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System Modelling and Simulation Analysisof Battery Pack with Passive Cell Balancing

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Abstract: This paper presents system modelling and simulation of lithium battery pack with passive cell balancing technique. A battery pack of 57.6 V, 27 Ah is modelled and simulated in MATLAB/Simulink environment. The balancing algorithm is triggered whenever the difference in State of charge (SoC) of series connected cells modules exceeds the threshold value of 0.1% of SoC. The balancing algorithm also provides an optimum value of shunt resistor value which is selected based on time taken to balance the cells and minimumpower consumption. Graphs of balancing time and power consumption versus resistor value were obtained. A shunt resistor of 4 Ω chosen as an optimum value among a set of resistors as its balancing time of 9636.9s and power loss of 26.2462W was satisfactory. The performance of battery pack was analyzed during charging phase using Constant Charging-Constant Voltage (CC-CV) approach and discharging at constant current of 20A.

Keywords: Battery pack, Balancing algorithm, Shunt resistor,State of charge, System Model

I. Introduction

In the recent years, Electric Vehicles (EVs) have gainedconsiderable attention as it is considered as a potential solution to reduce pollution and dependence on fossilfuels. In Electric Vehicle technology, challenges are mostly faced in design and development of primary energysource that is electrochemical batteries [1]. Li-ion batteriesare most preferred ones as compared to other rechargeable battery like Lead-acid, Nickel-Cadmium, Nickel-metal- hydride, etc. Lithium-ion batteries as they have the advantages of high energy density, long life, low self- discharge rate, no memory effect, comparatively low maintenance, fast charging, etc. over their counterparts. Alithium-ion cell can provide a nominal voltage is 3.7V whereas maximum voltage is 4.2V and minimum voltage is 2.6V. Any battery cell overcharged to over 4.2V or discharged to 2.7V, will result in unstable batterycondition and may even cause fire hazard. Hence a monitoring and control system named Battery Management System (BMS) is essential to monitor and regulate the performance of the battery resulting in effective-efficient-durable performance. It protects the battery system from damage, predicts and increases battery life, and maintains the battery system in an accurateand reliable operational condition. The BMS performsseveral tasks such as monitoring the system voltage, current and temperature, the estimation of state of charge (SoC), state of health (SoH), and remaining useful life (RUL), thermal management, control of the charge/discharge process, data acquisition, communicationwith on-board and off-board modules, monitoring and storing historical data and balancing of cells [2]. Among all the functionalities listed above, the cell balancing/equalization is of utmost interest a Li-ion batterypack which is widely used in EVs comprises of several cells assembled in series and parallel to supply the desired voltage and charge capacity. Any inconsistency in the capacity and voltage of the connected cells affect the efficiency of the whole battery pack. This may happen dueto various environmental factors or manufacturing differences which introduce variations in the EV cell specifications resulting in a performance degradation. Hence cell balancing is very crucial for a safe and reliable battery operation. Cell balancing is a method of equalizingthe voltages and SOC among the batteries when they are ata full charge. A cell balancing system categorized into passive and active systems based on the working principle.

This paper implements and simulates a passive cell balancing system for a lithium-ion battery pack. The section-II explains main concepts of battery management system. Section III discusses passive cell balancingprinciple and algorithm. Section IV outlines system modelof battery pack in Matlab/Simulink environment. Section Vpresents simulation results whereas Section VI concludes the work presented in the paper.

II. Battery Management System

Among all the promising storage technologies, lithium- based battery systems are being used widely in electric vehicles in recent years due to its high power and energy density, long cycle- life, and low self-discharge. However,Lithium batteries are very sensitive to overcharge and deepdischarge, which may shorten its lifetime, and even result in hazardous situations. Hence a sophisticated and intelligent BMS is needed Battery Management System (BMS) is needed to ensure reliable and safe operation of batteries. The main functions of the Battery Management system are to monitor and manage each cell of the battery within its reliable and safe operating range, cell balancing,charge and discharge process control, fault diagnosis and isolation, state of charge (SOC) and state of health (SOH) estimation and even thermal management of the cells [3][4].

