OPTIMISING THE CHARGING TIME OF ELECTRIC VEHICLES

Project report submitted in fulfilment.

Of the Requirements for ME 322

By

Group: REAPERS

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INTRODUCTION

With the increasing population, pollution and other overt things, there's an expanding need to shift to something that doesn't harm the environment even further. Something that goes heavily into the path of *Net Zero Emission*. Something that reduces the emissions rather than increasing them. When we say, 'Net Zero', we are talking about the balance between the carbon dioxide added into the atmosphere and removed from it. Compared to pre-industrial times, the rise in temperature due to global warming is quite significant. The future is at risk if this continues.

Electric vehicles (EVs) offer a promising solution to combat the environmental challenges posed by traditional internal combustion engine (IC) vehicles. While IC vehicles have long dominated market, due to their rapid refuelling and widespread availability of fuel stations stand in contrast to the longer charging times and limited charging infrastructure for EVs. However, EVs boast a significant advantage with a reduction in emissions. As the world demands achieving the sustainable development goal 12 with the pressing need to reduce carbon emissions, the transition to EVs becomes increasingly imperative.

Addressing the key challenges of charging times and limited charging infrastructure not only promotes the adoption of EVs but also contributes to relieving pollution and fostering a sustainable transportation ecosystem. One crucial aspect hindering the widespread adoption of EVs is the high cost of batteries, which typically accounts for 50-60% of the vehicle's total cost. To further incentivize the shift towards EVs, efforts must focus on reducing battery costs while simultaneously extending their range.

PROBLEM FORMULATION

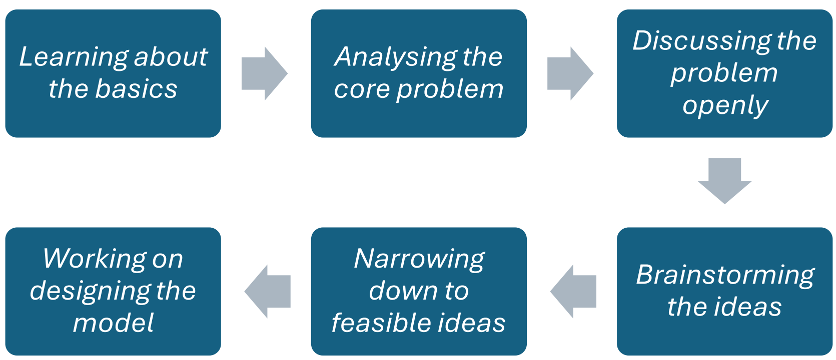
It can take approximately 30 minutes to upward of 6 hours to charge an electric vehicle with a 60-kWh battery, depending on the charging voltage, the size of the battery and many more factors. It is quite inconvenient for someone who's travelling long distances in an Electric vehicle. Even more so, they have no idea as to when they might find another charging station, what distance he or she might have to travel to find one and if their battery would run until then.

Which is why people prefer IC engine vehicles over Electric vehicles. The promising number of petrol bunks that are available along the way, be it a highway or any road running through a particular place. Of course, we would prefer a vehicle that makes our life easier rather than tougher.

So, for us to shift into these vehicles, two major challenges are coming our way. One is reducing the charging time. If we reduce the charging time, what other aspects of the battery as well as the vehicle we need to compromise? Can we implement fast charging in the battery like it is done in our mobile phones? If yes, how to solve the heating issue?

How are we going to increase the number of charging points efficiently and conveniently? How can we make it cost-efficient? These questions made us think about some possibilities that are feasible in the long run. Those possibilities just might work in our favour if done right.

METHODOLOGY



To solve problems effectively, it's important to understand the basics of what we're dealing with. This means knowing how electric vehicles and their battery's function, including how batteries are charged and discharged, their key features, and the challenges of fast charging. When designing batteries, we need to consider factors like optimal operating temperatures and the effectiveness of thermal management systems. Currently our focus is on reducing charging time as well as increasing the battery capacity. In this process we will come across heating issues which may lead to damage of the battery. Hence to overcome this issue we need to establish an efficient cooling system.

MARKET SURVEY

The global commercial vehicle market is expected to see substantial growth, reaching $1,712.44 billion by 2029 from $955.57 billion in 2022, with a compound annual growth rate (CAGR) of 8.7%. In 2022, worldwide commercial vehicle production rebounded to about 23.7 million units following a dip of three million units in 2020. Commercial vehicles encompass all motor vehicles designed for commercial transportation of goods and passengers, with light commercial vehicles typically weighing under 3.5 tons.

In India during 2022-23, total passenger vehicle sales rose from 3,069,523 to 3,890,114 units. This included increases in sales of passenger cars from 1,467,039 to 1,747,376 units, utility vehicles from 1,489,219 to 2,003,718 units, and vans from 113,265 to 139,020 units compared to the previous year.

Overall commercial vehicle sales also surged from 716,566 to 962,468 units. Medium and heavy commercial vehicle sales rose from 240,577 to 359,003 units, while light commercial vehicle sales increased from 475,989 to 603,465 units in FY 2022-23 compared to the previous year.

Considering the environmental impact, there's a growing need to transition from internal combustion engine (IC engine) vehicles to electric vehicles (EVs). Although EVs offer advantages in terms of fuel consumption and environmental impact, they often come with higher initial costs. Battery costs make up a significant portion of EV expenses, typically accounting for 50-60% of the total cost. Additionally, challenges such as the availability of charging stations and charging time during long-distance travel.

When comparing fuel consumption costs, EVs generally have lower costs per unit charge compared to petrol and diesel vehicles. Cost comparison:

1. Cost of Petrol per 1 litre : Rs 100
2. Cost of Diesel per 1 litre : Rs 90

3. Cost of EV per unit charge : Rs 6

	EV(charge)	Petrol (Litre)	Diesel(Litre)
Range or Mileage	120KM	16KM	18KM
Cost of charge per KWh	Rs 6-10	Rs 12	Rs 9

Here's a comparison of EVs available in the market based on brand, vehicle model, capacity, and mileage.

Sl. No	Brand	Vehicle	Capacity	Mileage/Max distance
1	Tata	Tata Nexon	30KWh	325KM
2	Tata	Tata Tiago	19.2KWh	250KM
3	BYD	BYD Seal	61.44KWh	510KM
4	BYD	BYD E6	71.7KWh	450KM
5	KIA	KIA EV6	77.4KWh	708KM
6	MG	MG Comet EV	17.3KWh	230KM
7	MG	MG ZS EV	50.3KWh	461KM
8	Mahindra	XUV400 EV	34.5KWh	375KM
9	Hyundai	Hyundai Kona	39.2KWh	452KM
10	Hyundai	Hyundai IQNIQ 5	72.6KWh	631KM

Let us consider a man who has car of fuel tank capacity of 45 litre . Each Litre of petrol gives a charge of 9KWh , total 45 litre gives 405KWh. Distance it may cover in 1 full tank capacity of petrol is 6480KM(gives a mileage of 16km per litre). Let’s say that for every 50km there is fuel station ,he will find around 130 fuel stations in his way.

Imagine a man has a car with a fuel tank that can hold 45 litres of petrol. Each litre of petrol provides 9 kilowatt-hours (KWh) of energy, so a full tank of 45 litters gives him 405 KWh in total. With a mileage of 16 kilometres per litre, he can cover 6480 kilometres on one full tank of petrol. Let's say there's a fuel station every 50 kilometres along his route; that means he'll pass around 130 fuel stations on his journey.

Based on our research, we assume that most people would require an electric vehicle with a battery capacity of around 50 kilowatt-hours (KWh), allowing them to travel roughly 400 kilometres on a single charge. In our initial plan, we aim to set up charging stations at intervals of every 100 kilometres in the first phase.

UNDERSTANDING ABOUT THE BATTERY

Lithium-ion batteries are designed for a high power-to-weight ratio and energy density. The Battery Cell is a small, rectangular component roughly the geometry of a paperback book. These battery cells are assembled in frames to form Battery Modules. These modules are then linked together via a myriad of electrical connections and enclosed in the Battery Pack which is assembled directly to the automobile frame. The arrow diagram below is a compass for understanding the process terminology.

