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DESIGN, DEVELOPMENT AND ANALYSIS OF PARALLEL OPERATION OF $LIFEPO_4$ BATTERY PACKS THROUGH SHUNT CURRENT LIMITER

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ABSTRACT: This study is based on the Parallel connections of battery packs using a shunt current limiter. It contains Battery packs, a BMS module (Battery Management System), and a Current limiter as the main components and total number modules required to build the electric vehicle two-wheeler. First Battery pack was assembled as per the standards then, BMS was implemented for battery modules to manage the functionalities regarding battery packs performance management and safety. After successfully implementing the BMS module with the battery pack the parallel current limiter is introduced in the system. The parallel current limiting module is a product accessory specially developed for the parallel connection of the Lithium Battery Protection Panel of the battery pack. It can control the current limiting unit according to the current limiting value of each current limiting series to limit the current of the parallel connection battery pack step by step, to prevent the battery pack in series charging because of the internal resistance and voltage of the different battery packs may damage to the protection plate, effectively ensure the safety of the protection Plate. After this, another module connection is preceded in the same way and after completion, they both are parallel connected. For monitoring the developed model performance, we use standard communication devices, so that the developed module performance and safety can be maintained.

KEYWORDS: Electrical vehicle, Battery management system, Lithium-ion cell, Shunt current limiter, Battery pack, State of charge estimation, State of Health, Pack Balancing.

1. INTRODUCTION

This work will mainly discuss the parallel connection of LiFePo4 battery packs using a shunt current limiter. As in the current scenario, we use BMS (Battery Management System) for cell balancing and monitoring of battery packs, but when we are required to connect the battery packs in parallel then there is an issue of rising current in the circuit which is intolerable by the BMS connected with the different soc battery packs, so we required to introduce the shunt current limiter to the circuit.

For developing this shunt limiter-based parallel module, firstly we develop battery pack modules having cell types and then integrate the BMS module with the battery packs. After this current limiter and accessories like smart BMS SOC indicator, Bluetooth module interface, and communication facilities like RS485 and CAN are connected in the model as per the standards.

LITERATURE SURVEY

1. CELL CHARACTERIZATION

Cell is an electrochemical energy storage device. LiFePo4 cells are more thermally stable and safe compared to LNMC cells. Lithium-ion cells are basically in four different physical sizes which are cylindrical, prismatic, coin cell, pouch cells. Lithium-ion cells having highest energy density and lost power density. Inside the lithium-ion cell having three major parts anode, cathode and electrolyte. With respect to cathode material used in development of cells. Lithium-ion cells classified into different types which are LiCoO2, LiMnNiCo, LiFePO4, LiMnO2, LiMn2O4…etc. Lithium-ion cell parameter like voltage, energy, power varies with respect to cathode material used in development of cell.

During charging and discharging process we have to use cell in safe operating areas like voltage limit, current limit, temperature limits. Operating lithium-ion cell outside the safe operating limits may damage the cell, Cell thermal runaway happens for thermal limit exceeds, Cell may loss its capacity during the charge and discharging process or it may degrade faster. Battery management system is required operate the cell in safe operating area.

At (25°C±2°C), the cell is charged with a constant current of 7.25A to a voltage of 3.65V and then switched to constant voltage charging until the charging current drops to 50mA then stop charging and we let it stand for 30 minutes after charging. At (25°C±2°C), the cell is discharged at a constant current of 14.5A to a voltage of 2.0V and then left to stand for 30 minutes after discharge.

For cell electrical characterization we used a Neware multi-channel cell cycler which is a programmable bidirectional DC power supply as shown in figure the results of IFR 32135-14.5 Ah lithium-ion cell performance by studying the charge discharge cycles at different C-rates, Life cycle, SOC vs OCV, HPPC, Pulse charge and Pulse discharge

This section applies to all lithium-ion cells used in various applications like electric vehicles and stationary energy storage systems. It covers the qualification process for performance testing. Continuous charge and discharge test for cell at 0.5C charge and 1C discharge. For capacity measurement. Cell characterization with charge and discharge cycles at different C-rates as per the specification as cell behave differently at different C-rates. Charge and discharge life cycle test as per the specification to capacity fade in cells shows the lithium-ion concentration decomposition. SOC vs OCV curves helps to estimation initial SOC in Battery management system for advance SOC estimation algorithms. Pulse charge and pulse discharge to know the steady state and transient behavior of cells. Hybrid pulse power characterization is used for estimation internal resistance of cells.

