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