Battery Cells → Battery Modules → Battery Pack

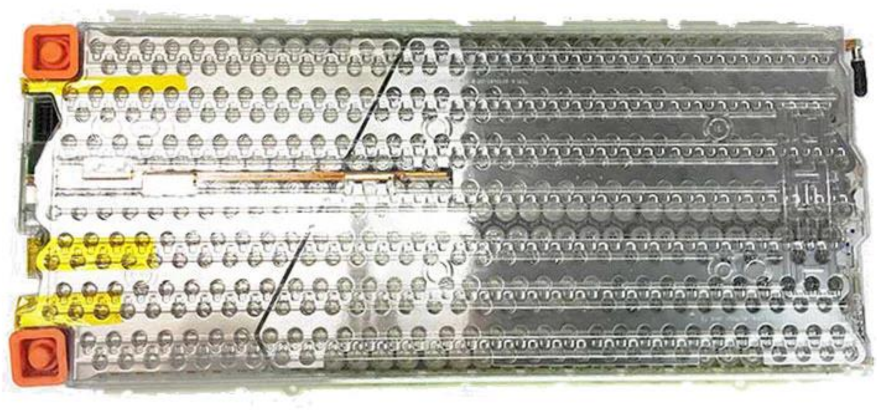


Fig.1. Module of a Battery Pack

The major parts of the Electric vehicle include a Charge port, a Traction battery pack, a DC-DC converter, a Transmission, auxiliary batteries, a Thermal system (Cooling), a Controller, an Electric motor, a Power inverter and much more.

The traction battery back is normally called an Electric Vehicle Battery (EVB) which acts as a power source. It’s a DC type of storage. These are made of small units called cells that store energy. These cells are assembled into larger packs to deliver the high voltage required to power an electric vehicle. In these cells, the energy is stored in the form of chemical potential which later gets converted to electrical energy that powers the vehicle. Lithium-ion batteries come in their configurations. Some may have good energy density while some offer faster charging. Here we confined to use Li-ion cells which offers a higher energy density, lighter weight, and faster charging capabilities.

WORKING IDEAS

1. Using of 3 Charging Pods for Vehicle.

Right now, it typically takes at least 30 minutes to charge an electric vehicle with a DC charger. Many individuals may find it challenging to endure such a prolonged period of waiting. They'd rather prefer IC engine vehicle that gets fuelled up in just 5 minutes. With one DC charger, it still takes 30 minutes. But if we use three charging pods instead of one i.e., like filling a bucket with three taps instead of one. This speeds up the process.

However, using multiple chargers might put a strain on the charging station and the vehicle's battery, leading to overheating. To address this, we can improve the cooling system in our design.

We follow a procedure to reduce the charging time by dividing the battery in the three sections with help of Mosfet and IGBT.A MOSFET, or Metal-Oxide-Semiconductor Field-Effect Transistor, is a type of transistor used for switching or amplifying electronic signals in many modern electronic devices.

MOSFETs are widely used due to their high efficiency, fast switching speeds, and low power consumption. They're integral components in various applications, including power supplies, amplifiers, and digital circuits.

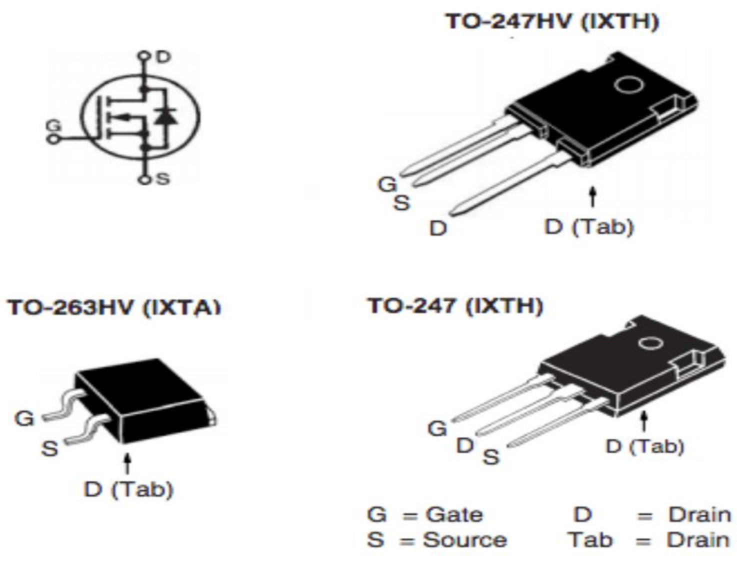


Fig.2.Mosfet

IGBT stands for Insulated Gate Bipolar Transistor. It's a semiconductor device used in various electronic applications, particularly in power electronics and motor control systems. IGBTs are primarily used as electronic switches. They can handle high voltage and high current, making them suitable for switching power circuits on and off rapidly.

Fig.3.IGBT

In our circuit design, we incorporate both MOSFETs and IGBTs to optimize functionality. Specifically, we utilize MOSFETs at M2 and M3 without affecting the operation of M1. This strategic arrangement allows us to efficiently manage the charging process.

When charging, we partition the battery into three distinct sections. MOSFET at M2 governs the charging of the first section, while M3 oversees the second section. Meanwhile, MOSFET M1 remains undisturbed, maintaining its original state throughout the charging process. This segmentation ensures precise control over the charging procedure, enhancing both efficiency and safety.

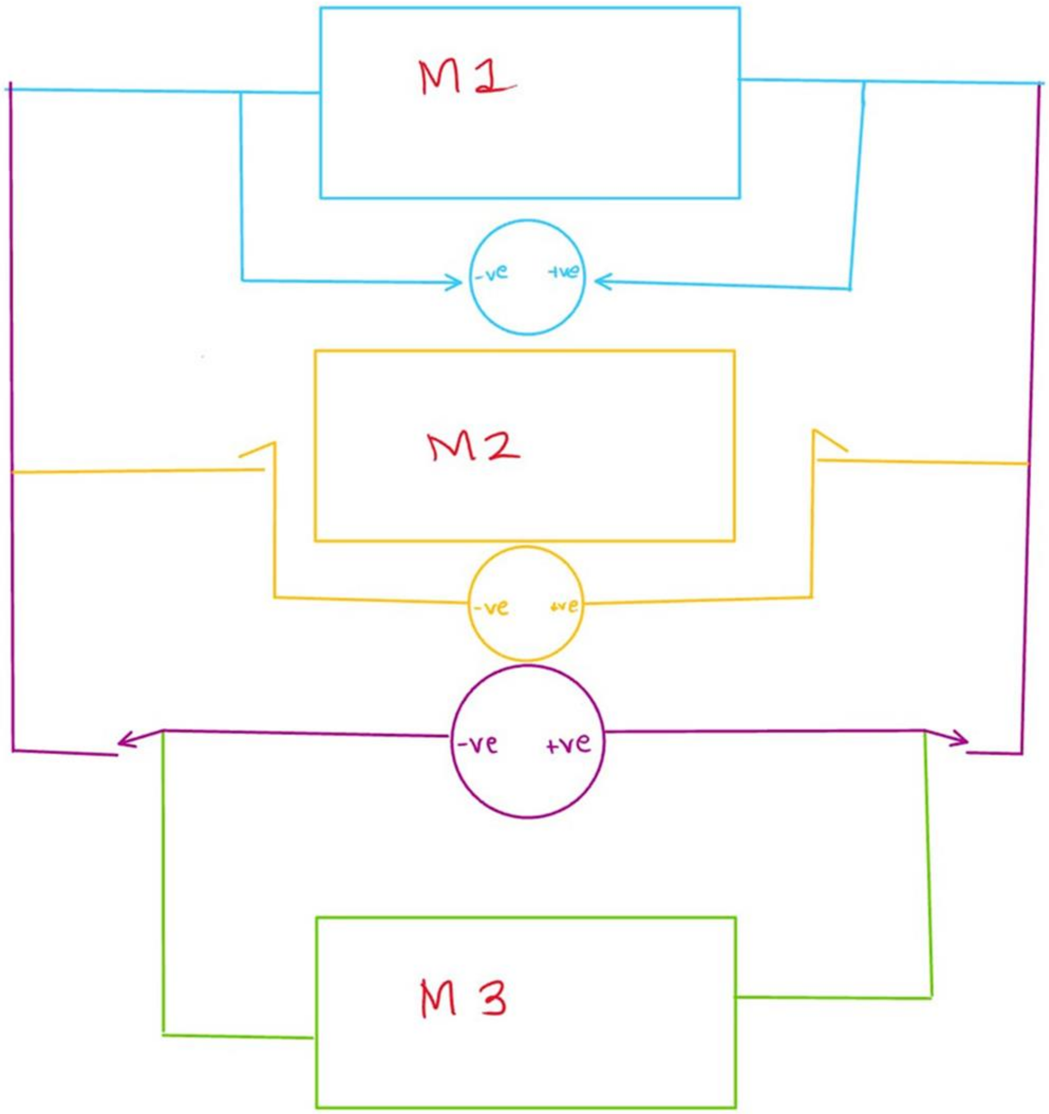


Fig.4.Circuit during Charging

During discharge, a single battery is connected in combination with IGBTs, as illustrated in the diagram.

