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Report on

"DESIGN AND DEVELOPMENT OF LI-IONBATTERY PACK AS PER THE AMENDED AIS 156/048"

By

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C E R T I F I C A T E

This is to certify that ***Mr. Samarth Prakash Malgave***, from BE C Roll no: BEMEC22359 have successfully completed Report entitled "***DESIGN AND DEVELOPMENT OF LI-ION BATTERY PACK AS PER THE AMENDED AIS 156/048***" under my supervision, in the partial fulfillment of Honors in "Electric Vehicles" along with Bachelor of Engineering –Mechanical Engineering of University of Pune.

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ABSTRACT

Development of alternate energy storage systems for transportation use has been driven by a combination of environmental preservation, fossil fuel price volatility and energy security concerns. Lithium-ion battery has emerged as a favoured choice; however, its energy density is still orders of magnitude lower than the fossil fuel. There is significant room for improvement in the battery cell and electric vehicle system designs. The objective of this thesis is to automate the design optimization of the lithium-ion battery pack. To achieve this goal three separate optimization problems were formulated to provide guidelines on the cell parameters at optimal solutions. The single cell design optimization is able to quantify the variations of morphological parameters as a constant active mass ratio; the plugin hybrid vehicle battery design demonstrates an automated design process that considers realistic performance constraints; the multi-cell design approach minimizes the battery pack mass by utilizing separate cell designs to satisfy different constraints. The usefulness of the current framework can be further enhanced by considering various aging mechanisms and to perform a design-control coupled multidisciplinary optimization. Lithium-ion battery (LIB) power systems have been commonly used for energy storage in electric vehicles. However, it is quite challenging to implement a robust real-time fault diagnosis and protection scheme to ensure battery safety and performance. This paper presents a resilient framework for real-time fault diagnosis and protection in a battery-power system. Based on the proposed system structure, the self-initialization scheme for state-of-charge (SOC) estimation and the fault-diagnosis scheme were tested and implemented in an actual 12-cell series battery-pack prototype. The experimental results validated that the proposed system can estimate the SOC, diagnose the fault and provide necessary protection and self-recovery actions under the load profile for an electric vehicle.

Chapter 1
Introduction

As one of many energy storage solutions, lithium-ion batteries (LIBs) are attracting more and more attention from researchers and users due to their high energy density, high power density, long lifespan and environmental friendliness. The LIBs have been used in energy- storage applications in solar panel systems from those that use a few kilowatt-hours in residential systems to multi-megawatt batteries in grid power systems. There are also broad applications in some high-power applications such as electric vehicles using large numbers of serial or parallel battery cells. However, despite being a promising candidate for energy storage solutions, these batteries are facing some challenges, such as ensuring safe operation of the battery-power system that depends on the accurate state-of-charge (SOC) estimation. The safety of the LIB power system is crucial, especially when the battery-power system is grouped by a considerable number of battery cells in serial or parallel topology, or in a battery stack, to give a higher power density. The LIBs can deteriorate if they are to operate beyond the battery specifications. The estimations of SOC in the battery management system (BMS) can improve the system performance and reliability. However, battery discharge and charge involve complex chemical and physical processes while in operation. It is therefore not easy to estimate the SOC accurately undervarious operational conditions. There are several kinds of LIBs in the market, such as thosecontaining LiFeO4, lithium polymers and LiCoO2. With the different dynamic behavior of the batteries and their topology, specific SOC algorithms are sometimes required. There have been many developments and research work in recent years to improve SOC estimation accuracy. Firstly, four types of critical faults, being the over-charged fault, over-discharged fault, over-current fault and external short-circuit fault, are considered. Secondly, different fault diagnosis algorithms are studied, and the corresponding solutions are proposed. Lastly, the proposed fault diagnosis and self-recovery schemes are appliedto the 12-cell battery pack prototype and validated experimentally. In summary, a structure of a smart multi-cell battery-power system is proposed to improve the safety and its operational intelligence. Hence, the smart battery-power system has the following features:

(1) compatibility and flexibility with different kinds of LIBs and battery pack configurations; (2) capability for SOC self-initialization and self-adjustment; (3) capability for fault diagnosis and self-recovery; and (4) ability to provide a human–machine interface for status report and system configuration, locally or in the cloud. A few designed modules, such as battery

data acquisition, battery pack SOC estimation, fault diagnosis, data communication, user-interface module for data display and system configuration, and dual-path switching for charging and discharging, are proposed. In the proposed smart battery-power system, the SOC self-initialization scheme coupled with fault diagnosis and the self-recovery algorithm were investigated and implemented in a 12-cell series (12S) battery-pack prototype. The experimental results show that the system can diagnose the faults and carry out the corresponding protection and recovery actions. In addition, the proposed battery pack has been shown to estimate the SOC successfully under the actual load profile from an electric vehicle.

1.1 Problem Statement

The rechargeable Lithium ion battery was invented in the nineties. Since then, they are widely used by many industries because of the interesting benefits they offer. Lithium ion batteries are light (Li is the lightest metal on the periodic table), very powerful and durable.

Demand for lithium ion batteries is increasing exponentially.

In recent years, car manufacturers have witnessed a huge increase in electric vehicles. The European Commission published the figures below on the global supply and demand of lithium ion batteries for electrical vehicles, based on today and the future.

It is our love affair with electronic gadgets, in combination with the need for renewable energy, that has led to a massive up-scale consumption. Lithium ion batteries are giving us many advantages. They have superior useable capacity, they charge fast and efficiënt, they are compact and lightweigth and have a prolonged battery life.

Lithium Ion Battery seems like the ideal solution for making our lives more comfortable and our world more durable. However, there is a major disadvantage which is that Lithium batteries can be life-threatening.

Why are these batteries so dangerous?

