Cell Balancing in Electric Vehicle Battery Pack

Passive and Active cell balancing techniques

M Sanath Kumar
Dept. Of Electrical and Electronics
PES University, RR campus
Bengaluru, India

G Pavan Kumar
Dept. of Electrical and Electronics
PES University, RR campus
Bengaluru, India

Fakeerappa Rathod
Dept. of Electrical and Electronics
PES University, RR Campus
Bengaluru, India

Sangeeta Modi
Dept. of Electrical and Electronics
PES University, RR campus
Bengaluru, India

Abstract — **Electric vehicles are the future of Transportation. There has been an increase in EV purchases of 109% worldwide in 2021[5] and in the last decade, EVs have become popular because of their zero tailpipe emissions and least reliance on oil and its byproducts [6]. The Latest fully Electric vehicles use Lithium-ion battery packs as their main energy source which comes with both merits and demerits. If the battery parameters are not maintained optimally in all conditions, catastrophic casualties can occur, e.g., toxic smoke or fire. The main aim of this paper is to demonstrate ways to balance the voltages in every cell of the Battery pack using more than one technique. This ensures the optimum performance of the Battery pack by not allowing any cell to over-charge or over-discharge hence, increasing its life and usable capacity. Detailed models and simulations of different types of cell balancing techniques are shown in this paper**

Keywords— Cell balancing; Active balancing; Passive balancing; Vehicle to grid

I. INTRODUCTION

Electric vehicles will be of great relevance in the coming years and so will the related technologies. Battery technology is one of them. Maintaining a Battery pack at its full capability is a crucial part of running an EV safely because if not, there can be severe concerns related to safety and logistics. Battery packs are made of many li-ion cells connected in series and parallel configurations to achieve a total battery voltage and power at the output [2]. These cells can often have voltage imbalances in them causing over-charging or undercharging. Differences can occur in the initial charge capacities and cell voltages due to temperature changes [3]. This will result in not being able to use the cell's capacity to its maximum hence, causing poor battery performance, Compromised battery life, and a potential fire hazard. Cell voltage balancing is one such technique that can be used to eliminate these imbalances where it makes sure that all the cells are equally charged and equally discharged by using either of these mentioned types of cell balancing: 1) Passive balancing 2) Active balancing. Both methods will be simulated and analyzed thoroughly.

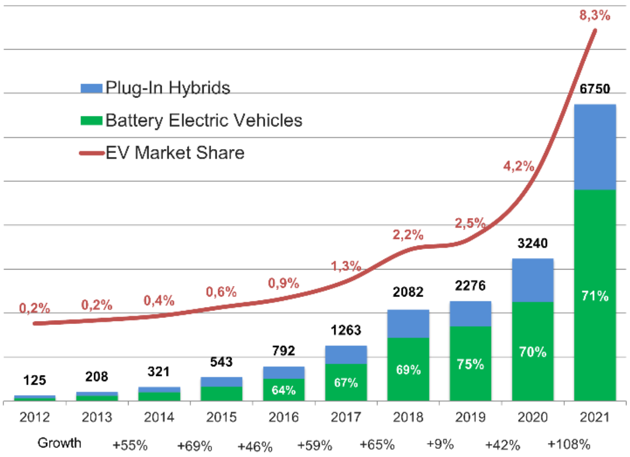


fig 1.0 - Increase in EV market share [4]

