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Development of Passive Battery Management System at TRL 4

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ABSTRACT

Nowadays, the usage of the electric vehicle (EV) is exponentially increasing. Therefore, a battery management system (BMS) is required to properly operate the Li-ion battery used in electric vehicles for extending the battery life. The main function of BMS is to sense the voltage, current, and temperature of the battery and cells independently. Further, it evaluates different parameters from the data fetched by the BMS. Finally, based on the evaluation, it controls the cell balancing. Presently, BMS is implemented using different microcontrollers and is under improvement with the advancement in existing technology. Passive balancing is commonly used in BMS, since, it is inexpensive and straightforward to implement. The passive resistor uses the passive balancing method to discharge the battery's excess charge. For small battery capacities, this resistor is very useful. This paper analyses BMS design which combines a power resistor and transistor as a balancing resistor. The proposed analyses were applied to a battery pack consisting of 13 lithium-ion battery cells which enabled a fast-charging scheme. The most significant features of the passive balancing system are based on the results of this experiment, taking into account the impact on battery performance and energy loss. The aim of this paper is to make a battery pack that is with high energy carrying capability and proper thermal runaway. Thus, extensive monitoring is needed to operate the battery within specified operating limits to avoid fire hazards and explosions. In order to achieve this, the proposed design creates a demand for a Sophisticated management system which not only optimize the power drawn from battery but also maintain the battery operation within specified limits.

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1. INTRODUCTION

Vehicles are causing environmental pollution due to the emission of gasoline-powered engines. In concern to reducing environmental pollution risk, the demand for electric vehicles (EVs) is increasing exponentially. EVs stores electricity in an energy storage device that acts as a transportation fuel such as a battery [1]. These batteries are of different types such as lead-acid, nickel-cadmium, nickel-metal hybrid, zinc-air and Li-ion. Although all the batteries are used in different applications, Li-ion batteries gained popularity because of their high open-circuit voltage and large energy density. However, the slight variation while manufacturing cells leads to cell unbalancing, degraded battery capacity and causes safety issues [2], [3]. Therefore, Battery Management System (BMS) is a vital component of EVs used to operate the battery in a safe operating area and extend the battery life. The primary function of BMS is to observe individual cells and the complete battery pack, then evaluate the required parameters and perform the cell balancing [4].

A BMS is a system that controls the charging and discharging of a lithium-ion battery. It guides the battery by monitoring its state, computing secondary data, reporting that data and assisting in its balancing. A BMS guarantees the battery pack's safety by continuously monitoring and adjusting factors such as temperature, voltage, and current while charging and discharging. The BMS evaluates the battery's state of charge (SOC) to optimize safety and performance [5]. It safeguards against overchargingor discharging the battery pack. Keeping charge levels within the maximum and minimum allowable capacities, prevents unexpected disasters by keeping charge levels within the maximum and minimum permissible capacities. Further, it is a pieceof essential equipment for ensuring the battery's and user's safety. There are some other advantages of adopting the BMS. While the circuit board is made up of multiple components and circuits. Moreover, if a problem with operational parameters (voltage, temperature, etc.) is detected the BMS sends an alert signal to the system which disconnects the battery pack from the load or charger because a solid current flow through the batteries which creates a fast temperature rise, causing battery packto explode spontaneously.

The BMS constantly monitors the battery's SOC and regulates it to the rated value. The charging and discharging values of a battery are determined by its charging level. The charging available in the battery can be calculated and indicated using a BMS by comparing the battery parameter to rated values, a BMS looks for anomalies. It is also capable of performing corrective actions to improve the battery's health. There are several different types of BMS available, ranging from 1S to 20S. The letter ”S” indicates the number of cells in series [6]. Finally, functional battery cell balancing is an integral part of any BMS sinceit keeps its SOC constant. Traditional passive balancing methods release the extra energy of an imbalanced cell by raising the cell body temperature. This technique is especially beneficial for small battery packs with low voltage. This method is affordable and straightforward to use, but it is only suitable for cells that do not suffer severe damage from overcharging. An active circuit transmits energy evenly between the cells in the active balancing technique. In the Passive BMS, the current enters the battery and fills the cells and charges the pack. When one cell is full the resistors take that energy and burn it off which finally converts it into heat, reducing the current flowing into that cell until all cells are balanced. Whereas, inactive BMS, the current is directed towards the most less charged cells and it discharges to the other cells which are unfilled. Finally, fully charged cells are discharged to charge the lowest cells. In this situation, instead of filling all cells at the same pace, the current enters the battery and focuses on filling the empty cells until they reach the same level as the other cells. The current is equal once all cells are equal. Until all cells are fully charged, the current is distributed evenly among them and fully balanced.