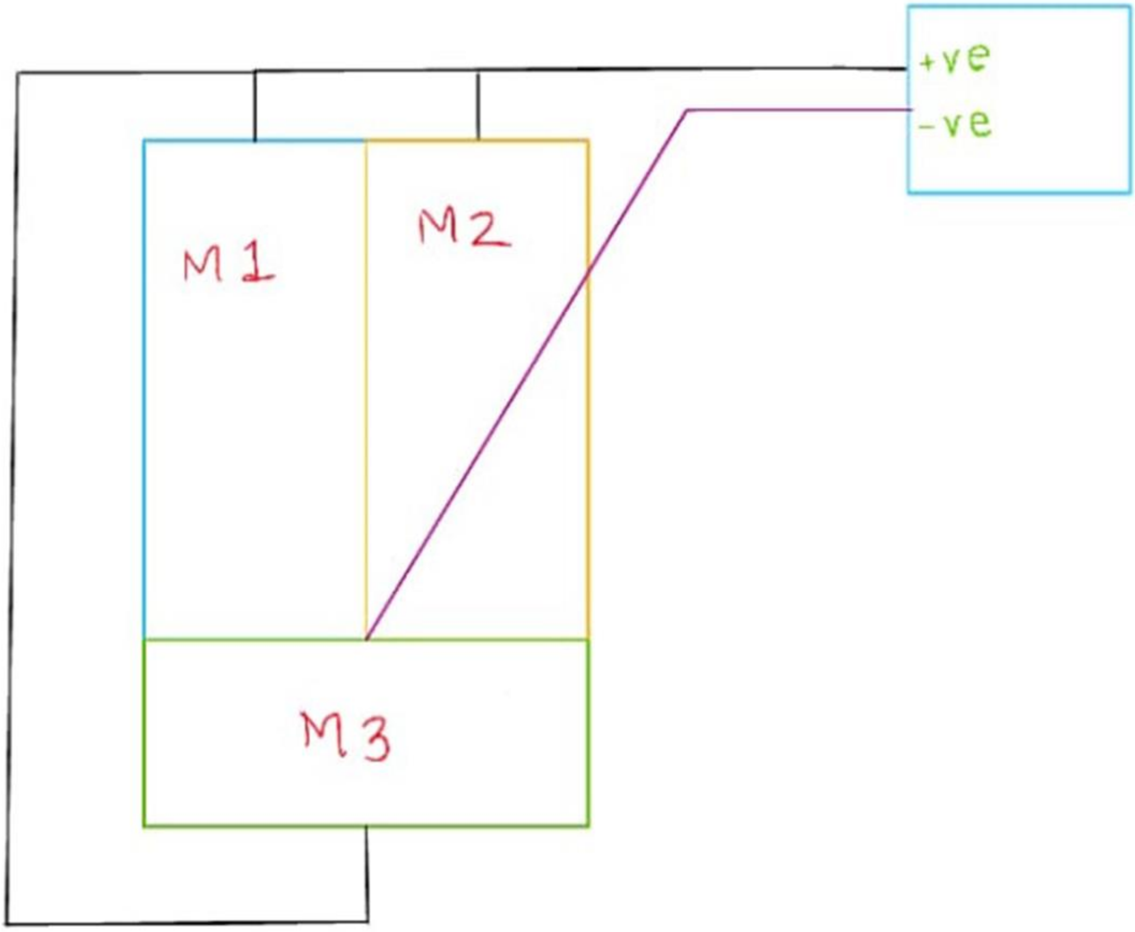


Fig.5. Circuit during Discharging

Battery Thermal Analysis :

Increasing the number of charging pods on the vehicle to decrease charge time. may lead to additional heating issues due to increased load on the battery. During both charging and discharging, energy is released as heat due to the exothermic nature of the process. Assuming a uniform distribution, the temperature generated inside the cell is given by:

$$T_i = T_s\left(1 + \frac{R_i}{R_e}\right) - T_a\left(\frac{R_i}{R_e}\right)$$

$$T_a = Ambient\ temperature$$

$$T_s = Surface\ temperaure$$

$$R_i = Internal\ resistance$$

$$R_e = External\ resistance$$

For a Lithium-ion cell to function, the temperature inside should be in the range of 15-35° C.

Currently, many electric vehicle (EV) companies use a single cooling tube that flows in one direction, which can take a while for the coolant to reach the last cell of the module. In our model, to efficiently reduce heat, we're employing phase changing material (PCM) because it's crucial to keep the cell temperature between 15-35°C.

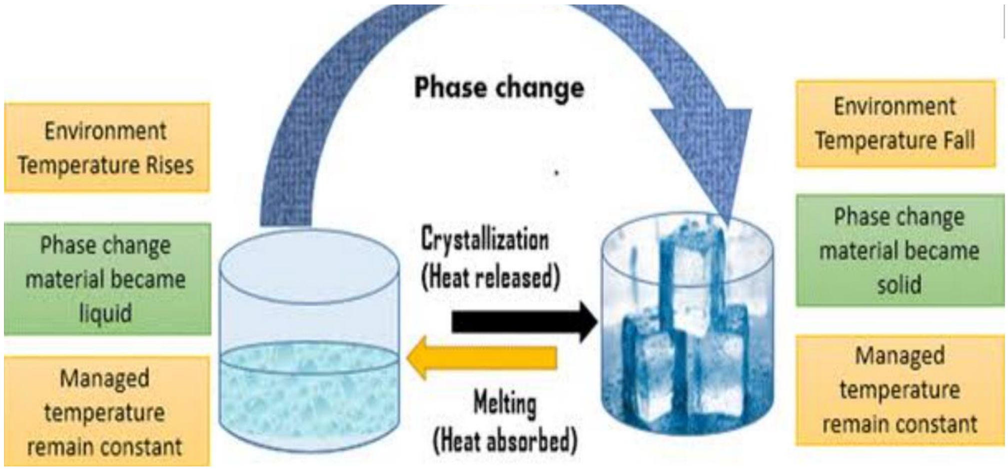


Fig.6. Phase Changing Material (PCM)

Our cooling system works like this: coolant falls from above and is collected at the bottom. We place fins between two cells to ensure they fit snugly. These fins are hollow, allowing the PCM (Paraffin) to pass through them from the top. They absorb heat from the cells and then exit through the bottom. This system effectively cools each cell twice as fast, with thin cylindrical fins fitted between cells separated by at least 2 mm.