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Fig .1 shows a general intelligent battery management system for battery systems with the following intended functionalities

1) An accurate battery model with real-time parameter estimator
2) An adaptive SOC and SOH estimation methods are proposed to accurately predict the battery status in different load and temperature conditions.
3) An accurate cell-balancing mechanism to enhance battery life-time
4) An efficient battery fault diagnosis system

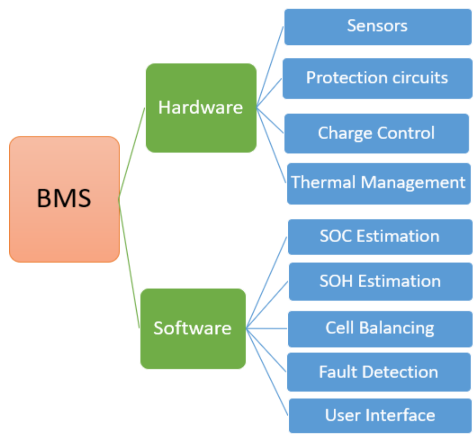

Fig. 1 General BMS structure.

III.Passive Cell Balancing

Imbalance of cells in a battery pack is an important factor to be dealt with in battery storage system. Without the balancing system, the individual cell voltages will drift apart over time. The capacity of the total pack will also decrease more quickly during operation and the battery system will fail prematurely [5].

The balancing topologies can be categorized as passive and active balancing as shown in Fig. 2. The passive balancing methods removing the excess charge from the fully charged cell(s) through passive, resistor, element untilthe charge matches those of the lower cells in the pack or charge reference. The resistor element will be either in fixed mode or switched according the system. The active cell balancing methods remove charge from higher energycell(s) and deliver it to lower energy cell(s). Differenttopologies are used according to the active element used forstoring the energy such as capacitor and/or inductive component as well as controlling switches or converters.

In this paper a shunt resistor balancing method is used toachieve cell balancing. The Fig. 3 shows the circuit for shunt resistor method of cell balancing.

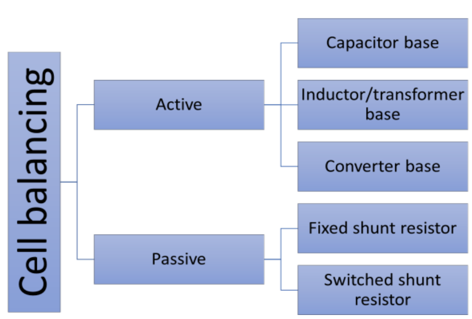

Fig.2 cell balancing classification.

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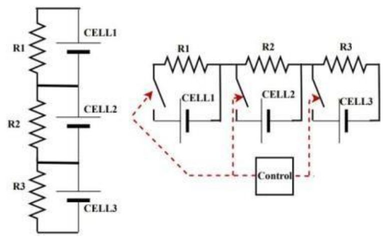
In shunt resistor method, cell balancing is achieved by dissipating the excess energy stored in the highest voltage cell in the resistor [6][7] It can be done in two ways:

First method is Fixed resistor method as shown in figure3 (a) in which a resistance is permanently connected across every cell and the cell dissipates energy throughout the timeperiod.

Second method as shown in figure 3(b) is by using a controlled shunt resistor. In this method a series combination of semiconductor switch and resistor is connected across a cell. Based on the requirement, theswitch can be opened or closed to connect and disconnect the resistance across the cell [8][9].



(a) (b)

Fig. 3 Shunt resistor a) fixed resistor b) Switched shunt resistor.

IV. The System Model of Battery Pack

A battery pack is built by connecting multiple battery module assemblies. These module assemblies, in turn, comprise a number of battery modules connected electrically in series or in parallel. The battery modules are made of multiple parallel assemblies which, in turn, comprise a number of battery cells connected electrically inparallel under a specific topological configuration or geometrical arrangement. Fig. 4. Shows the modeling of a single cylindrical battery cell with a height of 70mm and a diameter of 32mm.