Further, all the energy converting methods are examples of active balancing procedures. In energy flow, active balancing approaches encompass both dissipative and non-dissipative procedures. The additional energy is lost as heat across a resistor in dissipative systems. Even so, extra energy is diffused across the string cells in non-dissipative ways, resulting in the best system efficiency. One of the purposes of a BMS is to balance the cells in a battery. The capacity of an unbalanced battery can be limited. Whereas, balancing is having proper weightage with the cell's capacity for the lowest capacity in the SOC estimated design [7], [8].

A major advantage of balancing a lithium-based battery system is that it allows the system to run more efficiently. The capacity of the batteries decreases when they are charged and drained. Unbalanced cell discharging and charging shortens the time it takes for the cell capacity, to be depleted to the point where the system is no longer useful or shortens. The time it takes for the system to fail. Unequal charging and draining of individual cells let the end-user get more energy and reduce the life of the battery system, wasting the economy and resources. While battery capacity, weight, and environmental impact are all important and need to be improved all the time. The technology is still lagging behind to adopt the use of batteries as an energy source. As a result, the application of the relevance of current battery technology cannot be ignored.

1. *Motivation:* Implementation of BMS for EV is a diverse area for the researchers. Various models have been proposed to enhance the usage of EVs. However, the limitation is that with system improvement huge changes are expected in the existing models. In addition, limited work has been done to reduce the size of BMS and to make it respond in an even faster manner like a real-time system.
2. *Organization:* The following sections summarise the paper's overall structure: the BMS design and a brief description of how the model works are presented in Section II. The hardware explanation is discussed in Section III. In addition, SectionIV discusses the results and findings with their implications. Finally, Section V brings the conclusions.

2. METHODS

2.1 Design BMS

This section expresses the working of the proposed model with the functional architecture as mentioned in Fig. 1. The BMS is designed by keeping in mind that the system has been implemented to control the cell balancing of large Li-ion cells. In addition, it evaluates the parameters concurrently and delivers fast switching. Thus, it reduces the size and weight of the completeBMS. This concept builds a system that balances the cells to manage the battery pack's voltage and SOC. Further, when acell's voltage reaches a certain level during the charging procedure, the charging circuit gets disconnected. This approach for balancing consists of monitoring and comparing the voltages of all cells with the use of a threshold voltage. If a cell's voltage surpasses or the battery's energy level falls below a specific threshold voltage, the battery's energy will be depleted. Disposing of using a resistor and an internal circuit transistor resistance prohibits the cell over-voltage. If a cell's voltage is less than the threshold, the charging process accelerates.

The charge and discharge cycles can be controlled by the BMS to avoid power overloading and the thermal impact whichmay reflect the environment. The charging of the 48V battery through BMS is shown in Fig.1. Each cell has a limited numberof charging or discharging cycles, and the battery life diminishes as the number of discharging or charging cycles grows. BMS must confirm the charging and discharging operations. Further, it should keep the optimum SOC to guarantee that the battery life is maximised. To assure structure in this region, the BMS controls the charger current, turns ON/OFF active switches between the pack and load or charger, executes the well before sequence, establishes dynamic power constraints and performs passive and active balancing. The battery is charged at a steady current [9]. It is seen that there is a SOC, current and voltage battery monitoring output that is connected with the display, and the ideal switch is a combination of transistor and Zener diode, which turn ON the elementary circuit to pass power through resistance. MATLAB function blocks allow you to use the MATLAB language to define custom functionality in Simulink models. Toimport MATLAB code into Simulink the coder generates C++ code, which is supported by MATLAB function blocks.