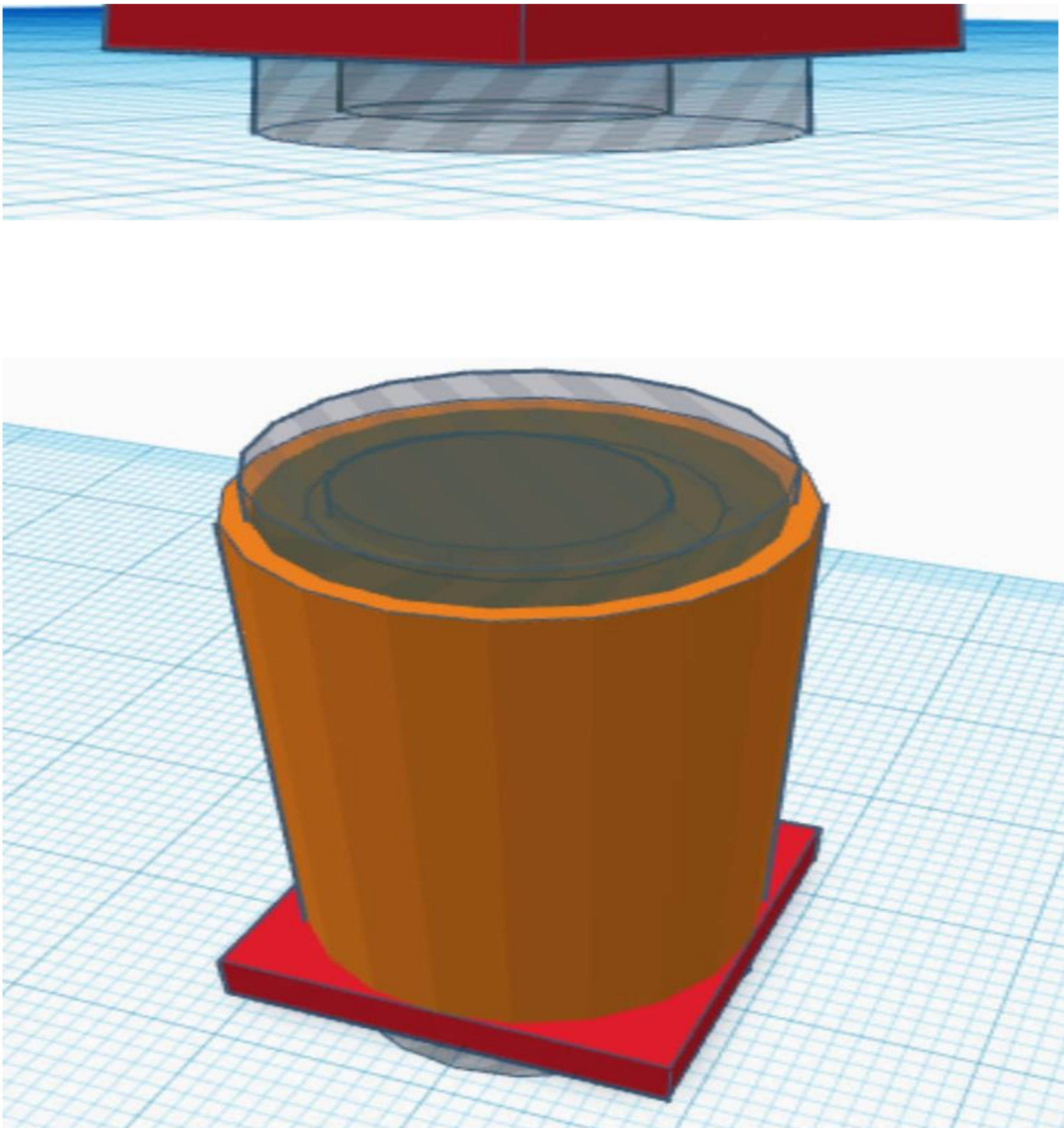


Fig.7. Arrangement of fins

The PCM crystallizes when heat is released and melts when heat is absorbed. Each module has a separate plate containing fins, with an inlet and outlet for easy entry and exit of the phase changing material.

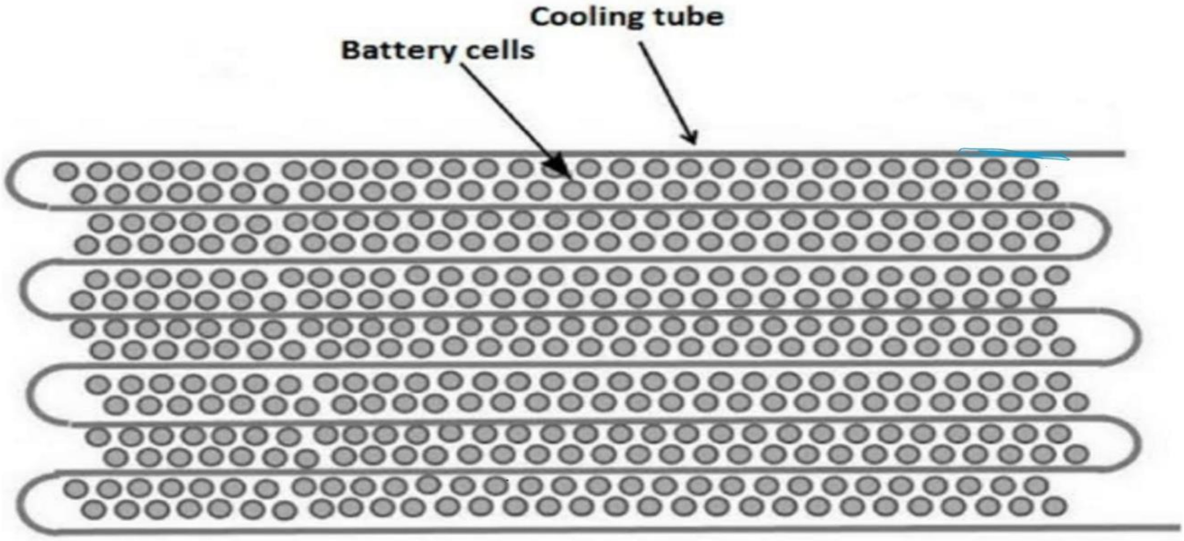


Fig.8. Cooling system used by Tesla.

DIMENSIONAL ANALYSIS

From our assumptions from the market survey Max energy of the battery is 50KWh (from the table), travel approximately 400Km.The largest-selling commercial vehicle (cars) in India is Maruti Suzuki Swift. Cost of the Maruti Suzuki swift Range 6 to 8.5 Lakhs. Wheelbase 2450mm, width 1735mm, height 1530mm.

Available area for battery pack width (1700*1345) Based on our market survey assumptions, we need a battery that can hold a maximum energy of 50 kilowatt-hours (kWh) and allow us to travel distance of around 400 kilometres. In India, one of the most popular commercial vehicles is the Maruti Suzuki Swift, priced between 6 to 8.5 lakhs. The Swift has dimensions of 2450mm wheelbase, 1735mm width, and 1530mm height. The available area for the battery pack is approximately (1700*1345)mm^2.