Part of the problem stems from what makes them so popular: They pack a lot of power for their size. But if they short-circuit they can overheat and create a chain reaction known as “thermal runaway,” a cascading effect in which they reach very high temperatures and emit smoke and toxic gasses that can fuel a fire or an explosion, especially if they’re packed tightly with other lithium batteries.

A thermal runaway can be caused by;

- Poor manufacturing, bad design
- External heating
- Over charging
- Over Discharging
- High current charging
- Structural damage

• Crush

• External short

So what is exactly happening here? Every lithium ion battery has two electrodes— there is the positively charged cathode and the negatively charged anode. They are separated from each other by a thin layer of microperferated plastic. When charging the battery, lithium ions move from the cathode through the tiny holes of the separator and an electrically conductive fluid, to the anode. The reverse happens when you discharge the battery and this reaction is what powers the electric device.

Because of bad design, manufacturing defects or several external abuse factors (described above), the separator can fail. When this happens, the anode and cathode will make contact and once they are together, the battery starts to overheat. The battery begins to hiss, bulge and leak elctrolyte. The overheating triggers an uncontrollable, explosive release of electric energy which generates smoke, flammable gas, heat (up to 600 °C to 1000 °C), fire, explosion, or a spray of flammable electrolyte. Before the cell combusts, a flare emerges briefly (~ 1 sec) The impact of the energetic release depends directly on the amount of energy stored and the type of battery.

1.2 Objectives

To Create a MATLAB model of electric car which uses lithium ion battery and suitable motor? Choose suitable blocks from Sim scale or Powertrain block set. Implement the vehicle speed control using PI controller and generate brake and accelerator commands. Avoid using readymade driver block for speed control

1.4 Methodology

1. Identification of Topic.
2. Literature survey.
3. Preparing synopsis.
4. Define design and dimension of battery pack.
5. Selection material.
6. Select the component and part to be use.
7. Analysis of Battery Pack
8. Assembly all part and model.
9. Testing.
10. Result and Report Writing.

Chapter 2

Literature Review

2.1 Various research studies by different authors

[1] Authors: YoonCheoul JEON, GunGoo LEE, TaeYong KIM, SangWon BYUN

"Development of Battery Pack design for High power Li-ion Battery pack of HEV."

Summary: In this paper, researchers are mainly focused on the design of compact battery pack with high Cooling performance and Desired Structural Safety. Due to the installation of battery pack under the seat, the height of the battery pack is reduced and also the weight of the battery pack is minimized by the using optimization methodology with Finite Element Analysis. By through the computational fluid dynamic element (CFD) analysis, for having the uniform temperature circulation and limited pressure drop inside the pack under typical charging and releasing conditions. By employing module frames and cooling system based on numerical simulations, a prototype of battery pack was manufactured. Experiments were also carried out on this optimized prototype of the battery pack to further validate numerical simulation.

[2] Authors: Zhitao Liu, CherMing Tan, Feng Leng

"A reliability-based design concept for lithium-ion battery pack in electric vehicles".

Summary: In this paper, an idea for plan in unwavering quality for Li-particle battery pack in EVs applications utilizing cells overt repetitiveness is presented, and the examination depends on the SoH of the phones in the battery pack. They compute the unwavering quality of the battery loads with various designs utilizing UGF procedure. Looking at the unwavering quality of two battery packs at various temperatures, we infer that the dependability could be improved by adding repetitive cells true to form, and the setup of the excess cells has huge impact on its unwavering quality. The proposed plan idea gives a method for choosing the best repetitive cells arrangement for good pack unwavering quality, while thinking about the complete expense through the ideal number of the excess cells.

[3] Authors: Shashank Arora, Ajay Kapoor

"Mechanical design and Packaging of Battery Pack for Electrical Vehicles".

Summary: In this paper, mechanical design elements affecting safety and reliability of EV battery packaging are discussed. Forces like mechanical vibration, impact energy and ambient temperature variations interact with the battery pack through different interfaces. These interactions need to be controlled for safe and reliable operation of battery pack. Restricting battery cell movement is found to be one of the successful strategies to achieve a higher degree of protection against all of them and mechanism that can be used for this purpose are presented. Other mechanical design solutions to increase crashworthiness and vibration isolation of the EV battery pack are also discussed. Lastly, a case study focusing on mechanical design of an eBus battery pack at Swinburne University of Technology in Australia is presented.

[4] Authors: Changhao Piao, Tao Chen, Anjian Zhou, Pingzhong Wang, Junsheng Chen

"Research on Electric Vehicle Cooling System Based on Active and Passive Liquid Cooling".

Summary: This paper proposes an active and passive liquid cooling-based EV cooling system, which is used for the battery cooling, motor, MCU, and DCDC. An movable intake grill is considered. The mathematical models for each component of the system are established by combining experimental data and component mechanism. The performance data for each component is obtained by experimental data fitting using linear interpolation. To show the proposed strategy, the reproduction tests are directed in light of the model worked by Flowmaster. The trial results show that the proposed strategy can fulfill the framework cooling prerequisite for various types of gadget. The combination of active and passive liquid cooling schemes can not only guarantee the battery operating temperature, but also save energy.

[5] Authors: Priyanka, R. Sandeep, V. Ravi, O. Shekar

"Battery Management System in Electric Vehicles".

Summary: Here are they developing the system model for battery management in the electrical vehicles. With changing or controlling such battery parameters such as Voltage, Current, State of Charge, State of Health, State of Life, Temperature. This paper mainly focusses on the study of the Battery Management System and optimize the power performances of electric vehicles. And they give various particular situations and different strategies for upgrades and optimize the performance of the BMS in EVs.

