AN INVESTIGATION INTO DUAL BATTERY PACK CONFIGURATION FOR OPTIMIZING ELECTRIC VEHICLE CHARGING TIME

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CERTIFICATION

1 hereby certify that this project work " AN INVESTIGATION INTO DUAL BATTERY PACK CONFIGURATION FOR OPTIMIZING ELECTRIC VEHICLE CHARGING TIME" was carried out by:

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DEDICATION

This project work is dedicated to God Almighty who granted us courage and patience to perform and carry out this project work, and without his help we would not have achieved what we have done so far.

Also, this project is dedicated to our parents for their great support, guidance, sacrifice and prayers throughout the duration of our course of study

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ABSTRACT

To understand the popularity of electric vehicles circa 1900, it is also important to understand the development of the personal vehicle and the other options available. At the turn of the 20th century, the horse was still the primary mode of transportation. Steam emerged as a reliable energy source with a proven track record, notably powering factories and locomotives. In the late 1700s, steam also played a role in some of the earliest self-propelled vehicles. However, despite its early adoption in various applications, it wasn't until the 1870s that steam technology began to gain traction in the automotive industry. One significant reason for the delayed adoption of steam technology in cars was its impracticality for personal vehicles. Steam-powered vehicles faced several challenges that hindered their widespread use. For instance, they required considerable startup times, often up to 45 minutes, particularly in cold conditions. Additionally, steam vehicles needed frequent refilling with water, which imposed limitations on their range and practicality for everyday use.

These drawbacks underscored the challenges associated with steam-powered cars and contributed to their eventual decline in favor of alternative propulsion methods, such as internal combustion engines and electric motors, which offered greater convenience and efficiency for personal transportation.

As electric vehicles came onto the market, so did a new type of vehicle, the gasoline-powered car thanks to improvements to the internal combustion engine in the 1800s. Although gasoline-powered vehicles had potential, they were not without problems. They took a lot of human labor to operate because shifting gears was a difficult operation, and starting them required turning a hand crank, which some drivers found challenging. Gasoline-powered vehicles were also notorious for their noisy engines and nasty exhaust. (TOTAL ENERGIES, 2020)

In contrast, electric cars did not suffer from the issues associated with steam or gasoline vehicles. They were quiet, easy to drive, and did not emit the noxious pollutants characteristic of other cars of the time. Consequently, electric cars rapidly gained popularity among urban residents, particularly women. They proved ideal for short journeys within the city, especially considering the poor road conditions outside urban areas, which limited the travel range of all types of vehicles. (Nilesh Wani, 2020)

CHAPTER ONE

INTRODUCTION

Background Of Study

Many innovators at the time took note of the electric vehicle's high demand, exploring ways to improve the technology. For example, Ferdinand Porsche, founder of the sports car company by the same name, developed an **electric car called the P1** in 1898. Around the same time, he created the world's first hybrid electric car, a vehicle that is powered by electricity and a gas engine. **Thomas Edison, one of the world's most prolific inventors**, thought electric vehicles were the superior technology and worked to build a better electric vehicle battery. Even Henry Ford, who was friends with Edison, partnered with Edison to explore options for a low-cost electric car in 1914, (**US Department of Energy, www.energy.gov**).

Indeed, the escalating costs of fuel are leading to higher travel expenses for vehicles powered by internal combustion engines (IC). This surge in gasoline prices directly impacts transportation costs, subsequently influencing the prices of various goods and services. Consequently, there's a growing trend towards the adoption of electric vehicles (EVs) as a viable alternative.

Key components of an electric vehicle system include the battery, electric motor, and controller. These components collectively facilitate the conversion of electrical energy into mechanical energy for vehicle propulsion. As the demand for EVs rises, advancements in battery technology, electric motor efficiency, and controller design continue to play pivotal roles in enhancing the performance, range, and affordability of electric vehicles.

The transition towards electric vehicles not only offers a solution to rising fuel costs but also contributes to reducing greenhouse gas emissions and dependence on fossil fuels, thereby fostering a more sustainable and environmentally friendly transportation sector.

The fascinating evolution of electric vehicles has been a culmination of technological advancements spanning several years. Unlike traditional automobiles, the invention of the electric car cannot be attributed to a single inventor or country. Rather, it was a series of breakthroughs in battery technology and electric motor development during the 1800s that paved the way for the emergence of the first electric vehicles.

One notable figure in this timeline is William Morrison, hailing from Des Moines, Iowa, who is credited with creating one of the earliest successful electric vehicles in the United States. Morrison's creation, though rudimentary by modern standards, resembled more of an electrified wagon than a contemporary car. Nevertheless, his achievement ignited considerable interest and curiosity surrounding electric vehicles.

An 1896 advertisement serves as a testament to the early stages of electric vehicle design, depicting how many of these vehicles resembled traditional carriages rather than the sleek automobiles we recognize today. This historical context highlights the humble origins of electric vehicles and underscores the gradual progression towards the sophisticated electric cars we see on roads today.

In the early part of the century, innovators in Hungary, the Netherlands and the United States including a blacksmith from Vermont began toying with the concept of a battery-powered vehicle and created some of the first small-scale electric cars.

Over the next few years, electric vehicles from different automakers began popping up across the U.S. New York City even had a fleet of more than 60 electric taxis. By 1900, electric cars were at their heyday, accounting for around a third of all vehicles on the road. During the next 10 years, they continued to show strong sales. **(US Department of Energy, www.energy.gov)**

BATTERIES USED IN ELECTRIC VEHICLES (EV's)

Due to the complication of electric vehicles and advancement made over the years. Emphasis has been keen on improving the charging speed, range, thermal efficiency and longevity of battery cells used in these vehicles. These have brought about the development of various battery types and these includes but not limited to;

1. **Lead-Acid Battery:**

Lead-Acid batteries has been in existence since it was founded in 1859, and was among very first types of battery that was used by electric cars during its infancy, some of the cars that featured this batteries includes the GM EV1 and Ford Ranger EV which were manufactured in the early 90s.

Due to inefficiency, lead-acid batteries are no longer used by EV manufacturers. Some of the major reasons for this /include the fact that lead-acid batteries are susceptible to cold temperatures, and they are not durable compared to other types of batteries.

However, they have suffered from memory impairment, a visual phenomenon that sees battery performance drop when under partial “charging” cycles. Usd in the production of electric vehicles in the 90s, Ni-Cd batteries have now been banned due to cadmium poisoning. (Nilesh Wani, 2020)

2. **Nickel-Metal-Hydride battery:**

Its performance is similar to that of the Ni-Cd technology, Nickel-metal hydride (Ni-MH) accumulators has been very successful due to the lack of heavy metals in its composition, it was s a portable battery and was very popular in the early 2000’s. But Nickel-metal hydride batteries didn’t become popular in the EV industry because it was expensive and highly inefficient in high temperatures. Also Nickel-metal hydride batteries discharged faster than other batteries. For the reason, Nickel-metal hydride batteries are more common in hybrid vehicles where they can be combined with IC engines to make up for the inefficiencies it possess rather than in Electric vehicles. (Tarabay & Karami, 2015)

3. **Lithium-Ion battery:**

This battery was developed in the early 90’s, the Lithium-ion battery gradually established itself as a leading technology both in the consumer electronics industry but also in the transportation world. However it requires proper packaging and precise control of the charging process, usually obtained by a dedicated electronic circuit.

Most electric vehicles nowadays used Lithium-ion batteries. This is because they are light weight with high energy efficiency than lead acid batteries or nickel-metal hydride batteries. They are also very less likely to overheat at high a temperature, which helps it to minimize the risk of a fire breaking out. Other than that, lithium-ion batteries also takes longer to discharge compared to the other types of batteries. Some of the longest range electric vehicles with lithium ion batteries can travel over 450 miles of range on a full charge. An example is a Tesla Model S with a lithium-ion battery pack comes with a warranty of eight (8) years but the expected lifespan is between 300,000 to 500,000 miles of range.

However, not all lithium-ion batteries have the same compositions. Most high-end electric vehicles have a positive electrode made from cobalt. While some other Electric vehicles (EV) manufacturers are shifting towards lithium iron phosphate batteries for entry-level electric vehicles due to the fact that it's cheaper to manufacture.

Despite the huge benefits of this battery one of the biggest disadvantages of the Lithium-ion batteries is that they are not environmentally friendly when disposed of after exhausting its lifespan. Also mining the raw materials for Lithium-ion can disrupt ecosystems vital to wildlife and indigenous communities. But due to advancements in technology efforts have also be made to recycle lithium-ion batteries are they're disposed of. (Nayak et al., 2018)

4. **Solid-State Battery:**

Solid state batteries are still currently in development and have not yet been used in electric vehicles. Scientific research has long tested the concept of a solid-state battery; the goal behind it involves replacing the liquid electrolyte with a solid material that can take the form of a polymer plastic, inorganic powdered powder or a combination of both. In theory, this technology is good, it makes it possible to increase energy density and stability while making temperature control relatively easier, the stable state is still in laboratory model phase. Another benefit of solid-state batteries is that they don't take up much space compared to lithium-ion batteries. Because of weight advantage, Solid-state batteries may double the range of electric vehicles and improve performance. (Pervez et al., 2019)

However, with solid-state batteries still in research phase, until they are mass produced, we won't know if they're practically better than Lithium-ion batteries.

5. **Lithium Sulphur Battery:**

The lithium-sulphur batteries are still another alternative to lithium-ion batteries. Similar to solid state batteries, lithium-sulphur batteries can deliver significantly more range that it's lithium-ion counterpart. They're also relatively cheaper to produce with less impact on the environment compared to lithium-ion made from cobalt. (Manthiram et al., 2015)

The major downside and the reason why we are yet to see lithium-sulphur batteries in Electric vehicles (EV's) is that they have short lifespan. Nonetheless researchers are working on several experiments that can solve the problem.

Advantages of Lithium –ion Battery:

1. High Energy Density: Lithium-ion batteries have a high energy density, providing more energy storage capacity per unit weight or volume compared to other types of batteries. (Nayak et al., 2018)
2. Long Cycle Life: Lithium-ion batteries typically have a longer cycle life compared to other rechargeable batteries, making them more durable and cost-effective in the long run. (Han et al., 2019)
3. Low Self-Discharge Rate: Lithium-ion batteries have a lower self-discharge rate compared to other rechargeable batteries, allowing them to retain their charge for longer periods when not in use. (Wang et al., 2016)
4. Quick Charging: Lithium-ion batteries can be charged quickly compared to other types of batteries, allowing for faster turnaround times and increased efficiency. (Weiss et al., 2021)
5. Wide Operating Temperature Range: Lithium-ion batteries can operate effectively over a wide range of temperatures, making them suitable for use in various environments and climates. (Hou et al., 2020)
6. Low Maintenance: Lithium-ion batteries require minimal maintenance compared to other types of batteries, reducing the overall cost and effort of upkeep. (Nayak et al., 2018)

7. Compact and Lightweight: Lithium-ion batteries have a high energy density per unit weight and volume, making them compact and lightweight, ideal for portable electronic devices and electric vehicles. (Zhengcheng Zhang, Jie Zheng, and Qiang Zhang, 2012)
8. Versatile Design: Lithium-ion batteries can be designed in various shapes and sizes, offering flexibility in integration into different devices and applications. (Qian et al., 2019)

Limitations of Lithium-ion batteries:

1. Limited Energy Density: The quantity of energy that lithium-ion batteries can store per unit volume or weight is constrained by their limited energy density. (Xiong et al, 2022).
2. Safety Concerns: Overheating in lithium-ion batteries can result in thermal runaway, fires, and explosions. (Gandoman et al., 2019)
3. Limited Lifespan: There is a certain number of charge-discharge cycles for lithium-ion batteries before their capacity is noticeably reduced due to gradual degradation. (Johnson et al, 2018)
4. High Cost: Lithium-ion batteries may be costly to produce due to the high cost of the materials and manufacturing techniques used in their production. (Brown et al, 2019)
5. Slow Charging Speed: The lengthy time it takes for lithium-ion batteries to fully recharge typically makes them impractical for use in several situations. (Weiss et al., 2021)
6. Limited Temperature Range: Within certain temperature ranges, lithium-ion batteries might have poor performance or possibly stop working altogether. (Hou et al., 2020)
7. Environmental Concerns: Because rare earth metals and other hazardous compounds are extracted during the mining and disposal of lithium-ion batteries, environmental concerns are raised. (White et al, 2019)
8. Capacity Fading: Lithium-ion batteries experience a gradual loss of capacity over time, even with proper usage and maintenance. (Atalay et al., 2020)
9. Size and Weight: Lithium-ion batteries can be bulky and heavy, limiting their use in certain portable applications where space and weight are critical factors. (Kim et al, 2018)
10. Resource Constraints: The availability of key materials used in lithium-ion batteries, such as lithium and cobalt, may become limited as demand increases. (Nayak et al., 2018)

Statement of the Problem:

Electric vehicle (EV) adoption is hindered by the long charging times compared to refueling conventional internal combustion engine vehicles. Despite advancements in battery technology, the large single battery packs used in most EVs require extended periods to charge fully, limiting their practicality for many users, especially in fast-paced urban environments.

This research investigates the potential of a dual battery pack configuration, where the overall battery capacity is divided into two smaller, independently charged packs. The goal is to assess whether this design, coupled with dual charging ports, can reduce total charging time by enabling parallel charging, and to assess what downsides this approach could present particularly in terms of temperature distribution. A comprehensive simulation will be conducted to determine the feasibility and efficiency of this approach, addressing a critical barrier to widespread EV adoption.

Aim of the Project:

The aim of this project is to investigate the effectiveness of a dual battery pack configuration in reducing the charging time of electric vehicles through simulation, with the goal of optimizing overall charging efficiency and improving the practicality of EVs for everyday use.

Objectives of the Project:

1. To simulate the charging process of a single large battery pack and a dual battery pack configuration under identical conditions.
2. To introduce and assess the effect of active cooling on both configurations during charging.
3. To determine the state of charge (SoC) and temperature distribution of each configuration after one hour of charging.
4. To compare the thermal performance and charging efficiency of dual versus single battery configurations in transient conditions.

5. To provide insights into the feasibility of the dual battery pack configuration as a means of reducing charging time while maintaining optimal temperature control.

Significance of Study

The development and implementation of dual battery technology in electric vehicles (EVs) has the potential to revolutionize the transportation sector. This study on dual battery systems holds significant value for several reasons:

1. **Enhancing Electric Vehicle Adoption**: As electric vehicles (EVs) become increasingly essential in reducing carbon emissions and promoting sustainable transportation, understanding and optimizing charging time is critical. By exploring the dual battery pack configuration, this research aims to contribute to solutions that make EVs more practical and convenient for consumers.
2. **Advancing Battery Technology Research**: The investigation into dual battery systems and their cooling mechanisms adds valuable insights to the field of battery technology. By analyzing the thermal performance and charging efficiency, this study will help advance knowledge regarding battery pack design and its implications for performance and lifespan.
3. **Informing Industry Practices**: Findings from this research can inform automotive manufacturers and engineers about alternative battery configurations that may enhance charging capabilities. Implementing these insights could lead to more efficient vehicle designs, ultimately benefiting both manufacturers and consumers.
4. **Supporting Policy Development**: As governments and policymakers work to incentivize EV adoption and improve charging infrastructure, this study can provide empirical data and recommendations that support the development of effective policies. The findings may guide investments in charging stations and battery technologies that prioritize efficiency and user experience.
5. **Contributing to Sustainability Goals**: By optimizing charging times and thermal management in electric vehicles, this research aligns with global sustainability goals. Improved battery configurations can enhance the overall efficiency of electric vehicles, supporting the transition to cleaner transportation solutions and reducing reliance on fossil fuels.

Scope of Study:

This study focuses on the evaluation of dual battery pack configurations in electric vehicles, specifically examining their impact on charging time and thermal performance. The scope includes the following key aspects:

1. **Battery Configurations**: The research will compare two configurations: a single large battery pack and a dual battery pack system. Each configuration will be simulated to assess performance metrics under identical charging conditions.
2. **Charging Scenarios**: The simulation will analyze four specific scenarios:
   - Single battery pack configuration without active cooling.
   - Single battery pack configuration with active cooling.
   - Dual battery pack configuration without active cooling.
   - Dual battery pack configuration with active cooling.
3. **Transient Simulation**: The study will utilize a transient simulation approach to accurately model the charging process over time. This will allow for the observation of changes in the state of charge (SoC) and temperature distribution throughout the charging period.
4. **Performance Metrics**: The primary metrics evaluated will include:
   - State of charge (SoC) after one hour of charging for each configuration.
   - Temperature distribution across the battery packs to assess thermal performance.
5. **Limitations**: The study will focus solely on simulation-based analysis, meaning that practical implementation and real-world testing will not be part of this research. Additionally, the findings will be constrained to the specific battery types and charging conditions modeled in the simulations.
6. **Exclusions**: While this study addresses the technical aspects of battery configurations and cooling mechanisms, it will not explore broader factors such as user behavior, charging station infrastructure, or economic implications of implementing dual battery systems.

