A Comprehensive Review of Li-ion Battery Cell Balancing Techniques & Implementation of Adaptive Passive Cell Balancing

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***Abstract*—the lowest capacity cell inside the battery pack limits the pack's performance since once that cell is aged, the whole battery pack is essentially depleted. Due to fabrication and temperature changes, fluctuations in internal impedances, and self-discharge rates, a mismatch of cells in series strings is inevitable. Since the weakest cell in the chain determines the performance of a battery, a mismatch leads to a loss of capacity or power in charge or discharge mode. It also shortens the life of the battery, with the potential for explosion if the cells are not balanced. Therefore, a fast and accurate cell balancing system should be developed and applied for a battery pack. This research will examine different battery cell balancing techniques and assess how they relate to battery performance. On the pack of a 3S1P lithium ion battery, a fast passive cell balancing technique is also implanted. The early-stage researchers specializing in cell balancing strategies will find this study to be helpful.**

Keywords—Battery, Cell balancing, Passive cell balancing, Active cell balancing, Battery pack manager

I. INTRODUCTION

The use of batteries is constantly increasing. Cell phones, laptops, electric vehicles (EVs), charge balancing, and other high-performance tools require power, which is provided by batteries [1]. A low-power device, such as a cell phone and other portable devices, may not need more than one cell to provide the required amount of power, but a massive number of cells (batteries) are required to fulfill the needs of mobile applications, high performance like electric ones, vehicles and load balancing [2].

The properties of the cells are identical when they are new and the battery behaves constantly. Capacity, OCV, self-discharge, and internal impedance are some of these properties. The performance evaluation of any battery pack is ensured by the low-performing cell in the battery pack, the inconsistency leads to a depletion in capacity and misspent energy in charge or discharge mode [3]. Since the number of charge-discharge cycles leads to a reduction in uniformity between the cells of the battery pack due to the deterioration of the cells over time. As cellular degradation increases, the effects of the compound and cellular degradation speeds up [4]. Cell degradation generally leads to poor battery performance and certain safety issues. To ensure the safe working of the batteries, appropriate cell balancing should be performed to make sure the good performance of the battery pack [5].

The primary responsibility of a battery pack manager is to maintain and balance the battery cells in a battery pack [6]. Internal and external influences are the two sorts of variables that affect cell imbalance. The kind of assembly (serial/parallel), charge/discharge current, and heat dispersion are extrinsic variables, while congenital factors are those connected to assembling techniques that lead to variation in the active material quantity and interior resistance [7]. The battery pack is stable if all cells are at the same SOC at a given SOC. The battery pack manager balances the cells to guarantee that the charge is enhanced at all times so that the battery can provide the needed amount of charge; otherwise, the imbalance could result in escalate losses and heating impacts, decrease charge, poor energy efficacy, and faster degradation [8].

If a single cell in any battery pack dies and is not changed quickly, the results might be devastating. However, replacing a dead cell in a battery pack is not a good practice since the new cell has dissimilar chemical properties to the old one, which might cause failure. As a result, it is recommended that cells with similar chemical properties be placed in a battery pack with cells of the same age [9]. As a result of these factors, the battery pack manager uses cell balancing as a control mechanism to prevent battery cells from being overcharged or over-discharged, which must occur when the cells are charging up or draining [10]. Cell balancing ensures that the amount of energy provided to the cells throughout the charging procedure is utmost, as well as the amount of energy delivered during the discharging phase from the battery pack [11]. A battery pack contains a succession of multi-cell to attain greater working voltages. A battery pack with many cells is more prone to failure, which, in turn, impacts dependability since a greater failure rate is more probable than with a single cell battery. This indicates that when there are a lot of cells in a pack, the chances of failure are larger. Therefore, if there are many cells in a battery pack, the rate of failure of the battery is n multiple of a single cell [12].

