Design, Analysis & Testing of Battery Pack for Off-Road Applications

Shantanu Bamane[1], Om Zaware[2], Rohan Dhaygude[3], Prathamesh Pawar[4]

Department of Mechanical Engineering, Dr.D.Y.Patil College of Engineering, Akurdi, Pune, Maharashtra, India

---***---

Abstract – *The increasing demand for safe, effective & sustainable battery packs has driven significant advancements in electric battery technology particularly for off-road applications where the battery pack must face harsh conditions (i.e. high temperature, high vibrations, etc.). This paper presents a comprehensive study on the design, analysis & testing of an electric battery tailored for off-road applications. The process involves selection of battery cells, bus bar materials, cell holder materials, choosing an effective battery management system, battery casing. For Analysis ANSYS & COMSOL Multiphysics software were utilized & for testing Vibration Test & Ingress Test were performed on the Battery pack. This paper encompasses the battery pack according to AIS 156/048 standards. This includes factors such as safety, performance, durability & environmental impact. The findings demonstrate the potential of the proposed battery pack for off-rode vehicles thus providing a viable alternative to the long-standing use of Internal Combustion Engines.*

***Key Words*: Lithium-ion Battery, Electric Vehicle, Battery Vibration Testing, Ingress Protection Testing**

1.INTRODUCTION

In this rapidly evolving landscape of automotive technology, the design and analysis of battery pack play a pivotal role in shaping the performance & efficiency of electric battery pack. Off-road vehicles, such as all-terrain vehicles (ATVs), require robust battery system which are capable of enduring harsh environmental conditions. Lithium-ion battery is favoured for its high efficiency, high energy density & long-life cycle. The primary objective is to design a battery having high energy density and power density while maintaining thermal stability and safety.

1.1 Objectives

1. Selection of cells having high energy density, high power density and durability.
2. Simulation of Battery cell using MATLAB Simulink to affirm the charge discharge cycle of battery cell.
3. Structural and Thermal Analysis of Battery pack using ANSYS and COMSOL Multiphysics.
4. Analysis of bus bar using COMSOL Multiphysics software to check its durability to high temperatures.
5. Manufacturing Battery Pack.

2.BATTERY DESIGN

2.1 Cell Selection

Following points were considered for cell selection

1. Internal Resistance
2. Cell Chemistry
3. Foam Factor
4. Capacity
5. Availability in market
6. Discharge & charge rate

Table -1: Battery Cell Comparison according to its technical specifications

Cells	Voltage	Capacity	Weight
18650 CYL LFP	3.2 V	3200 mAh	46 g
21700 CYL NMC	3.6 V	5000 mAh	70 g
Prismatic LFP	3.2 V	100 Ah	2210 g
32600 CYL LFP	3.2 V	6 Ah	145 g
Samsung 48X 21700	3.64	4.8 Ah	67.9 g

For designing a battery pack with the given parameters, lithium-ion Samsung 48X 21700 cells with NMC chemistry were selected due to their high-power density, higher voltage, good capacity-to-weight ratio and the reliability and availability associated with Samsung brand.

2.2 Battery Parameters

The parameters of the battery were chosen to balance voltage, capacity & manage current capabilities to ensure it meets performance, safety and durability requirements.

Table -2: Battery Parameters

Configuration	14S 24P
Peak Voltage (V)	58.8
Nominal Voltage (V)	50.4
Cut-off Voltage (V)	37.8
Peak Discharge Current (A)	180

Continuous Discharge Current (A)	100
Continuous Charge Current (A)	25
Total Capacity (Ah)	115.2
Weight (Kg)	39

2.3 Busbar Material Selection

In our Battery pack, we are using copper busbars for series connection between cells and a nickel strip for parallel connection between cells. We are using copper because of its high electrical and thermal conductivity and nickel for its high weldability.

Considering a pack discharge of 7.5 A from each individual cell, we have selected nickel strip of 0.3 mm thickness, and for a peak discharge of 180 A the thickness of a copper busbar is 2.5 mm.