By clearly defining the scope of this study, the research aims to provide focused insights into the effectiveness of dual battery configurations in optimizing electric vehicle charging processes, while acknowledging the limitations inherent in a simulation-based approach.

CHAPTER TWO

Literature Review

Many of the same factors that made electric cars popular when they were originally introduced more than a century ago still make them popular now. As the cost of electric drive vehicles decreases, demand for them will only increase. The following categories comprise electric vehicles: Autos that produce all of their own electricity internally are known as hybrid electric vehicles, or HEVs. All hybrid types that employ electric motors for propulsion, including as series, parallel, through-the-road, and mild hybrids, are referred to as HEVs. Cars that start on demand are not included in the HEV category. Two types of electric vehicles include plug-in hybrid electric vehicles (PHEVs), which use grid power as well as an internal combustion engine (ICE) to extend the vehicle's range. Three BEVs, or battery-electric vehicles: automobiles that utilize grid-stored energy. (1832-1839): Scottish inventor Robert Anderson invented the first crude electric carriage powered by non-rechargeable primary cells. (1835): American Thomas Davenport is credited with building the first practical electric vehicle -- a small locomotive. (1859): French physicist Gaston Planté invented the rechargeable lead-acid storage battery. In 1881, his countryman Camille Faure improved the storage battery's ability to supply current and invent the basic lead-acid battery used in automobiles. (1891): William Morrison, a chemist from Des Moines, Iowa, built the first successful electric automobile in the United States. (1893): A handful of different makes and models of electric cars exhibited in Chicago. (1897): The first electric taxis hit the streets of New York City early in the year. The Pope Manufacturing Company of Connecticut became the first large-scale American electric automobile manufacturer. (1899): Believing that electricity will run autos in the future, Thomas Alva Edison began his mission to create a long lasting, powerful battery for commercial automobiles. Though his research yielded some improvements to the alkaline battery, he ultimately abandoned his quest a decade later. (1900): The electric automobile was in its heyday. Of the 4,192 cars produced in the United States 28 percent were powered by electricity, and electric autos represented about one-third of all cars found on the roads of New York City, Boston, and Chicago. (1908): Henry Ford introduced the mass-produced and gasoline-powered Model T, which had a profound effect on the US automobile market. 1912: Charles Kettering invented the first practical electric automobile starter. Kettering's invention made gasoline-powered autos more alluring to consumers by eliminating the unwieldy hand crank starter and ultimately helped pave the way for the electric car's demise. (1920): During the 1920s, the electric car ceases to be a viable commercial product. The electric car's downfall is attributable to a number of factors, including the desire for longer distance vehicles, their lack of horsepower, and the ready availability of gasoline. (1966): Congress introduced the earliest bills recommending use of electric vehicles as a means of reducing air pollution. A Gallup poll indicated that 33 million (18%) Americans are interested in electric vehicles (out of 179 million total population America, 1960 census). (1970s): The Clean Air Act was established, which required states to take control of their air quality and meet certain standards by deadlines. The OPEC oil embargo of 1973, which skyrocketed gasoline prices, also sparked interest in alternatives to fueled vehicles. (1972): Victor Wouk, the "Godfather of the Hybrid," built the first full powered, full-size hybrid vehicle out of a 1972 Buick Skylark provided by General Motors (G.M.) for the 1970 Federal Clean Car Incentive Program. the US Environmental Protection Agency certified that Wouk's vehicle met the strict guidelines for an EPA clean-air auto program and REJECTED IT. The story about the vehicle and its inventor, who died in May, 2005, at age 86, is unknown to today's hybrid/electric car movement. America was ahead of all other countries in hybrid car science, at least by three decades ahead, but squashed it under the weight of the Auto Industry and Oil Industry. So much for the constitutionally mandated protections for inventors, the democracy, the free market economy, and we love to harangue about other countries, the Environmental Protection Agency killed the program in 1976. The hybrid killer award goes to the Iron Duke aka Mr. Clean Air aka Eric Oswald Stork, born Jan. 8, 1927, in Hamburg, Germany, came to the United States at 13 and grew up in the state of Washington. A market economy is when competition from free enterprise makes economic decisions. The United States is considered the world's premier free market economy, because the US Constitution guarantees the three critical elements that create a free market,

1. ownership of private property
2. a competitive market
3. unregulated prices.

The law of demand and supply sets prices and distributes goods and services. In 2004, one year before his death, Dr. Victor Wouk (doctorate in electric engineering from the California Institute of Technology, magna cum laude) recorded an oral history interview with the CalTech Archives, " If we must reduce automobile pollution and reduce automobile fuel consumption a large amount in a short period of time. The only thing you should do is use existing technologies, and as these technologies improve, you just go ahead. But nobody did anything about it until, independently, the Japanese—Toyota and Honda.”(1974): Vanguard-Sebring's CitiCar makes its debut at the Electric Vehicle Symposium in Washington, D.C. The CitiCar has a top speed of over 30 mph and a reliable warm-weather range of 40 miles. By 1975 the company is the sixth largest automaker in the US but is dissolved only a few years later. (1975): The US Postal Service purchases 350 electric delivery jeeps from AM General, a division of AMC, to be used in a test program. (1976): Congress passes the Electric and Hybrid Vehicle Research, Development, and Demonstration Act. The law is intended to spur the development of new technologies including improved batteries, motors, and other hybrid-electric components. (1988): Roger Smith, CEO of GM, agrees to fund research efforts to build a practical consumer electric car. GM teams up with California's AeroVironment to design what would become the EV1, which one employee called "the world's most efficient production vehicle." Some electric vehicle enthusiasts have speculated that the EV1 was never undertaken as a serious commercial venture by the large automaker (1990): California passes its Zero Emission Vehicle (ZEV) Mandate, which requires two percent of the state's vehicles to have no emissions by 1998 and 10 percent by 2003. The law is repeatedly weakened over the next decade to reduce the number of pure ZEVs it requires. (1997): Toyota unveils the Prius. Nearly 18,000 units were sold during the first production year. Released in Japan in 1997, the Prius became the world’s first mass-produced hybrid electric vehicle. (1999): Honda released the Insight hybrid in 1999, making it the first hybrid sold in the US since the early 1900s. (2000): Prius was released worldwide, and it became an instant success with celebrities, helping to raise the profile of the car. To make the Prius a reality, Toyota used a nickel metal hydrid battery, a technology that was supported by the Energy Department’s research. 1997 - 2000: A few thousand all-electric cars (such as Honda's EV Plus, GM's EV1, Ford's Ranger pickup EV, Nissan's Altra EV, Chevy's S-10 EV, and Toyota's RAV4 EV) are produced by big car manufacturers, but most of them are available for lease only. All of the major automakers' advanced all-electric production programs will be discontinued by the early 2000s. 2002: GM and DaimlerChrysler sue the California Air Resources Board (CARB) to repeal the ZEV mandate first passed in 1990. The Bush Administration joins that suit. (2003): GM announces that it will not renew leases on its EV1 cars saying it can no longer supply parts to repair the vehicles and that it plans to reclaim the cars by the end of 2004. (2005): On February 16, electric vehicle enthusiasts begin a "Don't Crush" vigil to stop GM from demolishing 78 impounded EV1s in Burbank, California. The vigil ends twenty-eight days later when GM removes the cars from the facility. In the film "Who Killed the Electric Car" GM spokesman Dave Barthmuss states that the EV1s are to be recycled, not just crushed. 2006: Tesla Motors publicly unveils the ultra-sporty Tesla Roadster at the San Francisco International Auto Show in November. The first production Roadsters will be sold in 2008 with a base price listing of $98,950. (2008, January): The Israeli government announces its support for a sweeping project to promote the use of electric cars in Israel. The effort will be a joint venture between Better Place, a Palo Alto start-up founded by software maven Shai Agassi, and French automaker Renault-Nissan. Agassi's plan is to create an extensive network of charging spots and to sell EV drivers' mileage in their cars like minutes on a cell phone plan. The first Renault electric cars are scheduled to hit the streets of Tel Aviv and other cities in 2011. Better Place announces a host of partnerships to support electric vehicle projects in Denmark, Canada, Japan, Australia and the US. (2008, July): Gas prices reach record highs of more than $4 a gallon and car sales drop to their lowest levels in a decade. American automakers begin to shift their production lines away from SUVs and other large vehicles toward smaller, more fuel-efficient cars. (2008, August): On the campaign trail, presidential candidate Barack Obama says he will push to have one million plug-in hybrid and electric vehicles on America's roads by 2015. 2008, November: Struggling to remain profitable during the economic downturn, executives from the Big Three American automakers go to Washington to make the case for a $25 billion Federal bailout of the US automotive industry. (2008, December): BYD, a Chinese battery manufacturer turned automaker, releases the F3DM, the world's first mass produced plug in hybrid compact sedan. Though they pack less energy than more conventional lithium ion batteries, BYD opts to power the F3DM with a more stable lithium iron phosphate battery. BYD plans to release the F3DM in the US in 2011, but some industry insiders have doubts about whether the car is ready for the US market. Though sales of the car remain sluggish, Warren Buffett's Berkshire Hathaway purchases a 10% stake in the company. The National Bureau of Economic Research states officially that the US has been in a recession since December 2007. The economic downturn is global in scope and will continue to exert financial pressures on the already battered US auto industry. (2008): Engineered by Mercedes-Benz, Smart For-two is an all-new brand and vehicle in the US, a miniature twoseat car that was available at select dealerships. In 2009, a new sport trim was added and flexible door storage nets were made standard. New options were introduced for 2009, including optional leather seating, automated lights and automated wipers. While no changes were in store for 2010, the 2011 model year got LED daytime running lights, a new dash panel, cruise control, more storage options, an improved stereo system and new side curtain and knee airbags. Optional GPS and an updated stereo system marked the only changes for 2012. 2009, February: The American Recovery and Reinvestment Act of 2009 allocates $2 billion for development of electric vehicle batteries and related technologies. The Department of Energy adds another $400 million to fund building the infrastructure necessary to support plug-in electric vehicles. (2009, April): Prime Minister Gordon Brown announces that the British government will promote the use of electric vehicles in the U.K. by offering a £2,000 subsidy to purchasers. A high-ranking government official estimates that 40% of all cars in Britain will need to be electric or hybrid for the country to reach its goal of cutting 80% of its CO2 emissions by 2050. Chrysler files for Chapter 11 bankruptcy. As part of its restructuring, Chrysler forms a partnership with the Italian car maker Fiat. 2009, May: President Obama announces a new gas-mileage policy that will require automakers to meet a minimum fuel-efficiency standard of 35.5 miles a gallon by 2016. (2009, June): The Department of Energy awards $8 billion in loans to Ford, Nissan, and Tesla Motors to support the development of fuel efficient vehicles. The automaker loans are the first distributions from a larger $25 billion fund created under the Energy Independence and Security Act of 2007. General Motors, the leading producer of automobiles for most of the 20th Century, files for bankruptcy protection. While strong GM brands such as Chevrolet, Cadillac and GMC are slated to continue, smaller names like Saturn, Hummer and Pontiac will be sold or closed. The federal government will hold a 61 percent stake in the reborn General Motors. 2009, August: Nissan unveils its new electric car, called the LEAF ("Leading, Environmentally Friendly, Affordable, Family Car"). The LEAF is capable of a maximum speed of more than 90 mph, can travel 100 miles on a full charge, and has a battery that can be recharged to 80% of its capacity in 30 minutes. Similar to the Better Place initiative in Israel, Nissan plans to work with the Japanese government and private companies to set up charging station networks across several countries. The first production LEAFs are scheduled to go on sale in Japan, Europe, and the US in the fall of 2010. (Late 2009): Though a few electric cars and plug-in hybrids are currently available on the market, several new models including the Nissan LEAF, Chevrolet Volt, and Mitsubishi i MiEV are scheduled to hit the streets in the near future. Toyota, creator of the popular Prius hybrid, has thus far declined to deliver a fully electric car. (2010): Tesla received at $465 million loan from the Department of Energy’s Loan Programs

Office to establish a manufacturing facility in California. Tesla Tesla repaid the loan nine years early. In the short time since then, Tesla has won wide acclaim for its cars and has become the largest auto industry employer in California. In late 2010, the Chevy Volt and the Nissan LEAF were released in the US market. The first commercially available plug-in hybrid, the Volt has a gasoline engine that supplements its electric drive once the battery is depleted, allowing consumers to drive on electric for most trips and gasoline to extend the vehicle's range. In comparison, the LEAF is an all-electric vehicle, meaning it is only powered by an electric motor. (2012): President Obama launched the EV Everywhere Grand Challenge, a Department of Energy initiative that brings together America's best and brightest scientists, engineers and businesses to make plug-in electric vehicles more as affordable as today's gasoline-powered vehicles by 2022. The Department's Joint Center for Energy Storage Research at Argonne National Laboratory is working to overcome the biggest scientific and technical barriers that prevent largescale improvements of batteries. (2013): A slightly updated exterior, a new driver seat armrest and updated trim level options as well as the release of the electric version, the Electric Drive, earmarked the key changes for 2013 Smart For-Two ED. (2016): Tesla has secured an estimated 500,000 pre-orders for the Model 3 since the vehicle was first unveiled in March 2016. Starting at $35,000, the Model 3 is Tesla's first car geared at a consumer audience. Tesla will offer six color options for the Model 3: black, midnight silver metallic, deep blue metallic, silver metallic, pearl white multi-coat, red multi-coat. Tesla's big selling point for the Model 3 is its affordability, with a starting price of $35,000 before tax incentives. The base Model 3 can drive 220 miles on a single charge, accelerate to 60 mph in 5.6 seconds, and reach a top speed of 130 mph. Tesla will also sell a premium version of the Model 3 with a range of 310 miles. Priced at $44,000, the car can accelerate to 60 mph in 5.1 seconds and reach a top speed of 140 mph. Today: There are 23 plug-in electric and 36 hybrid models available in a variety of sizes -- from the two-passenger Smart ED to the midsized Ford C-Max Energi to the BMW i3 luxury SUV. As gasoline prices continue to rise and the prices on electric vehicles continue to drop, electric vehicles are gaining in popularity -- with more than 234,000 plug-in electric vehicles and 3.3 million hybrids on the road in the US today. Despite promising signs, the electric car will need to navigate a bumpy road before it can become a viable option for many drivers. Challenges to mass adoption include high sticker prices, limited battery life and travel range, and building charging stations and other infrastructure to support electric vehicles. It's sporty. It's progressive. It's mobility in its purest form, reducing every type of waste, indulging all the senses, and accelerating towards the future.

There have been many different innovations on how to improve the limitations posed by traditional charging speeds of electric vehicles but we will now be looking at adaptation of dual charging ports to improve the charging speed in comparison to traditional single charting port.