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Charge and discharge amounts differ due to the differences in battery cells. Consequently, the voltage crossways the battery cells in sequence in the pack is inconsistent. This process may cause cells to overcharge up or undercharge, reducing battery pack lifespan, safety risks, and capacity loss over time [13]. The battery pack manager uses the cell equalization technique to ensure an even charge level between different cells by releasing extra energy as heat or transmission the additional energy to the lower charged battery cells to protect batteries from these and many other unforeseen problems. The control goals and algorithms should be integrated into every battery module, according to the literature, to be utilized to bias single cell states and affect pack efficiency [14]. The cell voltage balancing will occur in either a dissipative or active balancing method, where the surplus energy from highly charged cells is released as heat in the former and transported to the cells with low energy in the latter, making them stronger cells to sustain the weaker cell [15]. The cell charge equalizer works in the battery pack manager and controls the driving indications of the primary and secondary switches to operate in three different operations: cell charging balance, cell discharging balance, and idle operation, because the batteries are not always discharged to their maximum capacity thus it is not essential to maintain the SOC balanced at every time. The cell charge balancing operation occurs when the equalizer charger transmits pack energy to a low-energy cell, resulting in a pack-to-cell mode, while the cell discharging balancing mode occurs when the equalizer charger delivers additional cell energy back to the pack, resulting in a cell-to-pack mode. When the cell charger balancer is not in use, it is referred to as the idle balancing mode [16].

Based on their active components, performance, benefits, drawbacks, and applications, we presented a comprehensive assessment of all cell-balancing methods utilized in the current battery pack management in this work.

II. Cell Balancing Techniques

Cell charge equalization is critical for safe and dependable battery pack management, as previously stated. When the batteries are fully charged, cell balancing balances the voltages and SOC among them. Even similar cells from the same model and brand are not identical. SOC, voltage (V), current (I), impedance (Ro), and temperature properties, among other things, are always somewhat different [17]. Without a stable system, the voltage of a single cell will fluctuate with time, reducing total pack capacity and causing the battery arrangement to fail. Generally, three different cell adjustment processes are used: charging, disconnected, and dynamic. The different reasons for cell imbalance and their possible treatments are shown in Fig.1. There are two kinds of cell balancing techniques: active and dissipative or passive cell balancing [18].

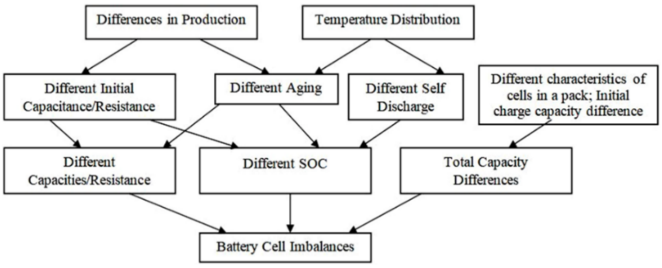

Fig. 1. Reason for Cell Imbalance inside a Battery Pack

A. *Passive Cell Balancing*

Dissipative or Passive balancing is a term utilized to describe the process of balancing circuits using a dissipative technique. Compared to active balancing circuits, passive balancing circuits are frequently simpler and less costly. A passive balancer functions in a very easy manner. The surplus charge is dissipated, as the term suggests. In most cases, the shunt element is positioned across one cell and releases the excess charge as heat while the other cells continue to charge. Each cell in the series string requires a shunt element. It is possible to switch on all of the shunts at the same time. The shunting element must be able to pass as much current as the charger produces to safeguard the cell from overcharging [19].

A switched resistor is one of a passive balancer's most basic shunting components. The resistor shunts part or all of the current around the cell after turning the switch on. When the cell's voltage reaches its maximum charging voltage, this is done. The switched shunt resistor technique is another passive balancer design in which every part is coupled with a resistor that balances and a switch for connection to the other parts, often a MOSFET. Most battery cell voltage measuring processors can control each balancing switch directly, and there are switches with some built-in that just need an external resistor [20].