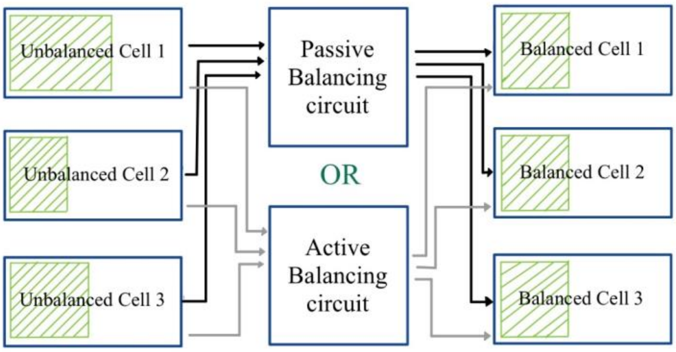


fig 1.1 - Cell Balancing techniques block diagram

1. *Cell Model*

Battery Model: Several cells of a specific nominal voltage and capacity are configured in series and parallel to create a whole battery pack of a particular rating of power, voltage and current. One such cell model is shown in fig 1.2 with a cell voltage of 7.2V and capacity of 0.00475Ah. Without any balancing circuits, this cell discharges from 100% to 0% in approx. 2500 seconds (fig 1.3).

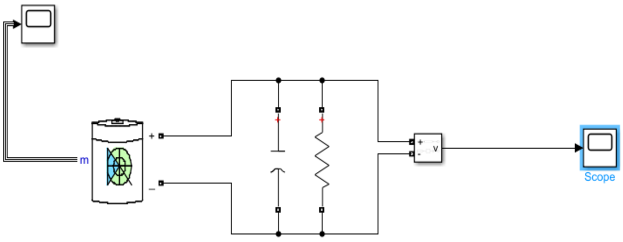


fig 1.2 - Battery model without Balancing

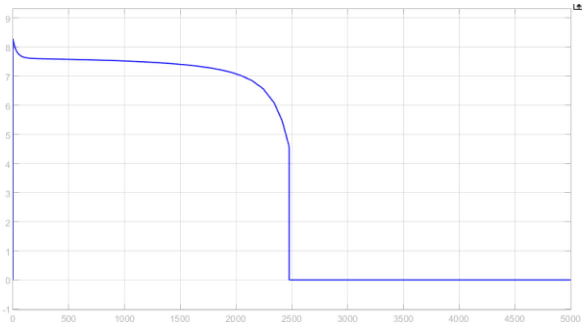


fig 1.3 - Discharge Characteristics

2. *Vehicle to grid/ Grid to vehicle*

This is a Bidirectional system where power can be transferred from both sides. The battery can transfer energy back to the grid through the inverter and the grid can supply energy to the battery through a rectifier. By implementing V2G technology, the supply grid operation can be improved and there will not be a high demand for EV loads from the supply and distribution grids, hence bypassing the expenditure for upgrading the existing grid infrastructure [6]. The inverter circuit that can convert DC to AC power is shown in fig 1.4 and the output in fig 1.5. The rectifier circuit that can convert AC to DC power is shown in fig 1.6 and the output in fig 1.7. The SPWM control that was used to generate gate pulses for the switches is shown in fig 1.8 and the output in fig 1.9. The Mathematical equations that were used to simulate these systems are mentioned below.

Inverter filter design

$$\text{Inductance } L = \frac{V_{dc}}{4\Delta I_{Lmax} F_{sw}} \tag{1}$$

$$\frac{\Delta V_o}{\Delta V_{in}} = \left(\frac{F_c}{F_r}\right)^2 \tag{2}$$

$$\text{Capacitance } C = \left(\frac{10}{2\Pi F_{sw}}\right)^2 \cdot \left(\frac{1}{L}\right) \tag{3}$$

Rectifier filter design

$$\text{Inductive Reactance } X_L = 2\Pi F L \tag{4}$$

$$\text{Capacitive Reactance } X_C = \frac{1}{2\Pi F C} \tag{5}$$

$$X_C = \frac{1}{10} Z_{load} \tag{6}$$

$$\frac{V_i}{V_o} = \frac{\sqrt{2}}{3}\left[\frac{1}{(2\omega)^2 LC - 1}\right] \tag{7}$$

