Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 4- Issue 2, Paper 13, July 2021

SIMULATION OF IMPROVEMENT OF EFFICIENCY AND THERMAL PROPERTIES OF BATTERY PACKS USING PASSIVE BATTERY BALANCING TECHNIQUE IN MATLAB

Pragya Jain ,Adarsh Unnithan, Mayuri Malvankar, AnaghaPadte, SamihanRaje,
Dept. of Electrical Engineering,
Atharva College of Engineering, Malad (West), Mumbai, Maharashtra, India

Abstract— *Over the past few decades, there has been a substantial boom in the usage of batteries; specifically, lithium-ion batteries This can be attributed to their high energy density and efficiency. Batteries promise excellent performance and there is a significant interest in studying battery management systems to improve the energy utilization of the battery without sacrificing flexibility, safety and lifetime of the battery.However, there are some barriers in the implementation of efficient battery usage and cell imbalance is a major concern. Balancing of these cells is a crucial step in improving the life and efficiency of the battery. This process includes either redistributing charges of the strong cells among the weak cells or draining the energy of the strong cells. It is impractical to test developments in battery management systems on physical prototypes of Lithium-ion batteries due to the unstable nature of the batteries. In this paper, a basic MATLAB simulation model which simulates passive shunt resistor balancingof a lithium-ion battery is developed and explored. This method is quite effective for batteries of small capacities.*

Keywords **—** *Lithium-ion Battery, Cell balancing, Battery management systems, Passive balancing techniques.*

I. INTRODUCTION

Due to the exponential increase in the usage of batteries in different machines including Electric vehicles, it is crucial to utilize the batteries to its full potential hence improving its efficiency. The life of the battery is an important aspect to be considered as it has scope for major cost savings. Battery management system keeps the battery ready to deliver full power when necessary. It also extends the life of battery.

There are multiple types of battery management system. The BMS is used to prevent battery failure by providing input to the protection devices. The monitoring circuit can disconnect the battery from the load if any parameters of the battery exceed its maximum permissible level. The battery monitoring system records the various parameters such as voltage, current, and internal battery temperature.

A. Batteries used currently in the market-

- *Lithium-Ion Battery:*

A lithium-ion battery is a type of rechargeable battery, which used for electric vehicles applications. In these types of batteries, lithium ions move from negative to positive electrode during discharge and vice versa during charging. These batteries have high energy density and low self-discharge rate.

- *Nickel-Metal Hydride batteries:*

This battery has energy density that can approach that of lithium-ion battery. As compared to lead acid battery, NiMH battery has high specific energy.These batteries have longer life than lead acid batteries. The main challenge with these batteries is high cost and high self-discharge.

- *Lead acid batteries:*

The lead acid batteries generate chemical reaction commonly known as double sulfate reaction. There are two active components on battery’s plates.The sulfuric acid reacts with the lead and lead dioxide to form lead sulfate. This reaction produces a voltage. This energy, when supplied to an external resistance, discharges the battery.

Owing to the high volumetric energy density, low self-discharge rate, light weight construction, and excellent performance, Lithium-ion batteries seem to be an ideal choice for high energy usage.In spite of the abovementioned benefits and advantages, Li-ion batteries are very sensitive to rough operation schedules such as overcharge and deep discharge.

Such unmonitored usage results in damage to the battery, shortening of lifetime of the battery and sometimes even hazardous situations if left unattended.

Dealing with these issues requires a proper Battery Management System (BMS).

B. Battery management system

A battery management system (BMS) is an electronic system that controls any cell or battery pack, bymonitoring its state, preventing the battery from functioning outside its safety limits, calculating secondary and tertiary data, reporting and recording that data, authenticating and / or balancing it.

A BMS would ensure efficient operation of each cell inside the battery pack and would keep individual cell parameters within safe operating limits.

BMS monitors and controls the charging and discharging process, hence risk of damaging the battery reduced. It always protects the battery cells from damage as Lithium-ion batteries need very careful monitoring.

It is important that the battery should never deep discharge or over charge that is why continuous monitoring of the voltage and current is necessary.

