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# Performance Checking of Active Cell in Series Connected Lithium-Ion Cells for Electric Vehicle Applications with Power Loss Analysis

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**Abstract -**The applications for lithium-ion batteries are extremely diverse. They can power everything from small smart watches to larger electric cars. They come in a variety of packagings because of their wide range of uses. Even when the voltage of a single cell exceeds 4.2 V by a few millivolts, it can cause thermal runaway and explode the cell. Cell imbalances make it difficult to use the battery to its full potential during the discharge cycle. This thus diminishes the battery lifetime. The singular battery cells ought to be leveled consistently to downplay the uneven characters and to have a decent battery duration. The most common way of adjusting the singular cell charges by estimating the cell condition of charge (SoC) and its voltage in a battery pack is known as cell adjusting. This paper tells about a functioning cell adjusting strategy that involves a buck converter for adjusting a series associated battery pack of lithium-particle cells. This experiment makes use of a buck converter and two MOSFET switches for each cell, one of which is activated while the cell is charging and the other while it is discharging. An algorithmic model reasonable for reconfigurable battery frameworks that actions the singular cell voltages and is produced for adjusting a pack of series associated Li-particle battery cells. The created model is reenacted involving MATLAB for checking its presentation. A condition of charge of 25% is kept up with across the cells and when SoC esteem dips under this even a distinction of 0.02% is detected by the calculation to start adjusting capability. This adjusting is found to take 275 ms to adjust three 3.7 V batteries and consequently the model is found to answer quicker. The outcomes demonstrate the way that this strategy can self-adaptively accomplish good execution inside a restricted balancing period.

## 1. INTRODUCTION

As the entire world has begun pushing toward "Green Technologies" fully intent on lessening an unnatural weather change, pretty much every nation is demanding the turn of events and utilization of electric controlled vehicles. Furthermore, when electric vehicles are discussed, the foundation of such a vehicle will be its battery. This demonstrates the significance of battery design and management research and development. In electric vehicles, the battery management system (BMS) continuously monitors, controls, and regulates the energy storage and transfer to guarantee the battery pack's safety. A BMS will gather data from sensors in the battery, controlling the charger to guarantee legitimate charge of the battery, overseeing cell balance, security control to keep away from over-charge or over release or other significant irregularities, revealing battery state, warm states of the battery, correspondence with the vehicle and information move to a PC. BMS charges a cell based on its state of charge and discharges a cell based on demand and charge available in the cell, taking into account the monitor and control of the charging and discharging of the battery. In a similar vein, monitoring and maintaining constant cell voltages in individual battery cells can reduce degradation of battery life. There is a separate cell balancing unit in BMS. The temperature is likewise observed and constrained by the BMS.In any multi-cell battery chain, there are no two cells that are indistinguishable, actually intending that there are dependably basically slight contrasts in the properties like self-release, limit, condition of charge, impedance and temperature qualities. Likewise, when a multi-rank pack security coordinated circuit (IC) is utilized, its inconsistent depleting might cause unevenness in the cells which might prompt debasement of battery duration. This paper discusses an active cell balancing topology based on an algorithmic model that is capable of reconfiguring itself in accordance with the state of charge (SoC) of individual cells in the battery pack. Given that reconfigurable battery systems that are able to reconfigure themselves in accordance with the need for optimal performance are the subject of the most current research, Cell Adjusting is utilized for leveling the voltage and condition of charge (SoC) of battery cells in a pack and uninvolved and dynamic cell adjusting are its sorts. Uninvolved cell adjusting utilizes a dis-sipative component to eliminate the overabundance charges from the high charged cells. Dynamic cell adjusting utilizes some power electronic switches alongside inductors and capacitors to move charges between cells to make them balanced. There are heaps of cell adjusting strategies

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accessible and they are recorded in Figure 1. Based on the SoC of the battery pack, Xu proposed a straightforward yet effective battery balancing strategy in [1]. Here releasing is postponed when the SoC is low and it is progressed when SoC is high with the goal of achieving a decent battery framework. As another strategy for finding the broken cell in a battery pack, [2] involves the power electronic gadgets in cell adjusting circuit to track down defective cells. In [3], a control algorithm is used to select a single gating device to gate energy between high and low voltage cells in order to quickly balance the battery pack. [4] provides a comprehensive examination of the battery management system and the requirements it must meet for a Li-ion battery. A survey of the latent and dynamic cell adjusting methods is made sense of and it is uncovered that a half breed procedure will assist with accomplishing better balanc-ing [5]. In [6], an outlier distance- dynamic adjusting is found to give better execution on account of Li battery in [7]. In [8], a comparison of active and passive balancing methods is made, and it is discovered that active balancing methods are more effective but cost more and have a more complicated design than passive balancing methods.

A simple yet effective way of computing the cell imbalance is done in [9] where the difference in open circuit voltage is changed over completely to address the SoC of the cell. In [10], an edge work is created to demonstrate the state and boundary contrasts between cells in a battery pack prompted because of assembling and ecological circumstances. What's more, this model thus is utilized to accomplish cell adjusting. The benefits and bad marks of different cell adjusting strategies say dynamic and aloof methods are checked tentatively in [11]. A model predictive control algorithm is used to predict how long a battery will last for different active cell balancing methods. The results show that the right balancing method can increase battery life by 10% [12]. A survey and reenactment of uninvolved cell adjusting methods is finished in [13]. Inductor based exchanging and current mode regulator for exchanging control is made sense of in [14].

A cell adjusting procedure for the instance of clinical gadgets is contemplated and a compelling DC converter-based plan is made sense of in [15]. In [16], the performance parameters of various battery management systems and their reviews are examined. [17] provides a summary of the various SoC estimations for Li-ion batteries. In [18], the most brief way between cells is found to further develop its productivity utilizing an Exchanged Capac-itor Construction in shut circle. This strategy for cell adjusting is viewed as affordable. Two different adjusting procedures each for the charging and releasing of the batteries is proposed in reference [19] and the outcomes show that the such an adjusting helps in lessening the irregularities and further develops the battery limit. A cell adjusting strategy that utilizes a resounding LC cir-cuit, converter, beat width regulation (PWM) exchanging circuit are utilized with equal battery packs for adjusting their charging and releasing in [20]. A technique for cell adjusting that paci-fies the effect of temperature on the cell is checked in [21]. In[22] dynamic cell observing is finished utilizing a transformer switch-ing. An AI based battery the board framework with a DC converter is found to deliver great effectiveness in offsetting batteries in lined up with a blunder of 1.15% [23].