EXISTING BATTERY TECHNOLOGIES AND THEIR LIMITATIONS

We are all witnessing a paradigm shift in the way we lead lives today. With automation overpowering all walks of life, we have an increased requirement for power generation and conservation. The functioning of smartphones, smart homes and smart gadgets are all limited by power. To meet the power demands, nano wire batteries that can withstand large number of charge recharge cycles, are seen as a replacement to solid state lithium ion batteries. Nano wires possess high storage density of electrons, fast rate of diffusion and hence can also be used for operation involving high power sources like metros and other automotives. Gold nano wires have been coated with manganese oxide and a gel type electrolyte to serve as safety protection layer. This electrolyte gel helps to bind the wires together and also helps to make the metal oxide smoother and breakage resistant resulting in large storage applications. It is observed that silicon nano wire batteries find applications in wearable devices as they provide a flexible sources of energy. Apart from this it can used in bio medical applications, smart cards, and sensors in power remotes. A company called Graphenano have come up with graphene batteries that can charge faster than Lithium ion batteries. Graphene batteries can sustain heat at high temperature and has higher efficiency of recharging. According to survey, from 2011 to 2015, the usage of portable devices has increased exponentially from 30% to 60% in US. The electric vehicle manufacturing too is increasing as depicted in Fig. 1. During 2008, the Environment Protection Agency (EPA) of US launched a National Emission Standard to control the emission of poisonous gases during battery manufacturing process such as cadmium and lead. The company says that these batteries can find applications in drones, cars and even at home. Another group of researchers are looking at laser-made micro super capacitors which can charge 50 times faster and discharge ever slower than existing batteries. These super capacitors are a combination of battery and capacitor that can undergo multiple charge and discharge cycles without change in their characteristics. This has been possible due infusion of carbon materials during super capacitor electrode fabrication. But these super capacitors weigh about 40% more than present day Li ion battery. To bring down the weight, researchers are looking at using carbon nano tubes and oxides of graphene as electrodes . These techniques would also bring down the manufacturing costs and effort enormously. Fig. 1: Electric vehicles manufacturing in world from 2010

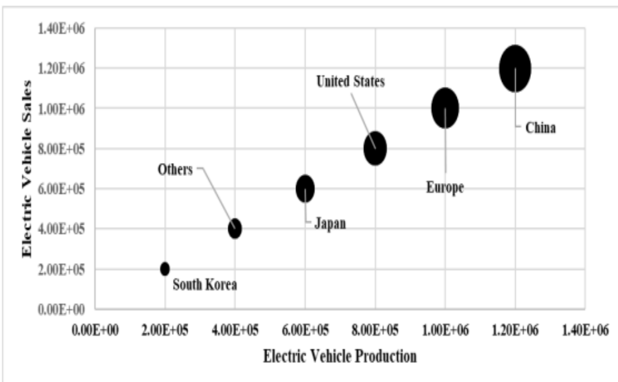

Figure 2.1 Electric Vehicle Production

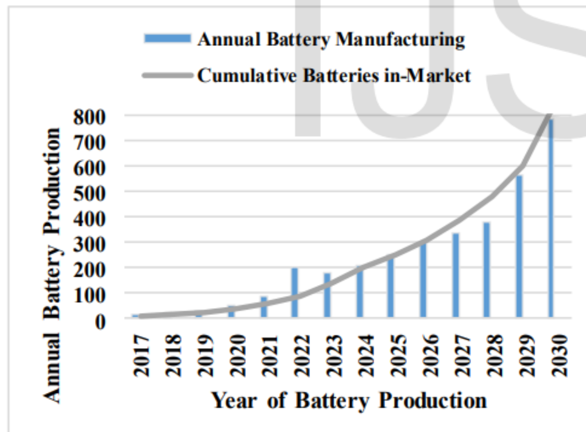

Figure 2. 2 Year of Battery Production

With the invention of electric vehicles, the demand for IC engine vehicles is decreasing slowly, and 2010 was called Year of Electric car. According to International Energy Agency (IEA) studies, it is presumed that the number of electric vehicles on road will reach 2.5 million by 2020. Looking at the demands and improvement of electric vehicles, it is stated that the production of electric vehicles will increase rapidly and may reach out to about 100 million by 2050. Fig.2 depicts the increase in the number of manufacturing units over time from 2017 At present, the defined rechargeable batteries should be improvised for longer mobility and greater efficiency. Rechargeable battery technologies, like Pb-acid (lead acid), Ni-Cd and Ni-MH are used in various fields. The usage is increasing over the last decade. Despite their usefulness, the natural limitations of materials used to manufacture them delay their application in extensive storage system. The main concern in using them is safety. However, low cost, long cycle life, high vitality efficiency and supportability are other concerns associated with their usage. When it comes to using batteries in automobiles, the other main issue is deployment of charging stations. Also, when a battery is no longer usable it should be recycled for preserving the ecosystem. Lead acid battery uses 85% of total lead available in world and its recycling is only about 60% of lead production. Refurbishing and recycling of batteries may help in reduction of chemical waste and help us save the environment. For instance, the Pb acid and Ni-Cd batteries experience energy density restrictions when it comes to automotive applications. Ni-iron battery is challenged by poor cycling efficiency and self -discharge identified with erosion of iron anode. Ni-MH batteries have higher density of energy while they exhibit poor temperature capacity. They can be safely operated around 200C only. When these batteries are employed for applications that require more power, the functioning of the battery cannot be guaranteed as more power consumption results in an increase in power dissipation and hence in an increase in battery temperature. The increase in battery temperature might result in battery damage. Ni-MH battery are seen to be incapable of withstanding an increase in temperature even for short duration. Ni-MH batteries also exhibit poor coulombic efficiency which is the ratio of discharge rate to the charge rate of a battery for one full cycle. Also, the initial cost of Nickel –Metal Hydride battery are more compared to that of Ni-Cd batteries. Apart from its disadvantages this battery seems to be ecofriendly since it does not contain any toxic elements and also Ni-MH is less cost compared to present Lithium-on batteries [18-19]. Lithium-ion battery (LIB) technology is relatively expensive because of material utilized, the cell outlining, producing procedure and assistant framework required for the task of making the battery. A major research area with respect to LIB is ability to draw more electrons i.e., more power (in case of electric vehicles) from the battery at its standard rate ability. Batteries with different energy density is as shown in Table I. While working with any rechargeable battery, necessary precautions should be taken to avoid short circuit during chemical reaction between natural electrolyte and electrodes inside the battery. Considering all these short comings of existing batteries, a novel battery has to be developed which can be operated safely, maintained easily and is eco-friendly. In addition to research in the study of alternate materials/combination of materials, innovations in designing a device that monitors the health of the battery is also of importance. A Battery Management System (BMS) device is required to ensure the working of battery as per designed specifications. Going forward, these devices also need to keep track of the amount of battery degradation and to guarantee safety of the battery and its users. In Fig. 3 shows that the energy density of phone batteries is increased by 7 times when compared over 7 years.

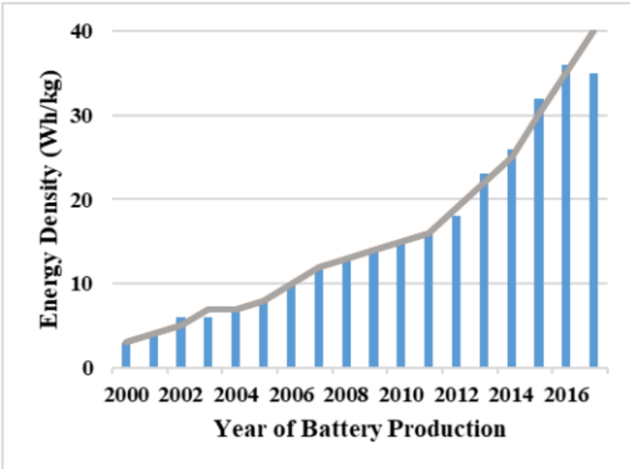

Figure 2. 3 Energy density of phone battery versus year

Table (a): Comparison of specifications of various batteries

Specifications / Batteries	Lead-acid	Ni-MH	Li-ion	Ultra-Capacitor
Energy density (Whr/kg)	40	70	110	5
Number of Charge and Discharge cycles	500	800	1000	500000
Working temperature (°C)	-300 to +500	-400 to +500	-400 to +600	-400 to +850

Figure 2. 4 Comparison of Specifications of Various Batteries

COMPARISION OF MAJOR BATTERY TECHNOLOGIES

Table 1 compares key features of several popular batteries. Compared to the specific fuel capacity of 13,000 Wh/kg, these batteries exhibit a power output nearly 50-100 times higher. This significant difference in energy density compared to fuel becomes apparent when illustrated with an example:

With 50 liters of fuel, a typical motor vehicle (such as the Suzuki SX4 achieving 16-20 km/L) can travel over 700 km. However, a battery with equivalent energy capacity to 50 liters of fuel would be considerably heavier and voluminous. For instance, using current battery technology, a 100 kWh lithium-ion battery capable of providing a 500 km range could weigh between 800-900 kg.

Table 1:

Battery Type	**Specific Energy**	**Specific Power (W/Kg)**	**Cell Voltage (V)**	**Cycles**	**Life (Years)**	**Maximum Depth of Discharge**	**Self Discharge rate**	**Efficiency (%)**

	(Wh/ Kg)							
Lead Acid	35-50	150-400	2.1	250-1,000	5 years	20-80%	2-8%/month, some 20-30%/month	75-85
Nickel-Iron	50-60	80-150	1.5	2000	20 years	80%	20-40% /month	-
Nickel-Cadmium	30-60	80-150	1.2	1000-50,000	10-15 years	60-80%	5-15% /month	60-70
Nickel-Hydrogen	50	220	1.4	1500-6000	15 years	-	Very high except at low temperatures	-
Nickel-Metal Hydride	60-80	200-300	1.2	300-600	2-5 years	-	15-25% /month	-
Nickel-Zinc	70-100	170-260	1.6	Up to 500	-	100%	<20% /month	-
Lithium Ion	80-180	200-1000	3.05 -4.2	3,000	5+ years	100%	2-10% / month	-
Sodium Sulfur	150-240	230	2.71	2,500-40,000	-	100%	-	86-89
ZEBRA	90-120	130-160	2.58	-	-	-	-	-
Vanadium Redox Flow	0-30	100	1.2	10,000	7-15 years	100%	-	85
Zinc-Bromine Flow	65-85	90-110	1.8	2,000	-	100%	-	75-80
Zinc Air	200	100	1.6	300	-	-	-	50

Table 2.1 Comparision Of Major Battery Technologies

Melissa Morris and Sabri Tosunoglu (2012)

Note:

- Energy density is measured in watt-hours per kilogram (Wh/kg).
- Power density is measured in watts per kilogram (W/kg).
- Cycle life denotes the quantity of charge-discharge cycles a battery can endure before experiencing a notable decline in capacity.Charge time indicates the typical time required to recharge a battery from empty to full.
- The nominal voltage of a battery refers to its average voltage output during normal operation.

FACTORS THAT AFFECT ELECTRIC CAR CHARGE SPEED

The duration required to charge an electric car is influenced by various factors, encompassing the size of the EV battery, the charging station's speed, the car's onboard charger's maximum capacity, the initial charge level upon plugging in, and the ambient temperature.

HOW DOES BATTERY SIZE AFFECT CHARGING

When all other factors remain constant, a larger battery will require a longer charging duration compared to a smaller battery. Electric vehicle (EV) batteries currently vary in size from approximately 30 kWh to over 200 kWh. To demonstrate the effect of battery size on charging time, let's consider two EVs utilizing Level 2 charging at a rate of 9.6 kW, which represents an optimal scenario for home chargers using the common NEMA 14-50 wall outlet. One of the EVs has a usable battery capacity of 40 kWh, while the other has 80 kWh. As expected, doubling the battery size results in a doubling of the charging time.

sable battery capacity	Level 2 charging time (9.6 kW)
40 kWh	4.5 hours from empty to full
80 kWh	9 hours from empty to full

Table 2.2 How Battery Size Affects Charging

DIFFERENT CHARGING STATION SPEEDS

This represents the speed equivalent of gas station pumps, with three distinct levels ranging from slowest to fastest: Level 1, Level 2, and DC fast charging, also known as Level 3.

LEVEL 1 CHARGING

Level 1 charging utilizes a standard outlet found in homes, offering convenience but at a slower rate of roughly 1.2 kW. For instance, a 2023 Chevrolet Bolt EV connected to a standard 120-volt outlet would require approximately 60 hours to achieve a full charge from empty. Conversely, a 2023 GMC Hummer EV with its large battery could take a staggering 200 hours—equivalent to eight days—to reach a full charge using the same outlet. This method of charging is ideal for plug-in hybrids like the Toyota Prius Prime, which boasts a modest 13.3-kWh battery fully replenished in about 12 hours. (Dericioglu et al., 2018)

LEVEL 2 CHARGING

Level 2 charging utilizes a 240-volt outlet, offering the fastest home charging option available, as higher voltage levels are typically reserved for industrial or commercial use. Level 2 chargers can be found in workplaces, public spaces, and residential settings. Installing a 240-volt outlet may require the expertise of an electrician to ensure compatibility with your home's electrical system.

For instance, the previously mentioned Chevy Bolt EV would take approximately 7.5 hours to charge from empty to full on a Level 2 charger, assuming a charge rate of 9.6 kW per the maximum output of a NEMA 14-50 setup. The Prius Prime, limited by its 6.6-kW onboard charger, could charge in about two hours. However, the Hummer EV would necessitate a substantial 24.5 hours to achieve a full charge from zero. (Khan et al., 2018)

Vehicle	Level 1 charging time (1.2 kW)	Level 2 charging time (9.6 kW)
2023 Chevy Bolt EV	60 hours	7.5 hours
2023 GMC Hummer EV	196 hours	24.5 hours

Table 2.3 Comparing Level 1 & 2 Charging Times

LEVEL 3 CHARGING

Level 3, also known as DC fast charging, offers a rapid charging solution capable of adding 180 to 240 miles of range per hour, according to estimates by the U.S. Department of Transportation. These chargers are commonly found in office parks, shopping centers, or specialized charging stations. Unlike other charging methods, DC fast charging delivers power directly to the battery, bypassing the vehicle's onboard charger.

DC fast charging stations typically range in output from 25 kW to 350 kW, although the actual charging speed may vary based on various factors. It's important to note that as an EV approaches a full charge, both the car and the charging station may adjust the charging rate accordingly.

While DC fast charging stations offer rapid charging, they tend to be the most expensive option due to high installation and maintenance costs. Additionally, prolonged use of DC fast chargers can increase battery temperatures, potentially shortening the battery's lifespan. As a result, DC fast charging is best suited for road trips or when quick top-ups are needed for extended driving.

(Falvo et al., 2014)

In the table below, we utilize the Tesla Model Y as an example of an EV compatible with DC fast charging, as opposed to the Chevy Bolt EV, which has limited compatibility with such chargers. The Model Y can achieve a charging rate of up to 250 kW, matching the maximum charge rate at Tesla Supercharger stations. Conversely, plug-in hybrids like the Prius Prime typically lack support for DC fast charging.

Charger speed	**EV charge time from empty (Tesla Model Y)**	**PHEV charge time from empty (Toyota Prius Prime)**	**Typical charger locations**
Level 1 (1.2 kW)	69.5 hours	12 hours	home
Level 2 (9.6 kW)	8.5 hours	2 hours	home, workplace, public
DC fast (250 kW)	about an hour	not supported	public

Table 2.4 Comparing Level 1-3 Charging Times

CHARGING SPEED COMPARISM OF POPULAR ELECTRIC CARS

Vehicle	**Level 2 charge time**	**Onboard charger max rate**	**Usable battery capacity**
2024 Audi Q8 e-tron	12.5 hours	19.2 kW	106 kWh

Vehicle	Level 2 charge time	Onboard charger max rate	Usable battery capacity
2023 Chevrolet Bolt EV	7.5 hours	11.5 kW	65 kWh
2023 Ford Mustang Mach-E Extended Range	10.5 hours	11.5 kW	91 kWh
2023 GMC Hummer EV	24.5 hours	11.5 kW	212 kWh
2023 Hyundai Ioniq 5 Long Range	8.5 hours	11 kW	74 kWh
2023 Kia Niro EV	7.5 hours	11 kW	64.8 kWh
2023 Nissan Leaf Plus	10 hours	6.6 kW	59 kWh
2023 Polestar 2	8.5 hours	11 kW	75 kWh
2023 Tesla Model 3 Long Range	8.5 hours	11.5 kW	75 kWh
2023 Tesla Model Y Long Range	8.5 hours	11.5 kW	75 kWh

Vehicle	Level 2 charge time	Onboard charger max rate	Usable battery capacity
2023 Volkswagen ID.4 Pro	9 hours	11 kW	77 kWh

Table 2.5 Charging Speed Comparism Of Popular Electric Cars

RELATED WORKS

Battery swap station (BSS)

The transportation industry emits huge amounts of carbon dioxide and pollutants into the environment on a global scale. The adoption of electric vehicles (EVs) has the potential to significantly reduce carbon emissions while also providing critical energy storage to aid in the adoption of distributed renewable power. This study focuses on a design concept and methodology for promoting EV adoption by automating the switching of battery packs at battery sharing stations (BShS) as part of a battery sharing network (BShN), which would eventually become integrated into the smart grid. Current battery switching approaches are evaluated, and a new practical methodology is offered that takes into account both technical and socioeconomic implications. The suggested BShS/BShN provides unique answers to some of the most important difficulties with EV adoption.(Adegbohun et al., 2019)

Bidirectional DC/DC Converter with Dual-Battery Energy Storage

A bidirectional dc/dc converter architecture with two-phase and interleaved features was implemented by Lai et al. The converter features an increased voltage conversion ratio for EV and dc-microgrid systems. Additionally, Lai researched a high voltage conversion ratio bidirectional DC to DC converter (BDC) topology for EV batteries linked to a DC microgrid system. The primary battery storage component in FCV systems is often utilized to power the propulsion engine and initiate the FC. By giving the battery storage devices their maximum power when the vehicle accelerates, they help the FC stack's intrinsically poor response time. Additionally, it has a high power density component that removes peak power transients during braking and acceleration, such as supercapacitors (SCs). SCs can generally store regenerative energy during deceleration and release it during acceleration, thereby supplying additional power. (Lai et al., 2018)

Wireless power transfer

In wireless power transfer, an air-core wireless transformer proposal is used to transfer electrical power from the source to the receiver sides. the various designs for the WPT system includes; numerous planar coil shapes, including circular, rectangular, and hybrid configurations, were used to recover performance and solve misalignment issues among the transmitter and receiver. Multiple wireless power transfer structures for motorized applications are evaluated in the literature to assess magnetic couplings and feasibility. Most of these studies focused on structures with circular designs, and recently and tested a circular planar structure for a 2 kW inductive power transfer. The null zone has been shown to be the least effective among various models. The efficiency of resonant coupling in power transmission largely hinges on the characteristics of the resonators employed. An effective resonator for wireless power transfer (WPT) should exhibit a high quality factor (Q factor) and a high coupling coefficient, which is defined as the ratio of mutual inductance to self-inductance. (Lukic & Pantic, 2013)

CHAPTER THREE

METHODOLOGY

Overview of Modelling and Simulation

Modeling and simulation are crucial techniques in engineering analysis, offering deep insights into complex systems and enabling optimization without the need for costly physical prototypes. These approaches are widely used to predict system behavior, test design improvements, and increase efficiency across a range of engineering disciplines.