$$\text{Capacitance } C = \frac{1}{4\Pi^2 F_c L} \tag{8}$$

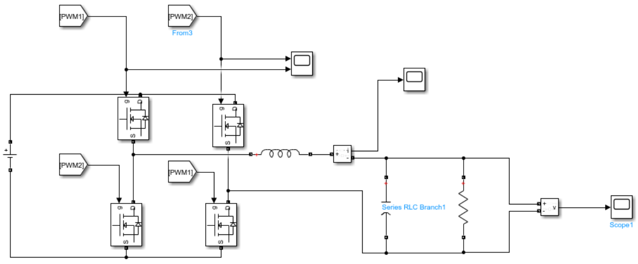


fig 1.4 - Inverter model

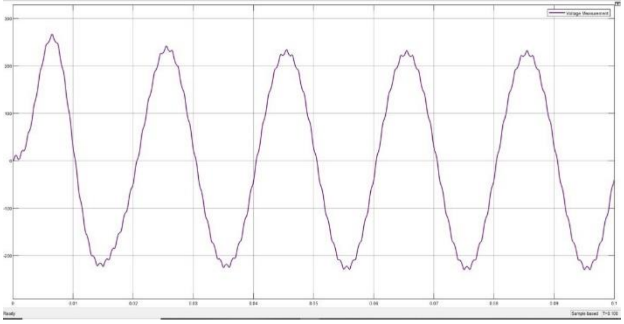


fig 1.5 - Inverter output

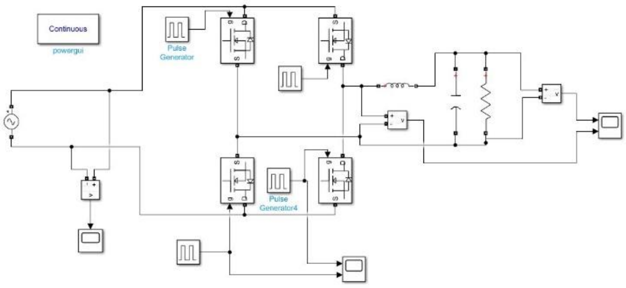


fig 1.6 - Rectifier model

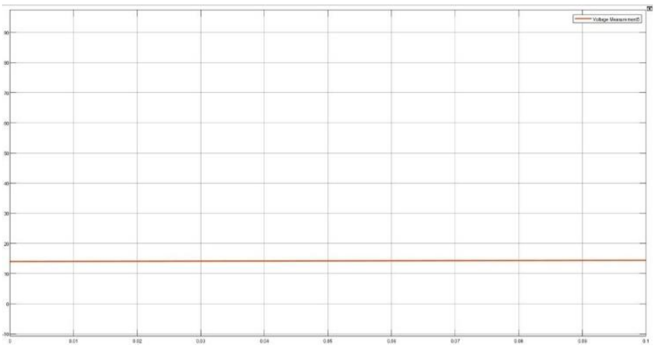


fig 1.7 - Rectifier output

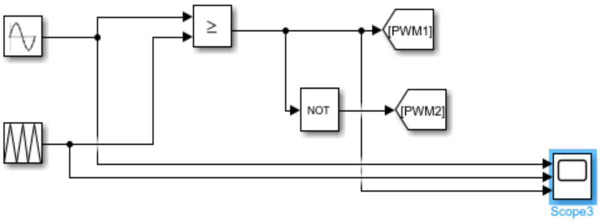


fig 1.8 - SPWM model

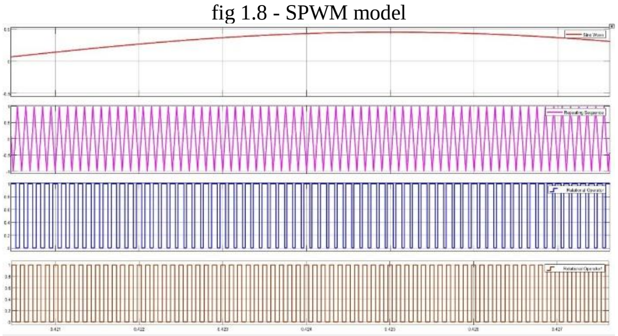


fig 1.9 - SPWM output

SPWM control

$$RS = Repeating\ sequence$$
$$f(x) = \{1, if \ \sin(\omega t) \geq RS\}$$
$$f(x) = \{0, if \ \sin(\omega t) < RS\}$$