A complete survey of the dynamic and detached cell bal-ancing is made sense of in paper [24]. Lei and co. A non-dissipative equalization strategy for balancing cell charging and discharging is suggested in [25]. [26] suggests using in-cell thermal monitoring to examine the temperature profile. In [27], an adap-tive adjusting control strategy is proposed in the survey and its charging and it are examined to release modes. A crossover converter circuits that involves a fly back converter for charging and buck con-verter for releasing is proposed for cell adjusting in [28]. As Inactive cell adjusting strategies are the minimal expense strategies, it is carried out by utilizing AI based algo-rithm to choose the fitting adjusting resistor esteem in light of different variables and the subsequent framework is assessed utilizing various back spread methods [29]. To the extent that cell bal-ancing by bidirectional flyback converters are considered [30], the essential downsides are the exchanging misfortunes related with the huge number of switches utilized and the decreased productivity. Be that as it may, for minimal expense and low power application fly-back converter's efficiency can be improved when used with a lossless snubber and transformer [31].

The requirement of large capacitors for cell balancing while using a combination of buk-boost converter and cuk converter is explained in paper [32]. Such larger capacitors also lead to larger charging and discharging currents that requires high-current tolerant switches for switching which are costlier. A high voltage stress which leads to high electrical weights on switches and diodes is the main drawback of using a bidirectional Cuk converter in balancing operation [33]. Mohamed et al., in [34], explains a switched capacitor method for battery equalization. It is found that the charge equalization takes low equalization time and requires huge number of switches. Whereas in [35], Markus Einhorn, explains the use of a multi-winding transformer for active cell balancing in Electric Vehicles and found that the multi-winding requires complex control and use a greater num- ber of cells. A fuzzy based control for cell balancing is explained in [36]. In [37], Chol-Ho Kim et al., says that it requires more equalization time an accurate voltage sensing for a fly-back con-verter to work. In [38], Maharjan proposed a full bridge cascade pulse width modulation (PWM) Converter and found that it requires a high-cost intelligent control. In [39], Hong et al., pro-posed a buck boost converter-based charge equalization. The deterrents to the design and use of different converter-based cell balancing models is described in the following subsection.