Passive balancing is a simple approach for protecting cells in a series stack from getting overcharged. When compared to more intricate balancing procedures, they may be less costly . However, they squander energy by converting the surplus into heat. This heat that has dispersed might create problems. Dissipative balancers waste energy and are unable to offer to balance when the battery is draining. This makes them a realistic option for someone less concerned with energy waste and more worried about the initial expense [21]. This research work implements a switched shunt resistor passive balancing mechanism on a 3S1P lithium-ion battery pack.

B. *Active Cell Balancing*

Capacitors, inductors, transformers, and many common power electronic converter topologies are used in active balancing to allocate force between the units in the package. The transfer takes place to the lesser charged bodies from the more charged units, avoiding the energy loss associated with dissipative processes. The key benefits of active cell balancing are that it may accomplish a reasonably good balancing speed and efficacy. On the other hand, this approach includes many components, which increases the expense and complexity of the balancing circuitry [22].

1) *Cell Balancing Based on Inductors*

One or more inductors are used for cell balance in inductor-based approaches. A single inductor is utilized in the single-inductor balancing system to transmit charge from the package to the lowest cells. The monitoring system activates the necessary switches to transmit energy to the faded cell with fewer SOC levels. For balancing n cells, the multi-inductor approach uses n 1 inductor. The controller detects the potential difference between two adjoining cells and sends a control indication to the controls, requiring the greater cell to be turned on 1st to transmit charge to the weaker cell. The inductor-based cell equalization techniques feature a faster and more efficient balancing speed. However, they have a larger switch current pressure than the other approaches [23].

2) Transformer Based Cell Balancing

The power is transmitted through transformers to every unit, cell, and part from the transformer individually. Multiple numbers of transformers, transformers with many auxiliary windings, and a single transformer switched across cells are some of the variants of this system. Multiple transformers are used in this manner, with all of the main windings linked in correspondence and each secondary winding linked to a distinct cell through a diode. A switch connects the main winding to the pack voltage, and power is transmitted to each unit from the package at a 50% duty cycle. A single multi-auxiliary winding transformer in the multi-auxiliary windings transformer technique replaces the many transformers employed in the preceding technique, and the balancing methodology remains the same. However, the number of secondary windings that may be used restricts the number of cells in this approach. The secondary winding is shifted among cells in the single transformer approach to energize the weaker cells until the balance is accomplished. The switched transformer approach is more compressed but needs a more sophisticated control procedure to assure proper cell equalization than the other transformer-based systems [24].

3) Converter Topology-Based Cell Balancing

Balancing may also be done using common dc-dc converter topologies such as bidirectional buck-boost, bidirectional Cuk, bidirectional flyback, full-bridge, and quasi-resonant converters. In most cases, single converter is used per cell, with the converters transferring electricity across nearby cells. Instead of just matching the voltage of the cells, as many of the previous approaches did, the converters able to manage the movement of energy in whatever manner the battery management system instructs, giving them greater freedom in maintaining the cells' SOC [25].

This research study uses a bidirectional buck-boost converter to transmit energy between two nearby cells of the battery [26]. The Cuk converter, a bidirectional converter that uses capacitors instead of inductors as energy transfer components, operates on the same concept [27]. To accomplish cell balance, the bidirectional fly-back converter, which evolved from the buck-boost converter, uses a transformer and less numbers of elements. The benefit of bidirectional converters is that they can transmit energy into or out of cells [28]. The multi-module full-bridge converter is a completely regulated converter that transmits charge from one cell to another or from the pack to the weakest cell in the group. The benefit of this approach is that it may be scaled for larger power applications [29]. To accomplish cell-to-cell balance, zero-current quasi-resonant or zero-voltage quasi-resonant converters may be utilized. Switching loss is reduced by tuning the resonant circuits to obtain zero switching current and voltage [30]. Overall, converter-based cell balancing systems produce great efficacy and matching speed, but these systems are costly and need a more complicated control system.

Table 1 compares the different cell balancing strategies, with the active components in par, as well as the benefits and drawbacks of each approach. Generally, disintegrating offsetting is a dependable, low-cost, and straightforward approach of cell consideration.