Fig -1: Copper Busbar

Fig -2: Nickel strip

2.4 Battery Casing

The Casing is the outer enclosure of the battery pack that protects the battery from the outer environment. It provides for rigidity and durability to the entire battery pack. The casing can be made of various metallic and non-metallic materials which are of high strength and stiffness. Various parameters were taken into consideration while selecting casing material such as:

1. The Strength of material
2. The Density of material
3. Thermal conductivity and convective rate of heat transfer
4. Manufacturability

For our battery pack, we are using a T6-6061 grade Aluminum sheet of 3 mm thickness. We are considering aluminum over other materials due to its higher strength-to-weight ratio and better thermal properties.

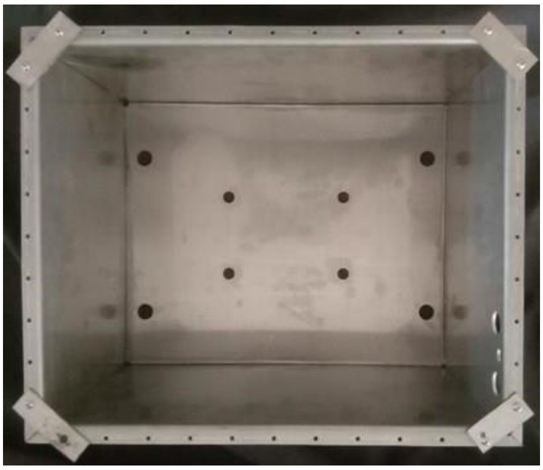

Fig -3: Battery Casing

Fig -4: Side view of battery Casing

2.5 Assembly of Battery Pack

1. Busbars were mounted on machined cell holders and then sent to welding of nickel and copper busbars.
2. After welding, cells were arranged in cell holders and were packed between two cell holders
3. The module of 168 cells was sent for laser welding
4. After laser welding of both modules, the wiring harness and Battery Management System were connected to the battery (DALY BMS of 14 S configuration with rated current of 200 A was used in our battery)

5. Insulation of FR4 sheet was covered from both top and bottom side
6. Both modules were stacked on each other in series configuration with the help of copper washers.
7. The wires are connected to the battery terminal.

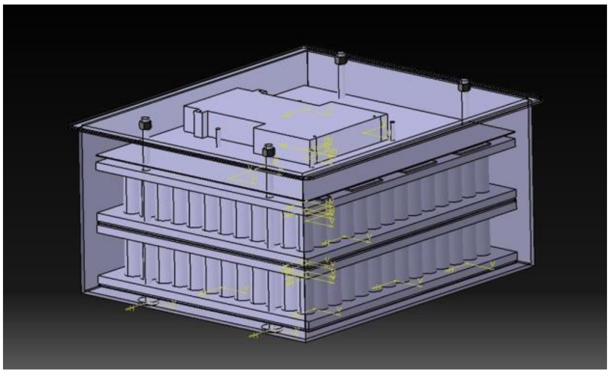

Fig -5: Final Model of Battery Pack

3. SIMULATION

A MATLAB Simulink model was designed to demonstrate variations in cell performance corresponding to C-rate. In this model, we have the capability to adjust parameters such as charge current, discharge current and depth of discharge (DOD) over various time intervals. In this simulation, we conducted both charging and discharging cycles.