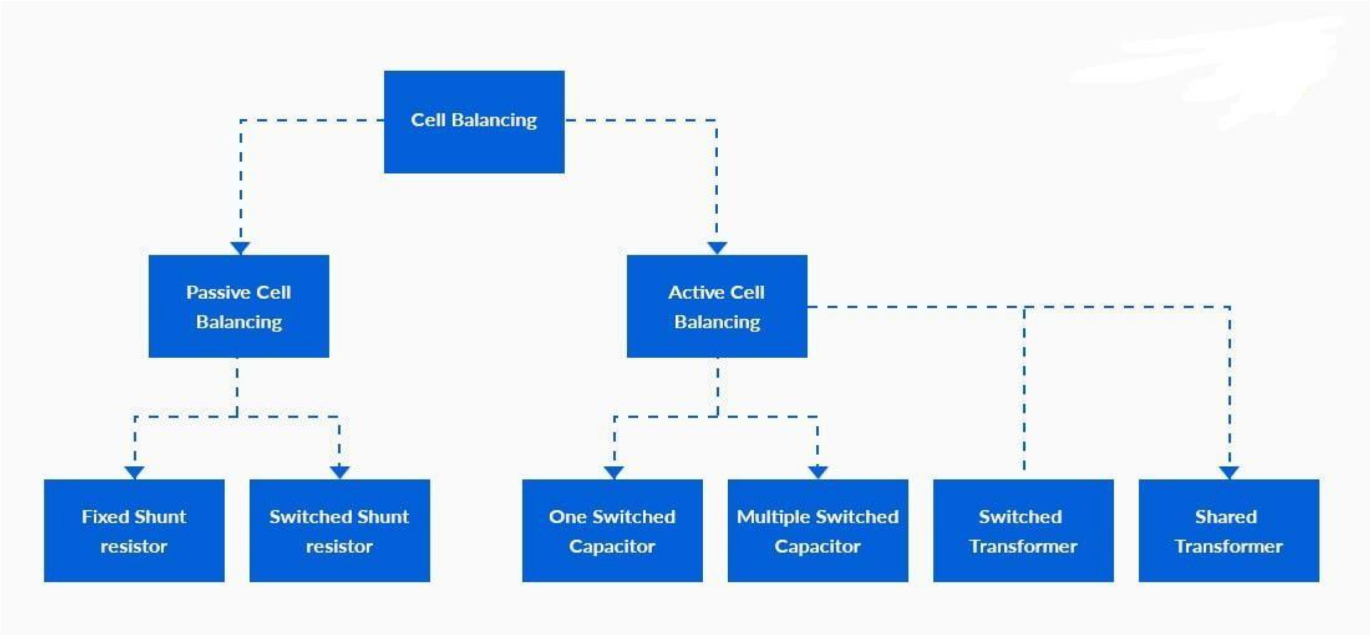


**Fig 1:** Classification of cell balancing.

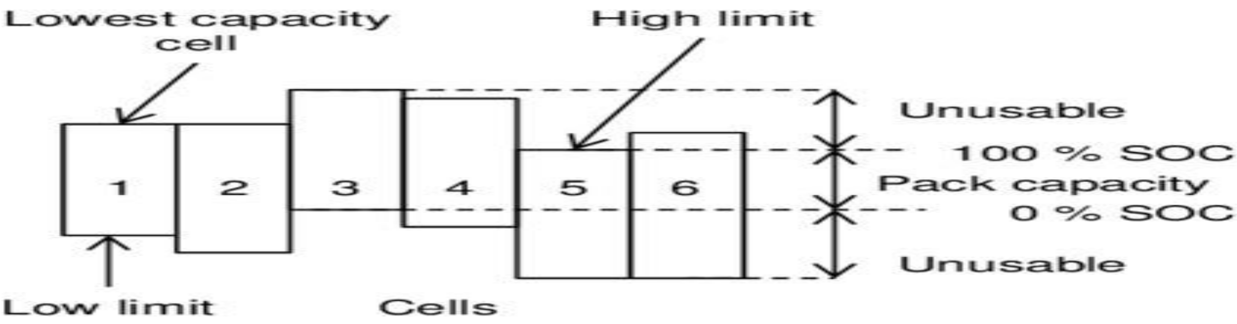


**Fig 2:** Charge imbalance

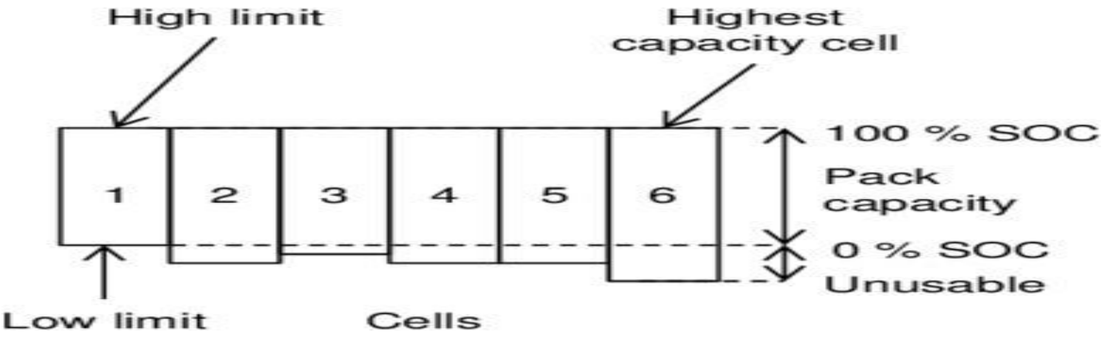


**Fig 3:** Charge equalized after cell balancing

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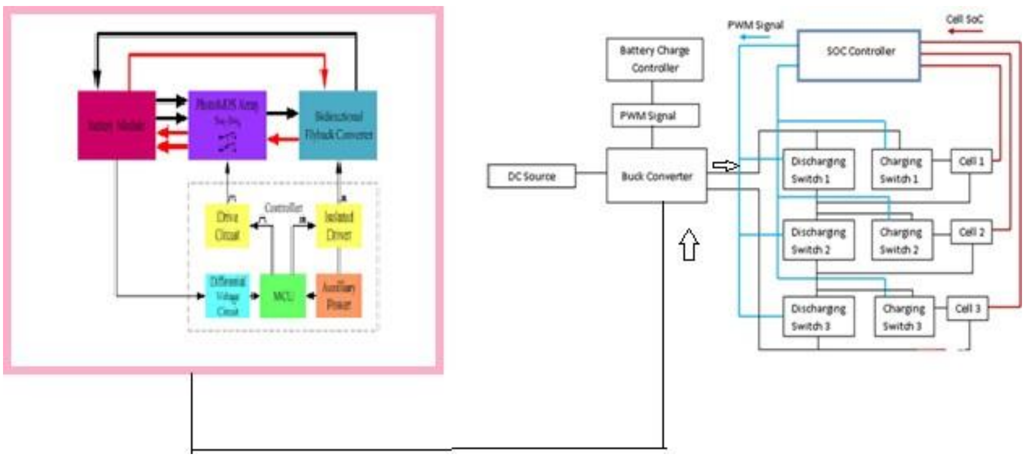