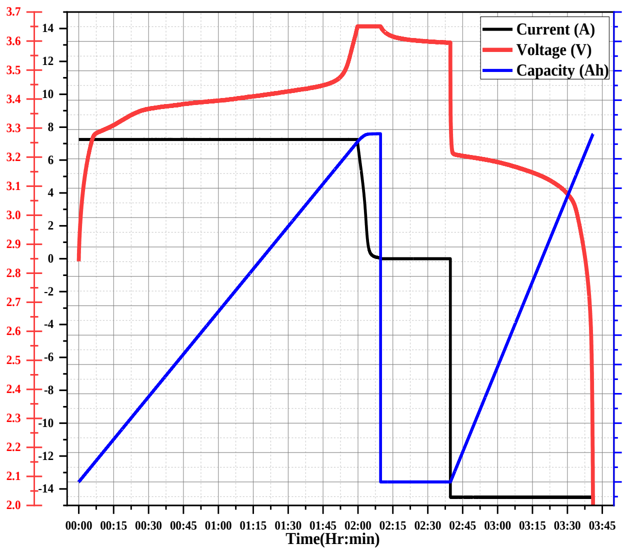


Fig 1: Cell continuous charge and discharge.

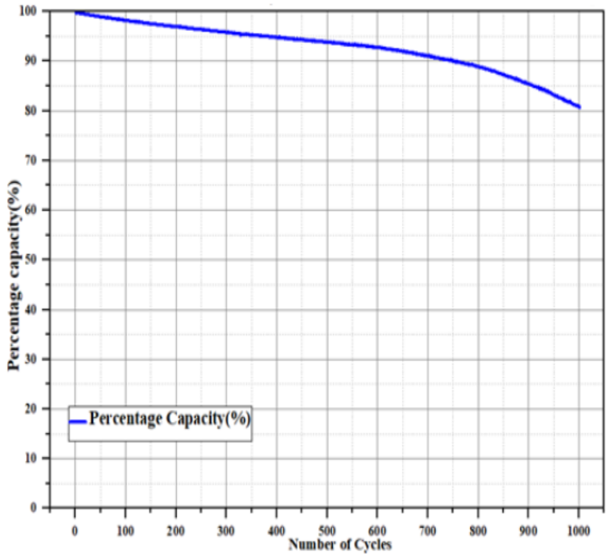


Fig 2: Cell capacity fade curve (Life cycles curve).

2. BATTERY PACK TWO PARALLEL MODULES

A battery pack is a series and parallel combination of cells to meet design requirements. The battery pack used in this model consists of a 16S2P configuration of the cylindrical cells. Cell connected 16S2P means 16 parallel cells for voltage requirement and 2P means 2 parallel cells for current requirements. One of the most successful Li-ion cathode formulas developed to date is obtained by combining Lithium -Iron & Phosphate, abbreviated as LiFePo4, which has become the go-to cathode powder to develop batteries for power tools, e-bikes, and other electric powertrains. It delivers strong overall performance, excellent specific energy, and the lowest self-heating rate of all mainstream cathode powders, which makes it the preferred option for automotive batteries.