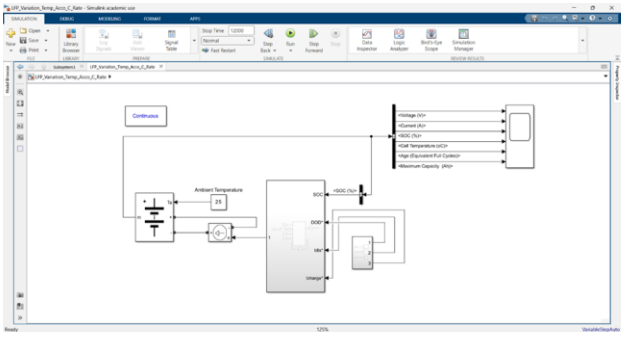

Fig -6: MATLAB Simulink model 1

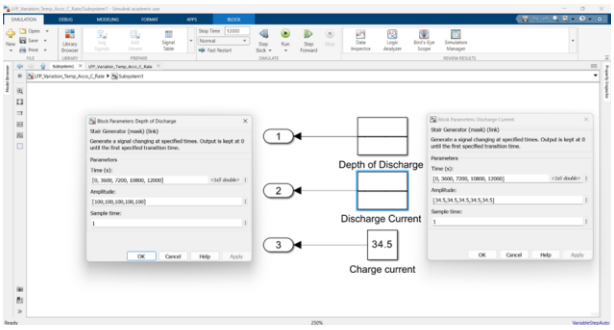

Fig -7: MATLAB Simulink model 2

Results of Simulation Model

The results generated illustrate the variation in key parameters like current, voltage, state of charge, capacity and cell temperature over time. The voltage curve shows typical charging and discharging cycles, while the SOC graph indicates the amount of charge remaining in the cell. Additionally, the temperature graph indicates the thermal behavior of the cell, which is crucial for understanding its performance and safety.

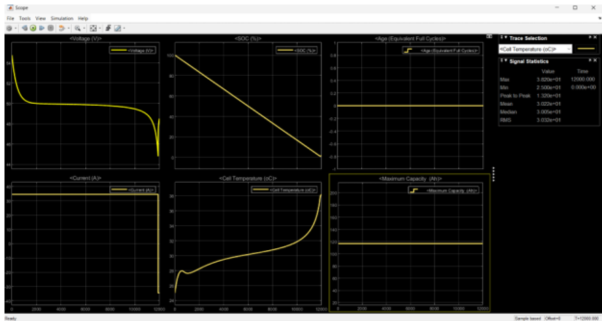

Fig -8: Results at 0.3 C Discharge rate

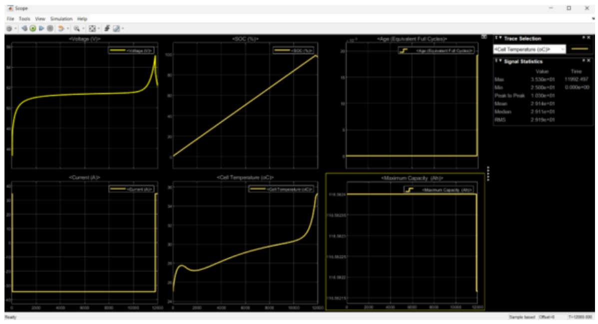

Fig -9: Results at 0.3 C Charge rate

4. ANALYSIS

The structural and thermal analysis of the battery pack was conducted using ANSYS for structural analysis and COMSOL Multiphysics for thermal analysis of the battery pack as well as the busbar. This analysis provides valuable feedback on the safety and durability of the battery pack. Structural analysis reveals the mechanical integrity of the battery pack ensuring that the battery pack can withstand physical stress without failure during off-road applications. On the other hand, thermal analysis highlights the thermal distribution in the battery pack during operation. This analysis is crucial for identifying hotspots to ensure thermal management and prevent overheating. The thermal analysis of the busbar ensures that the busbar can handle high loads without overheating. The results of the battery pack are as follows:

Static Structural of Battery Pack

Boundary Condition	Two-wheel landing condition of e-vehicle
Fixed Support	Mountings of battery casing
Force	981 N
Result	Stress induced: 29.10 MPa; FOS: 3.67

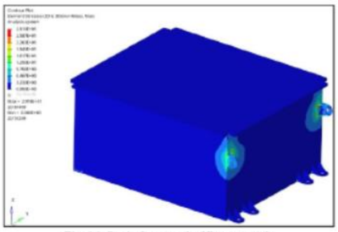

Fig. 16. Static Structural of Battery pack

Fig -10: Results of Static Structural Analysis using ANSYS

Thermal Analysis of Battery Pack

Software	COMSOL Multiphysics
Boundary Condition	Max. acceleration of the vehicle
Discharge rate	1.45℃
Current	170 Amp.
Study	Time dependent
Max Temperature	310 K

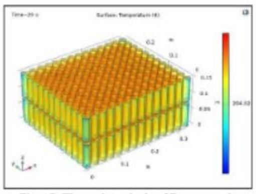

Fig. 17. Thermal Analysis of Battery pack

Fig -11: Results of Thermal Analysis of Battery Pack using COMSOL Physics

Analysis of Bus-bar

Software	COMSOL Multiphysics
Boundary Condition	Max. acceleration of the vehicle
Discharge rate	1.45℃
Current	170 Amp.
Study	Time dependent
Max Temperature	310 K