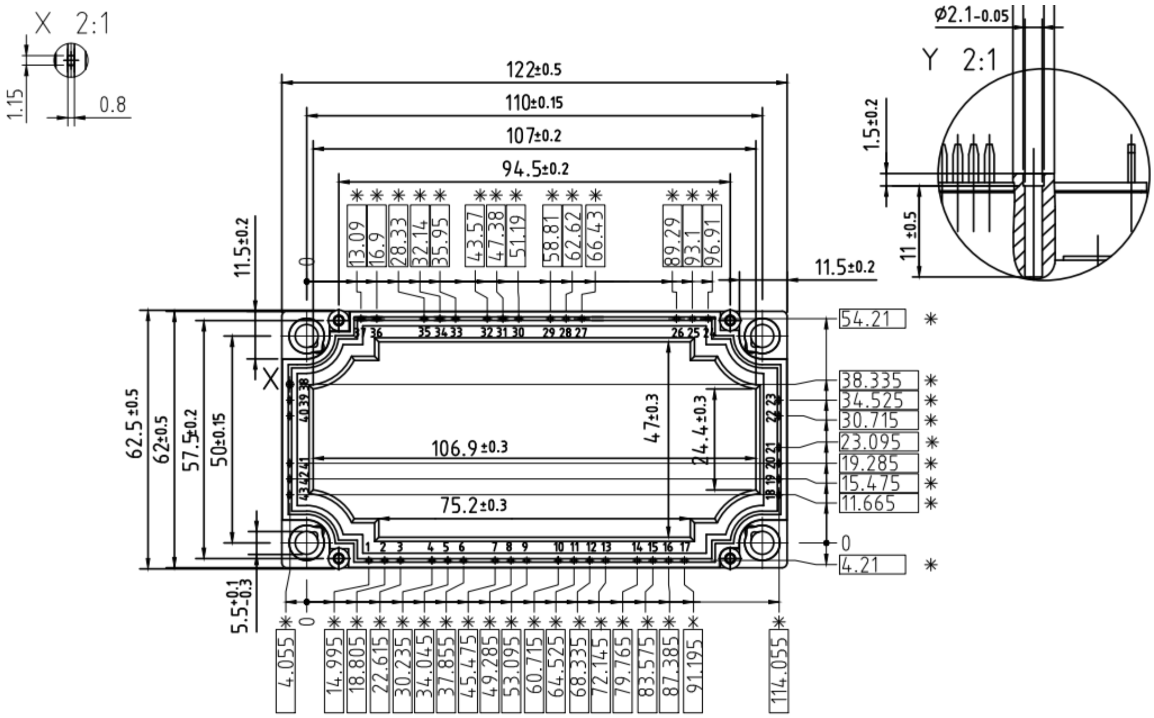
Fig.9.Dimensions of Battery Pack

Battery specifications

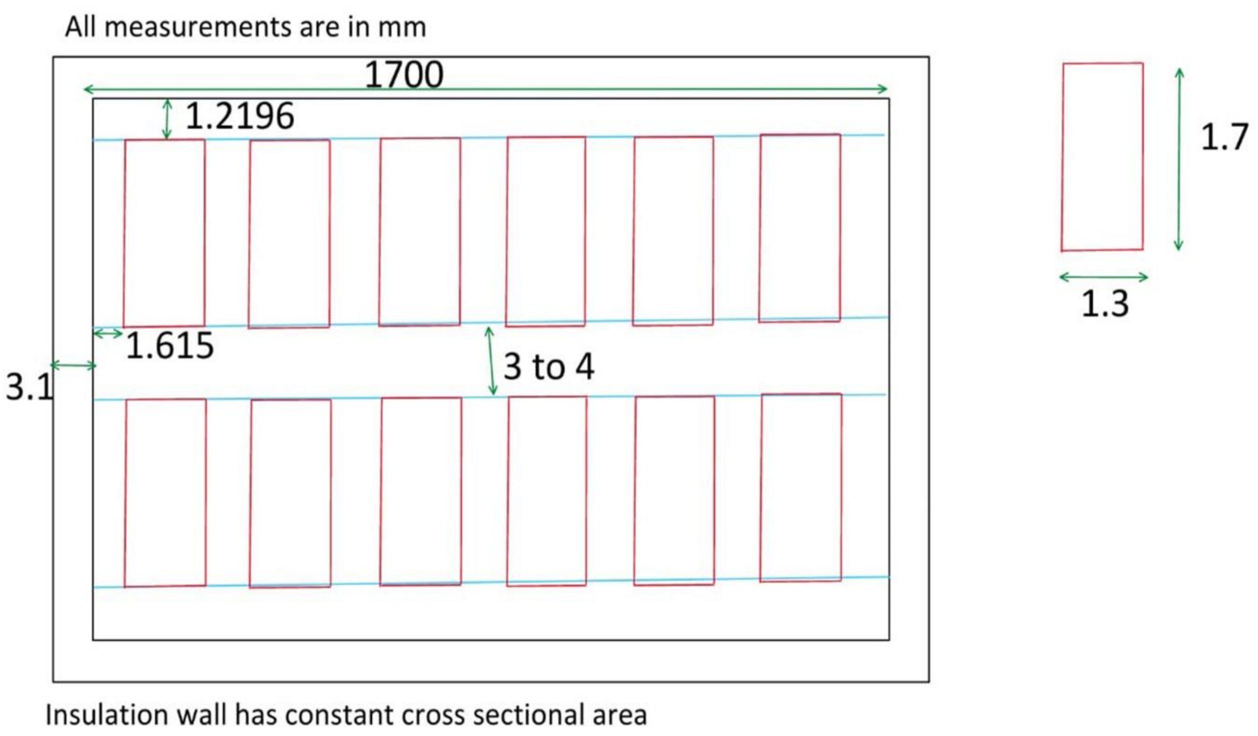
Lithium-ion Cell has a Specifications of nominal voltage 3.7 V, maximum voltage 4.2 V, cutoff voltage as 2.5 V, cell capacity as 3.5 Ah, optimum Temperature 15-35°C The lithium-ion cell has some important specifications. Its nominal voltage is 3.7 volts, with a maximum voltage of 4.2 volts, and it stops working when the voltage drops to 2.5 volts. It has a capacity of 3.5 ampere-hours (Ah). For the best performance, it works optimally at temperatures between 15-35°C.

Sl. no	Parameters	Values
1	Battery Configuration	6s46p
2	Battery Energy Capacity	50Kwh
3	Battery capacity = (50000/22.2)	2252.25Ah
4	Voltage series	22.2V
5	Number of modules	14
6	Total No cells in parallel = (2252.5/3.5)	644 Cells
7	Parallel cells with series = (644/14)	46 Cells
8	Total cells in battery = 46*6*14	3864 Cells

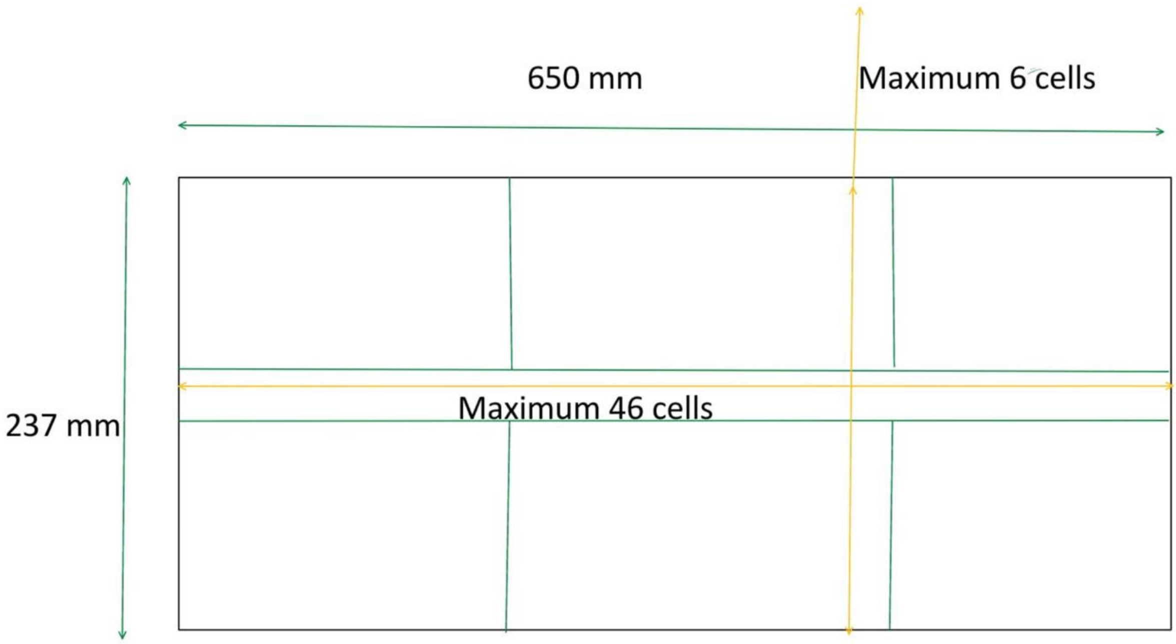
Our Engineering drawing for IGBT is-



Our Battery pack design is as follows -



Our module design is as follows -



INSULATION

In our electric vehicle design, we need a tough outer casing to safeguard the battery. This casing must be strong to endure vibrations, yet lightweight to not burden the vehicle. It should resist deformation while being as light and stable as possible to ensure smooth driving. Also, it must shield the battery from external factors like heat and electrical interference. To meet these demands, we're using Polytetrafluoroethylene (PTFE) insulation. This insulation serves multiple purposes:

1.Electrical insulation: It keeps the battery safe from electrical disturbances.