[6] Authors: Y.Lyu, A.R.M.Siddique, S.H. Majid, M. Biglarbegian, S.A. Godsden, S. Mohmud

"Electric vehicle battery thermal management system with thermoelectric cooling".

Summary: In this paper, authors presented the use of TEC for BTMS due to low thermal efficiency, Research have been considered a few literatures have been came forward for reference. However, studies suggest that working at above 50 deg C can be harmful to the lifespan of batteries. Further studies indicate that a temperature range from 25 deg C to 40 deg C (a maximum 50 deg C difference from this temperature range) provides the best working environments for batteries such as Lead-acid, Ni Mh, and Li-ion. The battery thermal behavior by natural air cooling at different voltage supplies was investigated first.

The temperature rises in volume and the rate of change of increases significantly as the voltage supply increases. When the heater voltage changed from 30v to 60v, the steady temperature to almost doubled. Next, a study was carried out for a purposed liquid cooling and a hybrid study was carried out purposed of liquid cooling and a hybrid TEC-liquid-air cooling system. In one of the recent studies, researches used TEC for BTMS without any coolant where their temperature drop was 31.5 deg C which is 11.5 deg C less compared to the current work.

[7] Authors: Salagrama Aswatdha, Dwarampudi Avinash Raj, Kolapalli Usha Rani

"*Design of Battery Pack for Electic Vehicles."*

In this literature author discussed about Electrochemical batteries; working of a battery; battery technologies like nickel-based batteries, lead based batteries, lithium based batteries, lithium ion batteries, lithium polymer batteries; battery cell selection, battery pack design, safety of battery pack. It deals with fullfing the requirements of all the parameters required by an electric vehicle.

Chapter 3

Design Considerations for Battery Pack

3.1 Electrical/ Chemical Considerations:

a.) Connections

Batteries achieve the desired operating voltage by connecting several cells in series; each cell adds its voltage potential to derive the total terminal voltage. Parallel connection attains higher capacity by adding up the total ampere-hour (Ah). Most battery chemistries lend themselves to series and parallel connections. It is important to use the same battery type with equal voltage and capacity (Ah) and never to mix different makes and sizes. A weaker cell would cause an imbalance. This is especially critical in a series configuration because a battery is only as strong as the weakest link in the chain.

Fig. 1.. Connections

Series Connections: A series connection refers to a grouping of cells connected in series (e.g., negative to positive, etc.). Connecting cells in series increase the voltage of the overall system. The example below represents three cells: let us assume that they are 3.6V and 5Ah similar to our previous example,in a series configuration. This configuration would end up with 10.8V (3.6V×3 cells) but will remain at 5Ah. Putting lithium-ion cells in series is similar to connecting multiple garden hoses end to end, just as the garden hoses are in series so are the batteries. The difference is that in batteries connecting them in series increases the voltage but not the capacity—the same effect does not occur when connecting garden hoses in series.

Parallel Connections: A battery with parallel connections refers to cells that are connected in parallel (e.g., positive to positive, negative to negative, etc.). In a parallel connection, you are feeding current into all of the cells at the same time and pulling current out of them at the same time. When connecting cells in parallel, the system capacity is increased. The example below represents three cells: let us assume that they are 3.6V and 5Ah; in a parallel configuration, this would end up with still at 3.6V but the capacity would increase to 15Ah (5Ah×3 cells).

b.) Connector Selection

Choosing the right battery connectors is critical to creating a reliable solution. Parts can be mated with boards that are coplanar, parallel, or perpendicular. The selection of connectors refers to the drawings to confirm that the length of all pins and sockets does not exceed its mating counterpart.

Fig. 2. Connectors

The maximum carrying capacity of a battery pack connector cannot simply be calculated by multiplying the maximum current per pin by the number of contacts. The maximum current listed in TE's 108 specifications is for a single contact. Therefore, when many contacts are used to transfer power, the maximum current carrying capacity of each individual contact decreases as more than one contact is used to transfer power.

c.) Harness Design

The wiring harnesses in the Pack are generally divided into low-voltage wiring harnesses and high-voltage wiring harnesses. Low-voltage wiring harnesses refer to wiring harnesses such as voltage sampling wires, temperature sampling wires, communication wires, and control wires; high-voltage wiring harnesses mainly refer to main loop wiring harnesses with excessive currents, such as copper bars and connecting cables. There are generally two ways of wiring harness connection, one is the plug-in method, and the other is the bolt fastening method. In practice, how to choose depends on the needs of customers and products.

Fig. 3. Harness

The correctness of the low-voltage wiring harness must be fully checked before installation, otherwise, the wrong wiring or insertion of the wrong wiring will cause a short circuit and cause serious consequences. Generally, manufacturers will make test tooling to detect, so that the operation is convenient, the efficiency is high, and there is no error.

Before connecting the high-voltage wiring harness, you need to check the documents and memorize the connection sequence. When conditions permit, it is best to make fool-proof tooling to avoid short circuits of the electric box caused by the mis-operation of employees, which can lead to product damage and serious casualties.

d.) Variation in characteristics due to temperature

Battery capacity (how many amp-hours it can hold) is reduced as temperature goes down, and increased as temperature goes up. This is why a car battery dies on a cold winter morning, even though it worked fine the previous afternoon. If batteries spend part of the year shivering in the cold, the reduced capacity has to be taken into account when sizing the system batteries. The standard rating for batteries is at room temperature 25 degrees C (about 77 F). At approximately -22 degrees F (-30 C), battery Ah capacity drops to 50%. At freezing, capacity is reduced by 20%. Capacity is increased at higher temperatures – at 122 degrees F, battery capacity would be about 12% higher.