C. Battery balancing system

Maintaining SOC levels of each individual cell at equal levels is called cell balancing. When different cells are connected together then it is made sure that the cells should have same chemistry and voltage value. Even after taking these precautions, batteryimbalance is caused due to the following reasons-

- Causes of Battery Imbalance

i. Different coulombic efficiencies - Imbalance is caused by factors that make one cell's SOC diverge from another's

$$z(t) = z(0) - \frac{1}{Q}\int_0^t \eta(\tau) i_{\text{net}}(\tau)\,\mathrm{d}\tau$$

One example is when the individual cells do not have thecoulombic efficiencies. Cells may start with same initial charge, have same cell capacity, and accept same net current $i_{net}(t)$. But, because of dissimilar efficiency n(t), cell SOCs deviate during charging.

ii. Different self-discharge rates and leakage currents - Imbalance is also caused by cells having differing net current.

$I_{net}(t) = I_{app}(t) + I_{self\text{-}disch}(t) + I_{leak}(t)$,

Where $I_{app}(t)$ is load current, $I_{self\text{-}disch}(t)$ is rate of cell self-discharge, and $I_{leak}(t)$ is current that powers attached BMS electronic circuitry. Self-discharge rates of each cell can have relatively different values, leading to different $I_{net}(t)$. Leakage current can be unequal as compared to other cells, also leading to different $I_{net}(t)$.When cells draw unequal net current, they become unbalanced.

iii. Temperature differences - Coulombic efficiency, performance of electronics and self-discharge rates are the all functions of temperature. Therefore, increased temperature gradient of the pack can increase the rate of imbalance.

Different cell capacities - Different cell capacities cause short term imbalance that is corrected automatically when any one of the cells returns to its original SOC.

iv. But different cell total capacities do limit available pack energy. Some energy remaining in high-capacity cells is not usable when low-capacity cells are fully discharged.

Cell imbalance may lead to many problems like thermal runaway, cell degradation, inadequate charging of battery pack, under-utilization of pack energy.

So, cell balancing is required to utilize battery pack to its maximum efficiency.

- ***Classification of balancing techniques***

Battery pack balancing techniques are divided into passive cell balancing and active cell balancing techniques.

i. Passive cell balancing

Passive cell balancing is simplest balancing technique of all. In this method there are two types - charge shunting and charge limiting.

In charge shunting method bypass or bleeding resistors are used to discharge excess charge and equalize it with other cells. This excess charge is dissipated as heat. The balancing current is usually of the order of a few mA.This method provides a ratherlow-costtechnique for balancing the cells. Passive balancing is used to correct long term mismatch due to difference in self discharge currents of cells.Drawback of this method is that the energy dissipated as heat in resistors and circuit also have switching losses. Charge is limiting method is inefficient and rarely used.

ii. Active cell balancing

In this technique the surplus charge from one cell is moved to another cell of lower charge to balance the cells.

As compared to passive balancing technique this technique is more complex and it reallocates charge between battery cells thereby increasing the circuit runtime. It also decreases charge time and decreases heat generated during balancing

II. METHODOLOGY

A. Proposed battery model:

The battery block used in the simulation implements the generic dynamic model of a lithium-ion battery that represents most types of rechargeable lithium-ion batteries. For the sake of simplicity, the discharging and charging characteristics of the battery are assumed to be the same

However, the table-based battery block with three RC branches in conjunction with the parameter estimation tool may be used in the future in order to obtain an accurate representation of a real-world lithium-ion battery.

The model shows a maximum error of 5% for charge and discharge dynamics.

The battery to be simulated was SLPB78216216H manufactured by Kokam industries. Three cells were connected in series; the nominal voltage of each battery being 3.7V. The rated capacity of each battery was set to 31Ah. Each battery was initialized at a different state of charge so as to visualize the passive balancing process. This visualization can be seen in the later sections. For the sake of simplicity, the simulation of the temperature and aging effects have been neglected for the time being and will be added in later iterations of the model. To consider the temperature effects of the Lithium-ion battery, additional discharge curves that are recorded at ambient temperature (different from the nominal temperature) is

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 4- Issue 2, Paper 13, July 2021

required. More often than not, the discharge curves are not available on the battery data sheets and obtaining the discharge curve requires additional experimentation on the battery.