3. *Passive cell Balancing*

There will be a combination of both weak and strong cells in the pack and there is a high chance that the weaker cells are over discharged and the stronger cells are overcharged. In this method, a resistor with a switch is connected across the cell where if in case the stronger cell happens to achieve more potential than the weaker cell, the excess energy from the stronger cell is wasted in the resistor. The transistor switch enables quick control over the working of the resistor at the right time.

$$SOC(1) > SOC(2) \rightsquigarrow R(1)$$
$$SOC(1) > SOC(3) \rightsquigarrow R(1)$$
$$SOC(2) > SOC(3) \rightsquigarrow R(2)$$
$$SOC(2) > SOC(1) \rightsquigarrow R(2)$$
$$SOC(3) > SOC(1) \rightsquigarrow R(3)$$
$$SOC(3) > SOC(2) \rightsquigarrow R(3)$$

SOC(i)>SOC(j) then connects resistor R(i) via MOSFET

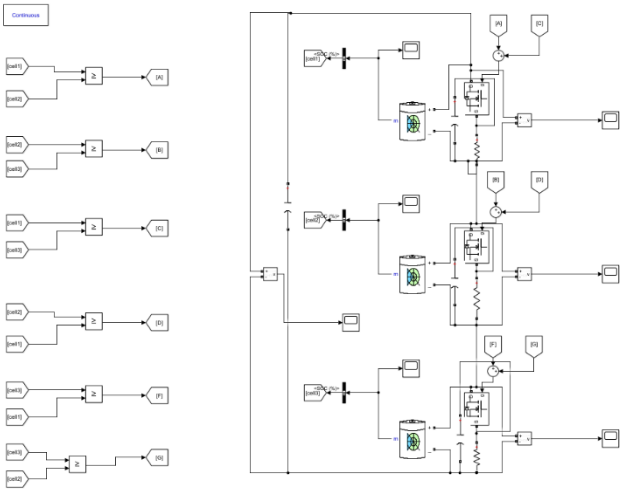


fig 2.0 - Passive cell balancing circuit

4. *Active cell Balancing*

In this method, the concept of a strong and a weak cell remains the same as the passive cell balancing method but the technique is improved. Here, the circuit tries to have more control over the cell voltages and extracts the full capacity of the cells to use. The excess energy in a stronger cell can be transferred into a weaker cell with less energy by means of different components like inductors or capacitors. The two main varieties are shown below.

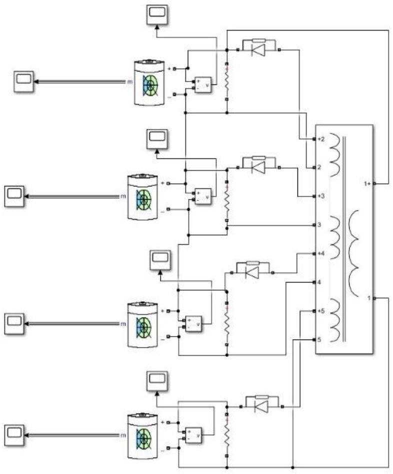
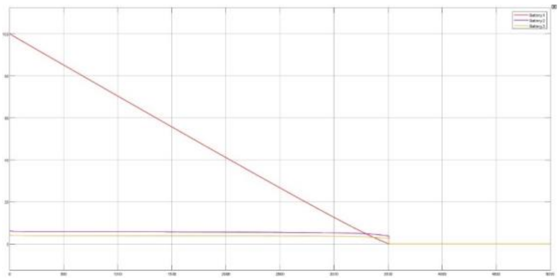


fig 2.1 - Active cell balancing circuit
(Multiple winding type)