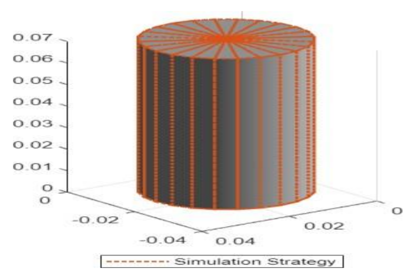


Fig. 4 System model a battery cell.

By using a battery cell model, a parallel assembly of 4 cells are built to obtain a higher current capability of 27 Ah.This is as shown in fig. 5.

The parallel assembly of 4-cells are connected in series to build a battery module. In this work, a battery module isbuilt by connecting 4 parallel assemblies in series. In the next level, a module assembly is built by connecting two modules in series. Finally, the battery pack is built by connecting two model assemblies in series which is as shown in Fig. 6.

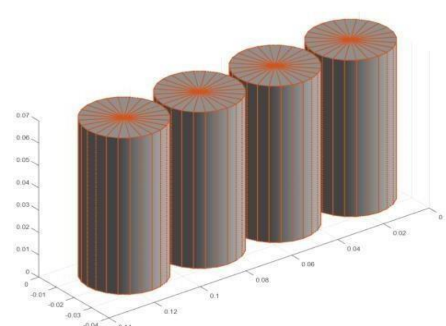


Fig.5 System model a battery parallel Assembly.

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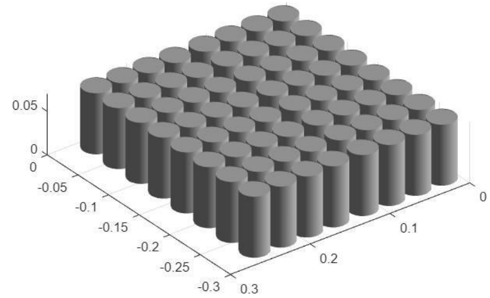

Fig. 6 System model a battery pack.

57.6V and 27 AH are the electrical specification ofbattery pack-built MATLAB/Simulink environment. The modelled battery pack is verified for its performance by discharging it across a resistor of 1Ω and this is shown in Fig. 7. The simulation is carried out for 1000 second and itis observed that SoC changes from 1 to 0.82. as shown in Fig. 8. Fig. 9 shows the variation in terminal voltage of battery cells and it varies from 4.1 V to 3.85 V. Theperformance of developed battery pack found to be satisfactory.

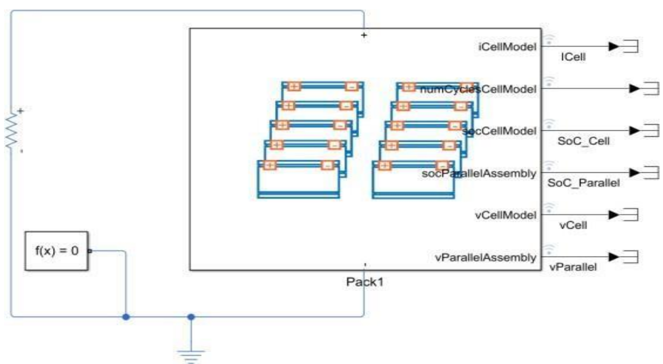

Fig. 7 Battery pack connected to a load resistor for discharging.

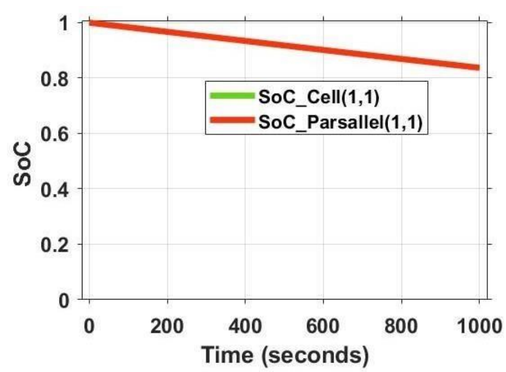

Fig. 8 State of Charge (SoC) Variation during discharging phase of thebatterycell.