At the core of modeling is the creation of accurate digital representations of real-world systems, which allow for detailed analysis of how various components interact and perform under different conditions. One common form of modeling is **structural analysis**, which involves using **finite element analysis (FEA)** to simulate how stress is distributed across a material or structure, how much deformation occurs under load, and how long the component might last before fatigue sets in. These simulations are instrumental in identifying weak points and optimizing designs to improve both strength and durability.

Simulations, on the other hand, use mathematical models to replicate the behavior of systems over time or under specific scenarios. These virtual tests allow engineers to observe how a design will respond to various factors, such as material properties, external loads, and environmental conditions. Such simulations help in predicting system behavior, making adjustments, and fine-tuning the design to enhance performance, all without the need for real-world testing.

This project involved two main types of modeling: **geometric modeling** and **mathematical modeling**.

Geometric modeling is a critical component of **computer-aided design (CAD)** and is used to create visual representations of physical objects, systems, or environments in a digital space. This modeling approach allows for the visualization and manipulation of complex shapes, making it possible to refine designs before manufacturing. In CAD, objects can be modeled in either 2D or 3D. While 2D models are useful for simpler shapes and layouts, 3D models provide a more detailed and realistic representation of intricate objects. These 3D models are often generated by taking 2D profiles and “extruding” them to create a full volumetric form. This allows engineers to fully assess how parts will look and interact in real-world settings.

In contrast, **mathematical modeling** involves the use of equations—ranging from simple algebraic to complex differential equations—to describe how a system functions. These equations provide a powerful framework for simulating the behavior of a system under various conditions. The use of mathematical models in simulations offers several advantages: they can accurately represent both simple and complex systems, and they are cost-effective because they eliminate the need for physical prototypes. Additionally, they offer flexibility, allowing engineers to adjust variables and instantly see how these changes affect the system.

However, mathematical models also come with limitations. One major challenge lies in balancing the simplicity of the model with the need to capture the complexities of real-world behavior. Models are often based on certain assumptions and approximations, which, while making the analysis more manageable, can lead to oversimplifications. As a result, while a model may perform well under controlled conditions, it may not account for all the variability and intricacy found in actual environments. This trade-off between simplicity and accuracy is a key consideration when using mathematical models to guide engineering decisions.

Mathematical modeling can be approached from two distinct but complementary perspectives: **analytical** and **computational**. These methods are particularly important in complex simulations, such as **flow simulations**, where fluid behavior needs to be accurately represented. Here’s how each approach works:

Analytical Approach:

The **analytical approach** to mathematical modeling involves deriving exact solutions to governing equations that describe the physical system. In the context of **flow simulations**, these governing equations are typically based on **fluid dynamics**, such as the **Navier-Stokes equations**, which describe how fluids (liquids or gases) behave under various conditions of pressure, velocity, and external forces.

- **Analytical models** use these equations to provide direct, closed-form solutions for simplified cases. For example, in simple laminar flows (like flow through a pipe), it's possible to solve the governing equations analytically to determine velocity profiles, pressure drops, or flow rates.
- **Advantages**: Analytical models provide precise and often elegant solutions to fluid problems. They are valuable for understanding the fundamental behaviors of fluids and serve as benchmarks for validating more complex computational models.
- **Limitations**: However, exact solutions are only possible for simplified cases (e.g., steady-state or one-dimensional flows). Real-world problems, such as turbulent flows or flows with complex geometries, are often too intricate to be captured analytically due to non-linearities in the equations.

Computational Approach:

The **computational approach** involves using **numerical methods** to approximate the solutions of the governing equations for complex flow scenarios. This is where **computational fluid dynamics (CFD)**, like in **ANSYS Fluent**, comes into play.

- **Numerical Discretization**: Instead of attempting to solve the equations analytically, the fluid domain is discretized into small elements (in 2D) or volumes (in 3D) through techniques like the **finite difference**, **finite element**, or **finite volume methods**. The continuous fluid equations (like the Navier-Stokes) are then solved numerically at discrete points within this domain.
- **Flow Simulations**: For flow simulations, computational methods break down the system into smaller parts, applying iterative algorithms to solve for flow variables (such as velocity, pressure, and temperature) across the domain. These techniques are powerful in handling non-linear, transient, and multi-dimensional flows.
- **Advantages**: CFD and other computational techniques can handle highly complex scenarios, including turbulent flows, heat transfer, chemical reactions, and multiphase flows. Unlike the analytical approach, computational models can simulate real-world situations with intricate geometries, boundary conditions, and material properties.

- **Limitations**: The computational approach, however, requires significant computational resources, especially as the complexity of the system increases. Also, the accuracy of the results depends on the quality of the grid and the solution algorithms used, and there is always some level of approximation in the solution.

Application in Flow Simulations:

In **flow simulations**, both analytical and computational approaches are used in tandem:

1. **Analytical methods** are often applied to simpler cases or used as a benchmark to validate computational models. For instance, engineers may use an analytical model to predict the pressure drop in a straight pipe as a reference case.
2. **Computational methods** take over when the flow behavior is too complex for an analytical solution. For example, turbulent flow in an engine or around an aircraft wing would require the full power of CFD tools to model accurately.

Both approaches play a role in achieving a comprehensive understanding of flow phenomena, with the analytical method laying down foundational principles and computational models expanding into more complex, real-world applications.

Overview Of Materials Used:

1. **SolidWorks**: SolidWorks is a feature-rich computer-aided design (CAD) software that is extensively used in the fields of engineering and product design for creating 3D models, assemblies, and simulations. Known for its intuitive interface and parametric modeling capabilities, SolidWorks allows users to design complex mechanical systems with high precision. In this project, SolidWorks is utilized to model the physical geometry of both the single and dual battery pack configurations, as well as the associated cooling systems. The software facilitates the creation of accurate 3D representations that are essential for the thermal and fluid simulations that follow.

Key functionalities of SolidWorks relevant to this study include:

a. **Parametric 3D Modeling**: SolidWorks enables the creation of battery pack models with precise dimensions and scalable features. This parametric modeling allows for easy adjustments to the design, ensuring flexibility when iterating between single and dual pack configurations. This is particularly useful when optimizing the design for thermal management.
b. **Assembly Creation**: SolidWorks allows for the integration of multiple components into assemblies. In this case, the battery cells, cooling systems, and external casing are combined to reflect real-world conditions. This assembly approach helps in modeling the interactions between the battery and cooling systems.
c. **Simulation and Stress Analysis**: Though not the primary simulation tool for this project, SolidWorks has basic simulation capabilities that can be used to verify the structural integrity of the battery pack and its components under various mechanical stresses, such as thermal expansion. This provides an additional layer of validation before exporting models to ANSYS Fluent for thermal and fluid analysis.
d. **Export for Simulation**: Once the battery packs are modeled, SolidWorks provides seamless export functionality (typically in formats like STEP or IGES) to ANSYS Fluent. The exported models preserve all geometric and material properties, ensuring accuracy in the thermal simulations.

2. **ANSYS Fluent**: ANSYS Fluent is a leading computational fluid dynamics (CFD) software that specializes in solving complex problems involving fluid flow, heat transfer, and related physical phenomena. It is particularly useful for simulating thermal behavior and fluid dynamics in systems with intricate geometries, such as battery packs. In this study, ANSYS Fluent will be employed to perform transient thermal simulations, with a focus on assessing temperature distribution during the charging process, both with and without active cooling systems.

Key functionalities of ANSYS Fluent relevant to this study include:

a. **Transient Thermal Analysis**: ANSYS Fluent allows for detailed transient simulations, which are critical in modeling the real-time behavior of temperature changes within the battery packs during charging. By simulating the thermal response over a set period (e.g., one hour), the software provides insights into how quickly the battery heats up and how efficiently the cooling system mitigates thermal buildup.

b. **Heat Transfer and Fluid Flow Simulation**: The software excels at modeling conductive and convective heat transfer within and around the battery packs. In the case of active cooling systems, Fluent simulates the flow of coolant (liquid or air) and evaluates how effectively it removes heat from the battery cells. This is particularly important for preventing overheating and ensuring optimal charging conditions.

c. **Battery Material Properties and Thermal Modeling**: ANSYS Fluent supports the application of specific material properties such as thermal conductivity, specific heat, and electrical resistance, which are critical for accurately simulating battery performance. This allows the software to predict temperature gradients and hotspots within the battery cells during charging, giving a clear picture of the thermal stress placed on each configuration.

d. **Active Cooling Systems**: For configurations that include active cooling, Fluent is used to model the dynamics of the cooling medium (air or liquid) as it interacts with the battery pack. The software provides insights into how different cooling designs (e.g., air ducts, liquid cooling channels) influence the temperature distribution and charging efficiency.

e. **Post-Processing and Visualization**: ANSYS Fluent includes advanced post-processing tools that generate detailed visualizations of the simulation results. This includes temperature contour maps, heat flux vectors, and flow streamlines, which are crucial for understanding the heat transfer dynamics and for comparing the performance of single versus dual battery pack configurations. These results will help to identify areas of thermal inefficiency and suggest improvements for future designs.

Governing Equations and Physics Models

This study employed a combination of governing equations and physics models to simulate the behavior of battery systems during charging. These equations and models were implemented in **ANSYS Fluent**, using a framework that integrates multiphysics interactions, including electrical, thermal, and electrochemical phenomena. The specific governing equations and models are outlined below:

1. **Electrochemical Model**

The electrochemical behavior of the battery was modeled using the **Equivalent Circuit Model (ECM)**, which simplifies the complex electrochemical processes into manageable electrical components such as resistors and capacitors. This model represents the battery as a combination of:

- **Open Circuit Voltage (OCV):** Represents the potential difference when no current flows.
- **Internal Resistance:** Accounts for ohmic losses within the battery.
- **Capacitance:** Represents the charge storage capability and transient response.

The ECM equations include:

$$V = OCV - IR_{\text{int}}$$

Where:

- V = Terminal voltage
- I = Current
- Rint = Internal resistance

2. State of Charge (SOC)

The **SOC** was tracked to measure the energy stored in the battery. It is calculated using the following relationship:

$$SOC = SOC_{\text{initial}} - \frac{1}{C} \int I \, dt$$

Where:

- SOCinitial = Initial state of charge
- C = Capacity of the battery
- I = Charging or discharging current
- t = Time

SOC contours were used to visualize and compare the charging efficiency of single and dual battery configurations.

3. Energy Equation

The **energy equation** governs the thermal behavior of the battery system, accounting for heat generation due to joule heating and electrochemical reactions. The energy conservation equation is expressed as:

$$\rho c_p \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = q$$

Where:

- ρ = Density of the material
- pc_p = Specific heat capacity
- T = Temperature
- k = Thermal conductivity
- q = Heat generation per unit volume

Simulation Workflow

The design phase of the simulation was carried out using **SolidWorks** to model the battery configuration. Given the goal of reducing computational resource demand, the complexity of a large battery pack (which typically contains hundreds of individual cells) was simplified. Instead of modeling a full-scale battery with intricate details, the battery cells were represented as **pouch lithium-ion cells**—a widely used battery format in electric vehicles. These cells feature a rectangular active region with two square terminals or "tabs" for the positive and negative connections. The single configuration consisted of six cells connected in series using five separate bussbars, while the dual configuration consisted of three cells each also connected in series by two bussbars. The final designs were saved in **.acis format** for compatibility with ANSYS.

