Methodology for Balancing LiFePo4 Battery Cells in Electric Vehicles to Improve Battery Pack Performance

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Abstract:

This research paper engages the reader to understand due to the increasing use of LiFePo4 batteries in Automobiles and home applications due to their high volumetric energy density, high gravimetric energy density, low self-discharge and high efficiency with high energy carrying capability. These batteries, on the other hand, are prone to failure due to charge imbalance in batteries connected in series or parallel, which can be catastrophic, and so they must be thoroughly monitored in real time. There are numerous battery balancing schemes, which can be classified as either passive or active. All of these schemes have their own set of benefits and drawbacks; therefore, it is up to the user to pick which one will work best for them. However, research has shown that the hybrid scheme, which combines the benefits of all schemes, will be the best. The numerous battery cell balancing approaches will be reviewed in this research paper study, and their link with battery performance will be evaluated. At present there are a few research papers tackling the mechanical vibration of battery balancing performance The results of this study demonstrate that battery balancing performance over time should be assessed using a variety of temperature and vibration frequencies.

Keywords: Battery Model (LiFePo4)**,** LiFePo4 Battery cell balancing, electric vehicles, Battery Management system, state of charge and performance optimization.

Introduction:

In the electric vehicle industry, large battery packs provide high output power individual battery in the pack equally contributes to the system, but, when it comes to batteries, all batteries are not made the same. Even if the batteries exhibit the same chemistry with the same physical size, shape, and weight, they can have different total capacities, different self-discharge rates, different internal resistances, and Various ageing factors all have an impact on the overall battery life equation. Because of these variances, batteries have a big issue in terms of battery life, which can be prolonged by cell balancing, according to study, and thus require the battery management system (BMS) to execute cell balancing at all times.

The lowest capacity cell in the battery pack limits the pack's performance since once that cell is drained, the entire pack is effectively depleted. The state of charge (SOC) measurement, which evaluates the ratio of the remaining charge to the cell capacity, is used to determine the health of each individual battery cell in the pack. Precision single-chip and multichip BMS improve battery pack performance by combining battery monitoring (including SOC data) with passive or active cell balancing. Ordinarily, the performance criteria of the battery balancing system normally include aspects such as the impact of state-of-health (SOH), balancing speed, efficiency, cost, and volume. As a result of these measurements, the battery SOC is healthy regardless of the cell capacity; the cell-to-cell SOC mismatch is eliminated; and the impacts of cell ageing are minimised (aging results in lost capacity).

A battery pack consists of several battery cells in parallel and in series to provide sufficient operating voltage and capacity to support the application. However, if there is a mismatch between the voltage and capacity of the connected battery cells, the entire battery pack cannot operate efficiently So far although research is commonly focusing on the evaluation of battery performances at room temperature, little is done concerning the balancing of the batteries at various temperatures they are cycled, as well as the load vibration frequencies. This is thought to lead to skewed and misleading judgments of the battery's true capabilities. Although most research has focused on evaluating battery performance at room temperature, little has been done in terms of balancing the batteries at various temperatures as well as the load vibration frequencies. This is thought to lead to skewed and unfair appraisals of the battery's true capabilities.

For accelerated ageing, tests carried out at different temperatures from room temperature, and different load vibration frequencies, there is a lack of knowledge about the impact of the temperature chosen in combination with vibration frequencies for evaluating battery balancing performances during long-term cycling. The influence of variable temperature and vibration on the assessments of lithium-ferrous battery (LiFePo4) cells balancing performances during long-term cycling is therefore the goal of this review article.