Battery life reduces at higher temperatures: Even though battery capacity at high temperatures is higher, battery life is shortened. Battery capacity is reduced by 50% at -22 degrees F – but battery LIFE increases by about 60%. Battery life is reduced at higher temperatures – for every 15 degrees F over 77, battery life is cut in half. This holds true for ANY type of lead-acid battery, whether sealed, Gel, AGM, industrial or whatever. This is actually not as bad as it seems, as the battery will tend to average out the good and bad times.

3.2 Thermal Considerations:

There are three different types of heat transfer that need to be considered in battery design: conduction, convection, and radiation. Conduction refers to a direct transfer of heat energy from two objects that are in direct contact. Convection occurs when heat is conducted through a liquid medium to a heat-sinking device. Radiative heat transfer refers to heat energy that is generated through electromagnetically thermally charged particles of matter that radiate from one source to another, generally through the air. All three methods of heat transfer must be considered in the battery system design, but conduction and convection will have the greatest impact on the thermal system design.

Sources of heat generation inside a battery system come from the chemical reaction within the cell (the main area of heat generation) as the lithium-ions move back and forth during operation; balancing of cells (usually while parked); electronics within the battery pack; and thermal management system. While lithium-ion cells are the primary source of heat generation inside a pack, the influence of the electronics must not be disregarded as it can be a significant source of heat creation that must be accounted for in your thermal management system design. If adequate shielding and consideration of the placement of these electronics are not considered, then the heat generated by the electronics may actually have a negative impact on the cell’s life.

Why Cooling?

In order to maximize the potential of lithium-ion cells, they need to be maintained at about 23–25 °C (73–77°F) throughout the majority of their use cycle. However, under operation, the cells experience an exothermic reaction—they begin generating heat due to the rate at which the chemical reaction occurs within the cell and the related increase in cell resistance. This reaction in combination with high ambient (outside) temperatures means that your battery design must be able to cool the batteries down and maintain them within their optimal operating range in order to ensure the performance and life of the overall battery system.

Additionally, high discharge rates generate exothermic temperature increases within the cells. And when these discharges come frequently, it means that the cells do not have time to cool down between these pulses, which again drives higher temperatures. In addition to this, there is less time for the thermal management system to engage and reduce the temperature of the cells back down. Think of this as a stair-step effect: when you hit your accelerator, a rapid discharge of the battery occurs; with frequent stopping and accelerating events the battery thermal management system will not have time to cool down the battery from the last discharge, causing the battery to gradually but steadily increase in temperature.

An example of this is the traditional HEV, which will continually discharge and then regeneratively charge the battery regularly during a driving cycle. In this type of usage cycle, the battery may not have time to cool down the cells before another discharge–charge cycle is initiated. This will cause a slow and steady increase in the temperatures within the pack. Allowing the pack to sit unused for a period of time will generally allow the system to reduce the temperature back down to its normal operating range.

3.3 Mechanical Considerations:

The mechanical design of the cell has to hold all of the elements of the cell together and provide a leakproof container over the lifetime. In the case of venting and thermal runaway this needs to be managed. The mechanics of a cell are quite dependent on cell format (button, cylindrical, pouch, prismatic). The fundamental requirements are:

- maintain sealing of the cell's active contents

- locate the positive and negative tabs
- controlled failure during venting
- controlled failure during thermal runaway

The prismatic cell case provides sealing, venting control and some structure, but still requires an external force applied to the largest surfaces to maintain the connection between active layers.

The pouch cell wrap is just a sealing system and all of the mechanical structure needs to be provided by the module or pack. Also, the pressure on the largest surface is required to stop the active layers from delaminating over the lifetime. This pressure can range from 0.25 bar up to 5 bar and is dependent on chemistry.

The mechanical design of a battery pack needs to consider every element of the system. You need to look at static stiffness, dynamic stiffness, and the behaviour of components.

For the design of the battery, housing is a load-bearing component of the body structure:

- truss-design battery frame with multiple subdivisions
- 28 bolts fix the battery to the body structure
- battery contributes ~10% of the vehicle's overall stiffness

Sealing: EV batteries are subject to increasingly stringent performance and safety standards. Increasing the significance of a reliable and repeatable pack seal is critical to the performance, safety, and longevity of the pack. The seal must meet design and compliance for enclosure standards, such as IP68, which means that the seal will protect against water intrusion, collision, and outside contaminants. Bead placement, the coziest volume of material, flow rate, and in the case of two-component materials, propel mix ratios are the most important factors in ensuing a quality bead. To ensure a durable and reliable seal, the application must be clean, precise, and repeatable.

Chapter 4

Selection of Components

4.1 Cell Selection

Type	Cylindrical CAN
Capacity	4800 Ah
Nominal Voltage	3.6 V
Charge Voltage	4.2 V
Max. charge current	1c
Max. discharge current	3c

Table No. 1. Specifications of Cells

Fig. 4 Cells for Battery Pack

4.2 Contactors/Relays

Relay type	Contactor
Contact Rating (Current)	30 A
Switching Voltage	6000VAC - Max
Contact material	Silver Cadmium Oxide (AgCdO)
Operating Temperature	40 ºC – 65 ºC
Coil resistance	7 Ohms

Table No.2. Specifications of Contactor

A contactor is essentially an electromechanical switch, or relay, that will close in order to make the connection and to allow current to flow, or open to stop the flow of current and voltage. This becomes another important design and safety component of the ESS as it will essentially start or stop the flow of current and voltage to and from the pack. The contactor is considered an electromechanical device as it is a mechanically driven device that makes the electrical connection.

Fig. 5. Contactor

The contactor switch is often enclosed in a hermetically sealed unit filled with a nonconductive gas mixture in order to prevent sparking as the connection is made or broken. Sealing it in a nonconductive gas prevents sparking when the switch closes; additionally, as a sealed unit, it can be used in corrosive environments such as the harsh automotive environment without becoming contaminated or corroded.