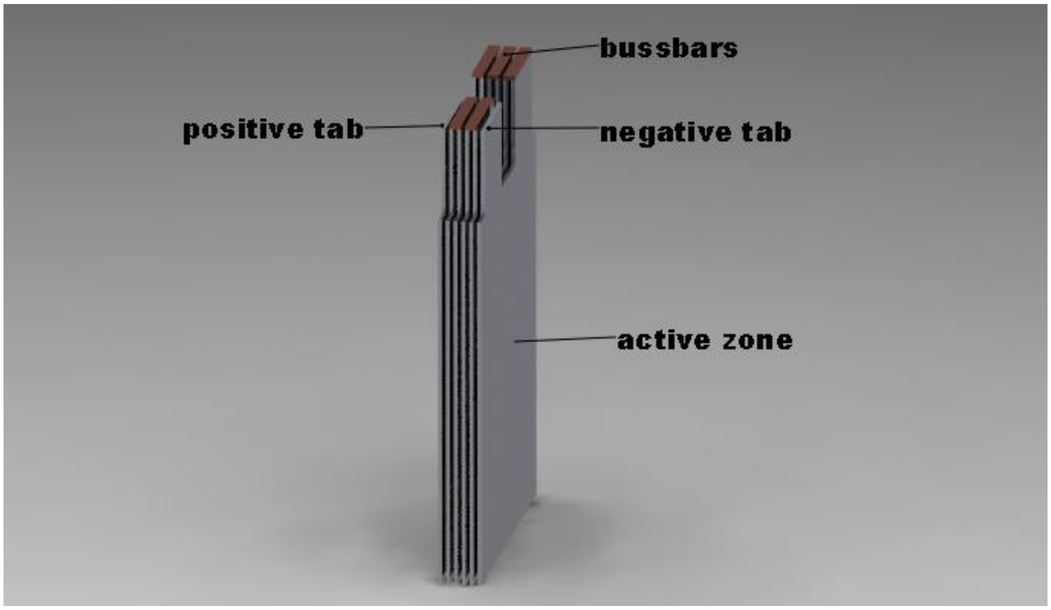

Figure 3.1 Single configuration without active cooling

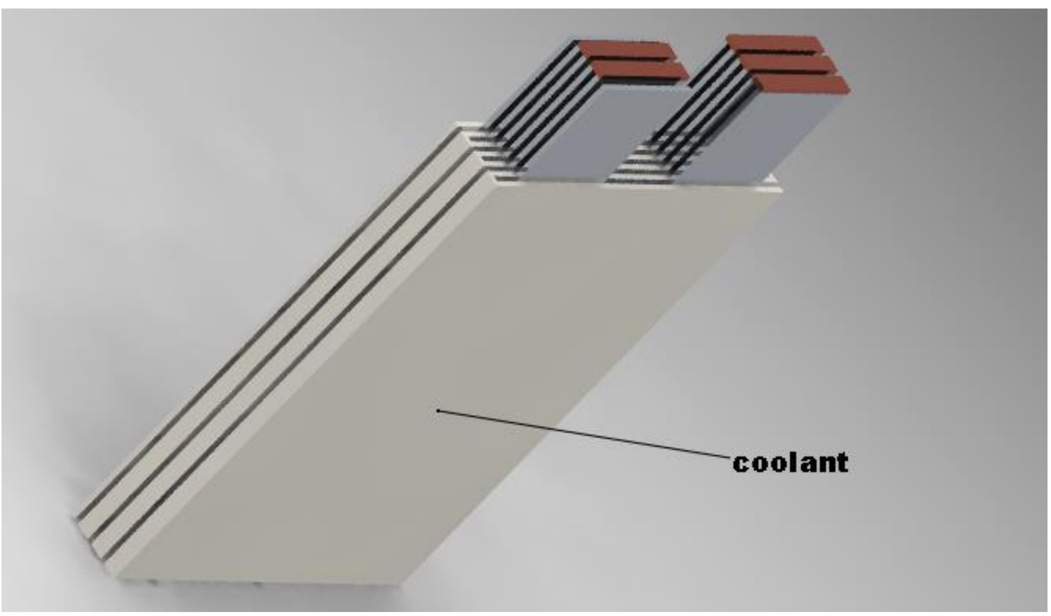

Figure 3.2 Single configuration with active cooling

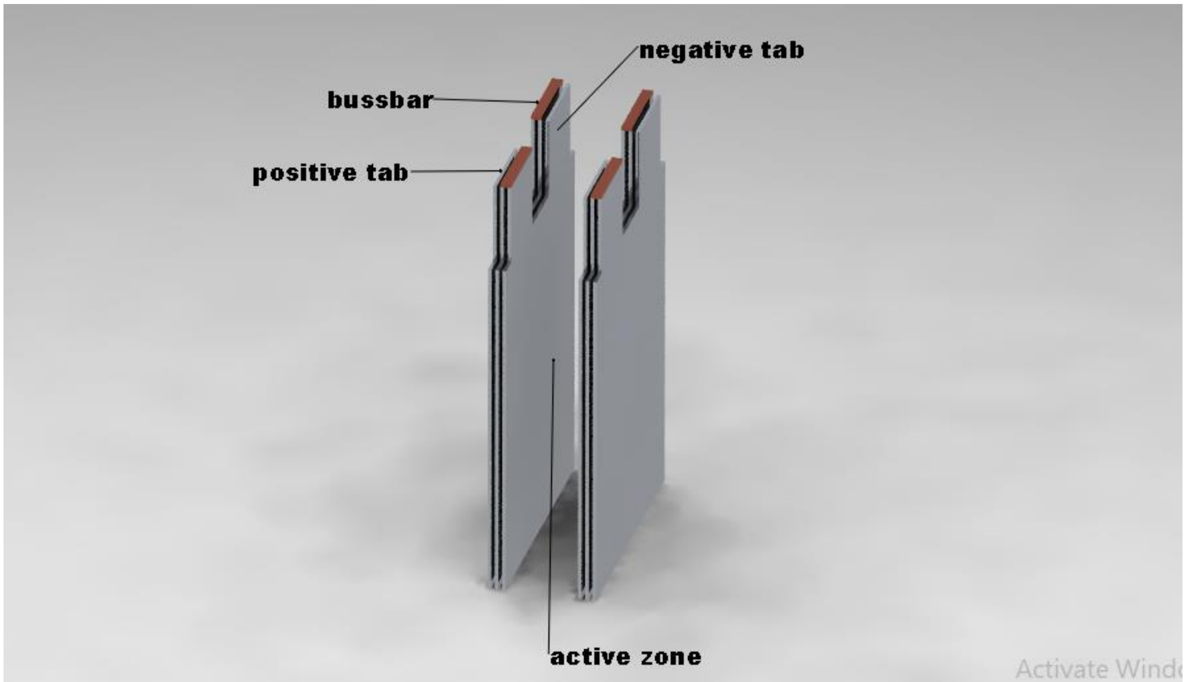

Figure 3.3 Dual configuration without active cooling

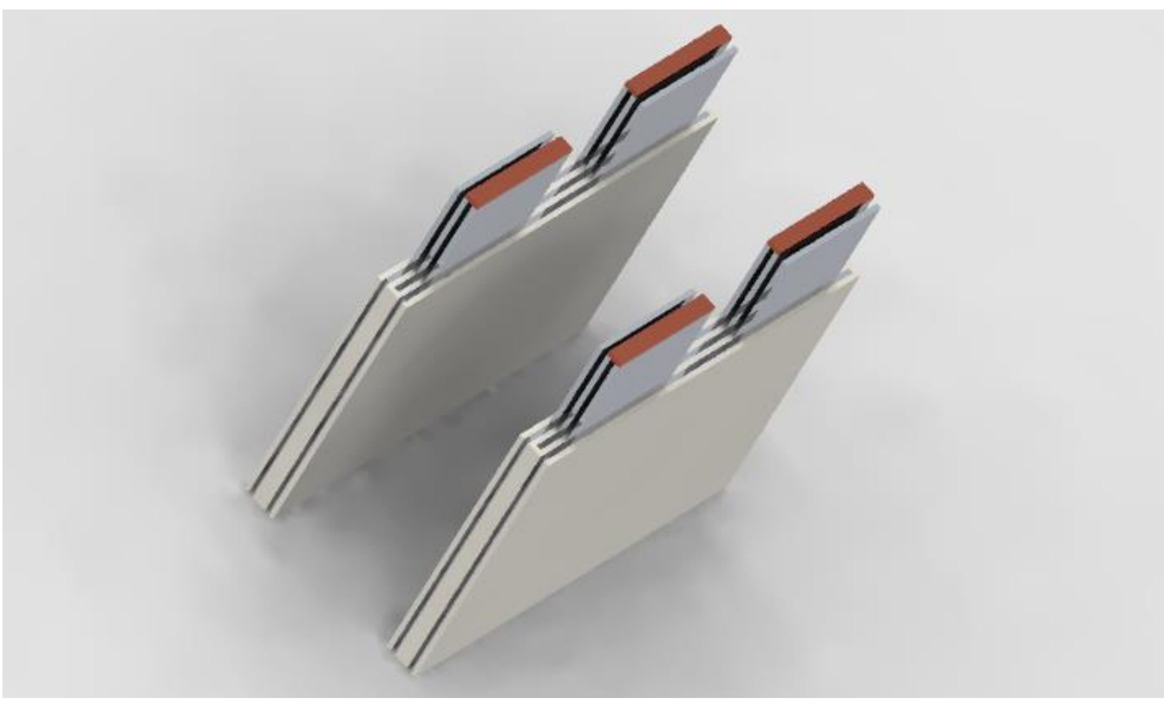

Figure 3.4 Dual configuration with active cooling

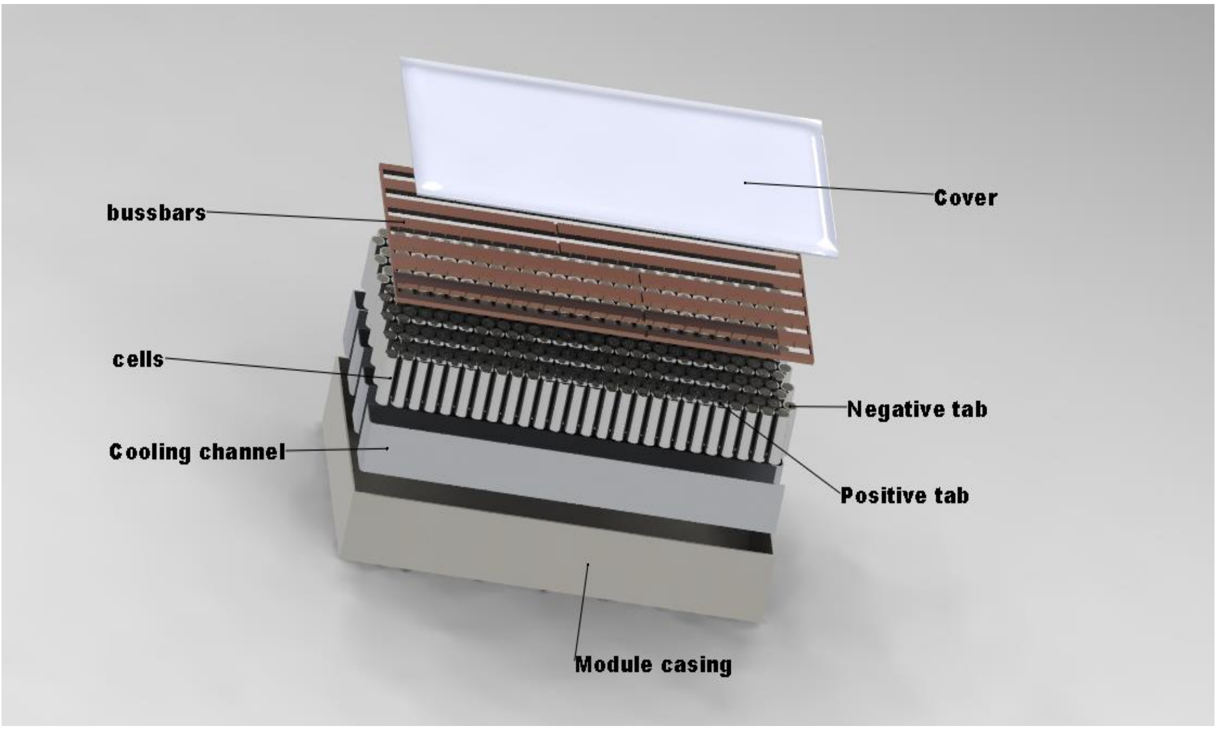

Figure 3.5 Actual battery module of most electric cars

The model was then imported into **ANSYS Fluent** using the **Fluid Flow (Fluent)** analysis system, where the next stage of the simulation began. In Fluent, a **meshing process** was applied to discretize the model. Care was taken to ensure a high-quality mesh that would capture the key thermal and electrical characteristics of the system. Several **named selections** were defined to facilitate the setup, including labels for the **active region**, **positive tab**, **negative tab**, and **busbars**.

After meshing, the model was transferred to **ANSYS Fluent** for detailed simulation setup. The **battery model** was activated, along with the **energy physics model** to account for heat generation and transfer during charging. The solution method was set to **Multi-Scale Multi-Domain (MSMD)**, a commonly used approach for battery simulations, which allows for accurate prediction of the electrochemical and thermal behavior of the cells. Additionally, the **Electrochemistry model (ECM)** was enabled to simulate the behavior of the lithium-ion cells during the charging process.

Conductive zones and **electric contacts** were assigned to model the flow of current and heat within the system, ensuring proper representation of electrical interactions. Parameters specific to the **equivalent circuit model** were also defined to represent the internal behavior of the battery cells. These settings allowed Fluent to calculate the heat generation, internal resistance, and state of charge (SoC) dynamics during charging.

The material properties of the battery components, such as thermal conductivity and electrical resistivity, were defined for the active zone, tabs, and busbars. The **cell zones** were set to capture internal heat generation, while the **boundary conditions** ensured accurate heat transfer and electrical flow at the interfaces between the tabs and busbars. Once all parameters were configured, **report plots** were created to track two critical metrics over time: **State of Charge (SoC)** and **temperature**.

Before running the simulation, a **hybrid initialization** was performed to set initial conditions across the model, ensuring the simulation would converge properly. The simulation was run for a **1-hour charging period**, tracking the evolution of both SoC and temperature throughout the process.

The simulation was conducted for both the **single** and **dual battery configurations**, with and without **active cooling**. The results were computed, and **contour plots** for SoC and temperature distribution were generated for each configuration. These plots provided detailed insights into how charge and heat were distributed within the cells over time.

Finally, the results for each configuration were compared, highlighting differences in charging performance and thermal management between the single and dual battery setups, with specific attention to the role of active cooling in improving thermal regulation. These findings were used to draw conclusions regarding the potential benefits of the dual-battery configuration for reducing charging time and managing thermal effects more effectively.

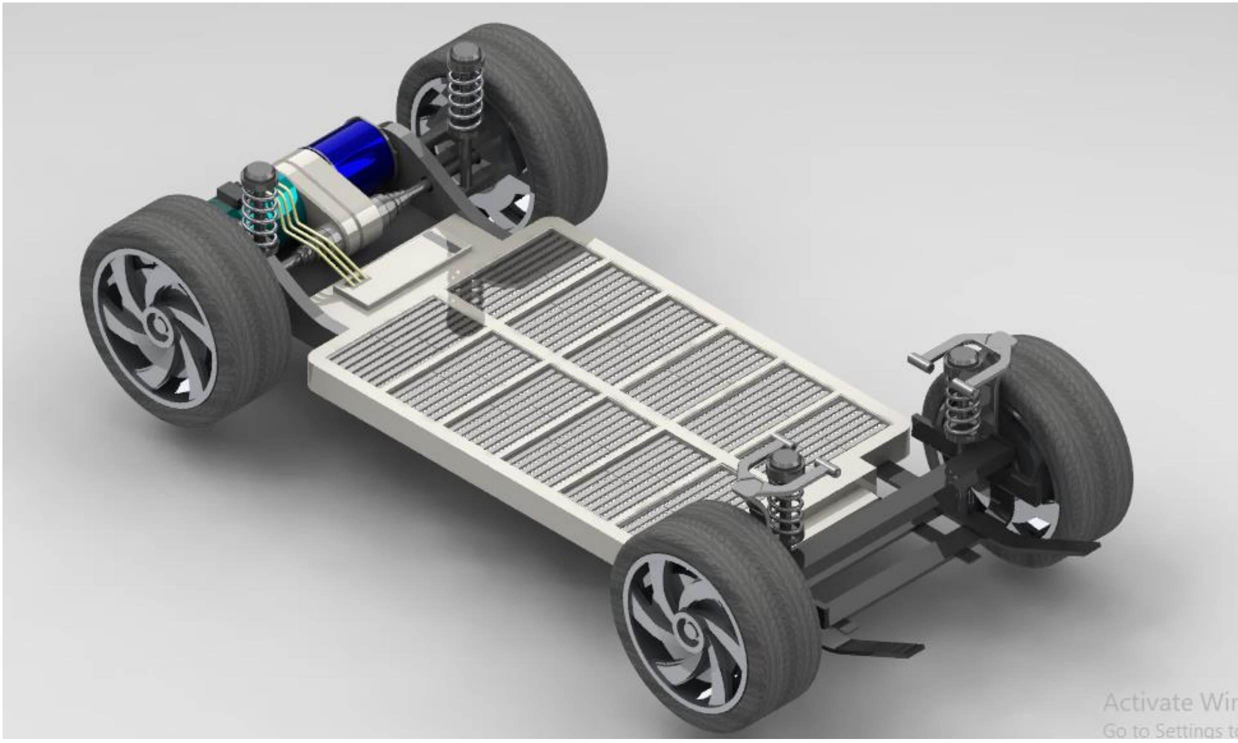

Figure 3.6 Solidworks model view of an electric vehicle base and chassis assembly

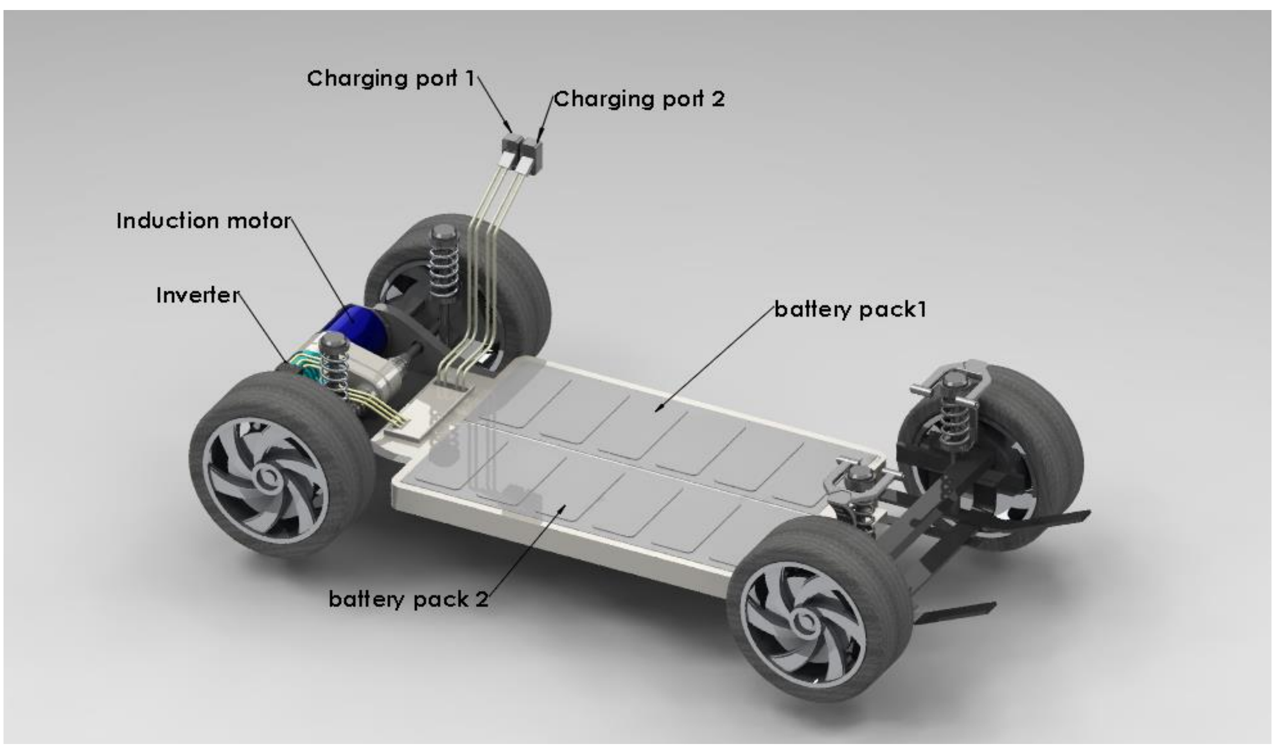

Figure 3.7 Model view with a dual battery pack configuration

CHAPTER FOUR

RESULTS AND DISCUSSIONS

This section presents the results obtained from the simulation of both the single and dual battery configurations under various conditions, followed by an in-depth analysis of their implications. The simulations were conducted with a focus on key parameters such as **State of Charge (SoC)** and **temperature distribution** during a 1-hour charging period. The performance of the battery systems was evaluated with and without active cooling, providing insights into the thermal behavior and charging efficiency of the configurations.

By comparing the results, this discussion aims to assess the potential benefits of the dual-battery configuration in reducing charging time and enhancing thermal management. Additionally, the effectiveness of active cooling in mitigating temperature rise during charging will be evaluated. The findings are analyzed to draw conclusions regarding the optimal configuration for improving electric vehicle battery charging performance and safety.