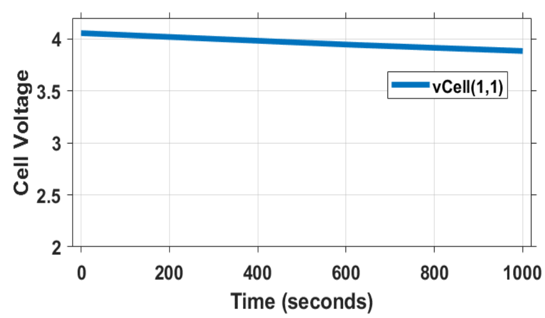

Fig. 9 Cell Voltage Variation during discharging phase of the battery cell.

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The cell balancing strategy incorporated adds an ideal passive balancing circuit to every parallel assembly inside the battery pack. The balancing circuit consists of a balancing resistor connected in series to a signal-controlledswitch controlled by a balancing algorithm. Fig. 10 shows the passive cell balancing circuit using a shunt resistor alongwith a controlled switch to balance every parallel assemblyof cells

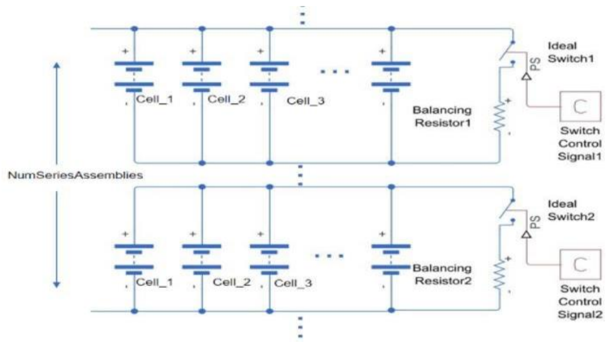

Fig. 10 Passive cell Balancing circuit.

V. Simulation Results

The simulation of modelled battery pack with cell balancing was carried out to analyze the performance of designed passive cell balancing algorithm. Simulation was carried out in two phases. In the first phase, idle battery packwith different SoC was considered and in second phase battery pack with charging and discharging condition was considered.

A. Simulation of battery pack in idle condition

Fig. 11 shows the system level modelling of battery packalong with a passive cell balancing strategy in MATLAB/Simulink. The threshold % SoC difference between cells is 0.1%. The initial value of SoC of cells set varies from 0.69 to 0.715. An algorithm was also implemented to determine power loss due to shunt resistor.Another algorithm was also implemented to choose anoptimum value of shunt resistor which provides a good trade of between balancing time and power loss.

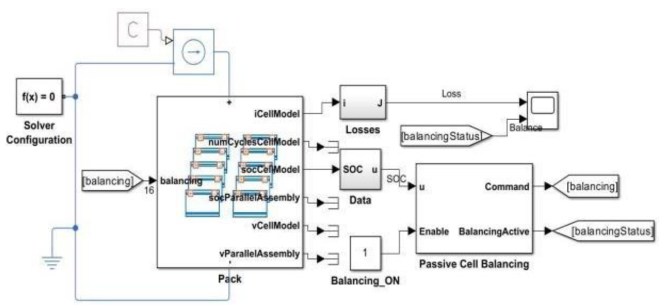

Fig. 11: System level modelling of battery pack with Passive cell balancing circuit.

Table 1 summarizes the simulation results. Among the resistor values considered for simulation, A shunt resistor value of 4Ω provided a good trade off results between balancing time and power loss.

Table 1. Summary Of Simulation Results

Resistor valuein ohms	Balancing time in second	Power lossin watts
2	4833.9	52.1775
3	7235.9	34.9237
4	9636.9	26.2462
5	12037.9	21.0226
6	14439.9	17.5326

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Fig. 12 and Fig. 13 shows variation of balancing time and power loss with shunt resistor value. It is observed thatbalancing time increases whereas power loss reduces with balancing resistor.