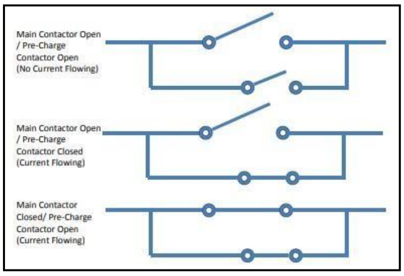

Fig. 6. Contactor Connections

This is a secondary switch that is connected in parallel with the main contactor. The purpose of this switch is to prevent a large inrush of current when the main contactor closes. It does this by closing the secondary contactor first and allowing a small amount of current to begin flowing into the system so that when the main contactor closes to complete the circuit it will do so without damaging any other circuitry or causing the main contactors to become welded together in a closed position, which could be very dangerous.

4.3 Fuses

Voltage required	Up to 1000 VDC
Current Rating	8 to 600 Amp
Interrupting Rating (IR)	20 kA
L/R	<= 1ms
Minimum Breaking Capacity (MBC)	< 3 kA

Table No. 3. Specifications of Fuses

Most automotive high-voltage energy storage systems are also designed with an MSD as an integral part of the HVIL circuit (as mentioned above). The MSD also called a mid-pack service disconnect or just a service disconnect, is a fuse that is usually placed at or near the “middle” of the pack so that when the fuse is removed the potential or energy of the pack will also be cut in half. The HVIL circuit opened so that the contactors will open. As mentioned above, the MSD is typically designed as part of the HVIL so that the HV power cables are connected through the MSD.

Depending on the size of the pack, there may be a need to include other fuses into the overall design along with the MSD. In low-voltage packs, it is generally not necessary to include an MSD; instead, it may be necessary to include one or more fuses depending on the system design. Additionally, when it comes to fusing, some OEMs have integrated small fuses directly into the control boards that interconnect the cells.

Fig. 7. Fuse

4.4 Connectors

Instantaneous Current	60 Amp
Rated Current	30 Amp
Contact Resistance	0.55 mΩ
Rated Voltage	500 VDC
Flammability Rating	UL94 V0
Metal material	Copper
Operating temperature	-20 ºC to 120 ºC

Table No. 4. Specifications of connectors

The other thing to make sure if evaluated when designing the controls and electronics systems are the connectors. While this may seem like a “no brainer,” the lithium-ion battery industry is only just beginning to get to some level of standardization so there are still many solutions available and each has different costs/benefits—and they are not all compatible with each other. Additionally, there are many portable electronics application connectors that may be evaluated but many do not yet meet the rigid performance or life requirements of the automotive application.


Fig. 8. Connectors

Connectors must be evaluated for the level of sealing that is required in the pack, their ability to withstand abusive environmental conditions, the amount of EMI shielding, and of course their ability to transmit the proper currents, voltages, and communications without adding excessive costs to the systems.

Chapter 5

Battery Thermal Management System

What if BTMS is not given?

The inappropriate battery temperature will have a negative impact on the performance, lifetime and safety of the batteries. Therefore, a BTMS is required for every battery system. The primary duty of a BTMS is to keep the batteries in the optimum temperature range and maintain an even temperature distribution in the battery pack. Afterward, other factors such as weight, size, reliability and the cost must be taken into consideration based on the application of the battery packs.

5.1 Cooling Methods

5.1.1 Air cooling

Air is the most conventional way for cooling and has been used widely in various industries. Due to low heat capacity and low thermal conductivity, air might not seem to be a good cooling medium. However, it is still an attractive cooling solution due to its simplicity and low cost.

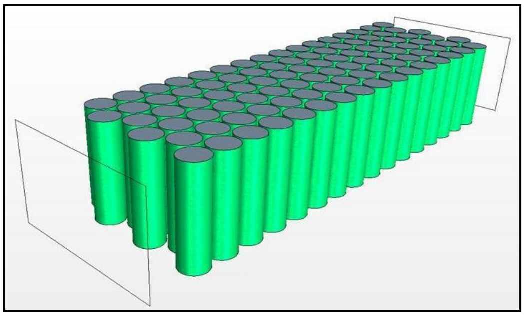

Fig. 9. Air Cooling

When air is used to cool a set of batteries arranged in series, its temperature raises significantly due to its low heat capacity. This leads to higher cell temperatures at the pack outlet and creates an uneven temperature distribution. Thus, it is important to take extra measures to ensure uniformity, such as Increasing the coolant medium speed, creating turbulence in the flow and optimizing the positioning of each cell.

5.1.2 Liquid cooling

Liquid coolants have several advantages compared to air. Liquid cooling is more compact than air without sacrificing any cooling capacity. Liquid coolants can be 3500 times more efficient than air due to higher density and heat capacity. They can save up to 40% of parasitic power compared to air cooling. In addition, liquid cooling can reduce the noise level. Nonetheless, there are downsides with liquids as well, such as cost, complexity and leakage potential.

Liquid cooling can be classified into direct and indirect cooling.

I) Indirect liquid cooling

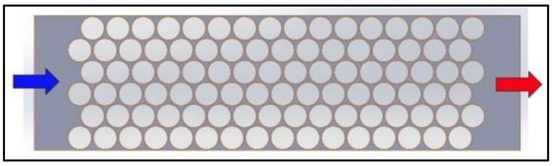

Fig 10. Liquid Cooling

Water is used in several industrial applications as one of the most efficient coolants. However, the main challenge with directly cooling batteries with water is the short-circuited potential. Therefore, indirect methods are used to prevent electrical conduction with the cells while maintaining high thermal conductivities. Adding an electrical resistance will also add extra thermal resistance, but if it is controlled it barely affects the cooling.