**Fig 4:** Proposed buck converter and state of charge controller-based cell balancing system block diagram.

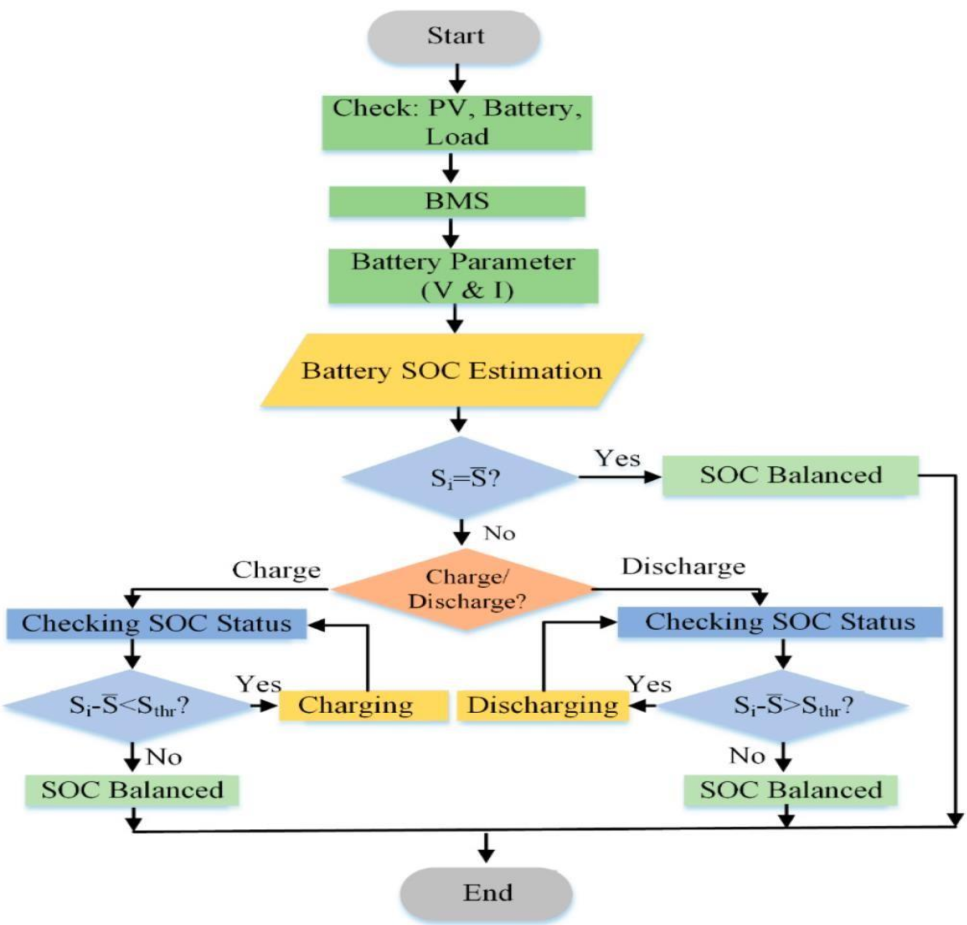


**Fig.5:** Flowchart

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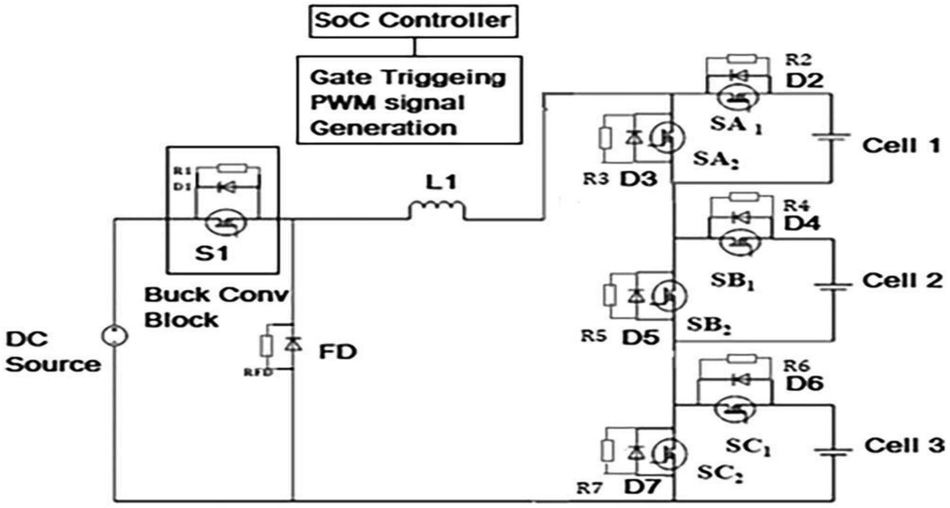


**Fig. 6:** Proposed circuit model.

The major causes for cell imbalances in lithium-ion batteriesare twofold, they are: (i) charge imbalances caused by manufacturing inequalities and (ii) cell Charge imbalances caused by repeated charging cycles. Such imbalances are intolerant towardsover charge which leads to explosion of battery and over dis- charge which may result in reducing battery's lifetime Thus cell balancing has to be done in two different phases say (i) charging phase and (ii) discharging phase of the battery. While charging battery compares the individual cell voltages with the voltage
.
The SoC is estimated by measuring the current, voltage and temperature of the individual cells and from which the imbalances are detected by the cell equalization. Cell balancing is achieved by transferring the required charge

The major merit of cell balancing and equalization is to enhance the efficiency and lifetime of battery and to protect the same. Cell monitoring and charge equalization along with other similar control are the parts of the battery management system.

## 2. SYSTEM DESIGN

### BLOCK DIAGRAM OF THE PROPOSED SYSTEM

The proposed system can be broadly classified as (i) the buck converter block (ii) SoC controller block and (iii) solid state switch array block. The DC source is connected to the battery cells through a Buck converter. A Battery charge controller will take the current feedback from the buck converter and the feed-back signal is filtered and then given to the Proportional Integral

regulation point to stop further charging. Hence weak cells are slightly over charged but stronger cellsare slightly under charged as depicted in Figure 2. This makes the degradation faster in weaker cells and thus the battery pack also experiences it. During discharge cycle, the weaker cell is dis-charged quickly whereas the stronger ones are still having some charge in them. Hence, again weaker cells face degradation due to over discharge. These issues can be rectified by using a propercell balancing method which helps improve battery life and its safety

to the undercharged cell either from the most charged cell or from any adjacent cell with the aim of equalizing the voltage or charge below the threshold operating point.

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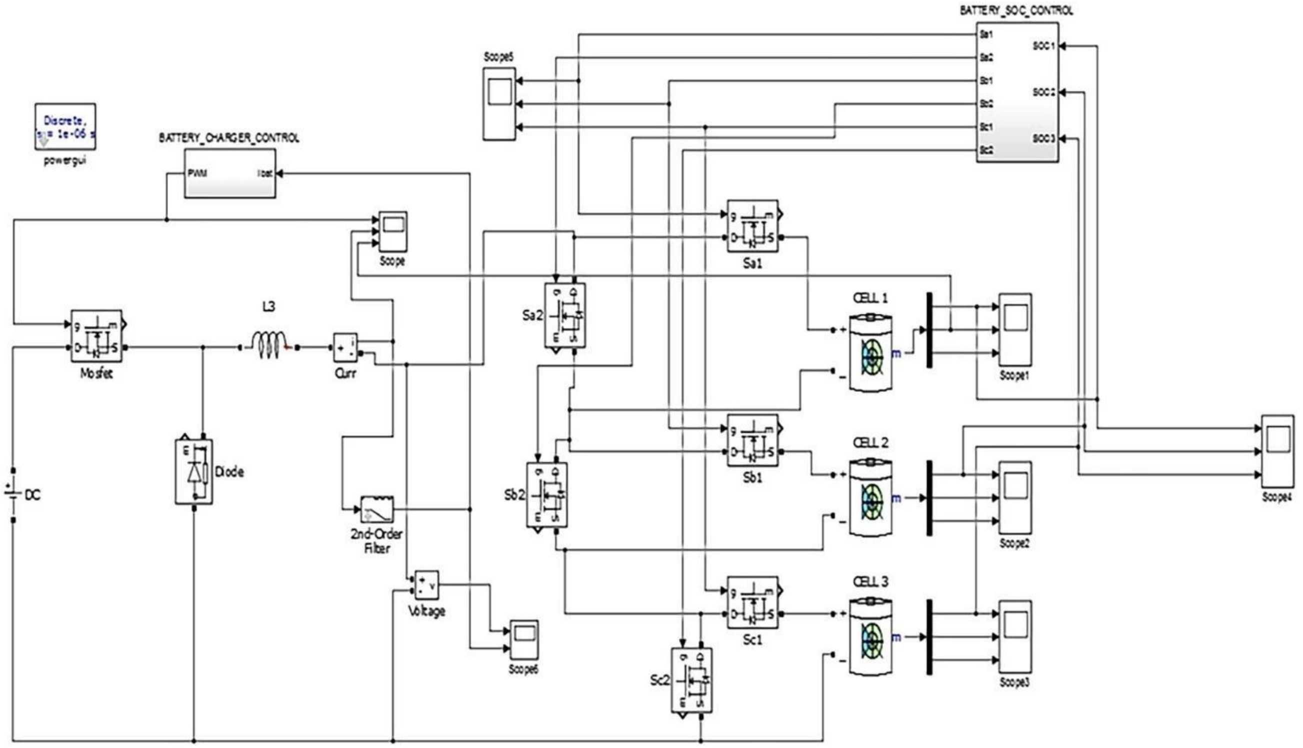