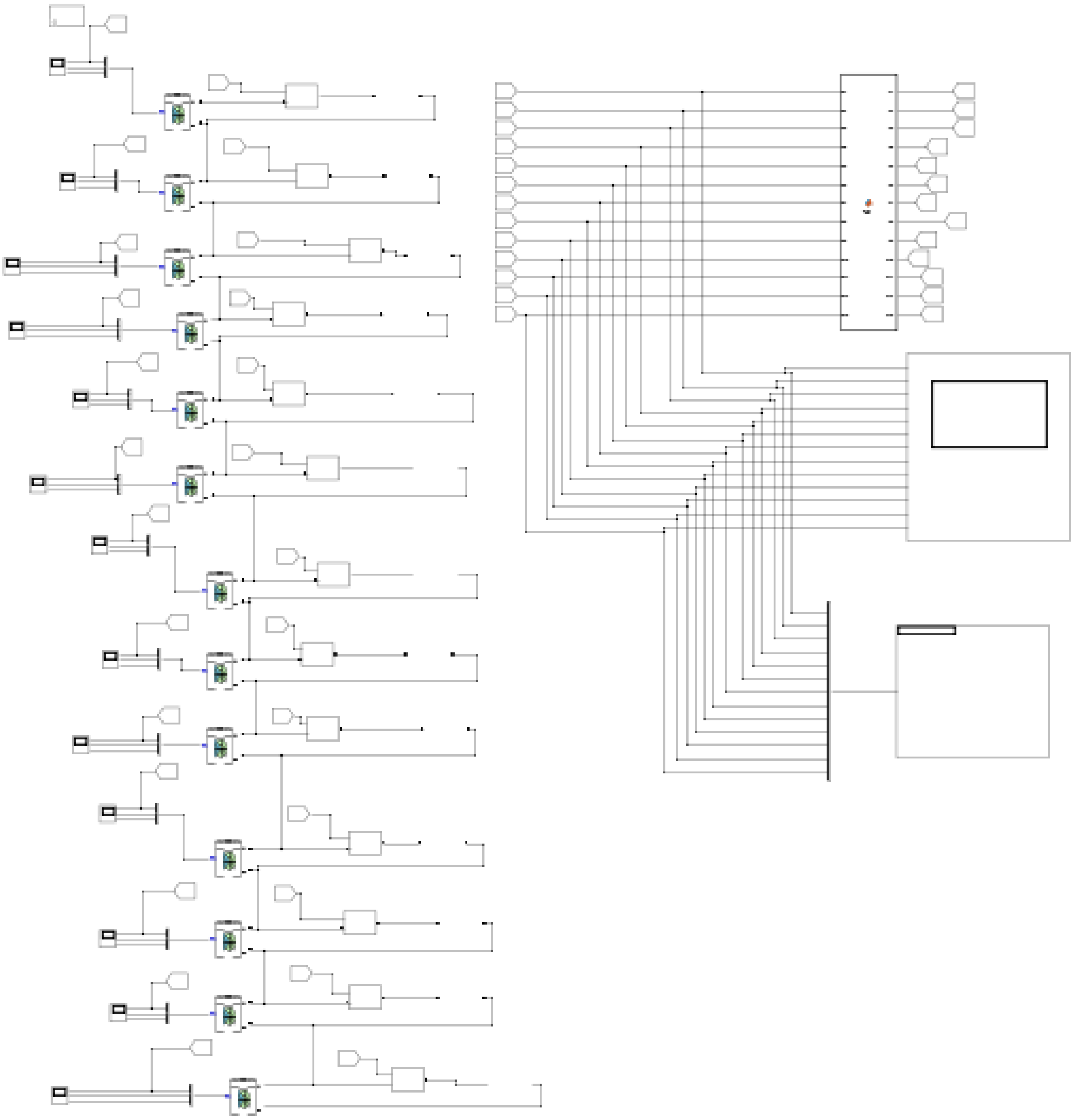

Figure 1: Charging Simulink

When a lithium-ion cell or battery discharges, it sends current to a circuit outside the cell. An oxidation process insidethe anode releases lithium ions, which pass to the cathode. The electrons that the

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ions have produced move in the opposite direction, into the electronic circuit that is being energized. This process converts chemical energy into electrical energy, then released from the cell. The electrons from the external circuit mix with the lithium ions to produce the stored electrical energy. When turned ON, a MOSFET can conduct both ways because it is simply a resistive channel that is opened or closed. (It opens with a minor resistance, closes with significant resistance, or has a slight gradation in between, just like a tap). Both MOSFET is now connected with their gates to an independent I/O pin for protection of the battery because when the cell is empty, it can be charged, and when it is complete, it can be allowed to discharge. So, the chip only turns on the MOSFET whose diode is blocking the permissible directions. Suppose the battery is at one extreme of its use case.

In that case, the diode allows the least current to flow in the opposite direction. Even if, it is the over or under-voltage situation persists for some time after the current begins to flow. Further, this causes problems with MOSFET heating when a battery behavesstrangely. The body diode usually only conducts for a fraction of a second before the over/under voltage vanishes and both MOSFET re-energize.