II) Direct liquid cooling (Immersion)

Direct cooling, also known as immersion cooling, covers the entire surface of the cell and cools it uniformly. This mitigates hot/cold spots in the cell and improves its performance of the cell. The coolant for direct cooling should be dielectric with low viscosity and high thermal conductivity and thermal capacity.

Immersion cooling is being increasingly used for data centre servers and power electronics. Using an immersion for BTMS has still not been widely used in the mass-produced EV market. This is probably due to cost and safety concerns.

5.1.3 Tube cooling (Side cold plate)

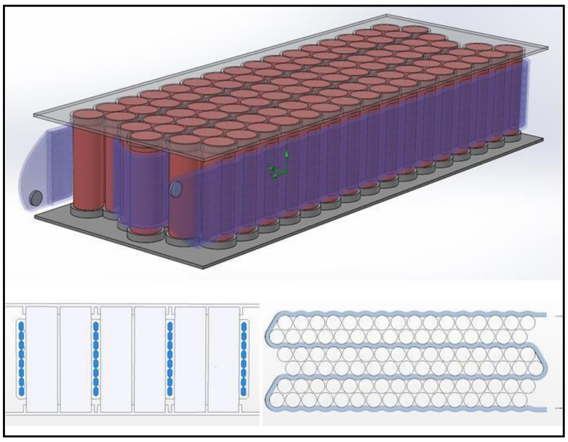

Fig.11. Tube Cooling

The geometrical model of tube cooling used in the simulation. A wave-formed aluminium extrusion with 8 microchannels passes by all the cells. The coolant flowing through the microchannels is a mixture of ethylene glycol with water (50/50% by volume). The cells are held in place with two polycarbonate clam shells (Two plates on each side with extruded rims to hold each cell in its specific place). The distance between two adjacent cells is 1,5mm (Minimum possible distance between cells provided by Northvolt).

The interface between the cells and the aluminium extrusion is filled with TIM (Thermal Interface Material) also known as gap pad or thermally conductive pad. TIM is a solid material (often wax or silicon-based) that aid heat conduction between the heat sink and the material that is being cooled. They are used to prevent air gaps on imperfect flat surfaces on a thermal contact interface.

5.1.4 Bottom cold plate

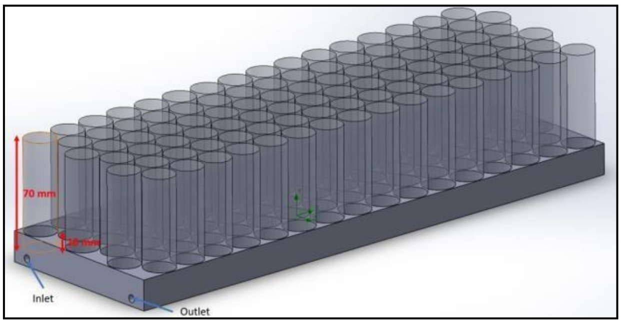

Fig. 12. Bottom cold plate

Bottom cold plate follows the same principle as tube cooling. The cells are placed more compactly relative to Tube cooling since there is no material between the cells. The advantage of this cooling method is that it takes advantage of the higher axial thermal conductivity of the cells. In this model the cells are inserted 10mm into a thermally conductive polymer, thus the cold plate acts as a clamshell on the bottom of the cells as well. There are a series of channels inside, the plate to ensure that the coolant can flow along the plate and cool it down uniformly. The coolant used is Ethylene-glycol and water mixture like the tube cooling.

Chapter 6

CAD Modelling & Analysis

6.1 Battery Pack Technical Specifications

Battery Pack Dimensions	X=420mm	Y=390mm	Z= 210 mm
Battery Pack Configuration	2 stack		
Battery nominal voltage (V)	50.4 V		
Battery capacity (Ah)	115		
Battery operating voltage (V)	Upto 50.8		
Casing material	Aluminium		
Battery operating temperature (ºC)	55		
Continuous discharge current (Amp)	150		
Instantaneous discharge current (Amp)	170		