Electrical Specifications		
1	Battery Chemistry	$LiFePo_4$
2	Pack nominal voltage	51.2 V
3	Each Pack capacity	1.5 KWh
4	Cell nominal capacity and voltage	14.5 Ah, 3.2 V
5	Pack configuration	16S2P
6	Type of cell	Cylindrical
7	Pack voltage range	48V – 58.4V
8	Recommended Cell charging current	7.5A
9	Recommended Cell discharging current	14.5 A
10	Charging cut-off voltage (based on cell cut-off)	3.65 ± 0.05V
11	Discharge cut-off voltage	3 ± 0.1V
12	Cycle life	2000 Cycles
13	Operating temperature	0°C to 60°C (Discharging) 0°C to 55°C (Charging)
14	Storage temperature	20°C to 40°C
Mechanical Specifications		
18	Dimension	230x190x170mm
19	Weight	14.5Kg ± 10%

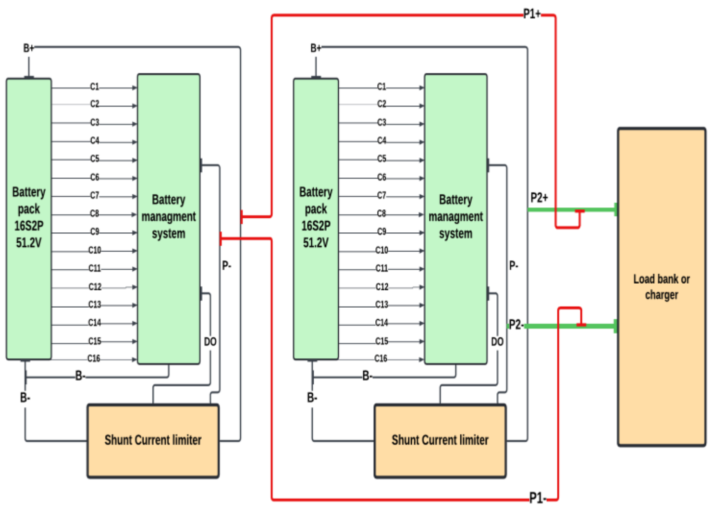
3. BMS MODULE:

The main functions of battery management system are it monitor the battery pack parameters, it protects the battery under abnormal condition, it estimate the battery state of charge through which we can know the how charge left in battery pack, it maximizes battery performance by making the battery to function safe operation area, it makes the communication to the external devices used by users. In study work we used the BMS R25T-GJ05 module. The microcontroller of the BMS measures the cell voltage and current in real-time and based on that it switches the charge and discharge of MOSFETs. The BMS uses only one bus for charging and discharging initially, both charging and discharging MOSFETs are off so there is no current flow. The microcontroller of the BMS senses the voltage at the input and it turns on the charging MOSFET which again starts charging the battery. If the voltage at the input pin is not present then BMS determines the load is connected and it turns on the discharging MOSFET.

Normally two types of cell balancing are used in BMS. Passive cell balancing as energy dissipation method. Active cell balancing as an energy transfer between the cells without wasting. The main functions BMS are : Safety, Battery performance optimization and Health monitoring and diagnostics.

4. SHUNT CURRENT LIMITING MODULE:

The parallel current limiting module is a product accessory specially developed for the parallel connection of the lithium-ion battery protection panel. It can control the current limiting unit according to the current limiting value of each current limiting series to limit the current of the parallel connection battery pack step by step, to prevent the battery pack in series charging because of the internal resistance and voltage of the different damage to the protection plate, effectively ensure the safety of the protection plate. As per figure below show the connection of Battery pack, BMS and Shunt current limiter.



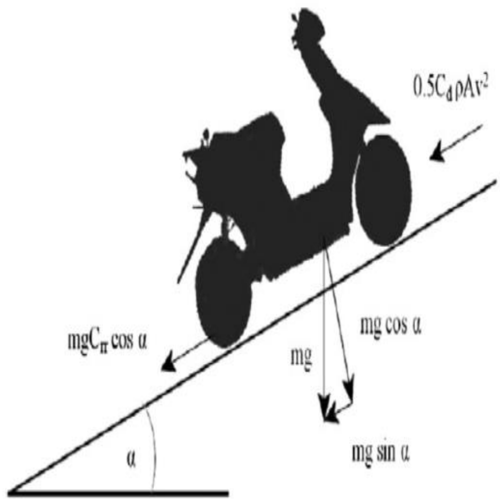


Fig 3: Battery pack, BMS and current limiter wiring connection.