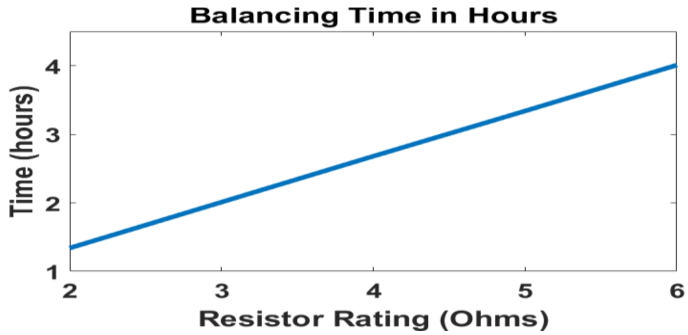

Fig.12 Balancing time variation with shunt resistor.

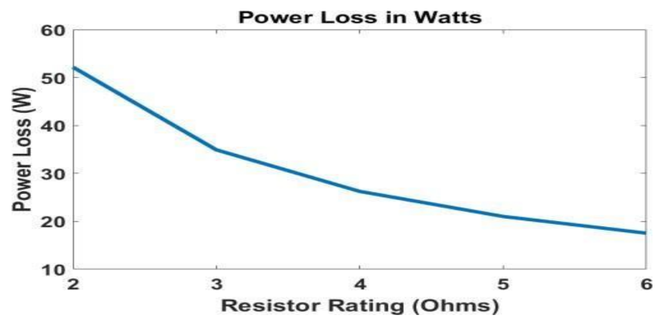

Fig.13 Power loss variation with shunt resistor.

Fig.14 and Fig. 15 shows the equalization of SoC and terminal voltage of battery by passing cell balancing algorithm for a value of 4Ω shunt resistor. The graphs showa balancing time of 9636.9 S which is also listed in table 1. The passive cell balancing algorithm equalizes the SoC of cells gets equalized to 0.691 and cell voltage 3.875V.

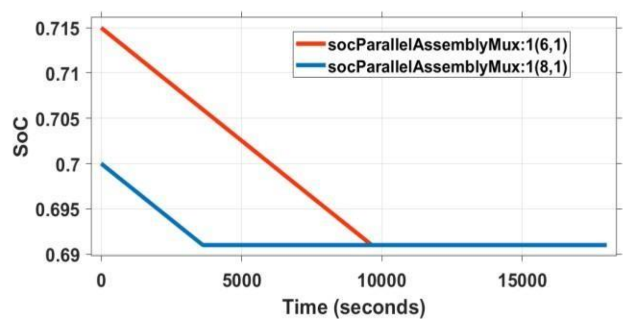

Fig. 14. The variation of SoC of battery for a balancing resistor of 4 ohm.

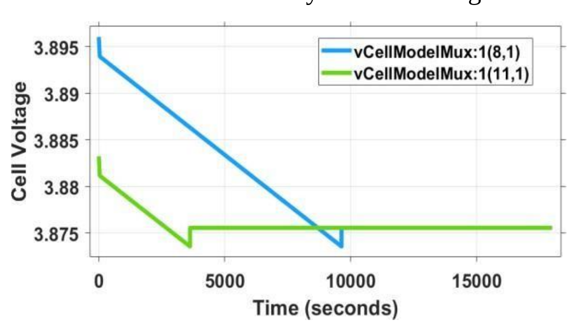

Fig. 15 The variation of terminal voltage of battery pack for a balancingresistor of 4 ohm.

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B. Simulation of battery pack during charging and discharging phase

The performance of battery pack with passive balancing algorithm was analyzed during charging and discharging phase. A charging/discharging current of 20A was considered. The battery charging is implemented using constant current charging, constant voltage algorithm (CC- CV). The CC-CV algorithm. The initial % state-of-charge of battery cells were set between 70% to 75%. When the battery is charging, the % current is constant until the batteryreaches the maximum voltage of 4.1V and then % thecurrent decreases towards zero. When the battery is discharging, a constant current of 20A is used.