III. IMPLEMENTATION OF FAST PASSIVE CELL BALANCING

A series, parallel structures combine to make a battery pack linked in battery units to match the voltage and power requirements, as previously mentioned. Due to mismatches in cell properties such as capacity, series impedance, self-discharge, and columbic efficacy, the sequential connection of cells produces an inherent sensitivity and restriction. Cell imbalance is a natural part of the production, and it may vary from 1 to 10 percent at the start of life span, relaying on the quality of the manufacture and the amount of cell binning used. Even more crucially, owing to the expansion of the early inconsistency, temperature distribution, and other visible inequalities throughout the battery pack, cells do not deteriorate equally during their lives. Regardless of any disparity in cell characteristics, charging up or discharging a of series attached battery cells effects in equal electric current through every unit.

Consequently, over time, the cell SOC, a quantity of stored charge within the cell, differs. For example, cells may have the equal SOC and capacity at first, but due to varying self-discharge rates, cell SOCs may gradually differ even while units are not being consumed. Different coulombic efficiency among cells may generate SOC imbalance when charging or discharging. Because temperature affects self-discharge rate, coulombic efficiency, and other cell properties, a temperature gradient across a large battery pack may increase the SOC imbalance across cells.

The simplest balancing approach is cell terminal voltage balancing, in which a equalizing circuit is utilized parallel to each cell. Surplus charge from cells that achieve maximum voltage is discharged through the other half of the circuitry. Voltage balancing may be accomplished with a very basic hardware structure and does not need high processing resources since balancing choices are made by detecting cell voltage and comparing it to the pack's lowest cell voltage. The method is widely employed when there isn't a significant disparity in cell properties at the start of life.

In this approach, a passive cell balancing mechanism is used. Extra energy from cells is dissolute as heat via a passive balancing mechanism. The balancing logic determines which cells required to waste excess charge and operates the equalizing circuit attached to the cell based on the balancing goal. Extra charge in the cells is dissipated as heat energy in the passive balancing circuits until all the cells have reached the same balancing goal state (voltage).

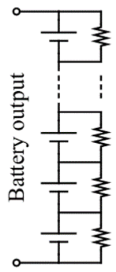

Fig. 2. Shut Resistor Passive Cell Balancing

A shunt resistor approach is a relatively basic passive balancing method, as shown in figure 2. A shunt resistor is directly linked in parallel with the battery cell. Because most battery cells' terminal voltage varies in lockstep with their state of charge, the cell with a higher SOC also has a higher terminal voltage and, as a result, drains quicker than the cell with a lower SOC. The discharge process, on the other hand, is uncontrollable. Even if the cells are balanced, they will continue to drain energy. A low charging current is required to keep the battery pack charged at all times.

Better inert unit stabilizing can be achieved by adopting controllable power dissipation through resistors, diode, and MOSFET internal resistance as a balancing resistor.

Because of its simplicity, durability, and cheap cost, this inert unit stabilizing technology is frequently employed in industrial applications. The passive approach typically disposes of some charge from the overcharged cell through a resistor element until it matches the state of charge (SOC) or reference voltage. In contrast to the previous methodology, this method uses an internal MOSFET impedance as a balancing resistor in addition to a resistor element to remove overloaded units and match the threshold voltage during the process of charging.

Passive cell balancing is often performed throughout the charging process when a cell's voltage has reached its full voltage limit. Because part of the energy in a battery will be wasted, this approach is only suitable for charging. Passive cell balancing techniques are mainly based on a voltage balancing approach. The cell with highest voltage (V-highest) is detected and compared to a baseline voltage in the balancing approach (Vtop). Suppose the voltage of a cell exceeds the baseline voltage. In that case, part of the energy in the battery is discharged via the balancing resistor, which is coupled with the internal impedance of the MOSFET, preventing the cell from overcharging.