B. Proposed balancing model

In case of passive balancing, the charge of the cell with the highest SOC is drained through a bleed/shunt resistor without getting any useful work out of it done. The method used in the proposed model is ‘Switched shunt passive balancing’.

Figure 1 represents a schematic diagram and figure 2 represents the MATLAB/Simulink®model created to simulate the balancing of the cells.The value of the bleed resistor used to balance the cells is decided based on the how quickly the balancing is needed to be executed and the heat dissipation tolerance of the balancing circuit.

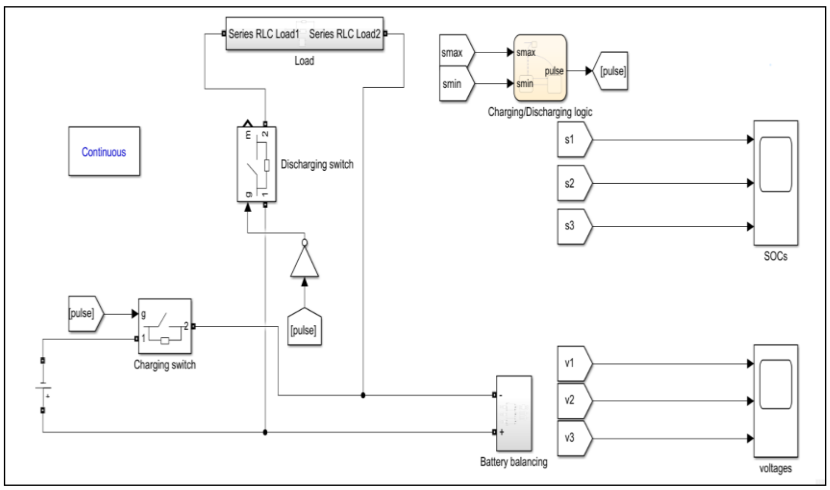

Fig. 1. Schematic diagram for switched shunt passive balancing circuit

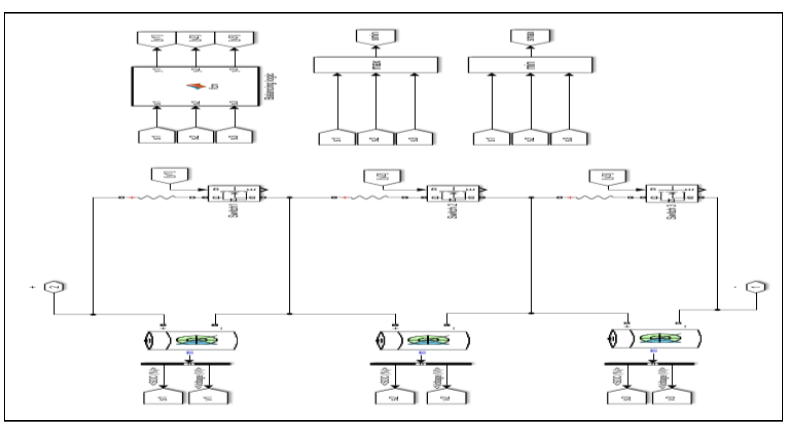

Fig .2. MATLAB/Simulink®Model

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 4- Issue 2, Paper 13, July 2021

```
function [y1, y2, y3] = fcn(s1, s2, s3)
s1 = int16(s1);
s2 = int16(s2);
s3 = int16(s3);

a = min([s1 s2 s3]);
if(s1 == a)
if(s1 == a && s2 == a)
y1 = 0;
y2 = 0;
y3 = 1;
elseif(s1 == a && s3 == a)
y1 = 0;
y2 = 1;
y3 = 0;
elseif (s1 == a)
y1 = 0;
y2 = 1;
y3 = 1;
else
y1 = 0;
y2 = 0;
y3 = 0;
end
```

Fig .3. Code Used To Balance The Lithium Ion Cells

Since the temperature rise of the model is not being monitored in the simulation model, the exact temperature effect is unknown for the time being. Based on online resources and other models, the bleed resistance was set to 3Ω. This was done solely to visualize the balancing process. In reality the bleed resistance should be much higher in order to avoid excessive balancing current and high temperature.