**Fig 7:** Simulink simulation of proposed system .

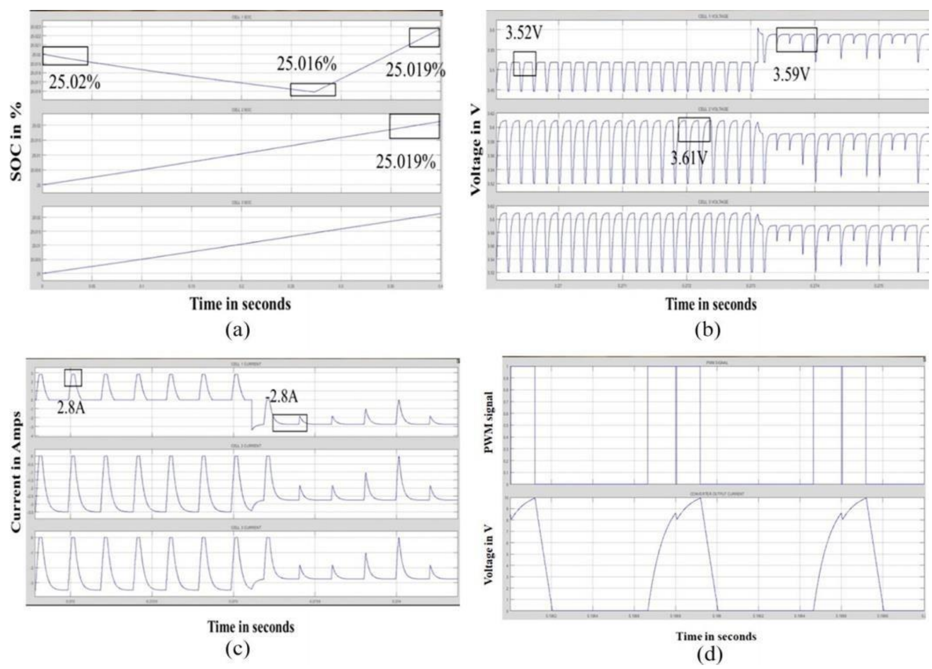


**Fig 8:** (a) State of charge (SoC) of three cells, (b) voltage comparison of three cells, (c) current comparison of three cells, (d) pulse width modulation(PWM) signal and converter voltage.

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**Fig 9;** Blocks in the hardware prototype.

## SoC equalization algorithm

Determining the SoC of a battery accurately is the factor thatdecides the effectiveness of any cell balancing model and thus this paper utilizes linear model for SoC prediction. This prediction method works based on the reference SoCs and present battery states. The present SoC value is predicted from input current $I_i$, output current $I_o$, output voltage $V_o$ of each cell at present and reference SoC values from available data. The cells that are overcharged and under charged are found by comparing the predicted SoC values with the allowed deviation $S_d$. Here, $\beta$, is found from the previous reference values by least square method, S($i$ ), is the present State of Charge, $\Delta S$ ($i$ ), is the difference in SoC, $V(i)$ represents the voltage and $I(i)$ represents the current at the present state.

An array of parameter values is generated for every individ- ual sample. The input current is given by Matrix $I_i$ whereas the different output parameters are represented by matrices $S_o$, $V_o$, $I_o$ and the deviation of SoC from allowed value $S_d$ is found. Thus, the SoCs computed by this linear model are comparedto achieve cell balancing between the battery cells. Figure 5 shows the flowchart for the charge equalization algorithm used for generating the complementary PWM signal for gating the charging and discharging bi-directional switches in the array.

In this model, a Peripheral Interface Controller, PIC micro-controller is chosen to hold the SoC based Control algorithmthat generates the PWM signal to gate the solid-state devicesthat control the charging and discharging of the various Cells inthe battery pack. The algorithmic controller compares the indi- vidual cell SoC with the SoC average. If an individual cell SoC is greater than average then the discharging switch of that partic-ular cell should be triggered ON and its charging switch should be turned OFF. Similarly, if SoC is not higher then, those cells should be turned ON for charging by triggering the charging switches and closing the discharging switches. Thus, the

SoCcontroller generates the appropriate PWM signals to gate the charging and discharging network of bi-directional switches andconnects the cells with the source in a balanced fashion.

## Circuit diagram of the proposed model

The circuit diagram of the proposed model is shown in Figure 6. The model uses a buck converter block represented by S1 and D1 along with inductor L1 and free-wheeling diode FD, con- stitute the conventional cell balancing circuit. The proposed cell balancing switch array consists of six switching blocks each made from a power switch S and diode D pair. SA1, SA2 along with D2, D3 form the charging and discharging block switches for cell1 respectively. Similarly, SB1, SB2 with D4, D5 and SC1, SC2 with D6, D7 form the block switches for cell 2 and cell 3 respectively. The SoC controller communicates regu-larly with the cells, switches and the buck converter and sends switch control signals accordingly. This control signal confirms the electrical path between the buck converter and the cells.