2.2 - Active cell balancing output
(Multiple winding type)

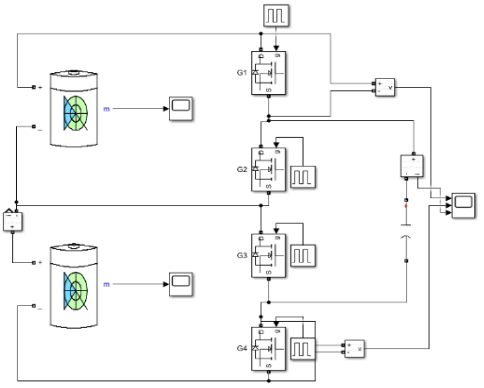


fig 2.3 - Active cell balancing circuit

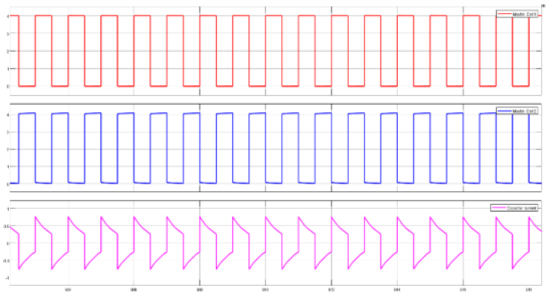


fig 2.4 - Capacitor current

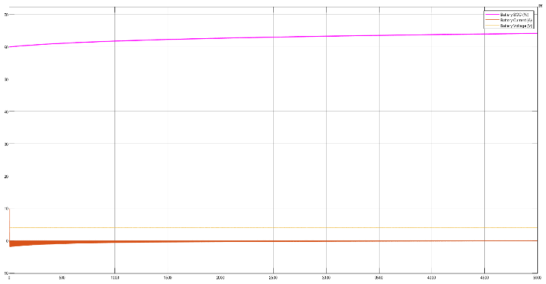


fig 2.5 - SOC cell 1

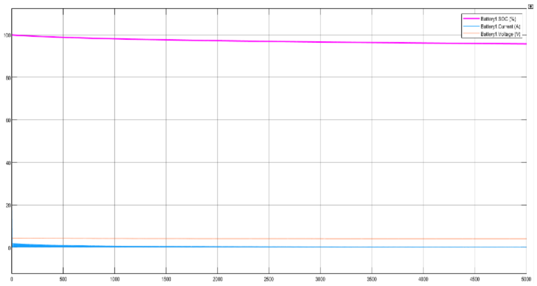
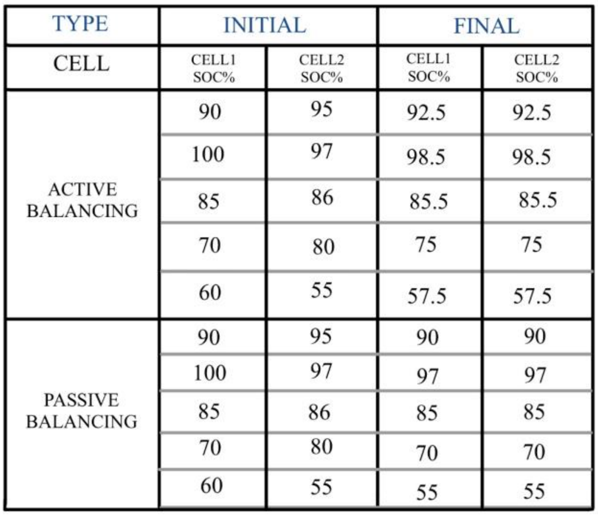


fig 2.6 - SOC cell 2

The SOC of Cell 1 was set to 100% and the SOC of Cell 2 was set to 60%. Here, Cell 1 starts charging the capacitor and as the capacitor is fully charged, it starts sending that energy into Cell 2 hence balancing the energy in both the cells. A comparison was made between Active and Passive balancing techniques and the following results were found (fig 2.7).