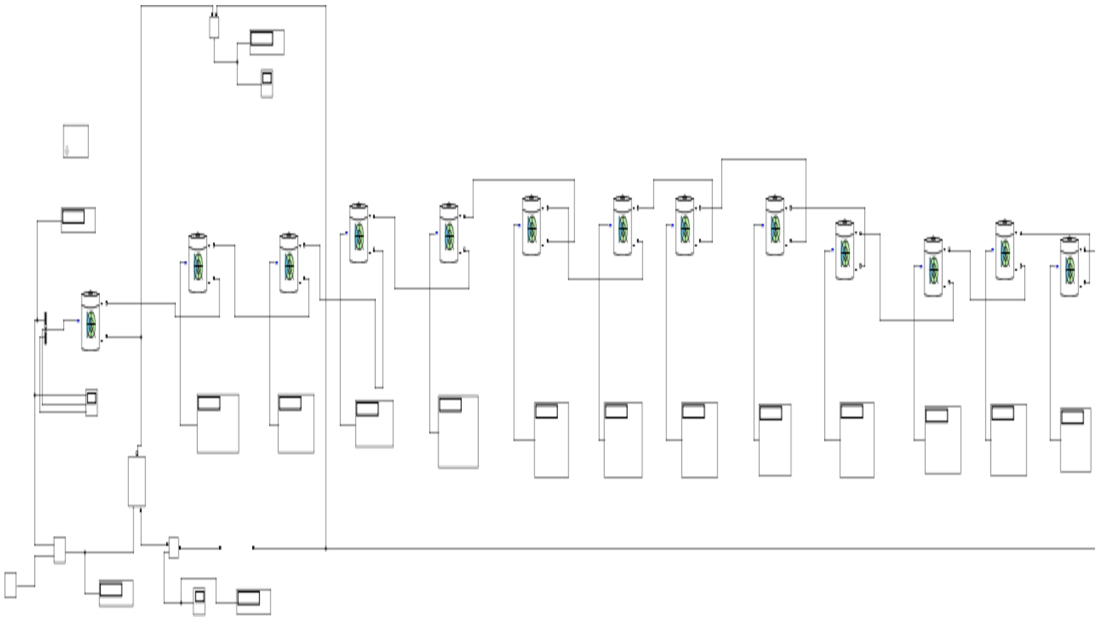

Figure 2: Discharging Simulink Model of BMS

2.2 Construction of BMS and PCB Layout

For the construction of the finalization of the circuit, Easy EDA software is used as a toolkit that enables hardware engineers to design and simulate. Under voltage is when the battery voltage falls below a predetermined level. The default setting for most BMS will be around 2.7V/cell. BMS systems will disconnect the load. Overvoltage is the battery voltage that exceeds a defined parameter, this is known as an overvoltage condition. The default setting for most BMS is roughly 4.2V/cell.

2.2.1 PCB

For the construction of the circuit, a PCB board design must be completed first to produce and fabricate electronic models. For the developer to construct and analyze the models, the electronic systems should be completed with detailed specific tools and with technical considerations. The following parameters need to be considered when designing the board: Tracks have a resistive effect. The length, thickness, and maximum current that the rails should carry must be considered while designing the circuit. To detect and determine the dimensions, software tools should be employed. The thermal effect is a phenomenon that occurs when heat is applied to a surface. The connections and thermal and electromagnetic interferences must be considered when locating the components. The capacitive and inductive effects are both present [10]. The BMS's power segment should be kept as far from the control section as possible. The analogic plane must be segregated from the digital plane to prevent electromagnetic interference (EMI) and offer electrical protection. The integration using the Single European configuration, as shown in Fig. 3.