Battery model (LiFePo4):

A LiFePo4 consists of three main parts, which are a negative electrode, electrolyte, and positive electrode whereby the charge and discharge principle takes place when the heavily charged ions are transferred between the two electrodes and it takes place in the electrolyte. The rechargeable LiFePo4 cells perform electrical work by exchanging ions through the electrolytes between negative and positive electrodes. The battery model is required to define and study voltage U, current I, SOC, temperature, and vibration

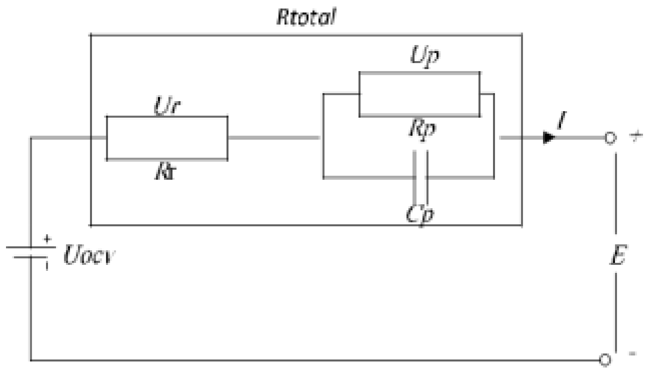

Figure 1. Thevenin battery model.

Several works of literature propose many battery models which are made of the equivalent circuit combination of capacitance and resistance. Taking temperature into consideration the study of Thevenin equivalent circuit model will be applied as shown in Fig. 1

The Thevenin battery model from Fig. 1 is used to analyse the battery discharging process.

Where:

Uocv is the open-circuit voltage,

Rr represents the ohmic resistance,

Ur is the voltage on *Rr*,

Cp is the polarization capacitance,

Rp is the polarization resistance,

Up is the voltage on *Cp* and *Rp*,

E is the terminal voltage,

I is the discharging current,

I *Rtotal* is the sum of *Rr*, *Cp*, and *Rp*.

Temperature has a significant impact on battery performance, shelf life, charging, resistance, and voltage regulation. There is greater chemical activity within a battery at very high temperatures than at lower temperatures. When the temperature is too low, such as when cars are used in the winter, the battery's capacity is reduced. If the battery is exposed to extreme weather, it may stop working, melt, create sparks, create Ames, expand, or even blow up in very extreme cases. The battery is affected by extreme cold because the internal components expand and electrons are blocked; nevertheless, when the temperature increases, the electrons are stimulated. As a result, high temperatures have a significant influence on battery performance, safety, and cycle life. Temperature control devices are necessary to monitor the temperature and block the current route when the temperature exceeds the permitted levels; otherwise, energy can be lost by conduction, convection, and radiation. The shielding keeps batteries from being damaged, extending their life and performance. This can be accomplished by even heat distribution and the prevention of overheating. The influence of temperature on a battery's voltage is an indirect effect that is linked to the temperature of the material. i.e., a conductor or semiconductor that alters its properties as a function of temperature. The resistance of the conductor increases as the temperature rises, as shown by the relationship:

$$R(T) = R0[1 + \propto (T - T0)] \text{ --(1)}$$

where T is the battery temperature, R0 is the conductor's internal resistance, T is the ambient temperature, and T0 is the temperature coefficient. As a result, we can see that resistance rises as temperature rises, implying that voltage drops. When a result, voltage drops as temperature rises and vice versa.