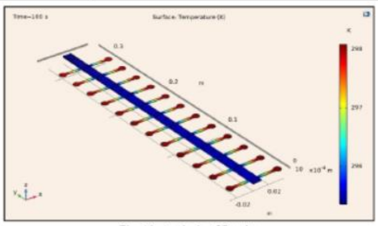

Fig. 18. Analysis of Bus-bar

Fig -12: Results of Thermal Analysis of Busbar using COMSOL Physics

5. TESTING OF BATTERY PACK

1. Vibration Test

The vibration testing is used to demonstrate a product's ability to withstand mechanical stress without hampering its structural integrity. This helps in identifying potential failure modes and ensuring the battery pack's performance over its expected lifespan. For testing of the battery pack, the battery pack was mounted on electric–dynamic stator and was subjected to a sinusoidal vibration test in accordance with AIS 048 at an acceleration of 3g in both axes and a frequency of 30-150 Hz at a sweep rate of 1 octave per minute. Testing was carried out for 45 minutes on each axis. A graph of acceleration vs frequency was obtained that showed a straight line without any deflection, implying that the battery pack's structure is stable. The test result was satisfactory, and the apparatus showed no physical damage to the casing or other mechanical parts and no fire or explosion after the test.

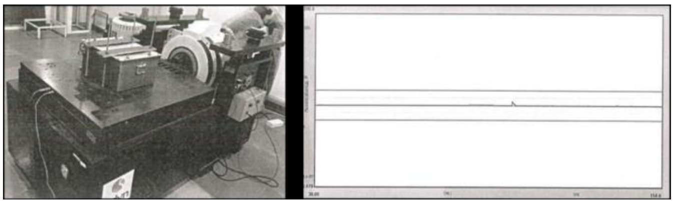

Fig -13: Battery mounted on Electro-Dynamic Stator and vibration plot

2. Ingress Protection (IP) Test

The IP test was conducted to demonstrate the robustness and reliability of the battery pack for use in challenging environments. IP6X and IP7X tests were conducted on the battery. An IP6X rating indicates that the battery is dust tight i.e. no dust can enter the battery and an IP7X rating means the battery pack can withstand immersion in water up to 1 meter for 30 minutes without water ingress. The test result of the battery pack was satisfactory, and no water was observed inside the enclosure after the test.

Fig -14: Battery pack immersed in water for IP testing

6. CONCLUSIONS

In conclusion, the developed battery pack for off-road electric vehicles not only meets but exceeds the stringent requirements of automotive applications. The project demonstrated the robustness and reliability of the battery pack for off-road application through comprehensive testing. The selection of NMC (Nickel Manganese Cobalt) cells for the battery pack provided high energy density and reliability, making them an ideal choice for demanding off-road applications. The vibration tests confirmed that the battery pack can withstand the mechanical stresses of the off-road environment without significant risk of failure. The IP6X and IP7X tests further validated the battery packs resistance to dust and water ingress ensuring their suitability for harsh conditions. Overall, the satisfactory results from these tests indicate that the battery pack is well designed to meet the demands for off-road use.

REFERENCES

[1] Smith, J. A., & Johnson, R. B. (2018). Advances in Lithium-Ion Battery Technology for Electric Vehicles. Journal of Power Sources, 392, 160-178.

[2] Li, Z., & Li, W. (2017). Advances in Lithium-Ion Battery Chemistry and Materials for Electric Vehicle Applications. Advanced Materials, 29(20), 1606822

[3] Chen, Z., & Qiu, X. (2019). Optimization of Lithium-Ion Battery Pack for Electric Vehicles Considering Dynamic Load Conditions. IEEE Transactions on Transportation Electrification, 5(1), 196-207.

[4] Zhang, Y., & Mi, C. C. (2021). Review of Lithium-Ion Battery Management Systems for Electric Vehicles. IEEE Access, 9, 19747-19759.

[5] Ma, X., & Zhang, G. (2019). Review of Battery Thermal Management Systems for Lithium-Ion Batteries in Electric Vehicles. Applied Thermal Engineering, 152, 190-205.

[6] Wang, L., & Liu, J. (2019). Development of Lithium-Ion Battery Pack for Electric All-Terrain Vehicles: Challenges and Solutions. Energy Conversion and Management, 198, 111852.