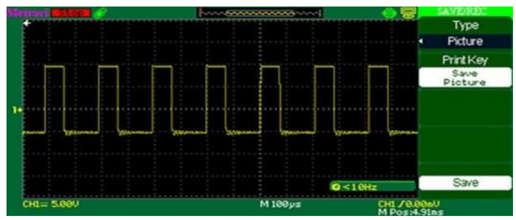



**Fig 10:** Buck converter switch gate pulse.

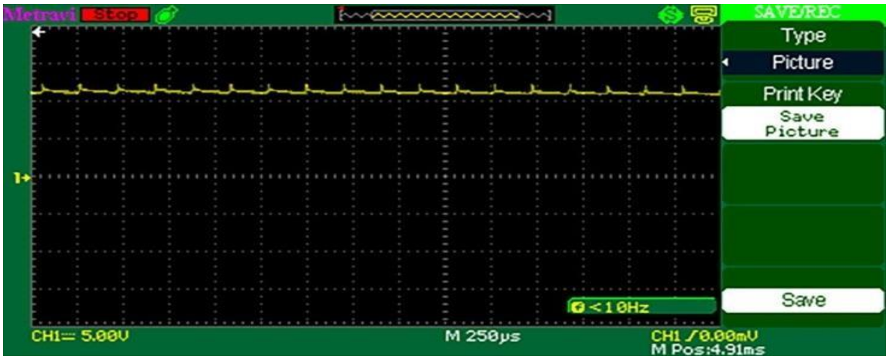
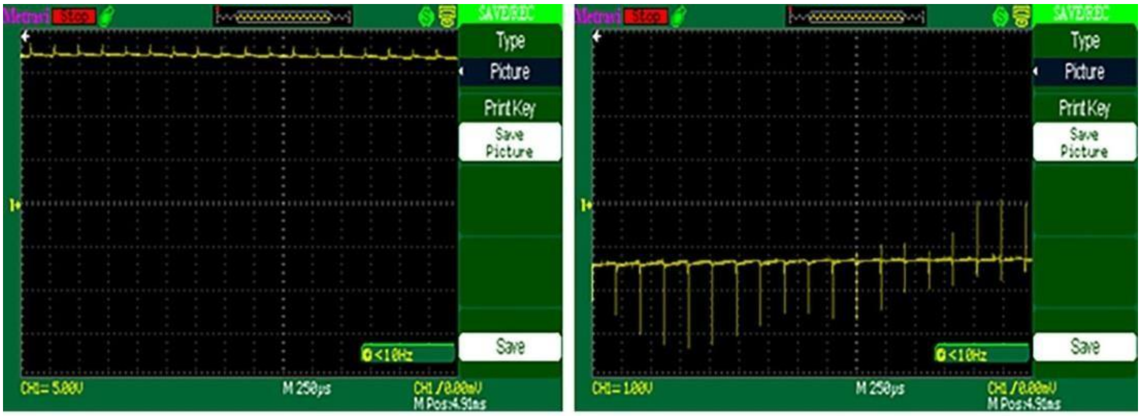
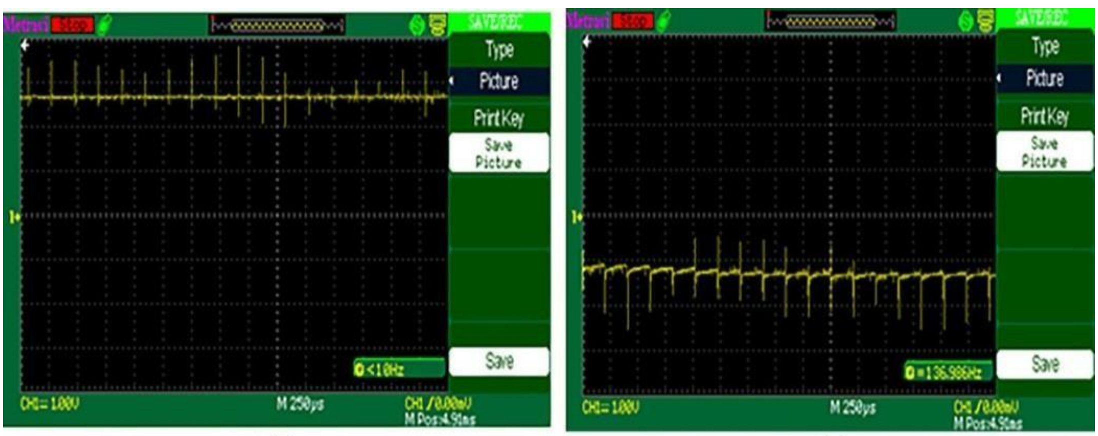



**Fig 11:** Output voltage of the buck converter



(a) (b)

**Fig 12:** (a) Output voltage of the buck converter, (b) current across the shunt resistors.



(a) (b)

**Fig 13:** (a) Current across the shunt resistor 1, (b) current across the shunt resistors 2 and 3.

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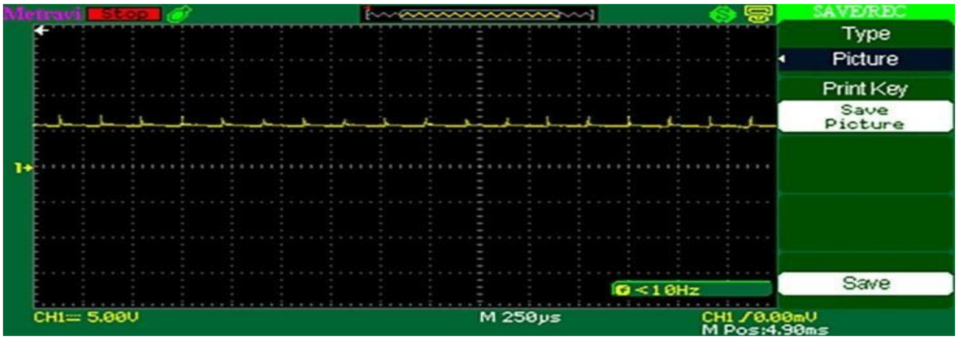



**Fig 14:** Output voltage of the buck converter.

– The Current flow path when all the cells are charging fromsource is (DC source – S1 –L1 – SA1 – Cell 1 – SB1 – Cell 2 SC1 – Cell 3 – DC source). In this mode, all the three cells are charging from the source. Now, an imbalance is introduced by making SoC of Cell 1 high and keeping SoC of Cell 2 and Cell 3 low. Under this experimental condition, excess charge in Cell 1 is discharged to Cell 2 and Cell 3 in two steps. And this is explained in the Step I and Step II and the current flow in each case is explained below.

**STEP I**

Expect cell 1 is higher energy charged contrasted with different cells, to adjust this, the beneath referenced cycle will happens. The buck converter switch S1 is in off condition. When switch S1 is turned on, the inductor's stored energy is lower than Cell 1's. Cell 1 energy charges the inductor by means of D2. The ongoing stream way is (Cell 1 - D2 - L1 - D1 - DC source-D7 - D5 - Cell 1). Here, the cell 1 alone is associated with the way subsequently releasing of Cell 1 happens. The step II procedure will begin once the inductor L1 has a charge greater than Cell 1..