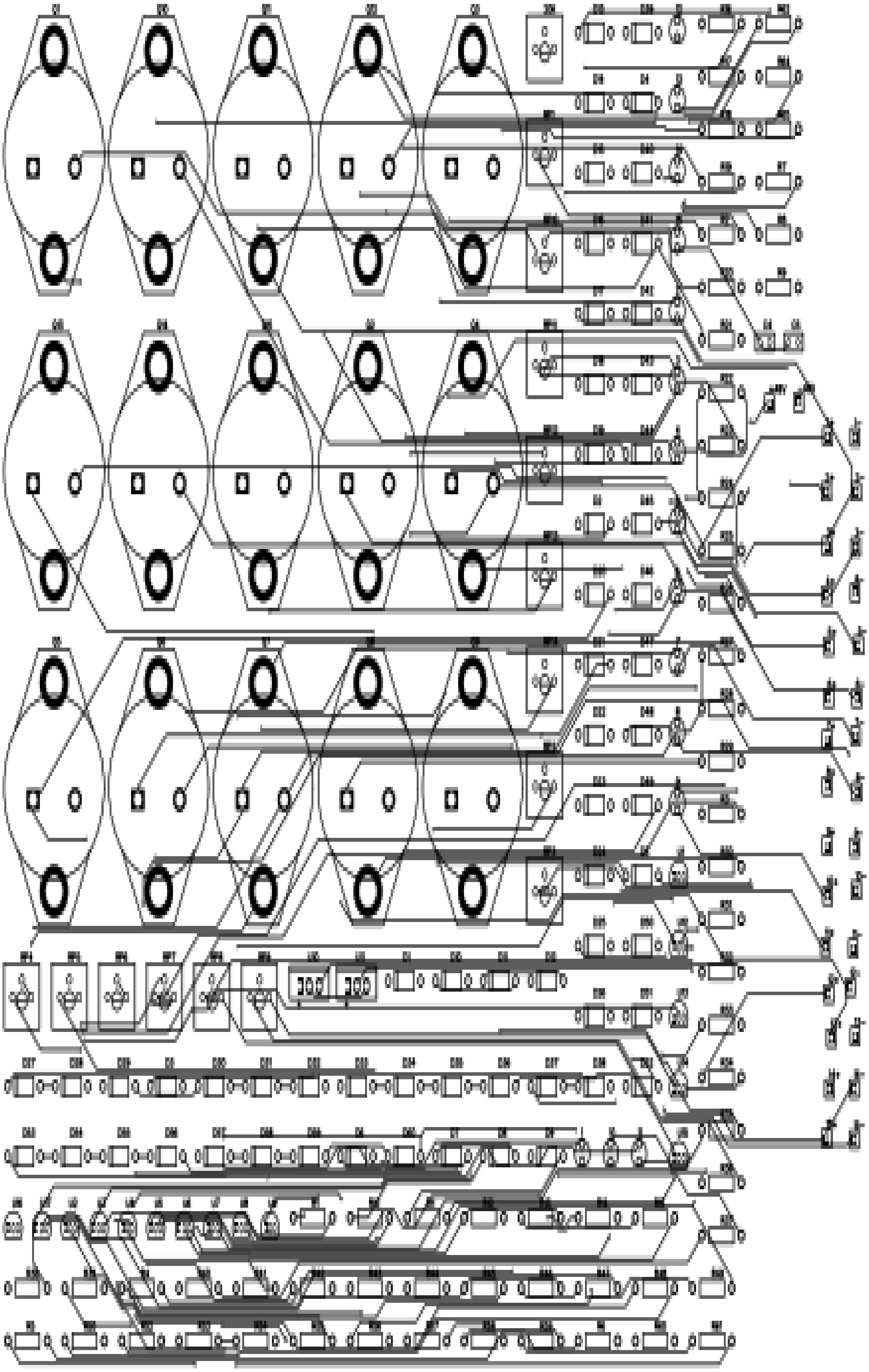

Figure 3: PCB Design

The verification for operation is carried out on a test bench. All of the status of the cell, as well as the switching between charging or discharging states and along with the charging phase balancing, are all monitored continuously. In the lithium battery charging process, the greater the current multiplying rate, the faster the battery group reaches to the predetermined charge cut-off voltage. After an hour of charging, the voltage parameter of the battery pack is used for testing. The internal resistance drops voltage levels in the system. The open-circuit voltage has an inverse relationship with the current charge ratio, which is growing. The discharge curves for a Lithium-Ion cell below illustrate that when the battery is drained at very high rates, the adequate capacity of the cell is diminished (or conversely increased with low discharge rates). The phenomenon is a proper operation of the BMS is confirmed by the test. A resistive power is used to discharge the cells. The mechanism is stopped whenever a cell voltage falls below 2.7 V (the minimum cell voltage, Vcell/min), and it is revived when all cell voltages rise over 2.8 V during the cell discharge process. When a cell voltage in a battery pack falls below 2.7 V, the system is fully disconnected [11].

2.2.2 BMS Specifications

317 HVT is used as a voltage limiter and current which is a combination of series and shunt in this circuit. When a battery of +48V is connected to this system it decreases the voltage to cell voltage 3.2V. Then, it is directly connected to the battery and the battery is charging. After the charging is completed the Zener diode is regulating the supply and turns on the transistor. When the voltage is increased from 3.7V we can also set the voltage by using a potentiometer according to our usage. When the transistor is turned on its auto cut the Battery power and the remaining apply voltage is passing through the diode. Diode produces losses to dissipate power.

Table 1: BMS specifications

No.	BMS	Rating
1	Passive BMS	Transistor
2	BMS voltage	48V
3	BMS Peak current	60A
4	BMS model	13S
5	Series Circuit	13
6	Balanced Type	Passive
7	Protection	SC

2.2.3 Battery pack construction

The 18650 battery is a Li-ion rechargeable battery with a capacity of 2000 mAh. This is not a conventional AA or AAA battery, but it is ideal for applications that require a constant high current, such as cameras, DVD players, iPods and other similar devices. A single 18650 cell may be charged and drained 1000 times without losing much capacity [12]. They are safe to use, have a long battery life, and are environmentally friendly. It has a high energy density and provides your device with good continuous power sources. It is used in conjunction with a protection circuit board that protects the battery from overcharging, over-discharging, and overcurrent draw.