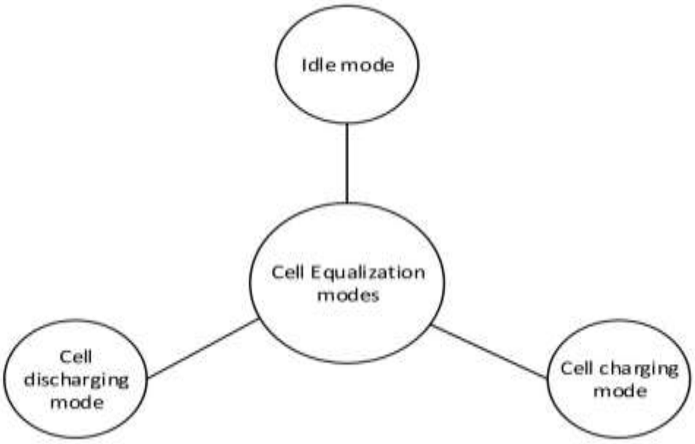

Figure 2: Cell Balancing Modes

If a single cell in a battery pack dies and is not replaced quickly, the results might be devastating. However, replacing a failed cell in a battery pack is not a long-term solution since the new cell has different chemical properties than the old cell, which might lead to failure again. As a result, it is recommended that cells with similar chemical properties be combined in a battery pack with cells of the same age. Because of these factors, the BMS uses cell balancing as a control measure to prevent battery cells from being overcharged or over discharged, and this balancing must occur when the cells are charging or draining. Cell balancing ensures that the amount of energy given to the cells during the charging process is maximised, as well as the amount of energy released from the cells during the discharging phase. To reach greater working voltages, the EVs battery pack has a succession of multi-cell batteries.
The cell charging balancing mode occurs when the balancer charger transmits pack energy to a low-energy cell, resulting in a pack-to-cell mode, whereas the cell discharging balancing mode occurs when the balancer charger transfers surplus cell energy back to the pack, resulting in a cell-to-pack mode.

Cell Balancing Schemes:

The purpose of cell balancing is to ensure that the voltage and state of charge (SOC) of the battery cells are equal when they are completely charged. The two batteries have different cell charges, as illustrated in Fig. 3, which necessitates cell balancing to bring the cells to the same SOC. The major cell balancing methods are currently in use.

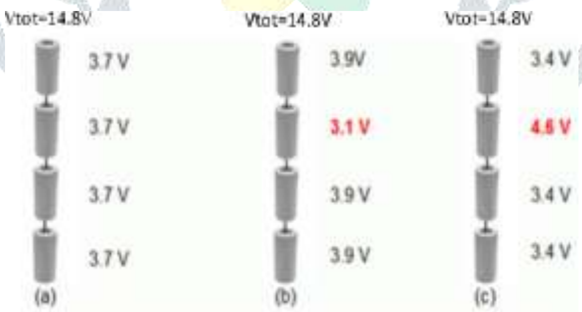

FIGURE 3. Example of Cell Charge Variations

(a) Fully charged cells with the same SOC
(b) Imbalanced battery with one low-charge cell
(c) Imbalanced battery with one high-charge cell.as well as passive approaches.

A voltage-based algorithm and a charge-based algorithm are two types of cell balancing algorithms. The algorithms produce active or passive cell balancing methods, which may be used to balance batteries.

1. Active Cell Balancing:

The capacitive or inductive charge shuttling technique is used to move charge from a cell with a high charge to a cell with a low charge. This means that active balance techniques balance out discrepancies between cells in series by transferring electrical energy from higher SOC cells to lower SOC cells with minimal loss. This approach is extremely efficient since surplus energy is transferred to a low-energy cell rather than being precipitated away, but it increases the complexity of the balancing circuit and reduces the LIBs' high performance. Relays, DC-DC connections, and current transducers make up the active cell balancing technique. The primary aim of an active balancing approach is to maintain an even charge distribution across a battery's series-connected cells over time, with minimal energy losses during the equalisation process.

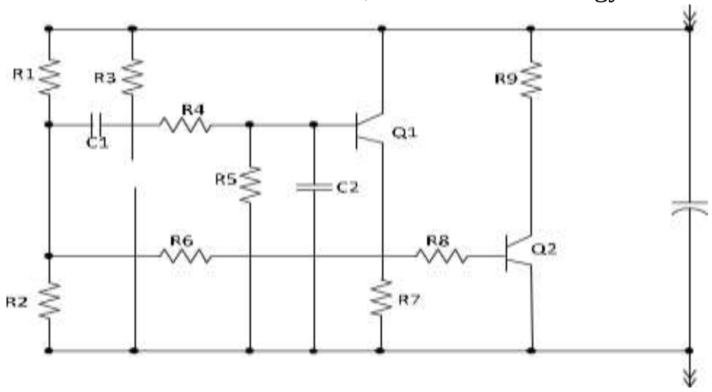

FIGURE 3. The active cell balancing circuit.