1. SINGLE PACK WITHOUT ACTIVE COOLING

a. Geometry and Mesh

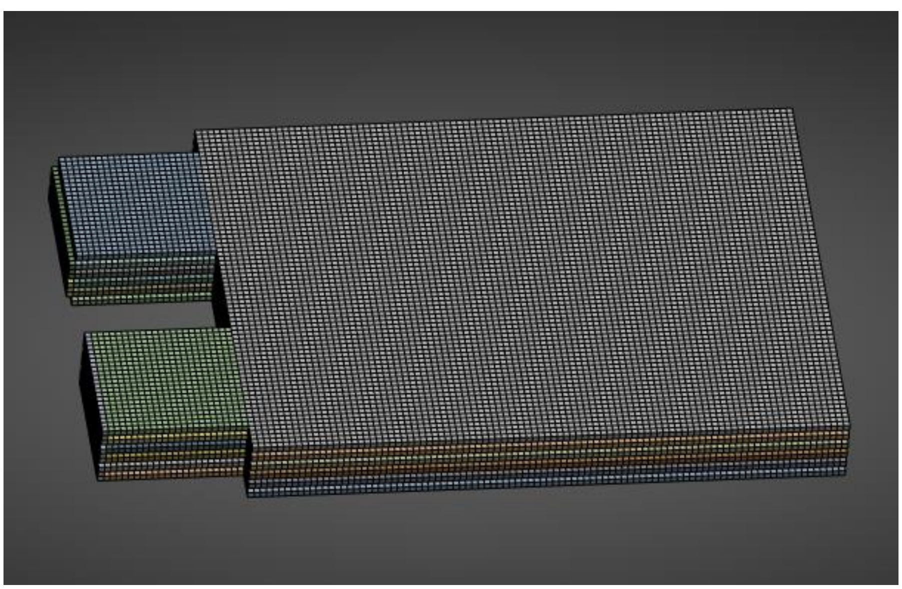

Figure 4.1 Mesh model for single pack without active cooling

- **Mesh Size**

Cells	Faces	Nodes
48741	197731	100920

Table 4.1 Mesh Size (SINGLE PACK WITHOUT ACTIVE COOLING)

b. Physics

- **Models**

Model	Settings
Space	3 D
Time	Unsteady, 1st-Order Implicit
Viscous	SST k-omega turbulence model
Heat Transfer	Enabled
Battery Model	Enabled

Table 4.2 Model (SINGLE PACK WITHOUT ACTIVE COOLING)

- **Battery Model**

Model Options	Settings
Solution Method	Multi-Scale Multi-Domain (MSMD)
E-Chemistry Model	Equivalent Circuit Model
Nominal Cell Capacity	214Ah
Specified System Current	-48A

E-Chem Stop Criterion	State of Charge (SOC) – Min and Max:1
Model Parameters	**Settings**
Initial State of Charge (SoC)	0.1 (10%)
Reference Capacity	214Ah

Table 4.3 Battery Model (SINGLE PACK WITHOUT ACTIVE COOLING)

- **Material Properties**

-Fluid	
Air	
Density	1.225 kg/m^ 3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)
Viscosity	1.7894e-05 kg/(m s)
Molecular Weight	28.966 kg/kmol
-Solid	
Tab material	
Density	8978 kg/m^3
Cp (Specific Heat)	381 J/(kg K)
Thermal Conductivity	387.6 W/(m K)
UDS Diffusivity	10000000 kg/(m s)
Active zone material	
Density	2092 kg/m^3
Cp (Specific Heat)	871 J/(kg K)
Thermal Conductivity	202.4 W/(m K)
UDS Diffusivity	35410000 kg/(m s)

Table 4.4 Material Properties (SINGLE PACK WITHOUT ACTIVE COOLING)

- **Boundary Conditions**

Type	Thermal
Condition	Convection
Heat transfer coefficient	25 W/(m^2 K)
Free Stream Temperature	300K

Table 4.5 Boundary Conditions (SINGLE PACK WITHOUT ACTIVE COOLING)

c. Solution and Results

- **Report Definitions**

temperature-vs-time	541.1166	K
cell-voltage-vs-time	11.96532	V
soc-vs-time	0.3253013 (32.53%)	
battery-max-temperature	561.8683	K
battery-terminal-voltage	71.8293	V
battery-terminal-current	-48	A
delta-time	60	s
iters-per-timestep	20	
flow-time	3600	s

Table 4.6 Report Definitions (SINGLE PACK WITHOUT ACTIVE COOLING)

- **Report Plots**

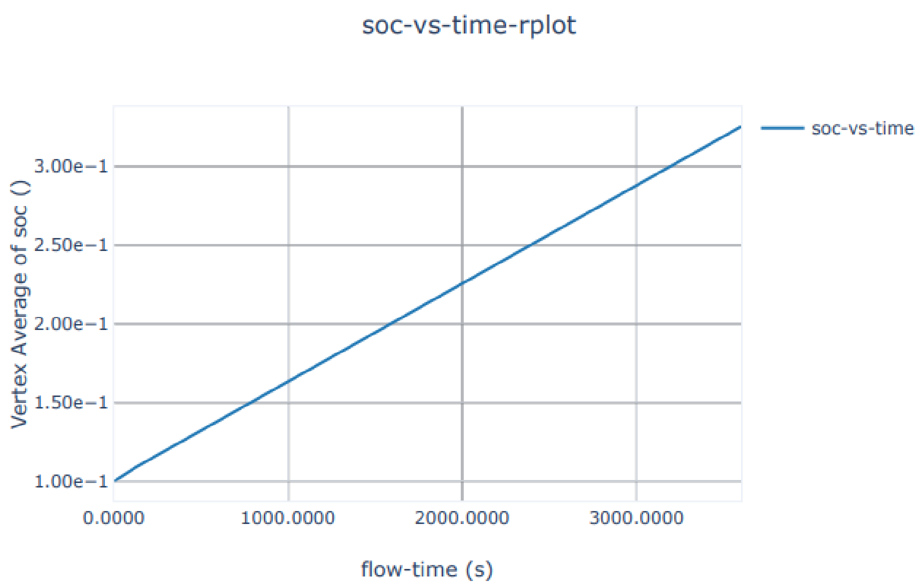

Figure 4.2 Graph of state of charge against time for single pack without active cooling

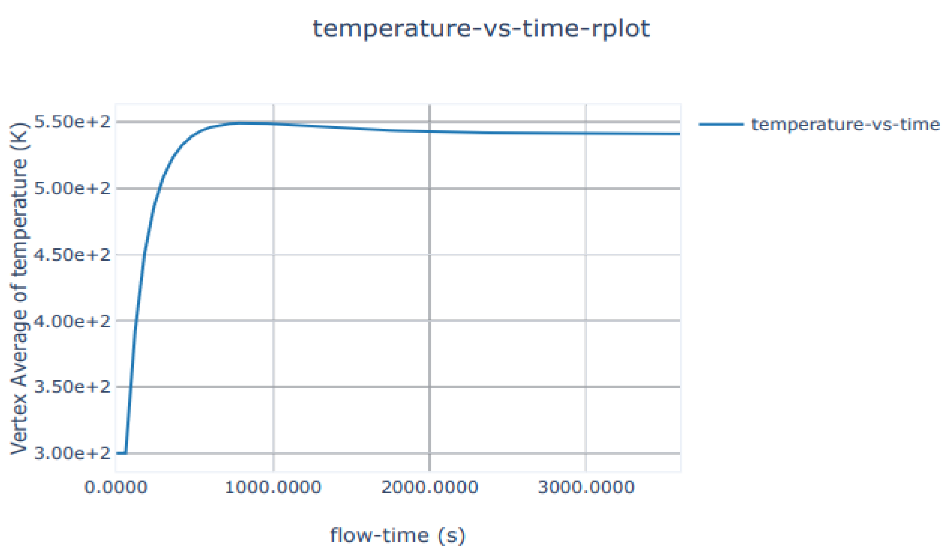

Figure 4.3 Graph of average temperature against time for single pack without active cooling

- **Solution Contours**

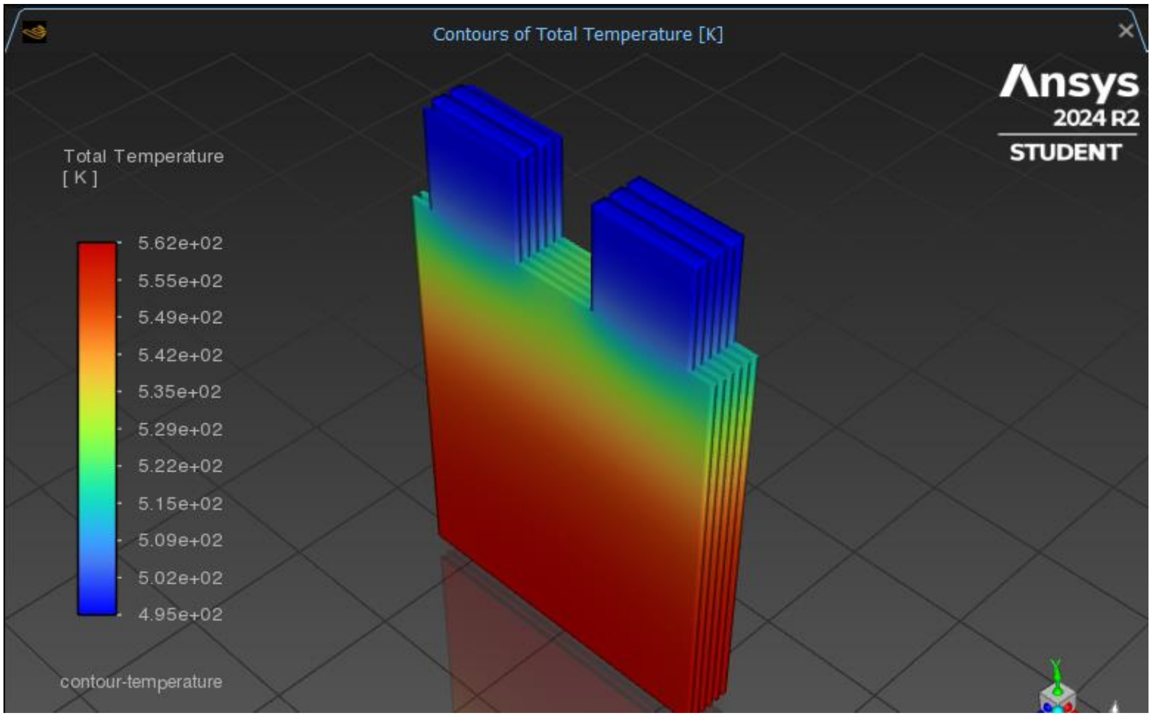

Figure 4.4 Temperature contour for single pack without active cooling

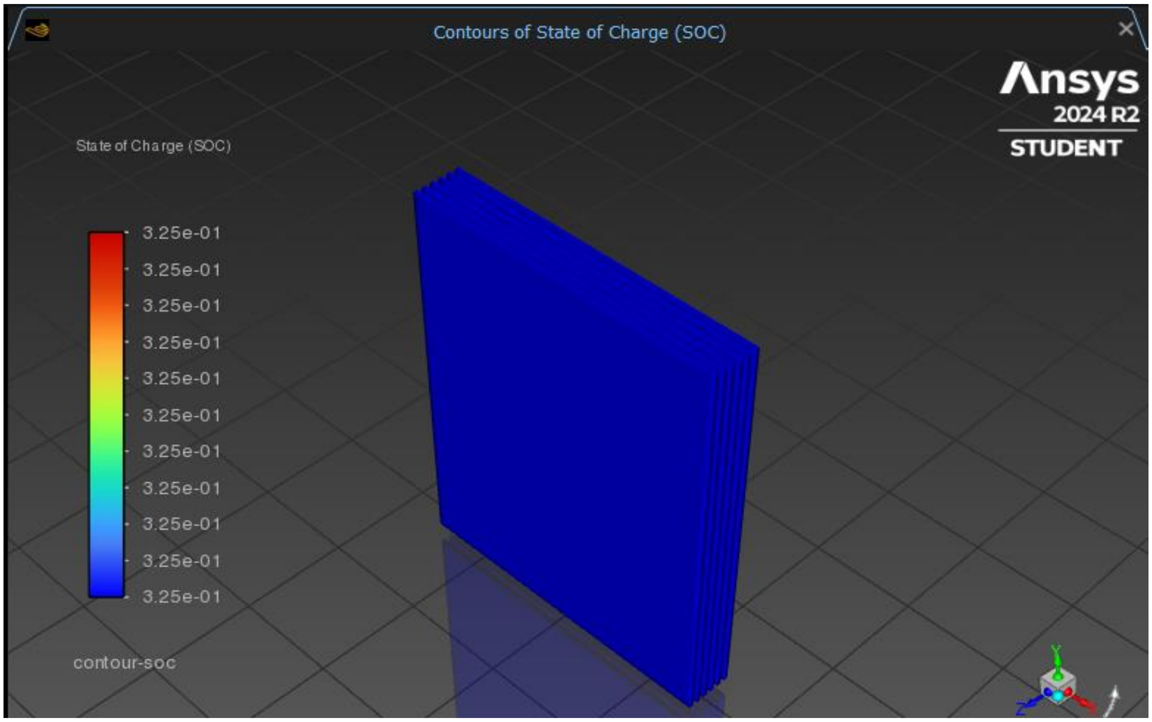

Figure 4.5 Soc contour for single pack without active cooling

2. DUAL PACK WITHOUT ACTIVE COOLING

a. Geometry and Mesh

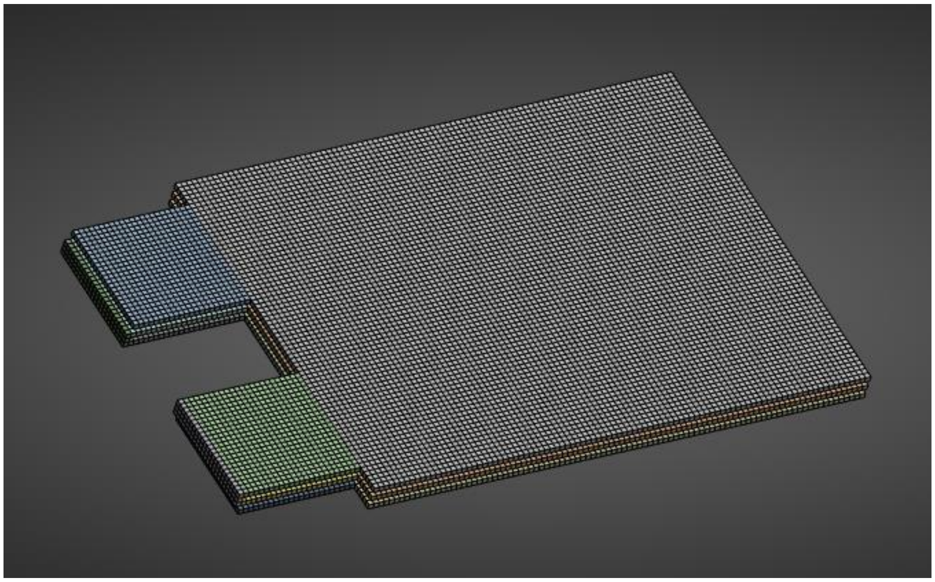

Figure 4.6 Mesh model for dual pack without active cooling

- **Mesh Size**

Cells	Faces	Nodes
24336	98680	50364

Table 4.7 Mesh Size (DUAL PACK WITHOUT ACTIVE COOLING)

d. Physics

- **Models**

Model	Settings
Space	3 D
Time	Unsteady, 1st-Order Implicit
Viscous	SST k-omega turbulence model

Heat Transfer	Enabled
Battery Model	Enabled

Table 4.8 Models (DUAL PACK WITHOUT ACTIVE COOLING)

- **Battery Model**

Model Options	**Settings**
Solution Method	Multi-Scale Multi-Domain (MSMD)
E-Chemistry Model	Equivalent Circuit Model
Nominal Cell Capacity	107Ah
Specified System Current	-48A
E-Chem Stop Criterion	State of Charge (SOC) – Min and Max:1
Model Parameters	**Settings**
Initial State of Charge (SoC)	0.1 (10%)
Reference Capacity	107Ah

Table 4.9 Battery Model (DUAL PACK WITHOUT ACTIVE COOLING)

- **Material Properties**

-Fluid	
Air	
Density	1.225 kg/m^ 3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)
Viscosity	1.7894e-05 kg/(m s)

Molecular Weight	28.966 kg/kmol
-Solid	
Tab material	
Density	8978 kg/m^3
Cp (Specific Heat)	381 J/(kg K)
Thermal Conductivity	387.6 W/(m K)
UDS Diffusivity	10000000 kg/(m s)
Active zone material	
Density	2092 kg/m^3
Cp (Specific Heat)	871 J/(kg K)
Thermal Conductivity	202.4 W/(m K)
UDS Diffusivity	35410000 kg/(m s)

Table 4.10 Material Properties (DUAL PACK WITHOUT ACTIVE COOLING)