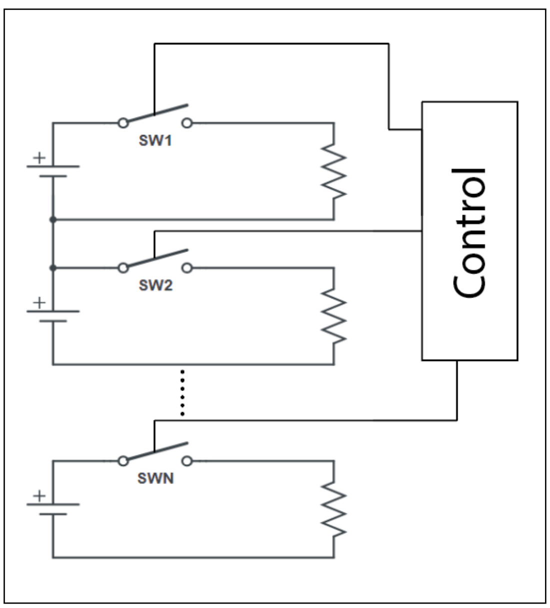

Fig .4. Charging/Discharging Logic

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 4- Issue 2, Paper 13, July 2021

The MATLAB function block is used to define the balancing logic for the cells. Figure 3 represents part of the code used to balance the lithium ion cells. As seen in the code, the SOCs of the 3 cells (s1, s2 and s3) are continously monitored. The cell with the maximum SOC is determined and the switch corresponding to that cell is closed using a MOSFET. so that the cell is connected across the bleed resistor. y1 y2 and y3 represent the pulses given to the MOSFETS corresponding to each cell respectively. This cell is continously drained until it no longer has the maximum SOC. In this manner, the SOC levels of all the cells are brought down to the SOC level of the cell with the least charge. This concludes the balancing process.

C. Battery charging and discharging circuit

An ideal voltage source was connected across the battery terminals during the charging phase. Therefore, mode of charging is Constant voltage (CV) charging. According to previous literatures, for Lithium-ion battery packs in particular, the ideal mode of charging is Constant Current Constant Voltage (CCCV) charging. This mode promotes the high-capacity usage of the battery as well as a stable terminal voltage.

Having stability in terminal voltage helps prevent overcharging of the lithium ion cells. The charging/discharging logic used in the MATLAB model can be represented by figure 4. The three cells were initialized at different SOC levels (95%, 97% and 100% respectively). The charging discharging circuit is represented by figure 5.

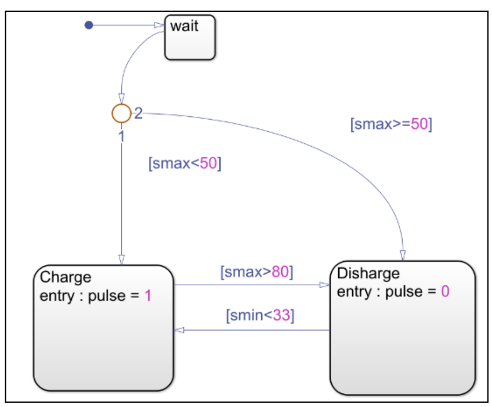

Fig. 5. Charging and Discharging MATLAB model

The battery models in previous literatures balanced the cells by monitoring the voltage of the individual cells. This was primarily because the OCV-SOC curve was linear and the voltage could be considered as an accurate representation of the SOC (for example the Nickel Manganese Cobalt Oxide battery). However, not all chemistries would have a linear curve and hence the OCV cannot always be assumed to be an accurate representation of the SOC. Cell chemistries such as Lithium Iron Phosphate have a much flatter curve and the voltage is not an accurate estimate of the SOC. Hence the proposed model constantly monitors the SOC instead of the voltage.