2.Chemical resistance: It protects against corrosive substances.

3.High-temperature tolerance: It can withstand high temperatures without losing its properties.

We're placing a 2mm layer of insulation between the battery cells to ensure proper protection. Additionally, there's a 0.6mm layer of PCM (Phase Change Material) to allow heat transfer. This setup ensures the battery remains safe and functional under various conditions, while also being strong, resistant to vibrations, and lightweight.

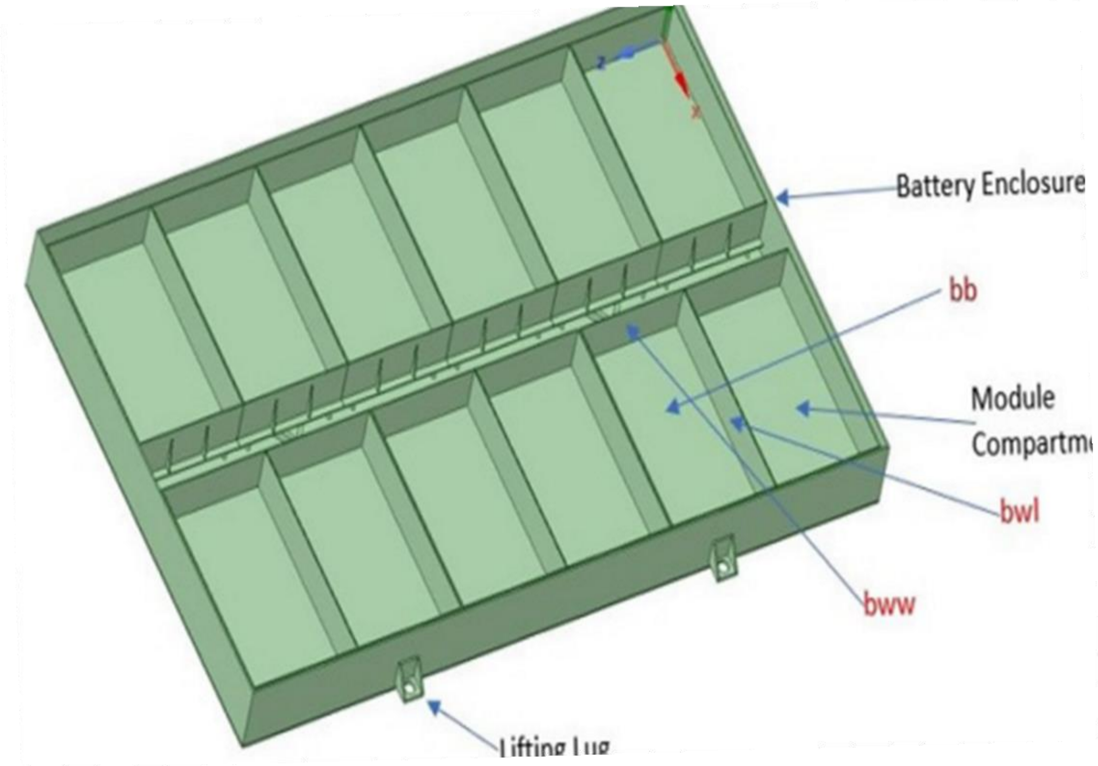


Fig.10. Insulation of Battery Pack

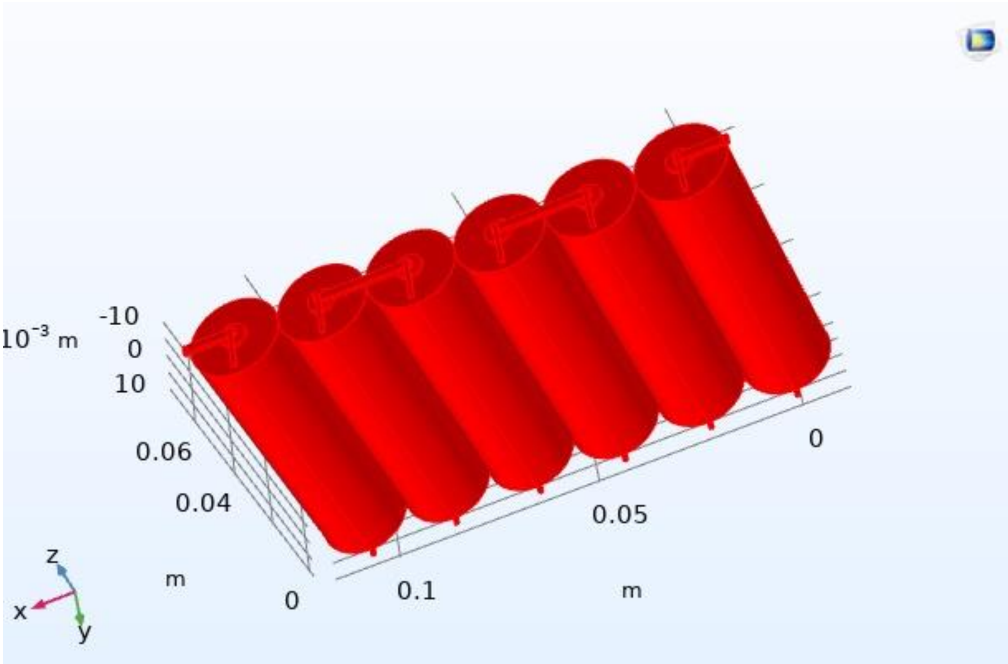
RESULTS

COMSOL Thermal Analysis of Small-Scale Module

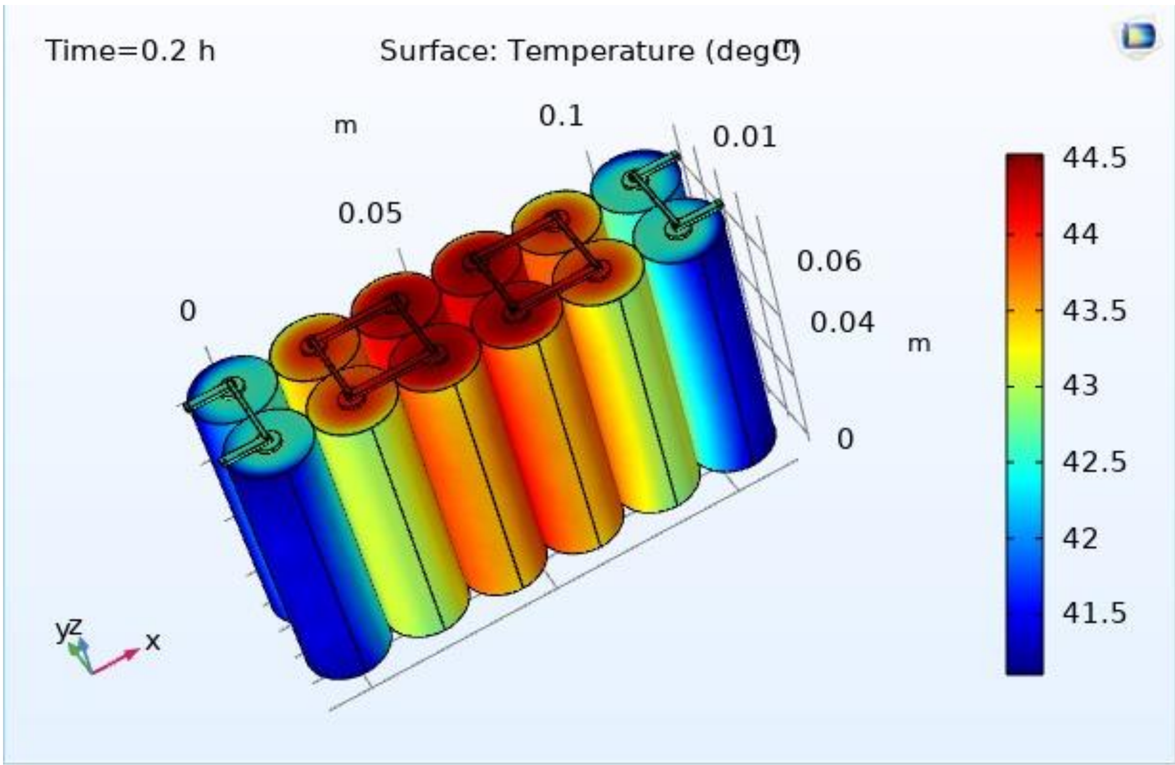
First, we wanted to analyse the temperature distribution in cells with respect to time without any coolant, for which we used COMSOL.