It is suitable for high cycle applications or where standby losses must be kept to a minimum; moreover, active cell balancing can prolong the battery cell lifetime and capacity, making this scheme more favourable than passive balancing. However, this technique has the disadvantage of requiring an additional component, which increases the cost and unreliability of the process, as well as the time it takes to equalise the cells.
The active cell balancing model's circuit is shown in Figure 3 . In active balancing, energy is taken from the highest charged cell and transferred to the least charged cell, generally using DC-DC converters, as shown in Fig. Because the active balancing scheme uses capacitance or inductive charge shuttling to transfer charge from a cell with a high charge to a cell with a low charge, a battery balancer, or battery regulator, based on the active balancing topology, is used to increase the available capacity of a battery pack with multiple cells and the longevity of each cell.
Any cell with a higher charge is freed of some charge, which is given to the cell with a lower charge, and an ultra-capacitor (supercapacitor) is employed, as shown in Fig. 3. Unlike passive balancing, this system does not release the surplus energy as heat into the air, making it more efficient and extending the battery life. However, if the capacitors or inductors used for active cell balancing are tiny, the balance current is minimal. The active balancing method works by moving surplus charge from a high-voltage cell to a low-voltage cell, with the middle-voltage (Vmid) cell serving as a reference. Each cell's terminal voltage (Vcell) is compared to (Vmid), and if the voltage difference is more than the threshold voltage (+Vth), the cell must be discharged; if the voltage difference is less than the threshold voltage (Vth), the cell must be charged; otherwise, no balancing is necessary.

2) PASSIVE CELL BALANCING:

When opposed to the active cell balancing approach, the passive cell balancing method is very straightforward. The surplus energy in the cells is released as heat by a dissipative bypass route until the charge equals that of the lower cells in the pack or the charge reference, which affects the battery run time. As a result, the charge is lost or discharged to the air via a resistor, making this technique inefficient and generating a lot of heat. The excess charge of cells with high SOC is dissipated as heat across a resistor in traditional cell balancing techniques, resulting in worse energy efficiency. This technique, on the other hand, is suitable for low-cost system applications that do not require active control to equalise. It is not suitable for lithium-ion batteries due to the significant danger of explosion. The resistor is put in parallel with each cell in this manner, and the size of the resistance sets the balancing rate. Figures 6 and 7 depict the passive battery cell balancing circuit and flowchart, respectively. Passive cell balancing topologies may be divided into two categories. The fixed shunting resistor and the switched shunting resistor are two of them. A resistor in parallel to each cell, controlled by the cell voltage monitoring chip, is used for passive balancing.