Fig 4: Vehicle Dynamics.

5. ELECTRIC VEHICLES FOR LOAD TEST

We may test the battery pack in continuous charge and discharge with charger and load bank but when comes to real-time there are a lot of parameters that affect battery performance such as temperature, and dynamic load profile concerning particular vehicles. We want to know how the packs behave on full load vehicle level test so we have done vehicle level testing on two vehicles.

The vehicle consists of a battery pack, BMS, BLDC – motor, Motor controller, DC-DC converter…etc. Below figure 13 shows the vehicle electrical wiring diagram. Which helps us understand the different components of the vehicle.

Where is ρ density of air, C_d is the aerodynamic drag resistance, V is vehicle speed, C_{rr} is the coefficient of rolling resistance, m is total mass of vehicle, rider, passenger, and load, g is the gravitational acceleration, and α is the angle of road slope and parameters for a typical scooter are listed in

$$P_{wheels} = V(F_{aero} + F_{roll} + F_{grad}) + maV.$$

$$P_{output} = \frac{P_{wheels}}{\eta_{drivetrain}} + P_{auxiliary}$$

Total weight two passenger's weight	= 140Kgs approximate
Vehicle bodyweight	= 120Kgs approximate
Shunter packs weight	= 40 Kgs approximate
Total load on motor	= 300kgs approximate

RESULTS AND DISCUSSION

Single battery pack analysis and testing are each when compared to two parallel modules. We can perform charge and discharge easily. When it comes to two battery packs in parallel, we have to consider various battery pack conditions like how their SOC, voltage…etc. differ. As per real-time scenarios, we come up with the following case to test the Two parallel-connected battery packs.

1.Packs balancing functionality

Ideal paralleling operation of two battery packs when Pack A at 53.5 V and Pack B at 43.9 V (without connecting to charger/Load). In this case, we have connected two packs at different SOCs. The below graph shows how the charge transfer happens in two packs in the ideal case. From graphs we have observed that charging of Pack-A (current flow is observed through the current limiter till 52.9V) and discharging Pack-B. Charging MOSFET is off from voltage range (43.9 V- 52V). Charging MOSFET switched on from voltage range (52 - 53V). We have seen that both the pack balance to same voltage levels.

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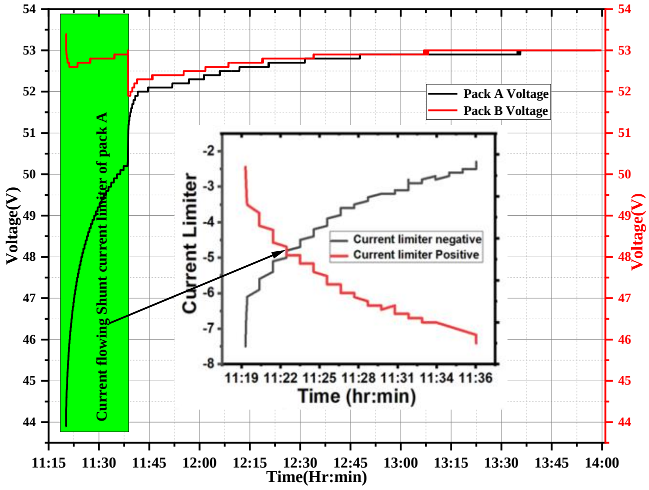

Fig 5: Response on pack balancing

2.Packs balancing and charging functionality

Paralleling operation in charging condition with a charger of 30A when Pack A at 52.9V & Pack B at 42.7V. In this test, we have made two packs at different SOCs and with 30A chargers. We checked packs balancing and charging functionality of packs.

From the graphs, we have observed that charging of Pack-A (current flow is observed through the current limiter till 52.9V) and discharging Pack-B. Charging MOSFET is off from the voltage range (43.9V- 52V). Charging MOSFET switched on from voltage range (52V - 53V). We have seen that both the packs balance to the same voltage levels.