Our results for Temperature distribution from COMSOL are as follows -

Firstly, our connection between batteries can be seen as follows:-

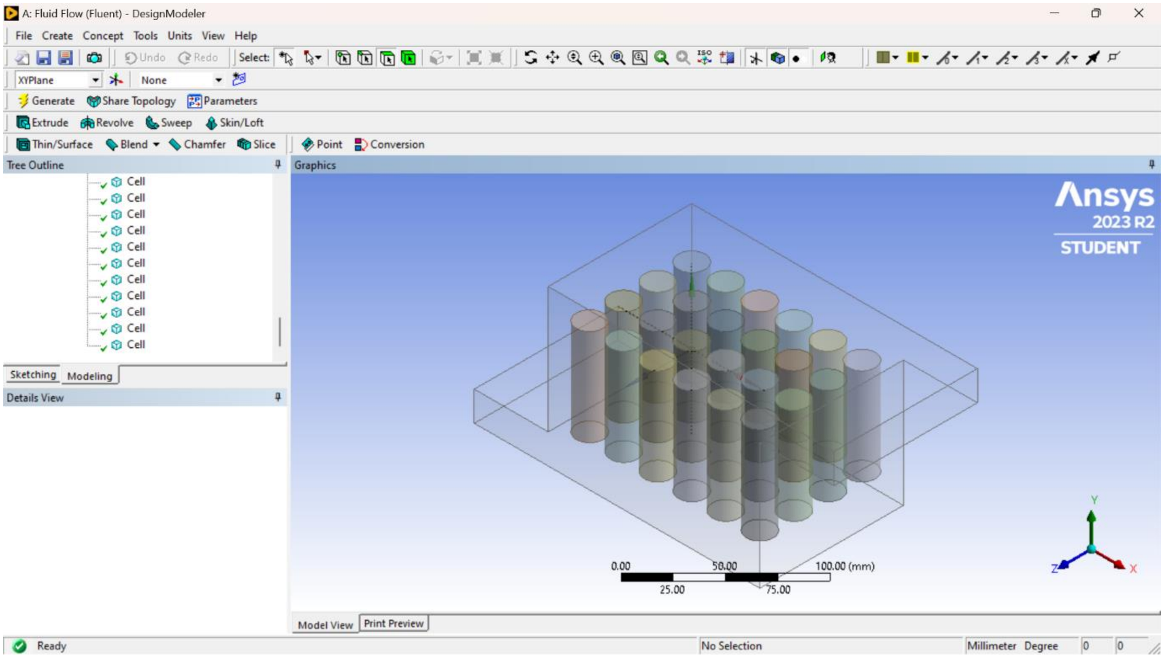


Next, our temperature analysis without any coolant for a small part of the module is as follows –

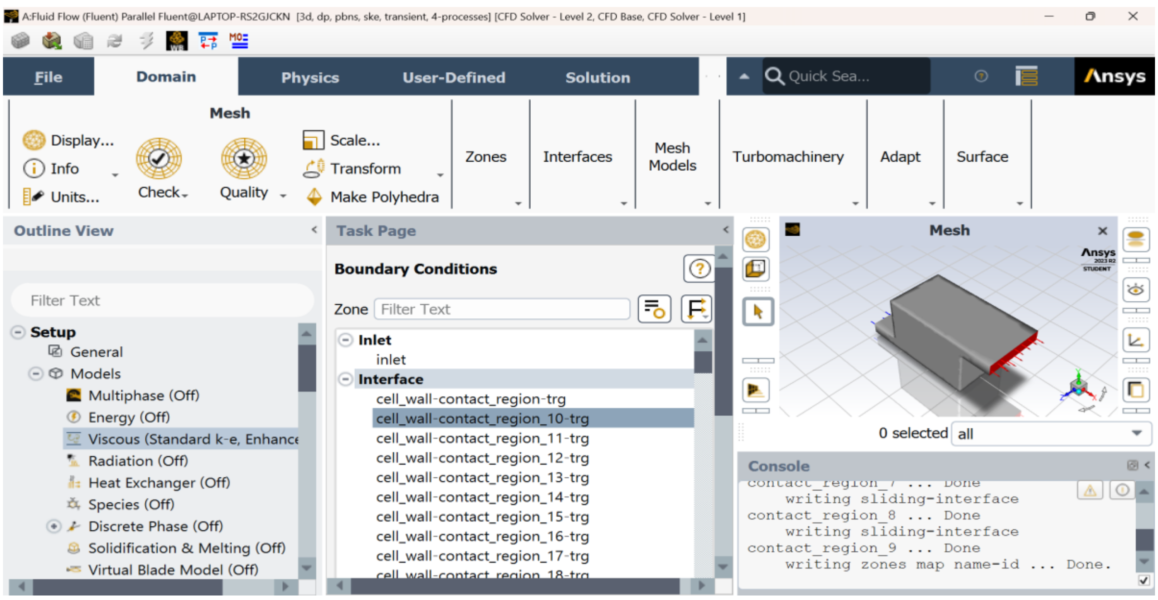


ANSYS Thermal Analysis of Small-Scale Module

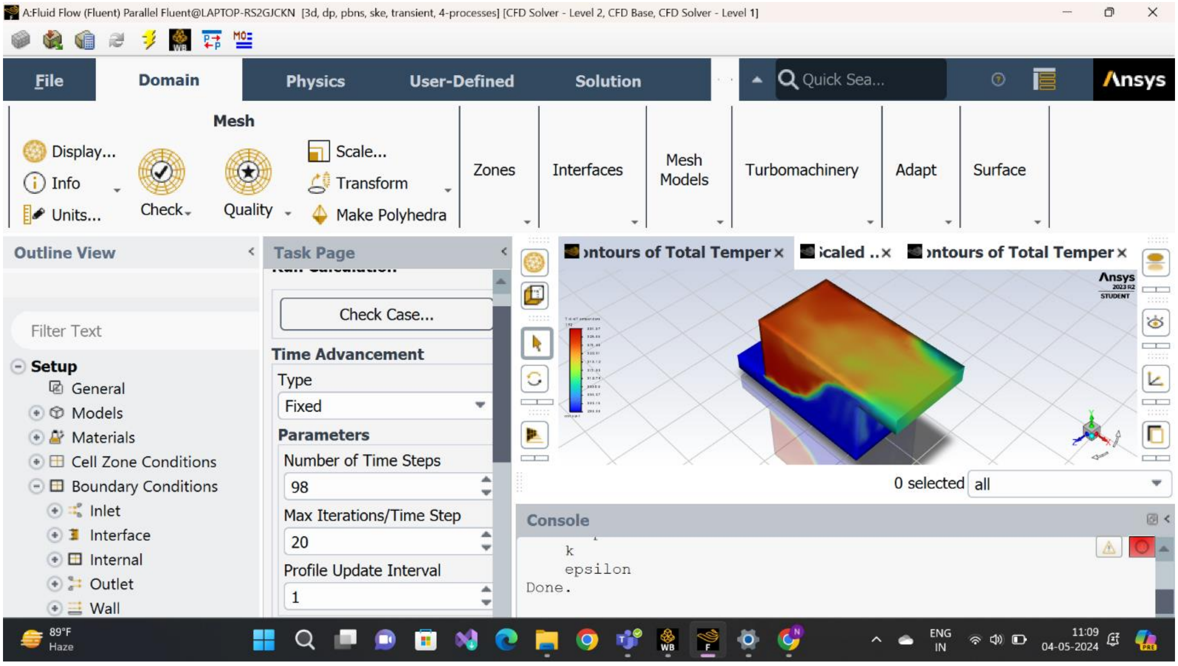
Firstly, we started by building a 3D version of our small-scale module on Ansys Geometry, the results are –