This electrical model of lithium-ion battery which has been modeled in Simscape by Javier Gazzarri [31] utilized here. This Simscape Electrical is used to apply the suggested approach on a 3S1P battery pack made up of three UR18650W cells. The Simscape model of the li-ion battery pack for cell balancing is used, and this section will show the cell balancing results. The 3S1P li-ion battery pack is subjected to an alternative C/2 charge/discharge cycle in this simulation. Charging of the battery pack is constant current constant voltage (CCCV), and discharging is constant current (CC). Cell balancing is achieved using the dissipative cell balancing technique, including the thermal effects. Figure 3 shows the state flow charts for charging up and discharging of the battery pack.

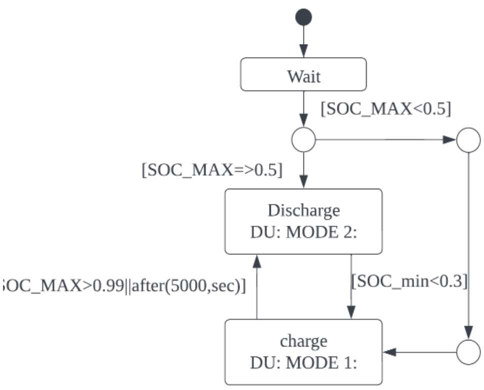

Fig. 3. State Flow Chart of Battery Pack Charging and Discharging

Figure 4 reflects the individual cell voltage and current inside a battery pack, and balancing is achieved for all the three cells of a battery pack.

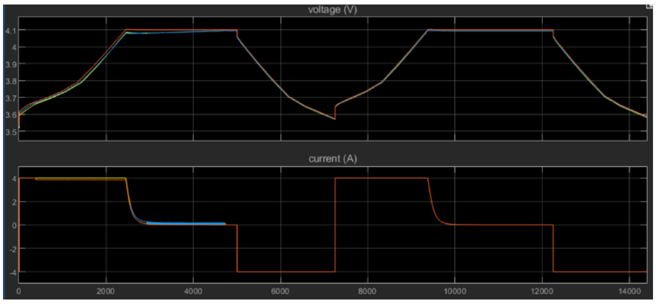

Fig. 4. Voltage and Current Balancing of all the Three Cell with Passive Balancing

Figure 5 exhibits the voltage and current of the battery pack. This battery pack include three cell in sequence so the voltage of battery pack will be the three times multiple of single cell voltage.

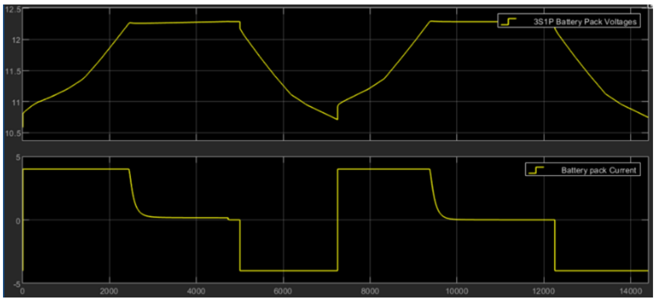

Fig. 5. 3S1P Li-ion Battery Pack Voltages and Current

Figure 6 shows the SOC of the cells during the charging up and discharging cycles. At the start of the charging cycle, battery cells are imbalanced, and balancing is achieved in the first discharge cycle for all three cells with the help of a balancing circuit and logic applied.

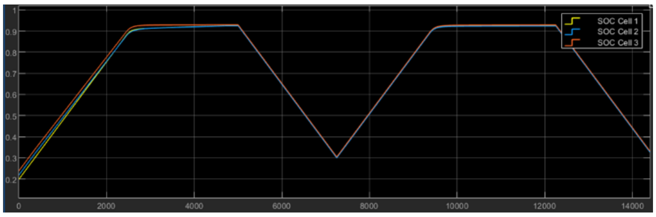

Fig. 6. SOC Balancing of the individual Cell inside a Battery Pack

IV. CONCLUSION

The batteries with Li-ion have been selected as the best candidate for moveable, and high-power operations due to their good energy densities, long life cycles, and high proficiencies compared to other battery chemistries, like lead-acid and nickel-based batteries recently. On the other hand, these batteries are disposed to failure due to charge imbalance in batteries linked in series or parallel, which may be disastrous. Therefore, they must be carefully managed in real-time. This research examined different battery cell balancing techniques and assess how they relate to battery performance. A fast passive cell balancing technique is also implemented in this article. The cost, size, control complexity, implementation, and application suitability of the various cell balancing topologies vary. Each topology has benefits and drawbacks of its own, as intended.