**STEP II**

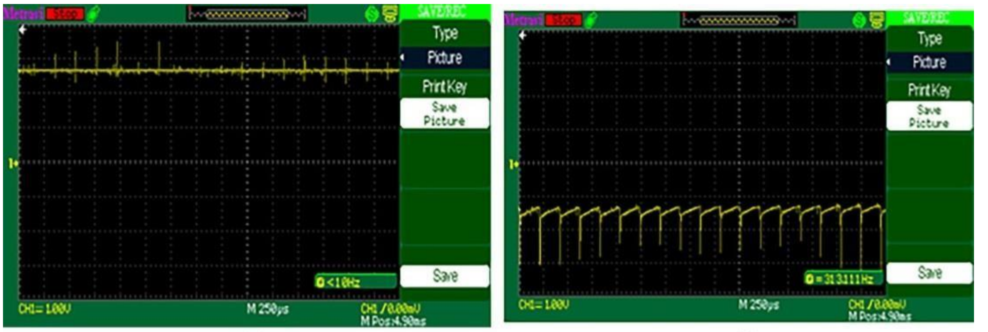
In step II operation, the buck converter switch S1 is in off con- dition and the inductor energy is higher than the energy of thecell then the inductor L1 will be discharged to the cells 2 and 3 through the conduction of the discharging switch SA2 and thecharging switches SB1 and SC1. Cell 1 is cut-off from charg-ing and only cells 2 and 3 are charging from the stored inductor energy through SA2 switch. The current flow path is (L1 – SA2 - SB1 – Cell 2 - SC1 - Cell3 - FD – L1). Respectively, all other cells are maintaining the balanced cell charging through the control process by switching ON and OFF the switches.

## 3. RESULT AND DISCUSSION

The proposed model simulink graph is displayed in Figure-8. The boundaries like cells SoC Correlation, Cells Current Examination, and Cells Voltage Examination for the proposed cell adjusting model are portrayed in the underneath figures. In addi-tion, the PWM signal and the converter voltage are likewise contemplated. Figure 9a portrays the correlation of SoC of three cells. At first, SoC of cell 1 is expected as 25.02% and that of cells 2 and 3 are kept at 25% SoC level. As the SoC of cell1 is higher than the other two cells, cell1 begins releasing and the other two cells will generally charge. Based on the findings, it can be deduced that the proposed model begins to restore cell equilibrium as soon as there is even a minuscule difference in SoC of 0.02%. After releasing up to 0.016 percent SoC, the cell1 begins charging, indicating its sensitivity. These three cells will have a greatest SoC dif-ference of 0.016% just and not more than that. The varieties in the voltage and current during the releasing and charging stages are given by Figures 9b and 9c separately. During the releasing stage, cell1 voltage lessens and its current is ascending in sure hub though while charging starts voltage raises and its ongoing switches to negative pivot which is obviously portrayed by Figure 9b,c. Figure 9d shows the PWM signal which is given to the buck converter by the charge regulator and the voltage produced by the buck converter.

**HARDWARE SETUP**

The hardware prototype is developed based on the require- ments and the same is as shown in Figure-10. The Figure-shows the developed prototype model in working condition and 1the blocks that constitute the hardware model are shown.. The prototype has three 3.7 V, 3 Ah lithium-ion cells that constitute the battery pack. The output voltage of the Buck converter will be 12 V.




(a) (b)

**FIG 15:** (a) Current across the shunt resistors 1 and 3, (b) current across the shunt resistor 2.

**TABLE 1** Comparison of the three states.

| Condition | SoC high | SoC low | $V_{DC}$ | Cell 1 | Cell 2 | Cell 3 |
|---|---|---|---|---|---|---|
| I | – | C1, C2, C3 | 17 V | Charging | Charging | Charging |
| II | C1 | C2, C3 | 11 V | Discharging | Charging | Charging |
| III | C1, C3 | C2 | 5.1 V | Discharging | Charging | Discharging |

## 4. HARDWARE RESULTS

The gating signal to the MOSFET switch of the buck converter as generated by the PIC controller is shown.The magnitude and time period of the gating signals are 5 V and 100 ms respectively.

The efficiency of the cell balancing model is found by conducting the experiment under three different operating con- ditions and studying the results and the same is explained below:

The buck convertervoltage $V_{DC}$ will be high having 17 V with a time period of250 $\mu$s and the current across each shunt resistor will be of mag- nitude −1.4 A and time period 250 $\mu$s. Here, 1 ohm resistorshunt is used across the three cells therefore the voltage acrossthe shunt resistors will be directly proportional to the current through the resistors.

The parameters of Cell-01 state of charge is kept HIGH, and the Cell 2, Cell 3 state of charge are kept in LOW condition. The converter voltage $V_{DC}$ under condition II is 11 V in magnitude. As there are only two cells charging from the DC source the voltage drops to 11 V by the very nature of buck converter. Because of higher SoC, the current through Cell1 will be raising whereas that of cells 2 and 3 will be drooping. It is found that the current through cell 1 is 2.6 A and that throughcells 2 and 3 is −1.2 A. As SoC is high in cell 1 it is discharging and hence its current raises and is positive whereas, the charging cells 2 and 3 shows a negative value of current.

The Table-3 shows the parameters of state of charge of Cell 1 & 3 are kept HIGH, and that of Cell-2 state of charge is keptLOW condition The converter voltage $V_{DC}$ under condition III is 5.1 V in magnitude and this is revealed. Asthere is only one cell charging from the DC source the voltage drops to 5.1 V by the very nature of buck converter. Because of higher SoC, the current through the cells 1 and 3 were raisingwhereas that of cell 2 will be drooping. It is found that the current through cells 1 and 3 is 2.6 A and that

through cell2 is −1.6 A. As SoC is high in cells 1 and 3, they are discharging and hence their currents raise and are positive whereas, the charging cell 2 shows a negative value of current. A comparison of all the three modes of operation is depicted in Table 1. And it is clearly seen that cells with a higher SoCdischarge to keep the cells balanced. When all the cells have a lower SoC they all charge simultaneously from the source whichis revealed from condition I.