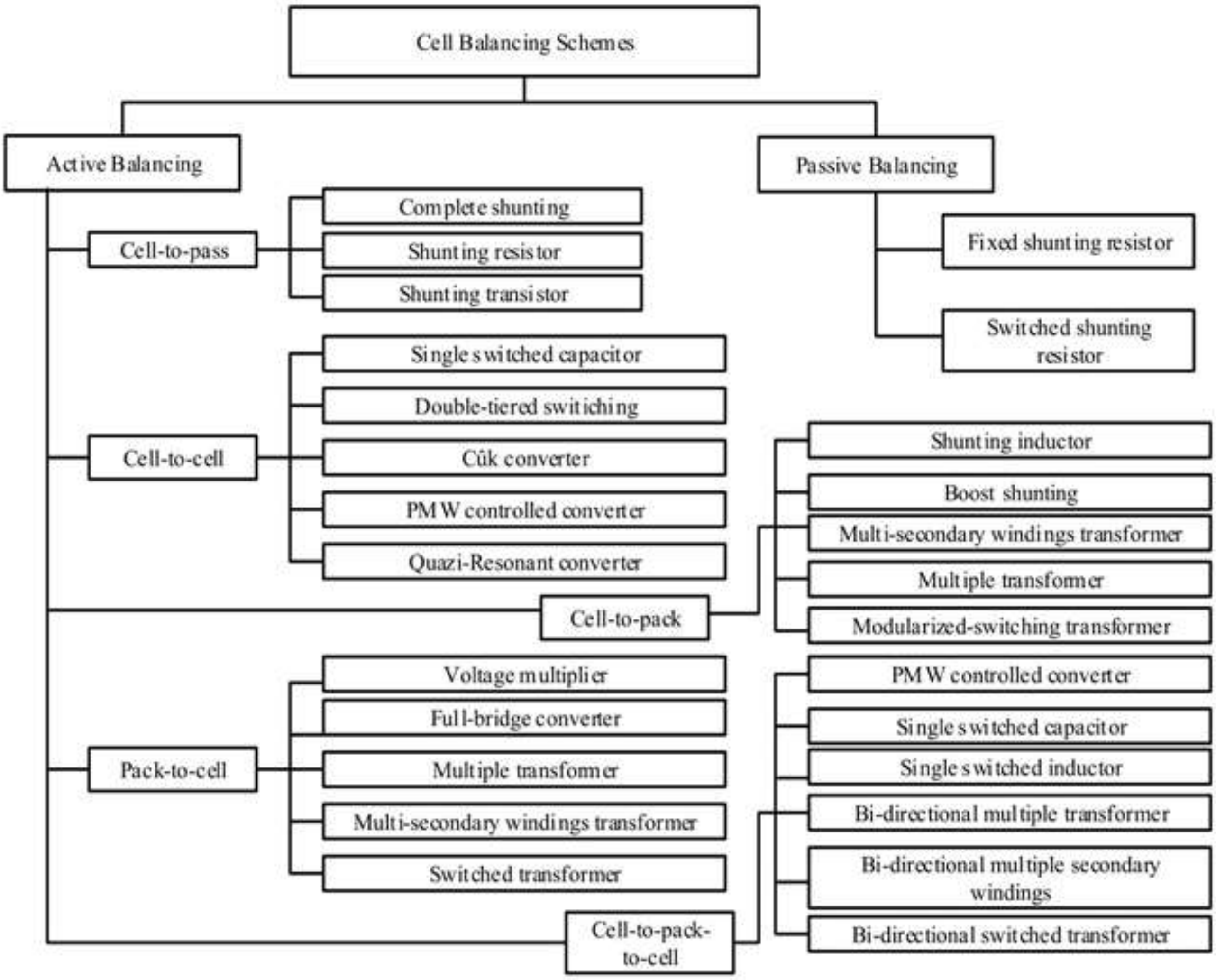

Figure 4: Active and Passive Cell balancing Techniques

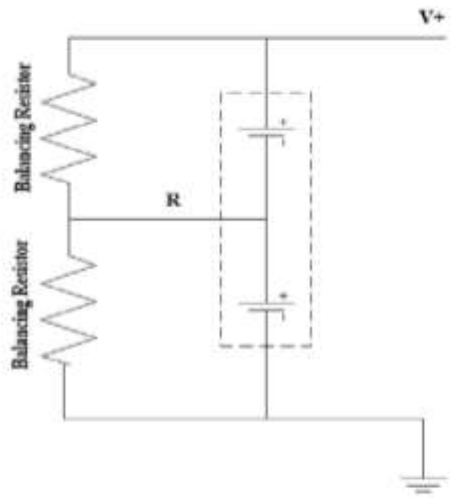

Figure 5:Passive Balancing Circuit

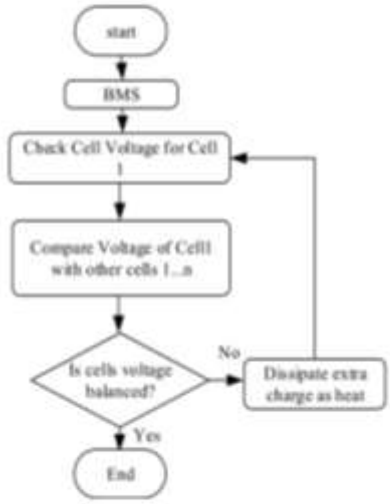

Figure 6:- Passive cell balancing flow chart

Various battery cell imbalances, such as SOC, impact the charge or discharge voltage of the battery cells. FIGURE 6: Flowchart for passive cell balancing. impedance discrepancies, and total capacity variances. These cell imbalances are divided into two categories: internal sources and external sources, and they are further demonstrated as follows. In Fig 7