Although measuring the SOC is an easy task in case of a simulation model, it is a rather tedious task in

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
JCRES

Volume 4- Issue 2, Paper 13, July 2021

case of prototyping a battery management system.

Therefore, different Kalman filters such as the Extended Kalman filter (EKF) or the Unscented Kalman filter (UKF) can be used.

Kalman filters are used to approximate the required variables when they cannot be directly measured.It is also used to find best state estimates by combining the estimated value with the measured value. It is recursivealgorithm-based filter.

D. Simulation results

Figure 6 represents the visualization of cell balancing of the Lithium-ion battery pack. The stop time of the simulation was set to 5000 seconds. Upon inspection of the SOC levels of the different cells at the end of the stop time as compared to the SOC levels of the cells at which they were initialized, it can be concluded that the balancing circuit minimizes the SOC gap between the cells and helps improve the life and efficiency of the battery.

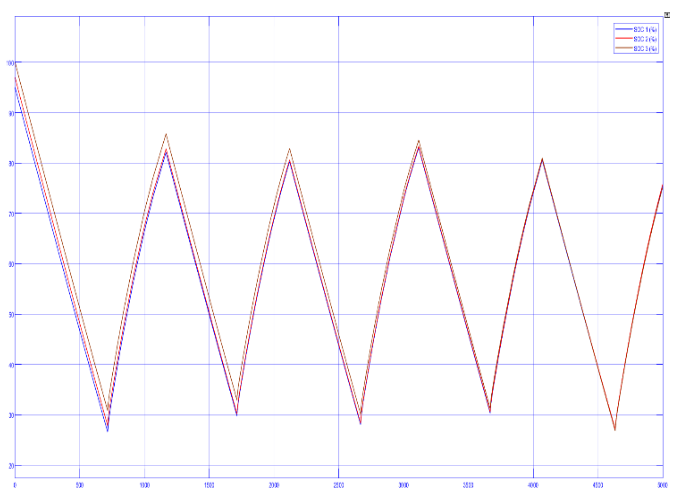

Fig. 6. State of charge waveforms of individual cells

III. BENEFITS OF PASSIVE BALANCING CIRCUIT

***A.* Complete usage of battery pack energy-** Even if the cells are manufactured by same manufacturer they may differ in physical properties because of environmental exposure or impurities. Due to this, weak cell in the pack will discharge quickly as compared to other cells & when it reaches lowest voltage, discharging process of the whole battery pack is stopped to avoid over-discharging. Because of this even if the weak cell is completely discharged there is some energy stored in other cells which is not completely utilized as discharging process is stopped. But when balancing of the battery pack is done, all the cells will have equal SOCs, so energy stored in each cell can be completely utilized during discharging process.

***B.* Complete charging of each cell in battery pack-** While charging, the good cell will charge quickly as compared to other cells & therefore charging of the whole battery pack is stopped to avoid over-charging.

Journal of Current Research in Engineering and Science
Bi-Annual Online Journal (ISSN : 2581 - 611X)
Volume 4- Issue 2, Paper 13, July 2021

Because of this phenomenon, other cells are not completely charged & their energy storage capacity is not completely utilized i.e., pack remains underutilized. But when balancing is done each cell's energy storage capacity is completely utilized as cells will have equal SOC therefore each cell will be fully charged.

***C.* To avoid thermal runaway condition-** Lithium-ion cells are very sensitive to over-charging and over-discharging. When the rate at which internal heat is generated becomes more than the rate at which the heat is released to atmosphere thermal runaway condition occurs. When the cell balancing is done, over-charging & over-discharging conditions that leads to thermal runaway are avoided.

***D.* Improved battery pack performance &improvement of life**- Cell degradation is one of the serious economic problems & battery balancing provides a good solution to it. Efficiency, capacity & life cycle of the battery reduces even if the Lithium-ion battery is slightly overcharged above its prescribed value. When we use battery balancing, overcharging of the battery is avoided which increases battery efficiency & its life.