TABLE I. A BRIEF COMPARISON OF CELL BALANCING TECHNIQUES IN LI-ION BATTERY PACK [15]

Technique	Methodology	Active Element	Advantage	Disadvantage
Passive Balancing	Fix Resistor	n number of resistors	Easy application and low cost	Less balancing speed, continually heat dissipation, and pack discharge
	Switched Resistors	n resistors, and n switches	good balancing speed, relatively fewer loss	high cost is limited to less power due to the need to dispose of loss
Capacitor Based Balancing	Double tiered switched capacitors	n capacitor and 2n switched	Average balancing speed, modularity, modest control	The high number of switches, high cost
	Single switched capacitors	one capacitor, 1 resistor, and n+5 switches	fewer components, most efficient	Low balancing haste
Inductor Based Balancing	Single Inductor	one inductor, 2n switches, and 2n diodes	Satisfactory balancing speed, higher efficiency	Complex control, high cost
	Multi-Inductor	n-1 inductors, 2n-2 switches	Decent stabilizing pace, smaller power complication	High cost
Transformer Based Balancing	Multi-transformer	n transformers, one switch, and n diodes	Good modular strategy, high balancing speed	Expensive, less effective, larger size
	Multi-windings transformer	1:n transformer, One switch, and n diodes	Relatively compact	Less useful, reduced number of cells
	Switched transformer	One transformer, n+6 switches, and 1 diode	Lower magnetic losses, relatively compact	costly, complex control is required
Common Converter-Based Balancing	Buck-boost converter	N converters	Good efficiency, satisfactory balancing speed	The greater size, cost, and complex control are needed
	Cuk converter	n-1 converters	Good balancing speed, satisfactory efficiency	Complicated control is needed, a large size
	Flyback converter	1 converter, 2n switches, and 1 transformer	fewer components, low complex control, high balancing speed	Transformer needed
	Multi-module full-bridge converter	N converters	scaleable to high power usage, decent balancing speed	big size, costly, and complex control is required
	Quasi-resonant converter	n-1 converter	Easy to implement, high efficiency	Higher cost, size

REFERENCES

[1] G. Jeong, Y. U. Kim, H. Kim, Y. J. Kim, and H. J. Sohn, “Prospective materials and applications for Li secondary batteries,” Energy Environ. Sci., vol. 4, no. 6, pp. 1986–2002, Jun. 2011, doi: 10.1039/C0EE00831A.

[2] F. Lv et al., “Challenges and development of composite solid-state electrolytes for high-performance lithium ion batteries,” J. Power Sources, vol. 441, p. 227175, Nov. 2019, doi: 10.1016/J.JPOWSOUR.2019.227175.

[3] Y. Hua et al., “A comprehensive review on inconsistency and equalization technology of lithium-ion battery for electric vehicles,” Int. J. Energy Res., vol. 44, no. 14, pp. 11059–11087, Nov. 2020, doi: 10.1002/ER.5683.

[4] H.-K. Kim, J. H. Choi, and K.-J. Lee, “A Numerical Study of the Effects of Cell Formats on the Cycle Life of Lithium Ion Batteries,” J. Electrochem. Soc., vol. 166, no. 10, pp. A1769–A1778, May 2019, doi: 10.1149/2.0261910JES/XML.

[5] Z. B. Omariba, L. Zhang, and D. Sun, “Review of Battery Cell Balancing Methodologies for Optimizing Battery Pack Performance in Electric Vehicles,” IEEE Access, vol. 7, pp. 129335–129352, 2019, doi: 10.1109/ACCESS.2019.2940090.