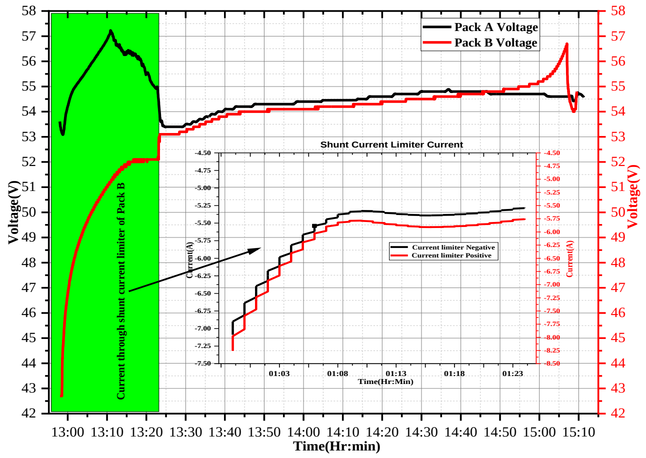

Fig 6: Response on balancing and charging.

3.Packs balancing and discharging functionality

During this analysis, we wanted to know what happens when two packs at different SOC levels while discharged. Paralleling operation in discharge condition with a load of 26A when Pack B at 53.5V & Pack A at 41.5V.

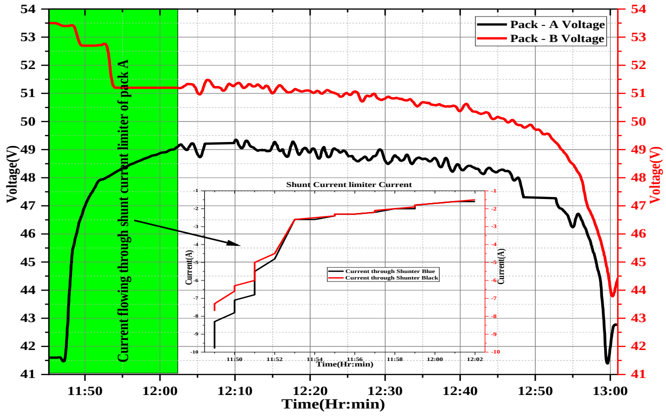

Fig 7: Response on balancing and discharging.

From the graphs, we have observed that Pack A gets charged very low, and Pack B is giving charge to Pack A and load. Charging of Pack-A (current flow is observed through the current limiter till 48V). Charging MOSFET is off from the voltage range

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(50.8V- 48V). Charge MOSFET switched on from voltage range (48V– 42.7V) in pack A. From the above graph SOC vs time, we can observe the SOC level in both packs.

4.Both packs charging from zero SOC's

In this case analysis we have charged both packs completely till 100% SOC connected parallelly and started discharging to know the paralleling operation in discharging condition with a load at 26A when pack A at 53.9V and Pack B at 53.6V.

From figure30, we have observed that both packs take appro equal current from the charger. Charging of Pack A and Pack B at different current rates. Both charge MOSFET is switched on from voltage range (44.5 V- 57.4 V). Both the packs at less voltage differences get charged with equal currents.

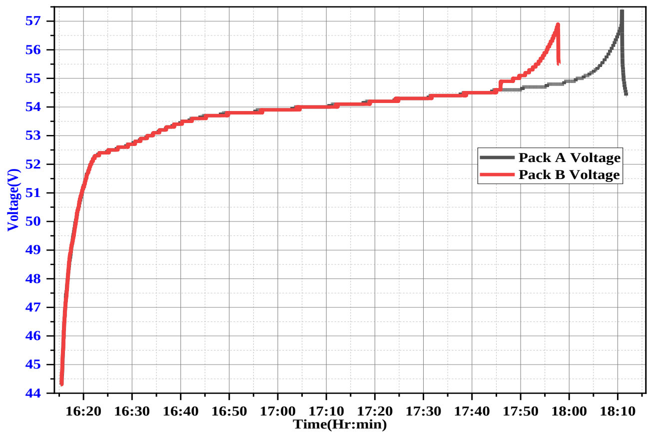

Fig 8: Response on parallel charging.