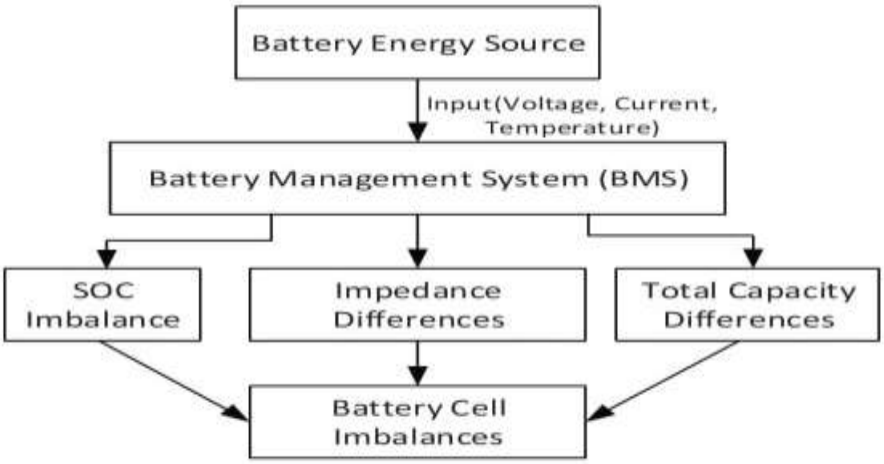

Figure 7: Causes of battery Cell Imbalance

Internal causes include manufacturing variances in charge storage value, internal impedance variations, and self-discharge rate changes. External sources are generated by multi-rank pack protection integrated circuits (ICs) that drain charge unequally from various series ranks in the pack. In order to compensate for their own unbalanced influence on the cells, these protective ICs must contain a cell-balancing mechanism. Another external source of the imbalance is a thermal difference throughout the pack, which results in varying rates of self-discharge for the cells.

IMPORTANCE OF CELL BALANCING:

Cell imbalance in battery systems is a critical issue for the battery's system life since, without a balancing mechanism, the individual cell voltages may drift apart over time, resulting in low efficiency and potentially danger. Cell balancing has a number of advantages, including:

• EVs have a longer range and have more energy.

• To achieve LIBs cell-to-cell (C2C) voltage balancing or to reduce the C2C SOC mismatch.

• To account for capacitance and leakage current fluctuations. Capacitance affects the initial charge and voltage. Leakage current determines how long a voltage may be maintained.

• Increased battery life.

• To reduce the effects of cell ageing, which is caused by a loss of capability.

• To enhance the overall dependability and safety of the individual cells by reducing voltage stress on them. Cell balance, according to experts, can help with battery management, maintenance, and repair. As a result, the procedure of cell balancing is unavoidable.

The results gained considerably outweigh the expenditures that may be paid by equalising the battery cells. However, this procedure can occasionally result in losses, since if a component of the battery pack fails, the entire battery pack can be changed, resulting in greater expenses.

Basic functions of BMS:

The functions of a BMS are to keep all cells within their pre-set safe operational limits by measuring voltage, current, and temperature, and to communicate with the master controller if any cell is out of bounds so that necessary steps can be taken to bring the cell back to its SOA or to deploy contingencies to prevent fire hazards. A complete BMS will include controlled charging using Constant Current Constant Voltage (CCCV) to ensure that all cells are charged to their full State of Charge (SoC), cell balancing techniques to ensure that all cells are at the same voltage after charging, and necessary failsafe and protection circuits to ensure that the user or the vehicle are not harmed in the event of unwanted battery operations. The goal of this article is to design and construct a passive balancing system that uses Constant Current Constant Voltage (CCCV) charging.