Table no. 5. Battery Specifications

6.2 CAD Model of Battery pack and its components

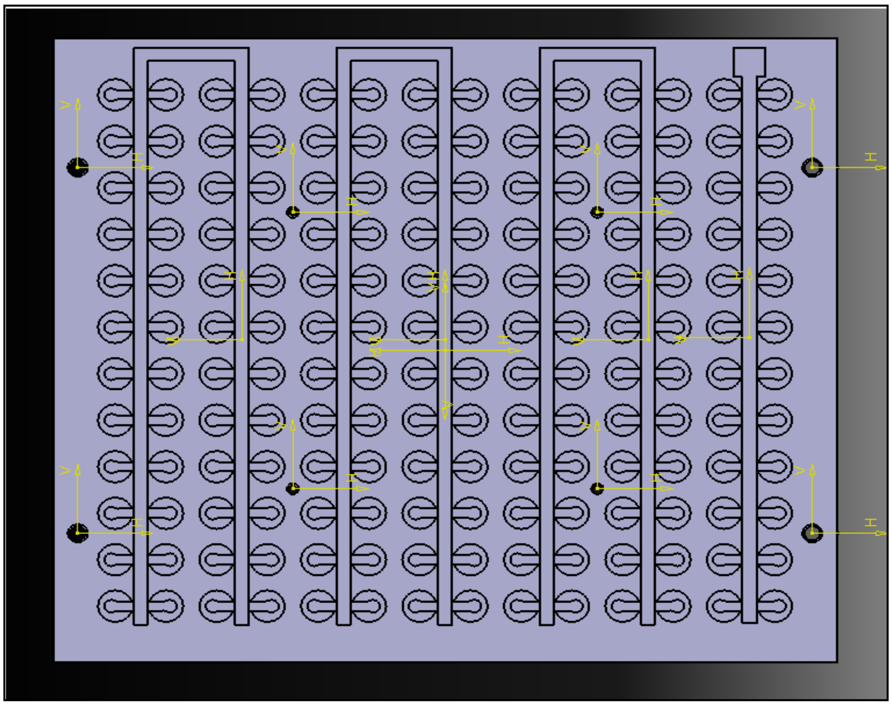

Fig. 13. Connections of cells in the Battery Pack

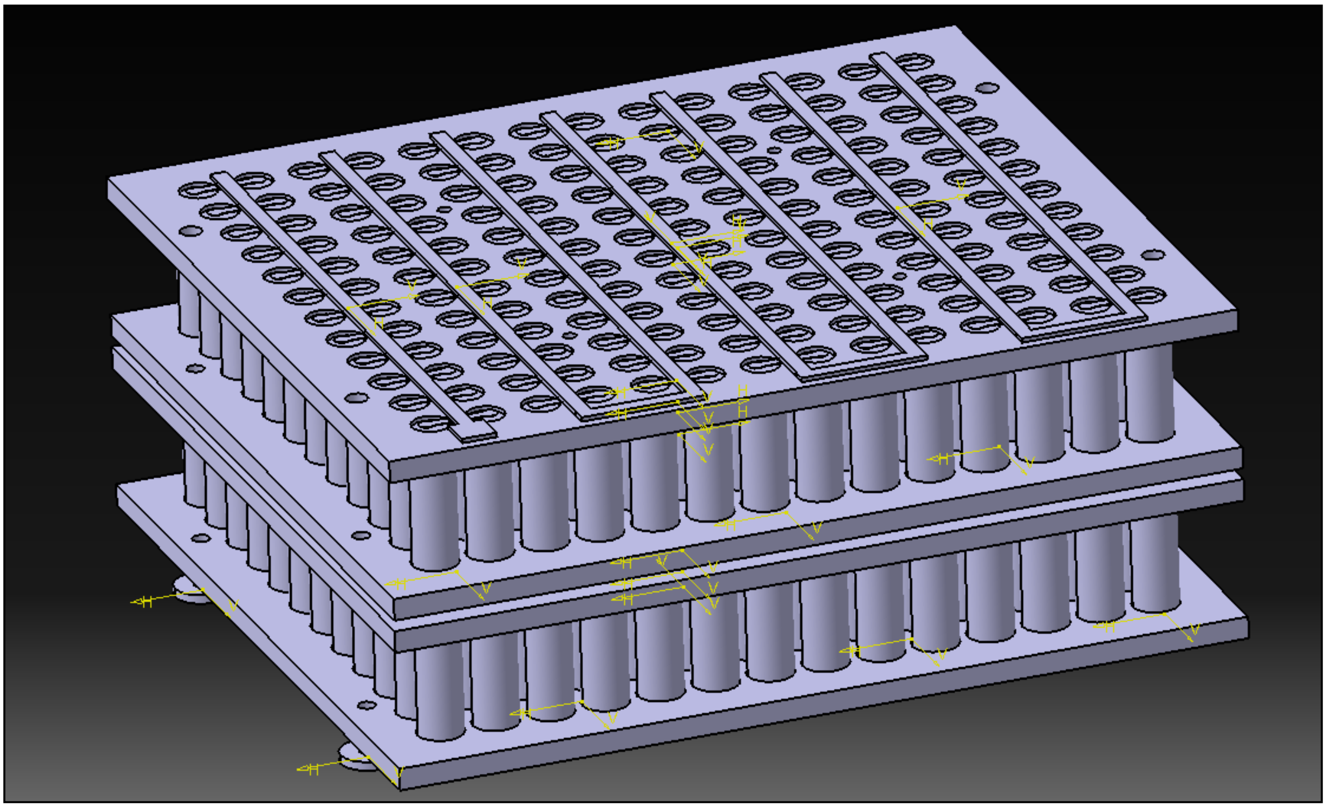

Fig. 14. Cell holder in the Battery Pack

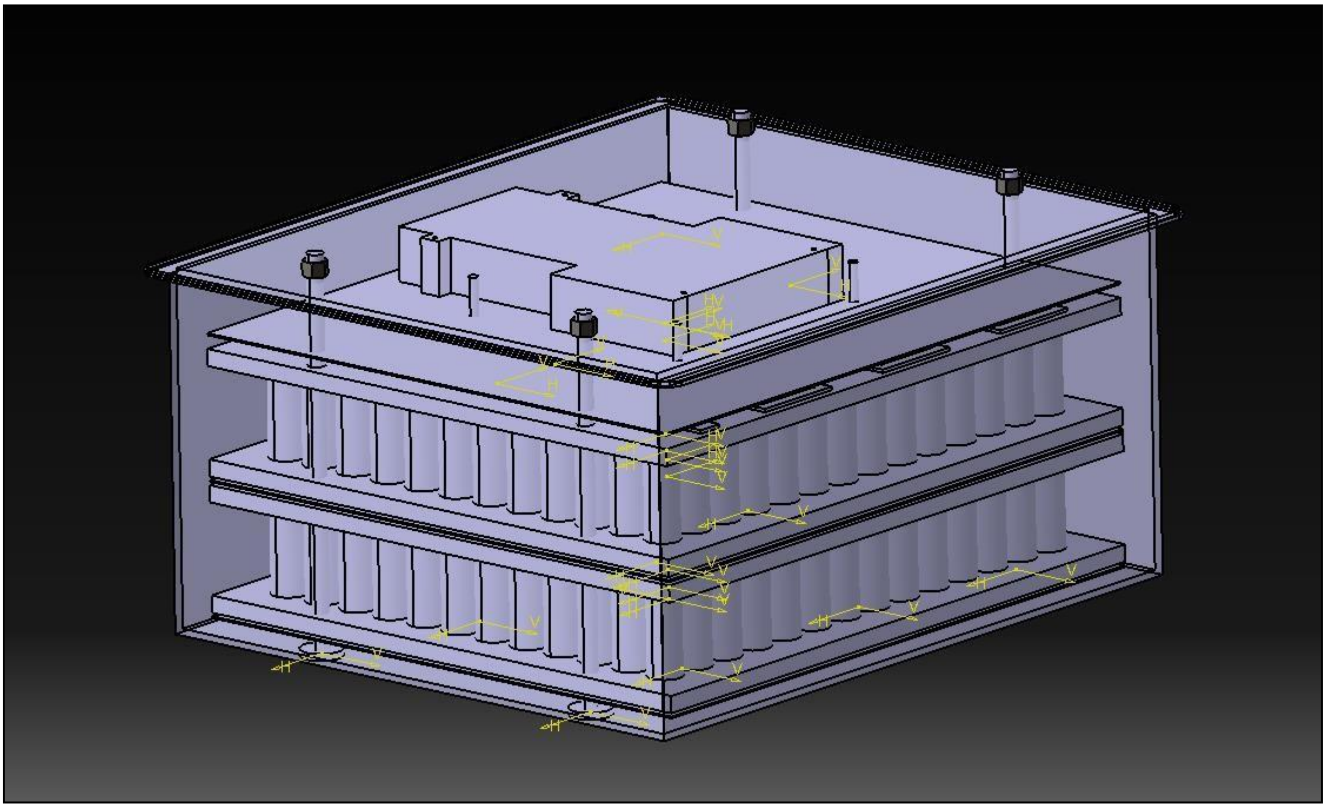

Fig. 15. Final Model of ***BATTERY PACK***

6.3 Analysis of Battery Pack

6.3.1 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