In the world of batteries, the C rating is a widely misunderstood notion. The charge or discharge of a battery determines the C rating. This circuit changes the rate, which has an inverse influence on the amount of time taken by the battery for discharging and charging. For example, if a battery has a capacity of 2000mAh or 2Ah and a 1C rate, charging or discharging the battery will take 60 minutes. The 1C rating is the starting point, which is always 1 hour or 60 minutes. The charge or discharge time for the C rate varies proportionally with the rating. 1C rating is equal to 60 minutes, a 2C rating is equal to 0.5h or 30 minutes, and a 0.5C rating is equal to 2h or 120 minutes. The formula is straightforward. To view hours or minutes, use t as 1/Cror time as 60 minutes / Cr (C rating) [13].

A new battery pack was created to boost battery performance. Lithium batteries with a capacity of 2Ah were used for the new pack. To make the mechanical assembly of the battery pack easier, 13 series linked cells were chosen, which yield a nominal voltage of 48V. Each cell's maximum voltage is 3.7V. When the battery is fully charged, then the maximum voltage is 49.9V.

Table 2: Battery pack description

No.	Battery Pack	Rating
1	Battery Type	18650 Battery
2	Normal Capacity	2000mAh
3	Normal Voltage	3.7V
4	Charging Voltage	4.20+/-0.05V
5	Discharge ending Voltage	2.75+/-0.05V

The minimum operating voltage of the cell is 2.7V. Compared to a lead-acid battery pack, the total weight of the battery pack is 1.2kg, almost twice as much. Another feature of this battery is its current capability: it can be discharged at 1 A for 5s. The battery construction is shown in Fig.4.

3. RESULTS AND DISCUSSION

The simulation results of a passive balancing circuit using Simulink are shown in this section. A single cell is coupled to a3.7V DC voltage source, as shown in Figure 5. It is first determined whether the voltage of the cell is greater than 2.7V. If the voltage is less than 2.7V, it is charged using a trickle charge method. To raise the voltage of the cell, a very low current (0.5C) is supplied. When the voltage of the cell hits 2.7V, the rated charging current has been used to charge it (usually 1C) as a non-active [14]. In series with the cell, there is a balanced bleeding resistor. When the cell voltage exceeds 3.7V, the charging switch has been switched off, and the balancing function has activated. The charging going to cease in this manner, and the cell has started to discharge through the resistance once the voltage has reached a safe level. When the balancing switch is turned ON, the power drops as seen in Fig. 5. This is due to a drop across the capacitor. As a result of the internal resistance, which shows as IR, the terminal voltage is V(terminal) is VOC (Icharge*R). The hardware circuit of the same is shown in Fig. 6.

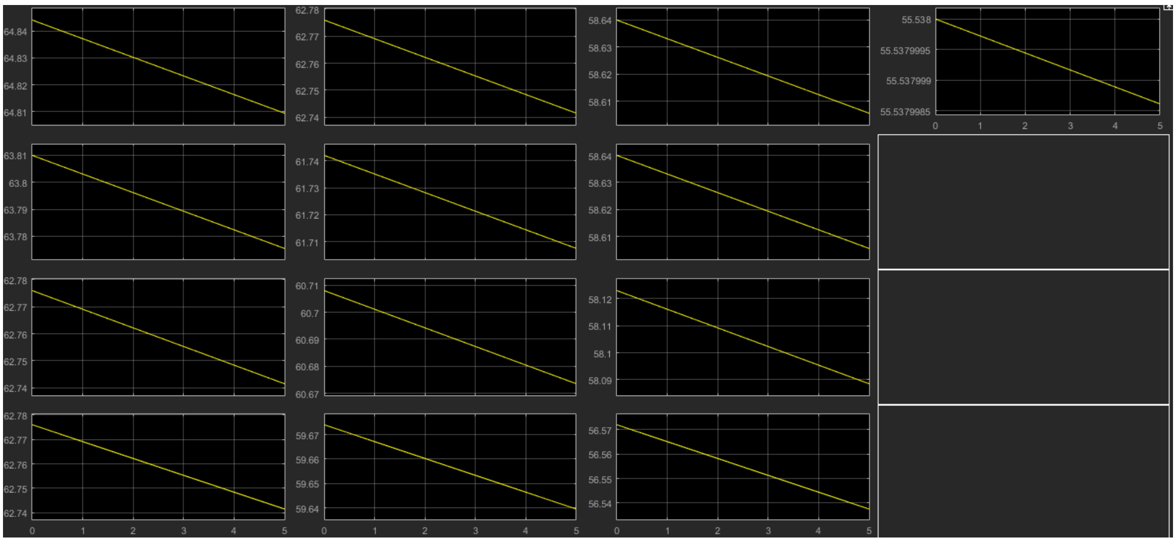

Figure 4: Discharging Graph

The cell is connected to a continuous current source that provides 1C of current and the cell voltage rises. When the voltage reaches 3.7V the current is exponentially reduced to zero and the device is switched to constant voltage mode Fig.7 depicts the circuit SOC charging current with the breakpoint indicating the point at which the circuit switches to CV mode.