The LiFePo4 cell BMS guarantees that the cells in the battery stay within safe operating limits, and it intervenes when a cell exceeds those limits. If the voltage drops too low, a BMS will disconnect loads, and if the voltage rises too high, it will disconnect charges. It will also ensure that each cell in the pack has the same voltage and will lower the voltage of any cell that is greater than the others. If the lithium battery's voltage (nominal voltage of 3.2V) rises over 4.0V to 4.2V or falls below 2.8V, two things can happen: the cell can explode, or its life is reduced. A BMS also regulates and monitors the temperature. Cell balancing, or equalising the voltages of all batteries in the pack, is accomplished via cell balancing, which is divided into two types: passive and active cell balancing. Voltage dips and spikes can be seen during the charge and discharge cycles of a Li-ion cell. The electrical equivalent circuit of the battery must be accurately described in order to understand the nature of these charging and discharging cycles.

Design approach:

Because of its simplicity and ease of management, the BMS is built utilising a passive balancing technique. To dissipate the charge once the cell is completely charged, passive balancing utilises a resistor, also known as a bleeding resistor, across each cell. This stops the cell from overcharging and allows the pack's other cells (the weaker ones) to charge to 4.2V. CCCV charging is the method used to charge LiFePo4 batteries (Constant Current Constant Voltage Charging). This technique provides constant current to the cell until it hits 4.2V, at which point it switches to constant voltage mode, which maintains 4.2V across the cell while reducing current exponentially. This technique ensures that the battery is fully charged (100 percent SoC).

EXPERIMENTAL RESULTS FOR BATTERY PACK HEALTH ANALYSIS:

The Panasonic 18650 battery cells were used to test the performance of LiFepo4 cells in this study, and the data was received from the National Centre for Materials Service Safety (NCMS). The Hybrid Pulse Tester is used to run the LiFePo4s cell's test profile, which includes both discharge and regen pulses The High-Performance Power Characterization (HPPC) test is used to assess the battery cell's useable voltage range's dynamic power capabilities. The HPPC test was performed using the battery testing equipment (Neware BTS 4000). The following is a list of resources. The notion of dissimilarities in battery cells produces charge fluctuations when they are subjected to various parameter changes, as seen in Fig. 8 in this section. This necessitates correct cell balancing. The batteries arrive at their maximum cut-off voltage at various times while charging or discharging with or without vibration.

Conclusion

This paper presented the basics and importance of battery management systems in a LiFepo4 battery pack. This is followed by battery modelling using equivalent circuit and the charge and discharge graph, which is explained with the help of the equivalent circuit model. Then the cell balancing techniques are discussed with major focus on passive balancing (switched resistor). The trade-offs of using active balancing are discussed so as to give a clear understanding of why passive balancing is chosen. MATLAB/Simulink modelling of single cell and four cells, with their charge and discharge graphs are discussed after balancing techniques. Finally, the charging method for LiFePo4 battery packs is discussed and it is highlighted as to why this method is the required to charge LiFePo4 battery packs. The battery cell balancing process is a critical problem in the electric vehicle industry since it improves the battery pack's performance while also extending its life cycle, reducing maintenance, and guaranteeing safe operation at all times. Many different battery balancing systems have been examined in order to highlight the different forms of battery imbalance and their impact on battery performance. In a nutshell, if correctly performed, the battery balancing procedure will help to ensure that the individual cell voltages do not drift apart over time During passive balancing, the highly charged cells can be given more rest time as the lower charged cells achieve uniform charge, and during discharging, the lower charged cells can be given more rest time as the highly charged cells are brought down to the same charge level. As a result, the estimation of battery SOCs improves as the resting durations for highly charged and weakly charged cells increase. As the battery's state of charge improves, balancing becomes similarly quick and painless, with no danger. The battery balance is extremely important, since there are numerous variations within the battery cells characteristics, according to the battery experimental results analysis. As a result, the BMS must keep track of this, and the balancing process must happen at the same time as the batteries are charged or drained.

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