5.Both packs discharging from zero SOCs

In this case analysis we have charged both packs completely till 100% SOC connected parallelly and started discharging to know the paralleling operation in discharging condition with a load at 26A when Pack A at 53.9V and Pack B at 53.6 V.

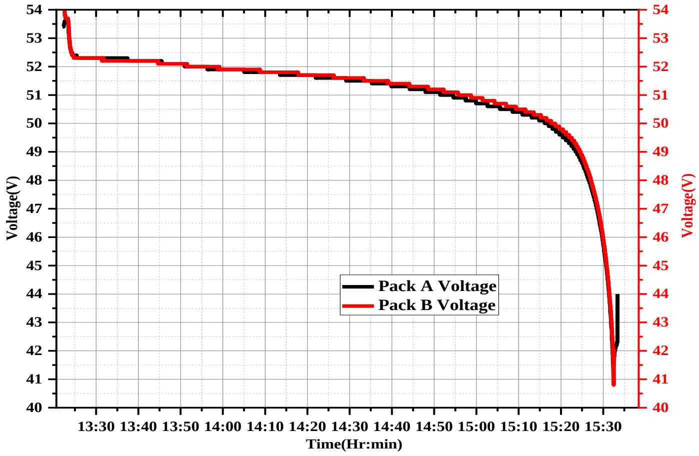

Fig 9: Response on parallel discharging.

From the figure 31, we have observed the discharge of Pack-A and Pack-B at different current rates. Discharging MOSFET is switched on for pack A from the voltage range (53.9V-40.8V). Discharging MOSFET switched on for pack B from voltage range (53.6V-41.4V). Both the packs at less voltage differences get discharged with equal currents.

6.Vehicle load profile analysis

During this test, we charged both the battery pack fully to 100%SOC. We connected both packs to bounce vehicles to know how they behave on vehicle level testing from SOC range from 100% to 80%.

From figure32 we have observed and data analysed. we come up that depends on packs time constant they release energy to vehicle load. We can see from the graph of current vs time we have observe that 22.1A peak current, 9A average current, 33.2A peak regenerative current take by that vehicle during the test. Also, we can observe the voltage response of the both the packs during load profile.

Total current drawn from paralleled shunter packs by bounce vehicle from the graph below shows total current profile from vehicle test at full load. We have added the both packs current profile to get this. From the graph analysis 42.5A total peak current,12.5A is total average current and 33.2A is total peak regenerative current from bounce vehicle.

From figure34 we have observed that the power profile we have observed that 2.2KW peak power, 0.75KW average power and 1.76KW is the peak regenerative power.