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Figure 5: Hardware Charging and discharging through the proposed passive BMS

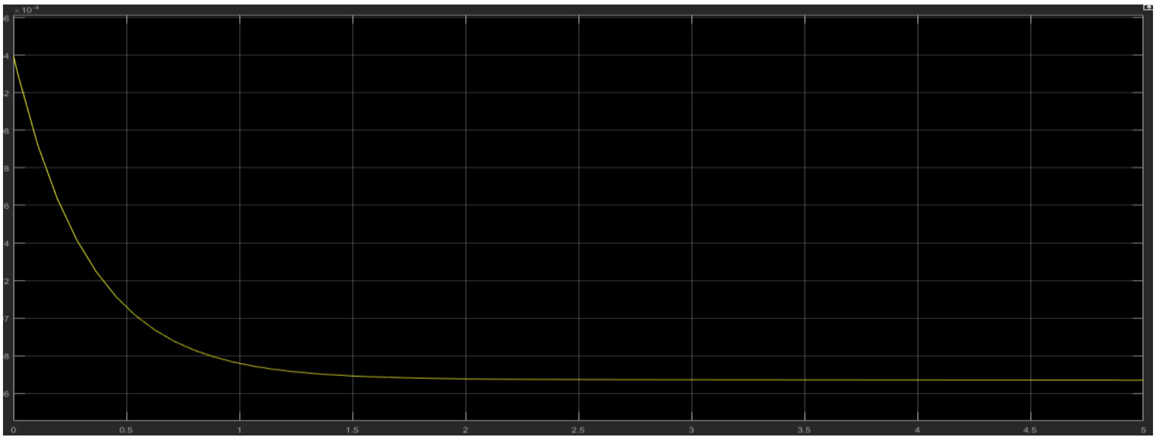

Figure 6: Discharging curve of the battery

Effective discharge performance is the rate at which discharging current holds up the potential. The terminal voltage lowers while discharge as voltage measurements with consistent charge and discharges current inputs which demonstrate a small, average, and high battery charging rate, respectively which can be used to assess the discharge dynamics of batteries. The high-rate discharge case denotes a rapid drop in voltage, allowing only a portion of the capacity to be used at high discharge rates.

Any battery management system considers the change in the rate of self-discharge of individual cells, which are caused by manufacturing flaws and cell temperature differences in the battery. This function is performed most of the time by passive or active balancing. This energy is supplied to the weak cells via active balancing. Several switches, capacitors, or inductances are necessary to appropriately handle this, which boosts the costs and scale of such a system [15]. A Simple way to be concerned is a single cell connected in the string is used to switch the complete cells. This carries the highest possible rate of charging and discharging currents. As the switch is required for expense, this does not appear to be practicable for most applications.

4. CONCLUSION

To achieve these objectives, mathematical models of each battery technology's behaviour have been developed. Advanced BMS is considered to increase the efficiency of electric vehicles and extend their battery life. As these two features are crucial for EVs' mobility and economic viability, improvements in this technique should mitigate the existing social acceptance issues. Passive balancing techniques based on resistor dissipation have been used while charging. However, they are inefficient. One solution that has been proposed for second-generation batteries is active cell balancing. It entails monitoring of power in each cell and temperature in many locations to ensure that no cell is functioning outside of its prescribed parameters. Its advantages included a cycle life, increased safety, and a higher power capability for a relatively small cost increase. It's vital for Lithium-ion chemistry. For the care of a battery pack, it is necessary to handle it properly; otherwise, the causes of an explosion will be enhanced and their high cost makes increasing their cycle and battery life even more imperative. In contrast to the previous work that only maintains one or two areas of the battery management system, the proposed research work maintains some parts of the system. The article describes different types of functions, requirements, BMS topologies, battery models and their comparisons. In addition, a comprehensive discussion of different challenges and their solutions that focuses on enhanced battery models, sophisticated prognostic techniques, efficient prototype design, and BMS virtualization approaches. A full comparison of alternative cell balancing strategies is carried out and proposed a passive cell balancing technique. The proposed technique balances energy efficiency and the LIBS' lifespan can be enhanced.