A threshold cell voltage difference of 0.1% is consideredin balancing algorithm. The shunt resistor is set at itsoptimum value of 4Ω as determined in phase-1. The simulation was carried out for 15 hours. A relay component was used to switch between charging and discharging.When SoC reaches a minimum value of 0.3, the relay will switch the battery pack to charging phase and when SoC reaches a maximum value of 0.918, the battery pack will start discharging. The Fig.16 shows the system model developed in MATLAB/Simulink tool.

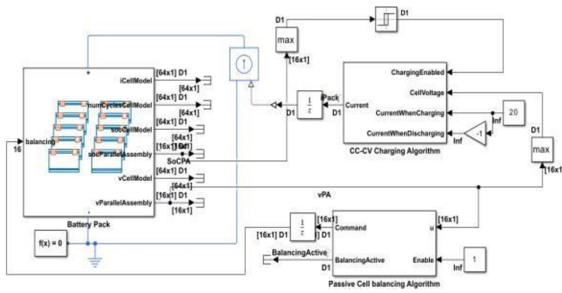

Fig.16 System Modelling of battery pack with passive cell balancing andcharging/discharging.

The Fig.17 shows the variation of battery Cell terminal voltage during charging and discharging phase. The voltage varies between the nominal value of 3.6V to maximum value of 4.1V. Logic-HIGH value of the balancing active signal shown in Fig.17 indicates the balancing circuit is on.

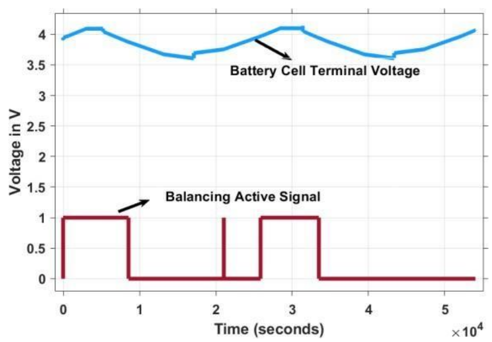

Fig.17 Battery Cell terminal voltage during charging and discharging

Fig. 18 shows the battery pack current during charging and discharging. It can be observed that during charging, initially the current remains constant and then starts reducing during constant voltage phase. The battery currentremains at -20A during discharging.

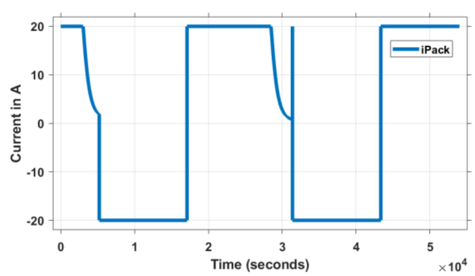

Fig.17 battery pack current during charging and discharging.

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The state of charge variation during charging and discharging is shown in Fig.19.The SoC varies between 0.3and 0.918 as per the relay setting. It is also observed that theSoC of all battery cells is equalized throughout its operation.

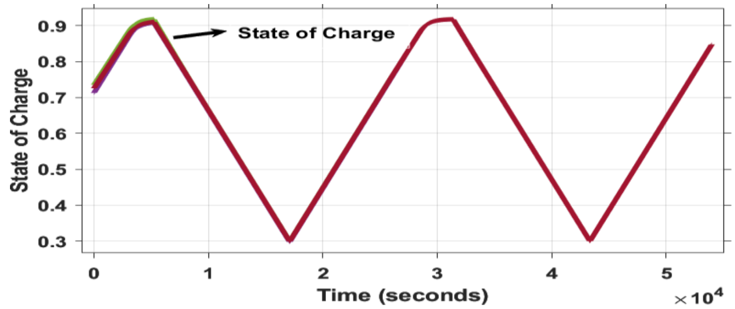

Fig. 18 Variation of SoC with time during charging and discharging

The battery pack with cell balancing circuit is analyzed during its charging. Fig. 19 shows the equalization of SoC with charging time. It's observed that the SoC equalizes zt 9636.9 seconds.