- **Boundary Conditions**

Type	Thermal
Condition	Convection
Heat transfer coefficient	25 W/(m^2 K)
Free Stream Temperature	300K

Table 4.11 Boundary Conditions (DUAL PACK WITHOUT ACTIVE COOLING)

e. Solution and Results

- **Report Definitions**

temperature-vs-time	541.5001	K
cell-voltage-vs-time	12.03017	V
soc-vs-time	0.5507243 (55.07%)	
battery-max-temperature	561.7719	K
battery-terminal-voltage	36.10904	V
battery-terminal-current	-48	A
delta-time	60	s
iters-per-timestep	20	
flow-time	3600	s

Table 4.12 Report Definitions (DUAL PACK WITHOUT ACTIVE COOLING)

- **Report Plots**

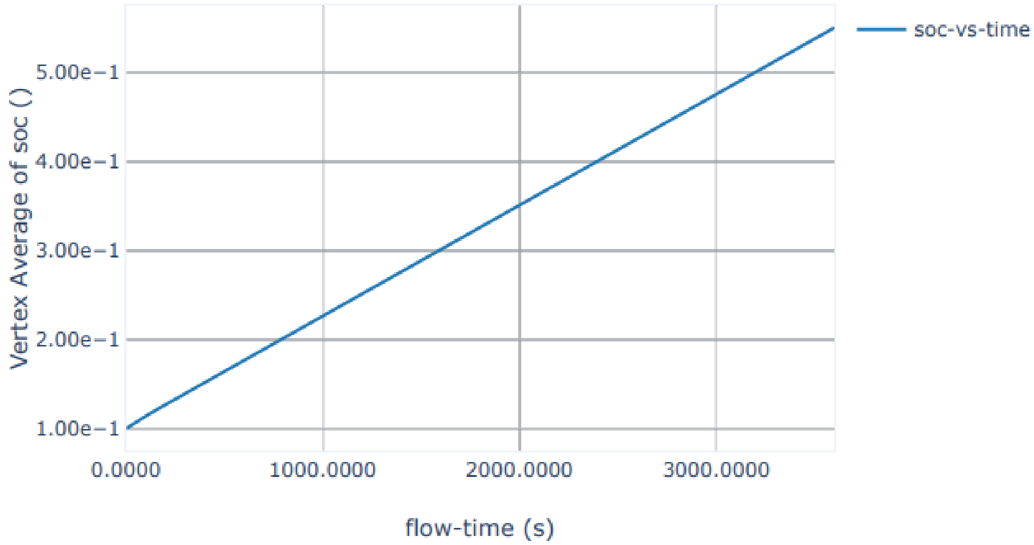

Figure 4.7 Graph of soc against time for dual pack without active cooling

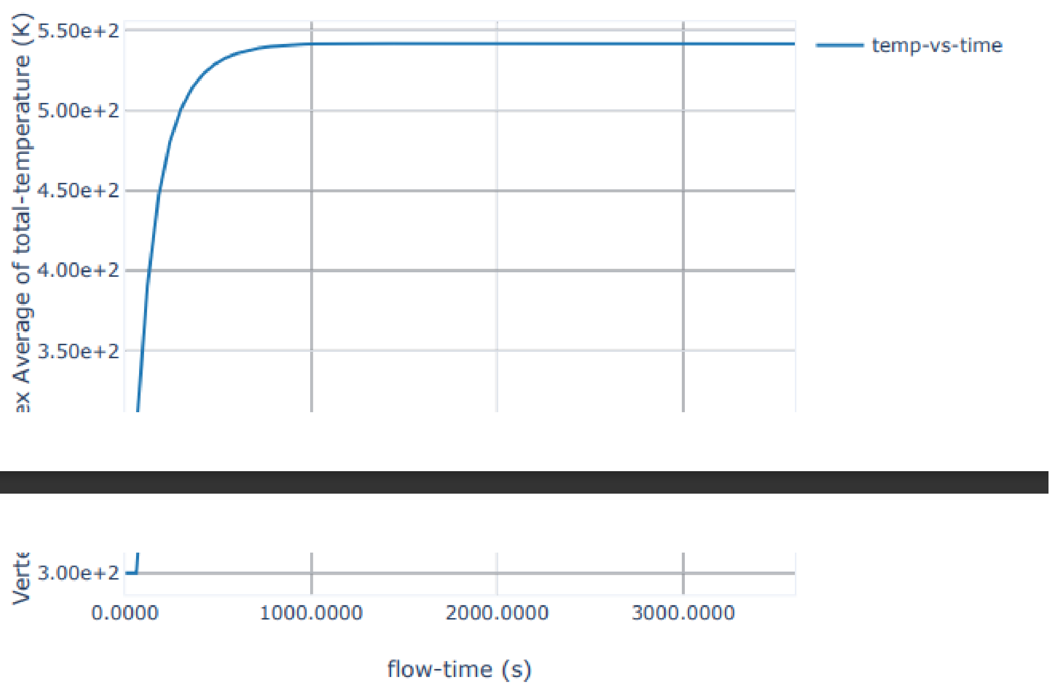

Figure 4.8 Graph of temperature against time for dual pack without active cooling

- **Solution Contours**

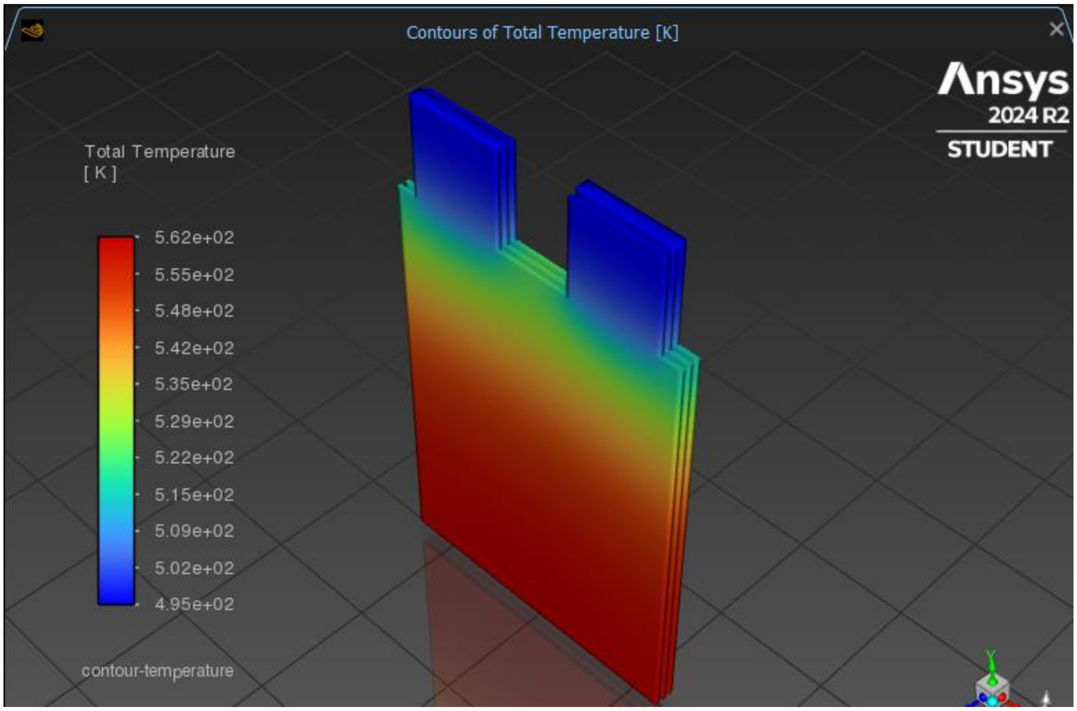

Figure 4.9 Temperature contour for dual pack without active cooling

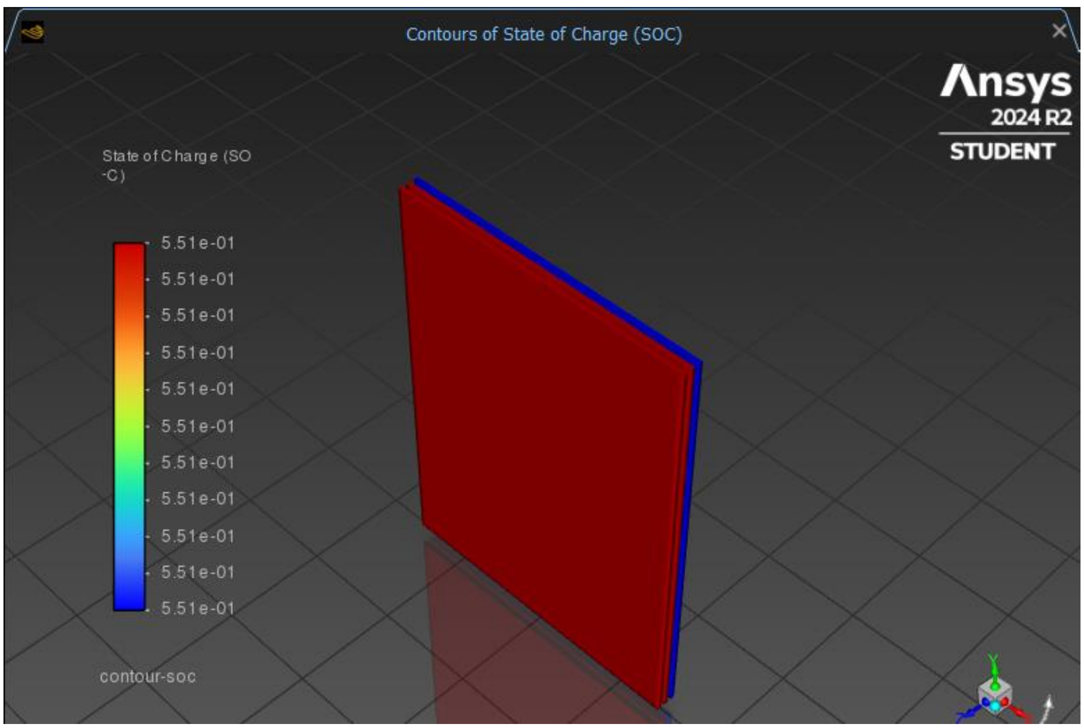

Figure 4.10 Soc contour for dual pack without active cooling

3. SINGLE PACK WITH ACTIVE COOLING

a. Geometry and Mesh

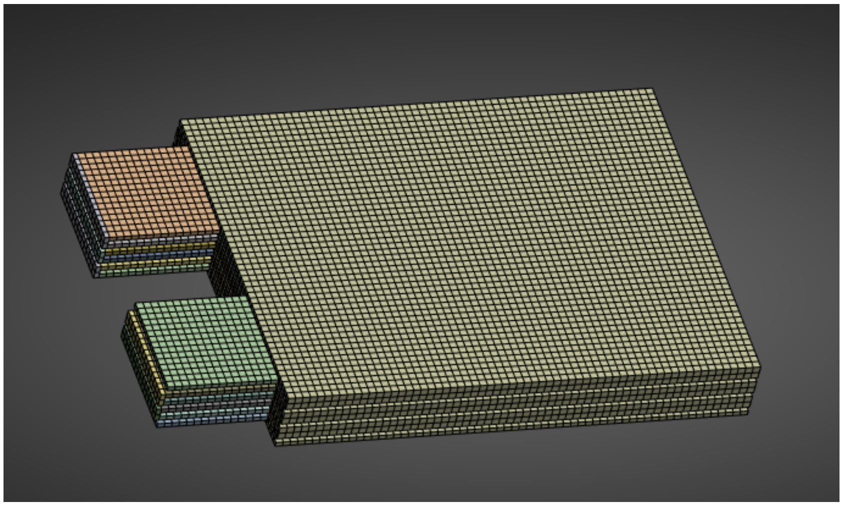

Figure 4.11 Mesh model for single pack with active cooling

- **Mesh Size**

Cells	Faces	Nodes
44066	327189	90864

Table 4.13 Mesh Size (SINGLE PACK WITH ACTIVE COOLING)

b. Physics

- **Models**

Model	Settings
Space	3 D
Time	Unsteady, 1st-Order Implicit
Viscous	SST k-omega turbulence model
Heat Transfer	Enabled
Battery Model	Enabled

Table 4.14 Models (SINGLE PACK WITH ACTIVE COOLING)

- **Battery Model**

Model Options	Settings
Solution Method	Multi-Scale Multi-Domain (MSMD)
E-Chemistry Model	Equivalent Circuit Model
Nominal Cell Capacity	214Ah
Specified System Current	-48A
E-Chem Stop Criterion	State of Charge (SOC) – Min and Max:1
Model Parameters	**Settings**
Initial State of Charge (SoC)	0.1 (10%)
Reference Capacity	214Ah

Table 4.15 Battery Model (SINGLE PACK WITH ACTIVE COOLING)

- **Material Properties**

-Fluid	
Air	
Density	1.225 kg/m^ 3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)
Viscosity	1.7894e-05 kg/(m s)
Molecular Weight	28.966 kg/kmol
Water	
Density	998.2 kg/m^3
Cp (Specific Heat)	4182 J/(kg K)
Thermal Conductivity	0.6 W/(m K)

Viscosity	0.001003 kg/(m s)
Molecular Weight	18.0152 kg/kmo
-Solid	
Tab material	
Density	8978 kg/m^3
Cp (Specific Heat)	381 J/(kg K)
Thermal Conductivity	387.6 W/(m K)
UDS Diffusivity	10000000 kg/(m s)
Active zone material	
Density	2092 kg/m^3
Cp (Specific Heat)	871 J/(kg K)
Thermal Conductivity	202.4 W/(m K)
UDS Diffusivity	35410000 kg/(m s)

Table 4.16 Material Properties (SINGLE PACK WITH ACTIVE COOLING)

- **Boundary Conditions**

Type	Thermal
Condition	Convection
Heat transfer coefficient	25 W/(m^2 K)
Free Stream Temperature	300K
Coolant Velocity	0.5m/s
Coolant Initial Temperature	290K

Table 4.17 Boundary Conditions (SINGLE PACK WITH ACTIVE COOLING)

c. Solution and Results

- **Report Definitions**

temperature-vs-time	292.9649	K
cell-voltage-vs-time	41.89712	V
soc-vs-time	0.3253013 (32.53%)	
battery-max-temperature	295.6208	K
battery-terminal-voltage	71.82896	V
battery-terminal-current	-48	A
delta-time	60	s
iters-per-timestep	20	
flow-time	3600	s

Table 4.18 Report Definitions (SINGLE PACK WITH ACTIVE COOLING)

- **Report Plots**

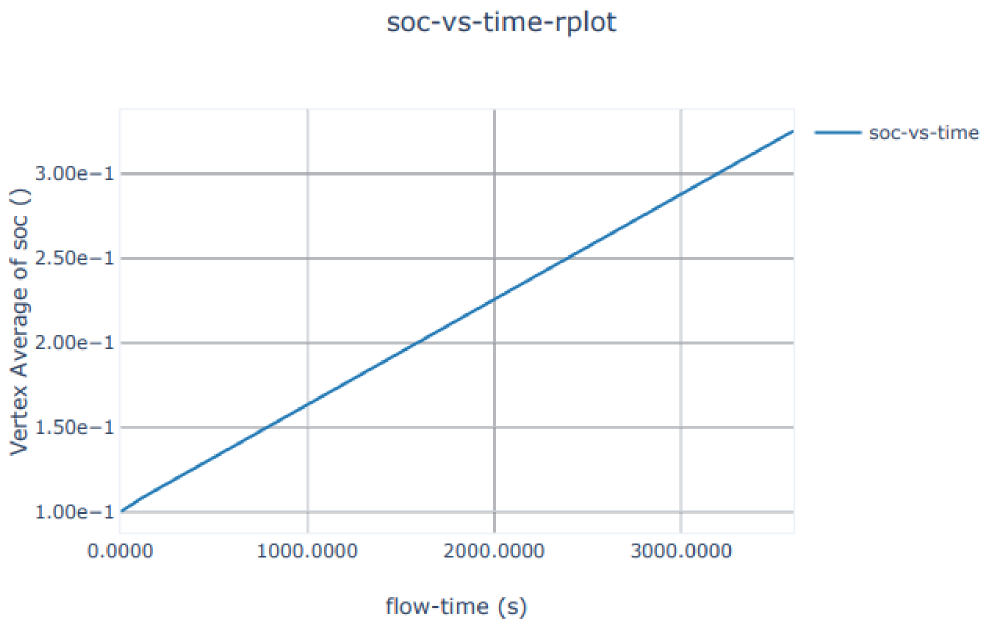

Figure 4.12 Graph of soc against time for single pack with active cooling

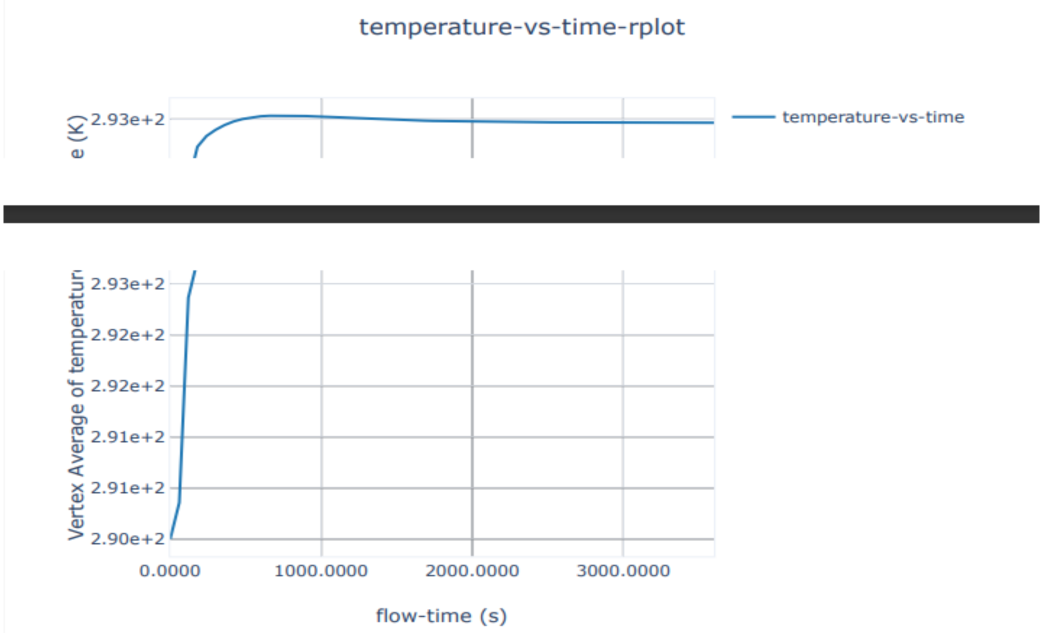

Figure 4.13 Graph of temperature against time for single pack with active cooling