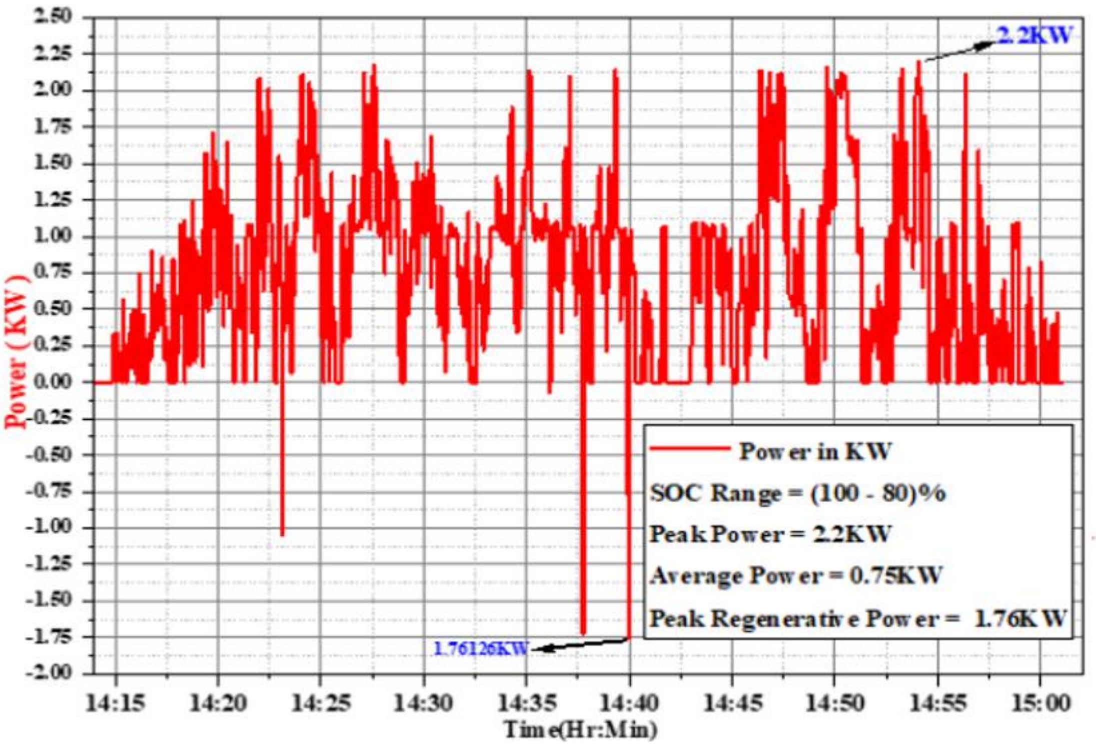

Fig 10: Power by vehicle response paralleled packs (100-80) %SOC.

CONCLUSION

After rigorous testing and analysing on bench level and vehicle level parallel operation of $LiFePo_4$ battery packs through shunt current limiter is working fine in all cases. We have got expected results in all area of functional testing. We have come to conclusion that shunt current limiter involvement is necessary for balancing unbalanced parallel operation of multiple battery packs. Design, development and analysis for three and four parallel modules connected in parallel with shunt current limiter to improve electrical vehicle mileage and modularity in energy storage system.

REFERENCES

1. B. K. Bose. 1997. Power Electronics and Variable Frequency Drives. IEEE Press, New York.
2. Ned Mohan, Undeland and Robbin, „Power Electronics: converters, Application and design", John Wiley and sons. Inc,Newyork, 2006.
3. Rashid M.H Power Electronics-Circuits, Devices and Applications„, Prentice Hall India, New Delhi, 2009.
4. P.C Sen., „Modern Power Electronics", Wheeler publishing Company, 1st Edition, New Delhi, 2005.
5. Andrzej M Trzynadlowski, „Introduction to Modern Power Electronics, John Wiley and sons. Inc, New York, 1998
6. Bin Wu, ' High Power Converters and AC Drives', IEEE press Wiley Interscience, a John wiley& sons Inc publication 2006
7. Kazmierkowski, R. Krishnan, Blaabjerg, Control in Power Electronics, Selected Problems.
8. Elham Hosseinzadeh, James Marco "Unbalanced Performance of Parallel Connected Large Format Lithium-Ion Batteries for Electric Vehicle Application".
9. Robert Luca, Michael Whiteley "Current Imbalance in Parallel Battery Strings Measured Using a Hall-Effect Sensor Array".
10. "Parallel Operation of Battery Power Modules" Chin-Sien Moo, Member, IEEE, Kong Soon Ng, Student Member, IEEE, and Yao-Ching Hsieh, Member, IEEE
11. "Management of imbalances in parallel-connected lithium-ion battery packs" Weiping Diaoa, Michael Pechta, Tao Liu
12. Simon F. Schuster "Current distribution within parallel-connected battery cells".
13. B. Duan, Z. Li, P. Gu, Z. Zhou, C. Zhang, Evaluation of battery inconsistency based on information entropy, J. Energy Storage 16 (2018) 160–166.
14. M. Baumann, L. Wildfeuer, S. Rohr, M. Lienkamp, Parameter variations within Li-Ion battery packs theoretical investigations and experimental quantification, J. Energy Storage 18 (2018) 295–307
15. F. An, J. Huang, C. Wang, Z. Li, J. Zhang, S. Wang, P. Li, Cell sorting for parallel lithium-ion battery systems: evaluation based on an electric circuit model, J. Energy Storage 6 (2016) 195–203.