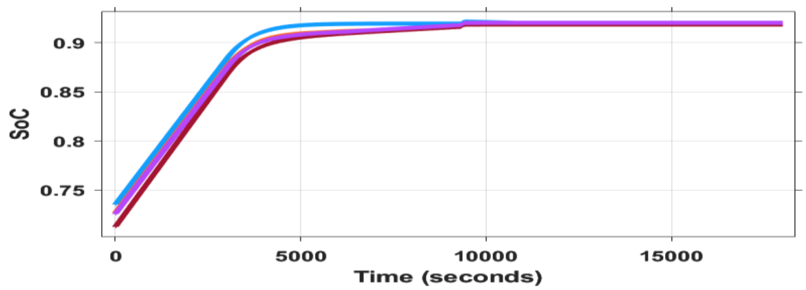

Fig. 19 SoC balancing during charging phase.

Fig. 20 and 21 shows battery cell voltage and current during its charging. It is observed that battery gets charged to its maximum value of 4.1V. The battery current shown inFig. 21 follows the CC-CV charging mechanism. The charging current is maintained constant initially as battery voltage increases and it decreases as battery voltage maintained constant at its maximum value.

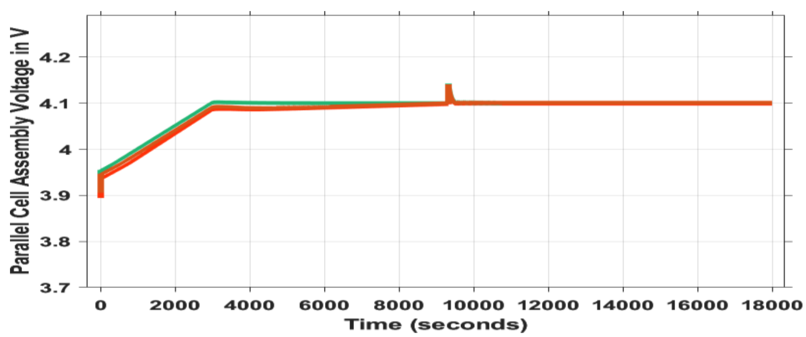

Fig. 20 Parallel assembly voltage during charging

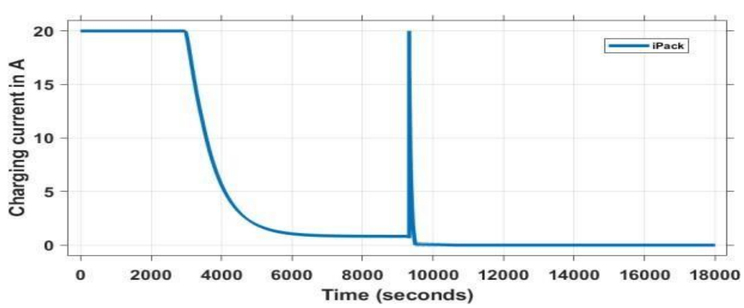

Fig.21 CC-CV charging waveform

VI. Conclusions

The paper presented a passive cell balancing algorithm adopted to improve the battery cell life-time and efficiency. A threshold difference value of 0.1% is considered inbalancing algorithm for SoC. The system model of batterypack is developed to accurately represent a real battery. The battery pack modelled consisted of a total of 64 lithium-ioncells arranged in modules in series and parallel combination. An algorithm was also implemented to choose an optimum value of shunt resistor considering balancing time and power loss as the main parameters. A resistor value of 4Ω gave an acceptable value of 9636.9s balancing time and power loss of 26.2462w. The battery pack performance was also analyzed during its charging and discharging phase. The SoC is maintained between theoptimum value of 0.3 and 0.918. It is observed that batterycurrent and voltage stays within its permissible limit during the simulation. As future work, the hardware implementation of passive balancing algorithm is planned as a future work. The active cell balancing will also be adopted for battery pack to improve the accuracy andefficient utilization of full capacity of battery pack.

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