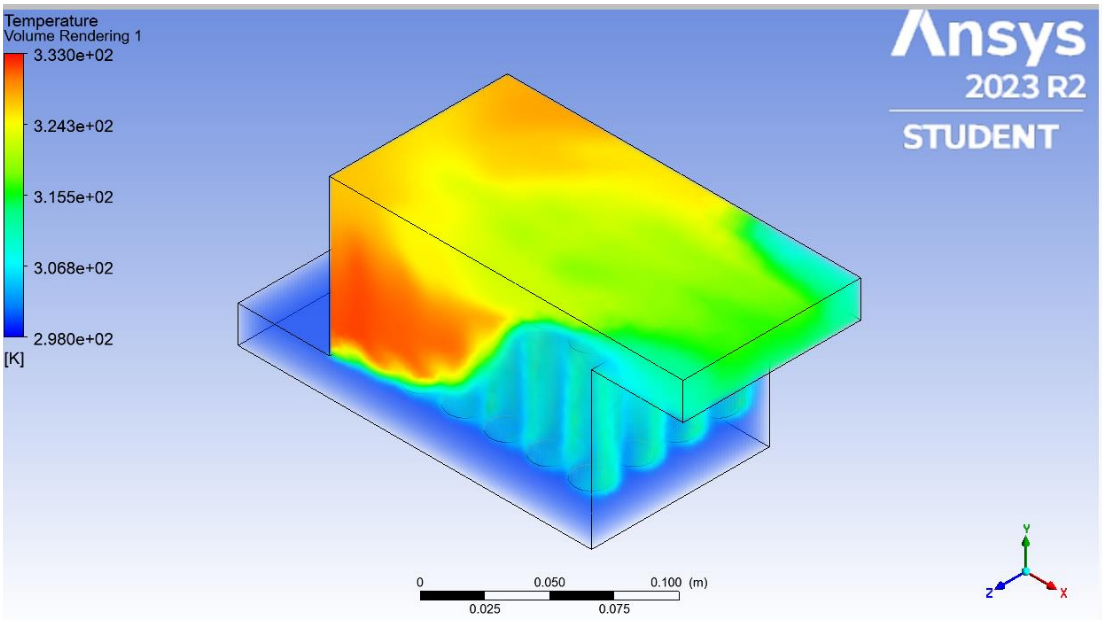
Then, we moved on to setting up the parameters using Ansys Setup, for example taking air our fluid and taking initial temperature of each cell as 333k. The result is as follows-



Then we moved on to meshing and results -



Finally, we have our results as follows-



Note – The inlet for coolant is below and exit is above.

COST ANAYLSIS

Here's a breakdown of the costs involved in our electric vehicle battery system:

1. The total cost of the 18650 cells in the battery is calculated by multiplying the number of cells (3864) by the cost per cell (150 rupees), which equals 5,79,600 rupees.

2. The cost of Polytetrafluoroethylene (PTFE) insulation is 27,810 rupees per kilogram.

3. The cost of the motors, sourced from Tata Motors, is 8,95,000 Rupees for two motors.

4. The cost of IGBT and Mosfet components is 72,500 rupees for two units.

5. The Phase Change Material (PCM) costs around 80,000 rupees.

Initially, the battery system's cost is 800,000 rupees, but after optimization efforts, it reduces to approximately 600,000 rupees.

This cost analysis helps us understand the financial aspects of implementing our electric vehicle battery system and allows us to make informed decisions regarding optimization and budget allocation.

2. Geo-Tagging of charging Stations

We have a smart idea to make electric vehicle charging easier and more widespread. Along the highways, there are lots of restaurants called Dhaba's. We'll use these Dhaba's to set up small charging stations for electric cars. Since Dhaba's are usually found every 10 kilometres along the highways, they make perfect spots for charging stations. We'll talk to the owners of these Dhaba's and pay them rent to let us use their space for the charging stations.

Our plan covers many major highways in India, like the one from Srinagar to Kanyakumari, Delhi to Chennai, Chennai to Kolkata, Chandigarh to Kanpur, Porbandar to Silchar, and Delhi to Kolkata. By putting charging points at these Dhaba's, we make it easy for electric car drivers to charge up while traveling long distances. This not only helps people who drive electric cars but also brings in extra money for the Dhaba owners. It's a win-win situation!

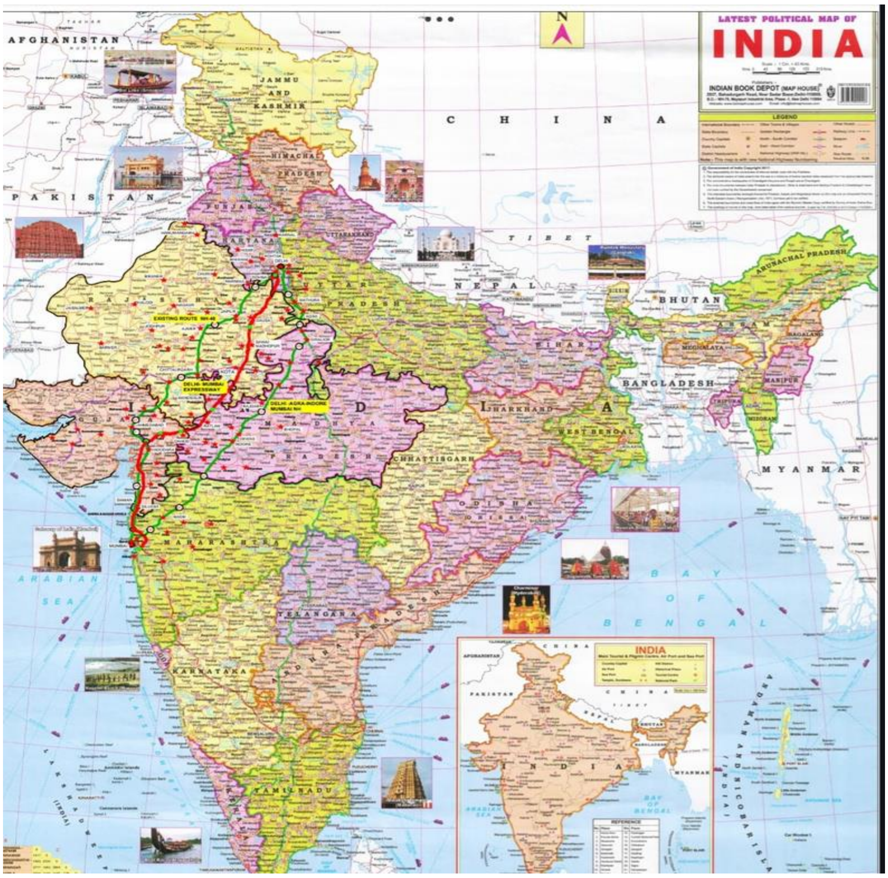


Fig.11. National Highways across India

Charging cost :

1. Cost for 1 Unit of charge is Rs 6-10.
2. We'll also include an extra 35% of the charging cost for the cooling station.
3. In our solution 2 we give rent and some commission to site (Dhaba) owner.

CONCLUSION

In conclusion, our electric vehicle battery system stands out in the market for several reasons. Despite being competitively priced at approximately 600,000 Rupees; our battery offers significant advantages over current models available from major companies like Tata. Firstly, it boasts a larger battery capacity and extended range, providing users with greater mileage and driving flexibility.

Moreover, our battery's charging speed is unmatched, with a 3C Super-Fast Charging rate, enabling three times faster charging than conventional methods. Additionally, our innovative cooling system not only efficiently regulates temperature but also stores released energy in Phase Change Material (PCM), allowing for its reuse. This unique feature significantly enhances energy usage and overall performance. With these advancements, our electric vehicle battery system represents a compelling option for consumers seeking enhanced capabilities and efficiency in their electric vehicles.

Link for all our COMSOL, ANSYS analysis and designing files is as follows-

https://drive.google.com/drive/folders/1m3xAtWysf81AKrIaeGn9vb3tJ2L2kdt4?usp=sharing

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