TYPE	INITIAL		FINAL	
CELL	CELL1 SOC%	CELL2 SOC%	CELL1 SOC%	CELL2 SOC%
ACTIVE BALANCING	90	95	92.5	92.5
	100	97	98.5	98.5
	85	86	85.5	85.5
	70	80	75	75
	60	55	57.5	57.5
PASSIVE BALANCING	90	95	90	90
	100	97	97	97
	85	86	85	85
	70	80	70	70
	60	55	55	55

fig 2.7: SOC Table

5.CONCLUSION

Electric vehicle Battery packs were considered to have voltage and energy imbalances in them that were hurting the overall performance of the pack. This issue was solved using Cell balancing techniques namely Passive balancing and Active Balancing. This made sure that the cells in the battery pack did not over-charge and maintained a balance of voltages throughout every cell hence, increasing the overall capacity of the Battery. The Balancing circuits were designed and simulated in MATLAB and the results were obtained in a graphical manner. A comparative study was done and it was found that the Active balancing technique was a better me of accounting for the imbalances in the cells compared to the passive balancing technique as it is more efficient with the energy management between the cells.

6. REFERENCES

[1] Bui, Thuc Minh & Kim, Changhwan & Kim, Kyu-Ho & Rhee, Sang-Bong. (2018). A Modular Cell Balancer Based on Multi-Winding Transformer and Switched-Capacitor Circuits for a Series-Connected Battery String in Electric Vehicles. Applied Sciences. 8. 1278. 10.3390/app8081278.

[2] C. Y. Chun, B. H. Cho, and J. Kim, "State-of-charge and remaining charge estimation of series-connected lithium-ion batteries for cell balancing scheme," 2015 IEEE International Telecommunications Energy Conference (INTELEC), 2015, pp. 1-5, oi: 10.1109/INTLEC.2015.7572280.

[3] S. Jeon, J. -J. Yun and S. Bae, "Active cell balancing circuit for series-connected battery cells," 2015 9th International Conference on Power Electronics and ECCE Asia (ICPE-ECCE Asia), 2015, pp. 1182-1187, Doi: 10.1109/ICPE.2015.7167930.

[4] Kelly Wong, ***www.twitter.com***.

[5] The Economic Times, "Global Electric Vehicle sales up 109% in 2021, Tesla leads with 14% share.", Feb 17, 2022, ***https://economictimes.indiatimes.com/industry/auto/auto-news/global-electric-vehicle-sales-up-109-in-2021-tesla-leads-with-14-share/articleshow/89590350.cms***

[6] M. Longo, F. Foiadelli, and W. Yaïci, "Electric Vehicles Integrated with Renewable Energy Sources for Sustainable Mobility", in New Trends in Electrical Vehicle Powertrains. London, United Kingdom: IntechOpen, 2018 [Online]. Available: https://www.intechopen.com/chapters/60938 DOI: 10.5772/intechopen.76788

[7] N. Srinivas, S. Singh, M. Gowda, C. Prasanna and S. Modi, "Comparative Analysis of Traditional and Soft Computing Techniques of MPPT in PV Applications," 2021 IEEE 4th

International Conference on Computing, Power and Communication Technologies (GUCON), 2021, pp. 1-6, doi: 10.1109/GUCON50781.2021.9573876.

[8] Durgaprasad S., Nagaraja S., Modi S. (2022) HVDC Fault Analysis and Protection Scheme. In: P. S., Prabhu N., K. S. (eds) Advances in Renewable Energy and Electric Vehicles. Lecture Notes in Electrical Engineering, vol 767. Springer, Singapore. https://doi.org/10.1007/978-981-16-1642-6_18