[6] U. Abronzini et al., “Optimal Modular BMS for High Performances NMC Battery Pack,” 2018 IEEE Int. Conf. Electr. Syst. Aircraft, Railw. Sh. Propuls. Road Veh. Int. Transp. Electrif. Conf. ESARS-ITEC 2018, Jan. 2019, doi: 10.1109/ESARS-ITEC.2018.8607379.

[7] M. Baumann, L. Wildfeuer, S. Rohr, and M. Lienkamp, “Parameter variations within Li-Ion battery packs – Theoretical investigations and experimental quantification,” J. Energy Storage, vol. 18, pp. 295–307, Aug. 2018, doi: 10.1016/J.EST.2018.04.031.

[8] R. Sreedhar and K. Karunanithi, “Design, simulation analysis of universal battery management system for EV applications,” Mater. Today Proc., Jan. 2021, doi: 10.1016/J.MATPR.2020.12.136.

[9] E. Hosseinzadeh et al., “Quantifying cell-to-cell variations of a parallel battery module for different pack configurations,” Appl. Energy, vol. 282, p. 115859, Jan. 2021, doi: 10.1016/J.APENERGY.2020.115859.

[10] A. Hauser and R. Kuhn, “Cell balancing, battery state estimation, and safety aspects of battery management systems for electric vehicles,” Adv. Batter. Technol. Electr. Veh., pp. 283–326, Jan. 2015, doi: 10.1016/B978-1-78242-377-5.00012-1.

[11] Y. B.-T. Instruments and undefined 2009, “Battery cell balancing: What to balance and how,” amarketplaceofideas.com, Accessed: Jun. 13,2022.[Online].Available:http://www.amarketplaceofideas.com/wp content/uploads/2018/09/Topic20220-20Battery20Cell20Balancing20 20What20to20Balance20and20How1.pdf.

[12] W. F. Bentley, “Cell balancing considerations for lithium-ion battery systems,” Proc. Annu. Batter. Conf. Appl. Adv., pp. 223–226, 1997, doi: 10.1109/BCAA.1997.574107.

[13] S. W.-A. A. Journal and undefined 2009, “Cell balancing buys extra run time and battery life,” ti.com, 2009, Accessed: Jul. 25, 2022. [Online].Available:https://www.ti.com/lit/an/slyt319/slyt319.pdf#pag e=14.

[14] M. Uzair and G. Abbas, “Characteristics of Battery Management Systems of Electric Vehicles with Consideration of the Active and Passive Cell Balancing Process,” 2021.

[15] M. Naguib, P. Kollmeyer, and A. Emadi, “Lithium-ion battery pack robust state of charge estimation, cell inconsistency, and balancing: Review,” IEEE Access, vol. 9, pp. 50570–50582, 2021, doi: 10.1109/ACCESS.2021.3068776.

[16] A. Tavakoli, S. Ali Khajehoddin, and J. Salmon, “Control and Analysis of a Modular Bridge for Battery Cell Voltage Balancing,” IEEE Trans. Power Electron., vol. 33, no. 11, pp. 9722–9733, Nov. 2018, doi: 10.1109/TPEL.2018.2798636.

[17] Q. Ouyang, W. Han, C. Zou, G. Xu, and Z. Wang, “Cell Balancing Control for Lithium-Ion Battery Packs: A Hierarchical Optimal Approach,” IEEE Trans. Ind. Informatics, vol. 16, no. 8, pp. 5065–5075, 2020, doi: 10.1109/TII.2019.2950818.

[18] A. B. Ahmad, C. A. Ooi, D. Ishak, and J. Teh, “Cell balancing topologies in battery energy storage systems: A review,” Lect. Notes Electr. Eng., vol. 547, pp. 159–165, 2019, doi: 10.1007/978-981-13-6447-1_20/COVER/.

[19] M. Daowd, N. Omar, P. van den Bossche, and J. van Mierlo, “A review of passive and active battery balancing based on MATLAB/Simulink,” Int. Rev. Electr. Eng., vol. 6, no. 7, pp. 2974–2989, 2011.