***E.* Economic Technique-** Passive balancing technique is economical & easy to implement than the active balancing technique as in active balancing, complex balancing algorithm is used which requires additional interfacing devices that increases the total cost of the circuit. Due to this in most of applications such as in electric vehicles, passive balancing is used & active balancing is preferred where cost is not a major constraint such as in satellites.

IV. CHALLENGES

A. Increased cooling requirements-Energy is wasted as heat in passive balancing technique. Fast balancing means more heat will be dissipated through resistors. This will require balancing resistors of high-power rating, and balancing transistors of high-current rating. Heat generated due to balancing in addition to the heat produced by normal operation increases the cooling requirements of battery pack & this will increase expenses.

B. Relatively inferior life improvement -Balancing process increases the life of battery pack, but with passive balancing increase in the life of battery pack is less as compared to that of active balancing as active balancing supports weak cells via strong cells & it brings battery pack to uniform condition.

V. CONCLUSION

Battery management system is very important in electric vehicles as it enhances the performance & increases the life span of the battery pack. Battery balancing is an important aspect of battery management system. A passive battery balancing algorithm that controls a Li-ion battery with series connected cells has been discussed in this paper. The algorithm effectively creates a balance in the charges stored in the cells. Cell balancing is obtained by monitoring the SOC levels. Simulation results demonstrate the functionality of the passive balancing circuit. Because of balancing all the cells are maintained at equal SOCs, therefore battery pack capacity can be fully utilized as well as over-charging & over-discharging conditions are avoided to increase the efficiency & life of battery pack.

Journal of Current Research in Engineering and Science
JCRES
Bi-Annual Online Journal (ISSN : 2581 - 611X)

Volume 4- Issue 2, Paper 13, July 2021

V. References

[1] Luo Wei, Lv Jie, Song Wenji, Feng Ziping, "Study on passive balancing characteristics of serially connected lithium-ion battery string,"2017 *IEEE 13th International Conference on Electronic Measurement & Instruments*, October 2017

[2] Zachary Bosire Omariba, Lijun Zhang, Dongbai Sun, "Review of Battery Cell Balancing Methodologies for Optimizing Battery Pack Performance in Electric Vehicles," *IEEE Access (Volume: 7)*, September 2019

[3] Mohammad Haris Shamsi, "Analysis of an electric Equivalent Circuit Model of a Li-Ion battery to develop algorithms for battery states estimation", *Researchgate*, July 2016.

[4] Hemavathi S "Overview of cell balancing methods for Li-ion battery technology", *Wiley Online Library*, August 2020

[5] Mohamed Daowd, Noshin Omar, Peter Van Den Bossche, Joeri Van Mierlo, "Passive and active battery balancing comparison based on MATLAB simulation," *2011 IEEE Vehicle Power and Propulsion Conference*, September 2011

[6] Erika Loniza, Johanes Andriano Situmorang, Dwi Dharma Arta Kusuma, Adha Imam Cahyadi, Oyas Wahyunggoro, "Passive Balancing of Battery Lithium Polymer using Shunt Resistor Circuit Method," *ResearchGate*, July 2016

[7] Amin, Kristian Ismail, Asep Nugroho, Sunarto Kaleg, "Passive balancing battery management system using MOSFET internal resistance as balancing resistor," 2017 *International Conference on Sustainable Energy Engineering and Application (ICSEEA)*, October 2017

[8] Yunlong Shang, Chenghui Zhang, Naxin Cui, Chris Mi, "A fast-speed heater with internal and external heating for lithium-ion batteries at low temperatures," *2018 IEEE Applied Power Electronics Conference and Exposition (APEC)*, April 2018

[9] I. Aizpuru, U. Iraola, J. M. Canales, M. Echeverria, I. Gil, "Passive balancing design for Li- ion battery packs based on single cell experimental tests for a CCCV charging mode," *2013 International Conference on Clean Electrical Power (ICCEP)*, June 2013