REFERENCES

[1] Dhingra, Karanveer, and Mukesh Singh. "Frequency support in a micro-grid using virtual synchronous generator based charging station." *IET Renewable Power Generation* 12, no. 9 (2018): 1034-1044.

[2] Hannan, Mahammad A., Md Murshadul Hoque, Aini Hussain, Yushaizad Yusof, and Pin Jern Ker. "State-of-the-art and energy management system of lithium-ion batteries in electric vehicle applications: Issues and recommendations." *IEEEE Access* 6 (2018): 19362-19378. DOI: 10.1109/ACCESS.2018.2817655

[3] Affanni, Antonio, Alberto Bellini, Giovanni Franceschini, Paolo Guglielmi, and Carla Tassoni. "Battery choice and management for new-generation electric vehicles." *IEEE Transactions on Industrial Electronics* 52, no. 5 (2005): 1343-1349. DOI: 10.1109/TIE.2005.855664

[4] Xu, Dongping, Lifang Wang, and Jian Yang. "Research on li-ion battery management system." In *2010 International Conference on Electrical and Control Engineering*, pp. 4106-4109. IEEE, 2010. DOI: 10.1109/iCECE.2010.998

[5] Brandl, M., Harald Gall, M. Wenger, V. Lorentz, Martin Giegerich, Federico Baronti, Gabriele Fantechi et al. "Batteries and battery management systems for electric vehicles." In *2012 Design, Automation & Test in Europe Conference & Exhibition (DATE)*, pp. 971-976. IEEE, 2012. DOI: 10.1109/DATE.2012.6176637

[6] Otero, Noemi, Habiballah Rahimi-Eichi, Juan J. Rodriguez-Andina, and Mo-Yuen Chow. "FPGA implementation of an observer for state of charge estimation in lithium-polymer batteries." In *2014 International Conference on Mechatronics and Control (ICMC)*, pp. 1646-1651. IEEE, 2014. DOI: 10.1109/ICMC.2014.7231839

[7] Hauser, A., and R. Kuhn. "Cell balancing, battery state estimation, and safety aspects of battery management systems for electric vehicles." In *Advances in battery technologies for electric vehicles*, pp. 283-326. Woodhead Publishing, 2015. DOI: 10.1016/B978-1-78242-377-5.00012-1

[8] S.Wang, Y. Fan, D.-I. Stroe, C. Fernandez, C. Yu, W. Cao, Z. Chen, Battery state-of-charge estimation methods, in: S. Wang, Y. Fan, D.-I. Stroe, C. Fernandez, C. Yu, W. Cao, Z. Chen (Eds.), Battery System Modeling, Elsevier, 2021, pp. 157198

[9] Madej, Wiesław, and Andrzej Wojciechowski. "Analysis of the Charging and Discharging Process of $LiFePO_4$ Battery Pack." *Energies* 14, no. 13 (2021): 4055. DOI: 10.3390/en14134055

[10] N. Kularatna, K. Gunawardane, Rechargeable battery technologies: An electronic circuit designer's viewpoint, in: N. Kularatna, K. Gunawardane (Eds.), Energy Storage Devices for Renewable Energy-Based Systems (Second Edition), second edition Edition, Academic Press, Boston, 2021, pp. 6598.

[11] Cabrera, José, Aurelio Vega, Félix Tobajas, Víctor Déniz, and Himar A. Fabelo. "Design of a reconfigurable Li-ion battery management system (BMS)." In *2014 XI Tecnologias Aplicadas a la Ensenanza de la Electronica (Technologies Applied to Electronics Teaching)(TAEE)*, pp. 1-6. IEEE, 2014. DOI: 10.1109/TAEE.2014.6900162

[12] Hoffart, Fran. "Proper care extends Li-ion battery life." *Power Electronics* 25 (2008). http://www.arocholl.com/Datos/804PET22li-ion-battery-life.pdf

[13] Kim, Chol-Ho, Moon-Young Kim, and Gun-Woo Moon. "A modularized charge equalizer using a battery monitoring IC for series-connected Li-ion battery strings in electric vehicles." *IEEE Transactions on Power Electronics* 28, no. 8 (2012): 3779-3787. DOI: 10.1109/TPEL.2012.2227810

[14] Manenti, Antonio, Andrea Abba, Alessandro Merati, Sergio M. Savaresi, and Angelo Geraci. "A new BMS architecture based on cell redundancy." *IEEE Transactions on Industrial Electronics* 58, no. 9 (2010): 4314-4322. DOI: 10.1109/TIE.2010.2095398

[15] Liaw, Bor Yann, F. Wang, and Y. Wei. "Managing safety risk by cell manufacturers." *Electrochemical Power Sources: Fundamentals, Systems, and Applications: Li-Battery Safety* (2018): 1.