[20] T. Duraisamy and D. Kaliyaperumal, “Adaptive passive balancing in battery management system for e-mobility,” Int. J. Energy Res., vol. 45, no. 7, pp. 10752–10764, Jun. 2021, doi: 10.1002/ER.6560.

[21] Amin, K. Ismail, A. Nugroho, and S. Kaleg, “Passive balancing battery management system using MOSFET internal resistance as balancing resistor,” Proceeding - ICSEEA 2017 Int. Conf. Sustain. Energy Eng. Appl. "Continuous Improv. Sustain. Energy Eco-Mobility", vol. 2018-Janua, pp. 151–155, 2017, doi: 10.1109/ICSEEA.2017.8267701.

[22] Z. Zhang, L. Zhang, L. Hu, and C. Huang, “Active cell balancing of lithium-ion battery pack based on average state of charge,” Int. J. Energy Res., vol. 44, no. 4, pp. 2535–2548, Mar. 2020, doi: 10.1002/er.4876.

[23] K. M. Lee, Y. C. Chung, C. H. Sung, and B. Kang, “Active cell balancing of Li-Ion batteries using LC series resonant circuit,” IEEE Trans. Ind. Electron., vol. 62, no. 9, pp. 5491–5501, Sep. 2015, doi: 10.1109/TIE.2015.2408573.

[24] K. M. Lee, S. W. Lee, Y. G. Choi, and B. Kang, “Active Balancing of Li-Ion Battery Cells Using Transformer as Energy Carrier,” IEEE Trans. Ind. Electron., vol. 64, no. 2, pp. 1251–1257, Feb. 2017, doi: 10.1109/TIE.2016.2611481.

[25] A. Turksoy, A. Teke, and A. Alkaya, “A comprehensive overview of the dc-dc converter-based battery charge balancing methods in electric vehicles,” Renew. Sustain. Energy Rev., vol. 133, p. 110274, Nov. 2020, doi: 10.1016/J.RSER.2020.110274.

[26] M. Daowd, M. Antoine, N. Omar, P. Lataire, P. Van Den Bossche, and J. Van Mierlo, “Battery Management System—Balancing Modularization Based on a Single Switched Capacitor and Bi-Directional DC/DC Converter with the Auxiliary Battery,” Energies 2014, Vol. 7, Pages 2897-2937, vol. 7, no. 5, pp. 2897–2937, Apr. 2014, doi: 10.3390/EN7052897.

[27] Y. S. Lee, C. Y. Duh, G. T. Chen, and S. C. Yang, “Battery equalization using bi-directional Cûk converters in DCVM operation,” PESC Rec. - IEEE Annu. Power Electron. Spec. Conf., vol. 2005, pp. 765–771, 2005, doi: 10.1109/PESC.2005.1581713.

[28] Y. L. Lee, C. H. Lin, and S. J. Yang, “Power Loss Analysis and a Control Strategy of an Active Cell Balancing System Based on a Bidirectional Flyback Converter,” Appl. Sci. 2020, Vol. 10, Page 4380, vol. 10, no. 12, p. 4380, Jun. 2020, doi: 10.3390/APP10124380.

[29] P. Xu, L. Kang, D. Xie, X. Luo, and H. Lin, “A Switch-Reduced Multicell-to-Multicell Battery Equalizer Based on Full-Bridge Bipolar-Resonant LC Converter,” Batter. 2022, Vol. 8, Page 53, vol. 8, no. 6, p. 53, Jun. 2022, doi: 10.3390/BATTERIES8060053.

[30] Y. S. Lee and G. T. Cheng, “Quasi-resonant zero-current-switching bidirectional converter for battery equalization applications,” IEEE Trans. Power Electron., vol. 21, no. 5, pp. 1213–1224, 2006, doi: 10.1109/TPEL.2006.880349.

[31] “Battery Modeling - File Exchange - MATLAB Central.” https://www.mathworks.com/matlabcentral/fileexchange/36019-battery-modeling?s_tid=srchtitle_Battery management system_10 (accessed Jun. 19, 2022).