## 5. CONCLUSION

Cell adjusting in Li-particle battery pack of three 3.7 V, 3 Ah, Li cells are laid out a by buck converter and a direct forecast based SoC algorithmic regulator. The adjusting current and MOSFET control recurrence are tuned adaptively by the control calculation. The proficiency of the proposed technique is found from the accuracy with which it changes the battery from charging and releasing states. The proposed active cell balancing method is also simulated in Simulink under various initial conditions. It is obvious from the outcomes that the model is proficient, strong than the regular buck converter- based cell adjusting strategy and the framework can adaptively work on its productivity to accomplish ideal execution in a recommended time of evening out. The proposed design is implemented as a hardware prototype, and the results show that the outputs match the simulation results. By employing them in a real-time environment where accurate SoC estimations are difficult, the robustness of the proposed model will be evaluated. Because of its most straightforward plan with least number of switches and strong state gadgets make such converters appropriate for use in future Crossover Electric Vehi-cles and other battery fueled frameworks. Further, enhancement can be accomplished by streamlining energy misfortune related with other electronic parts. Balancing systems for multi-cell loads with additional singular cells ought to likewise be a subject of thought for future investigations.

## REFERENCES


1. Xu, S., Sun, Z.: Research on balance control strategy of lithium-ion battery energy storage system. Int. J. Low-Carbon Technol. 17, 1145–1150 (2022) https://doi.org/10.1093/ijlct/ctac080
2. Choi, W., Hong, S.: An experimental study on the cell balancing parametersfor faulty cell detection in a battery module. Batteries 8(11), 218 (2022) https://doi.org/10.3390/batteries8110218
3. Pham, V.-L., Duong, V.-T., Choi, W.: A low cost and fast cell-to-cell bal- ancing circuit for lithium-ion battery strings. Electronics 9(2), 248 (2020) https://doi.org/10.3390/electronics9020248
4. Samaddar, N., et al.: Passive cell balancing of li-ion batteries used for automotive applications. J. Phys.: Conf.Ser. 1716, 012005 (2020)
5. Omariba, Z.B., Zhang, L., Sun, D.: Review of battery cell balancing methodologies for optimizing battery pack performance in electric vehi- cles. IEEE Access 7, 129335–129352 (2019) https://doi.org/10.1109/ACCESS.2019.2940090
6. Piao, C., Wang, Z., Cao, J., Zhang, W., Lu, S.: Lithium-ion battery cell-balancing algorithm for battery management system based on real-time outlier detection. Math. Prob. Eng. 2015, 168529, (2015) https://doi.org/10.1155/2015/168529
7. Babu, P.S., Ilango, K.: Comparative analysis of passive and active cell balancing of Li ion batteries. In: 2022 Third International Conference on Intelligent Computing Instrumentation and Control Technologies (ICICICT). Kannur, India, pp. 711–716 (2022) https://doi.org/10.1109/ICICICT54557.2022.9917778
8. Abdul-jabbar, T., Kersten, A., Mashayekh, A., Obed, A., Abid, A., Kuder, M.: Efficient battery cell balancing methods for low-voltage applications: A review. In: 2022 IEEE International Conference in Power Engineering Application (ICPEA). Shah Alam, Malaysia, pp. 1–7 (2022) https://doi.org/10.1109/ICPEA53519.2022.9744677
9. Chen, Z., Liao, W., Li, P., Tan, J., Chen, Y.: Simple and high-performance cell balancing control strategy.Energy Sci. Eng. 10(9), 3592–3601 (2022) https://doi.org/10.1002/ese3.1243
10. Hoekstra, F.S.J., Bergveld, H.J., Donkers, M.C.F.: Optimal Control of Active Cell Balancing: Extending the Range and Useful Lifetime of a Bat- tery Pack. IEEE Trans. Control Syst. Technol. 30(6), 2759– 2766 (2022) https://doi.org/10.1109/TCST.2022.3161764
11. Shukla, A.P., Patel, R.A.: Battery management system by passive cell bal- ancing for electric vehicle. In: 2022 2nd International Conference on Power Electronics & IoT Applications in Renewable Energy and its Con- trol (PARC). Mathura, India, pp. 1–6 (2022) https://doi.org/10.1109/PARC52418.2022.9726646
12. Al-Smadi, M.K., Abu Qahouq, J.A.: Evaluation of current-mode controller for active battery cells balancing with peak efficiency operation. IEEE Trans. Power Electron. 38(2), 1610–1621 (2023) https://doi.org/10.1109/ TPEL.2022.3211905
13. Nawaz, E., Ahmed, J., Abbas, G.: Energy-efficient battery management system for healthcare devices. J. Energy Storage 51, 104358 (2022). https://doi.org/10.1016/j.est.2022.104358 https://www.sciencedirect.com/science/article/pii/S2352152%D7;22003826
14. Reindl, A., Meier, H., Niemetz, M.: Scalable, decentralized battery man- agement system based on self-organizing node. In: Brinkmann, A., Karl, W., Lankes, S., Tomforde, S., Pionteck, T., Trinitis, C. (eds) Architecture of Computing Systems. ARCS 2020.

Lecture Notes in Computer Science, vol 12155. Springer, Cham. https://doi.org/10.1007/978-3-030-52794-5_13

15. Naguib, M.,Kollmeyer, P. Emadi, A.: Lithium-ion battery pack robust state of charge estimation, cell inconsistency, and balancing: Review. In: *IEEE Access*, vol. 9, 50570–50582 (2021)10.1109/ACCESS.2021.3068776
16. Singirikonda, S., Obulesu, Y.P.: Active cell voltage balancing of Elec- tric vehicle batteries by using an optimized switched capacitor strategy. J. Energy Storage 38, 102521 (2021)https://doi.org/10.1016/j.est.2021.102521
17. Zhang, A., Zhang, A., Hu, L., Huang, L.: Active cell balancing of lithium- ion battery pack based on average state of charge. Int. J. Energy Res. 44(4), 2535–2548 (2020) https://doi.org/10.1002/er.4876
18. Azad, F.S., Habib, A.K.M.A., Rahman, A., Ahmed, I.: Active cell balancing of Li-Ion batteries using single capacitor and single LC series resonant cir- cuit. Bull. Electr. Eng. Inf. 9, 1318–1325 (2020) https://doi.org/10.11591/ eei.v9i4.1944