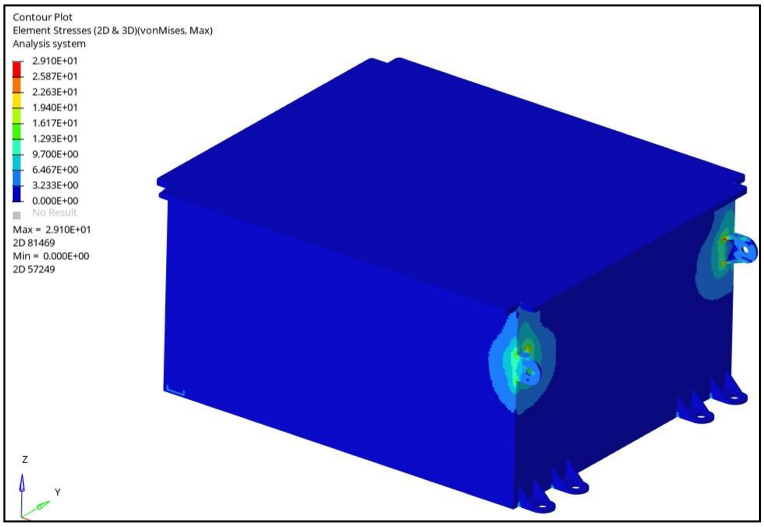

Fig. 16. Static Structural of Battery pack

6.3.2 Thermal Analysis of Battery Pack

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

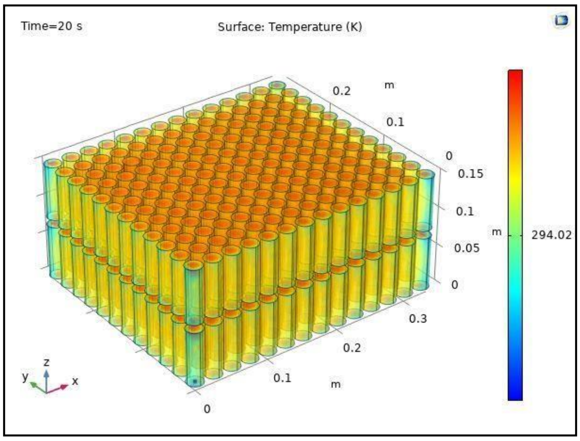

Fig. 17. Thermal Analysis of Battery pack

6.3.3 Analysis of Bus-bar

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

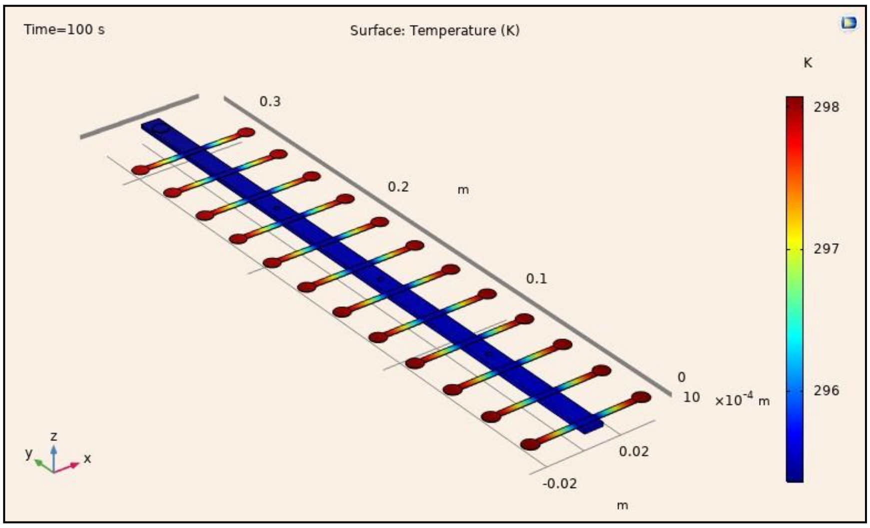

Fig. 18. Analysis of Bus-bar

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