- **Solution Contours**

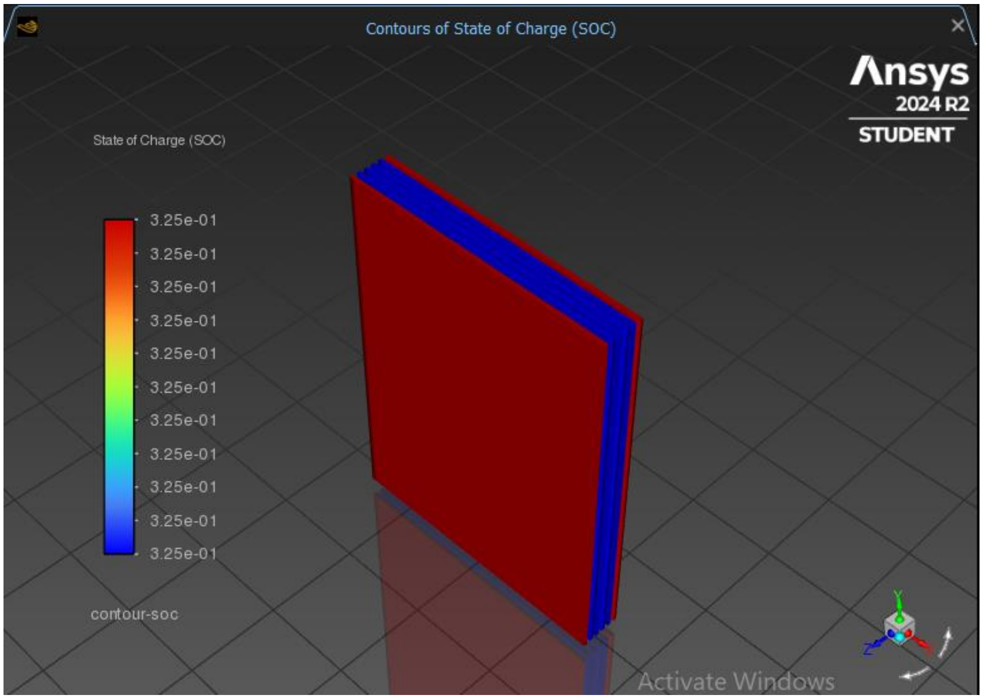

Figure 4.14 Soc contour for single pack with active cooling

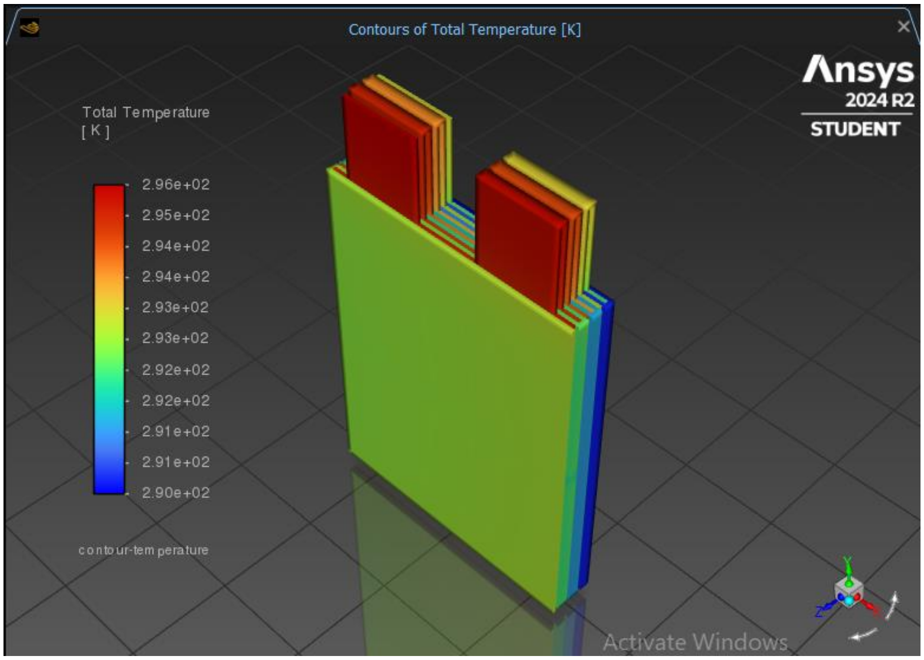

Figure 4.15 Temperature contour for single pack with active cooling

4. DUAL PACK WITH ACTIVE COOLING

a. Geometry and Mesh

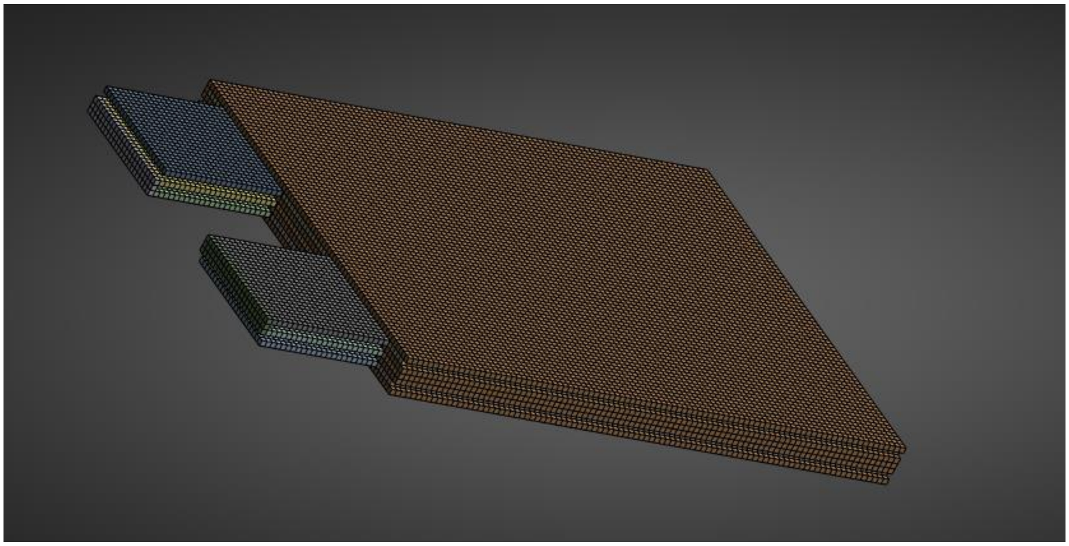

Figure 4.16 Mesh model for dual pack with active cooling

- **Mesh Size**

Cells	Faces	Nodes
53424	384199	109340

Table 4.19 Mesh Size (DUAL PACK WITH ACTIVE COOLING)

b. Physics

- **Models**

Model	Settings
Space	3 D
Time	Unsteady, 1st-Order Implicit

Viscous	SST k-omega turbulence model
Heat Transfer	Enabled
Battery Model	Enabled

Table 4.20 Models (DUAL PACK WITH ACTIVE COOLING)

- **Battery Model**

Model Options	**Settings**
Solution Method	Multi-Scale Multi-Domain (MSMD)
E-Chemistry Model	Equivalent Circuit Model
Nominal Cell Capacity	107Ah
Specified System Current	-48A
E-Chem Stop Criterion	State of Charge (SOC) – Min and Max:1
Model Parameters	**Settings**
Initial State of Charge (SoC)	0.1 (10%)
Reference Capacity	107Ah

Table 4.21 Battery Model (DUAL PACK WITH ACTIVE COOLING)

- **Material Properties**

-Fluid	
Air	
Density	1.225 kg/m^ 3
Cp (Specific Heat)	1006.43 J/(kg K)
Thermal Conductivity	0.0242 W/(m K)

Viscosity	1.7894e-05 kg/(m s)
Molecular Weight	28.966 kg/kmol
Water	
Density	998.2 kg/m^3
Cp (Specific Heat)	4182 J/(kg K)
Thermal Conductivity	0.6 W/(m K)
Viscosity	0.001003 kg/(m s)
Molecular Weight	18.0152 kg/kmo
-Solid	
Tab material	
Density	8978 kg/m^3
Cp (Specific Heat)	381 J/(kg K)
Thermal Conductivity	387.6 W/(m K)
UDS Diffusivity	10000000 kg/(m s)
Active zone material	
Density	2092 kg/m^3
Cp (Specific Heat)	871 J/(kg K)
Thermal Conductivity	202.4 W/(m K)
UDS Diffusivity	35410000 kg/(m s)

Table 4.22 Material Properties (DUAL PACK WITH ACTIVE COOLING)

- **Boundary Conditions**

Type	Thermal
Condition	Convection
Heat transfer coefficient	25 W/(m^2 K)
Free Stream Temperature	300K

Coolant Velocity	0.5m/s
Coolant Initial Temperature	290K

Table 4.23 Boundary Conditions (DUAL PACK WITH ACTIVE COOLING)

c. Solution and Results

- **Report Definitions**

temperature-vs-time	291.7718	K
cell-voltage-vs-time	12.03006	V
soc-vs-time	0.5507243 (55.07%)	
battery-max-temperature	294.1847	K
battery-terminal-voltage	36.10708	V
battery-terminal-current	-48	A
delta-time	60	s
iters-per-timestep	20	
flow-time	3600	s

Table 4.24 Report Definitions (DUAL PACK WITH ACTIVE COOLING)

- **Report Plots**

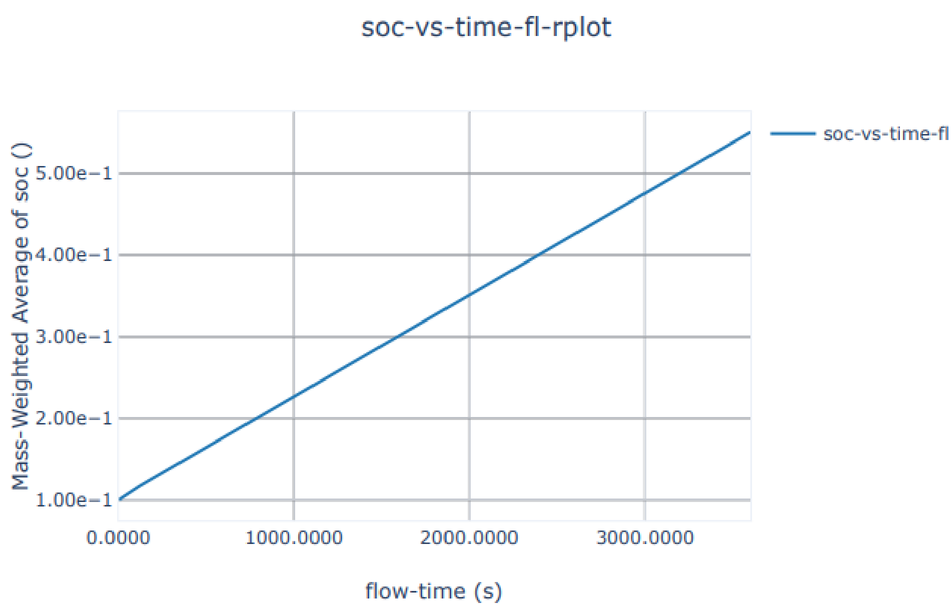

Figure 4.17 Graph of soc against time for dual pack with active cooling

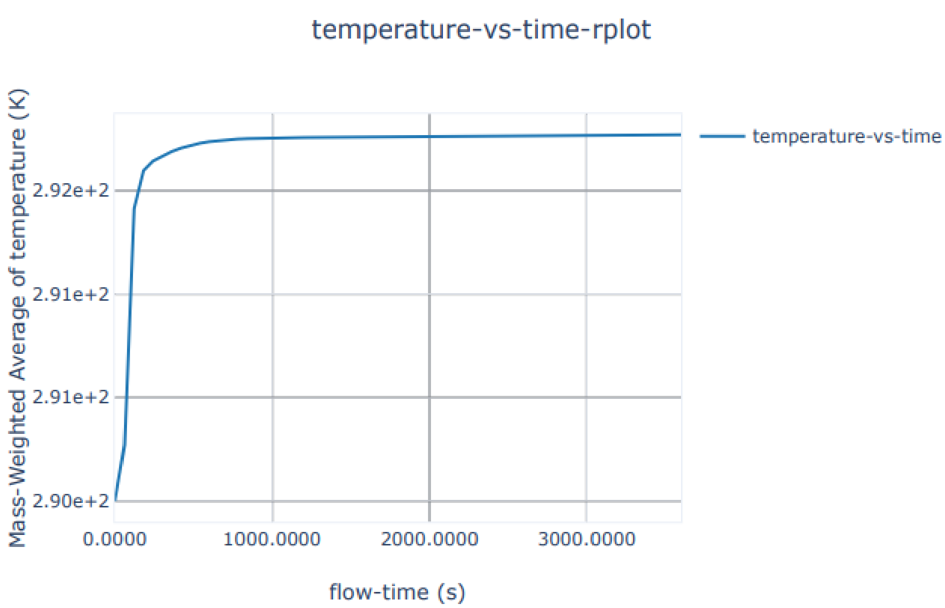

Figure 4.18 Graph of temperature against time for dual pack with active cooling

- **Solution Contours**

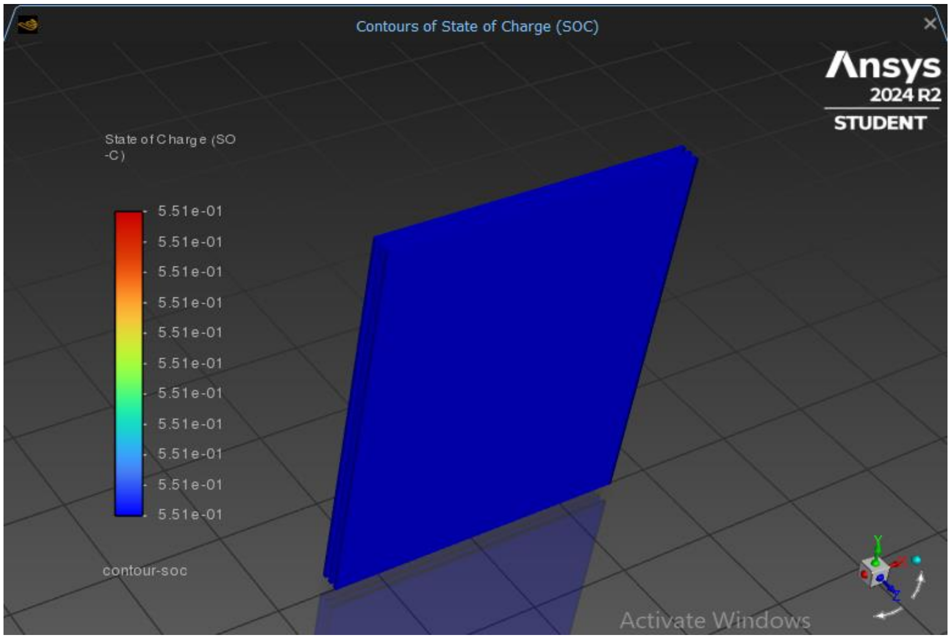

Figure 4.19 Soc contour for dual pack with active cooling

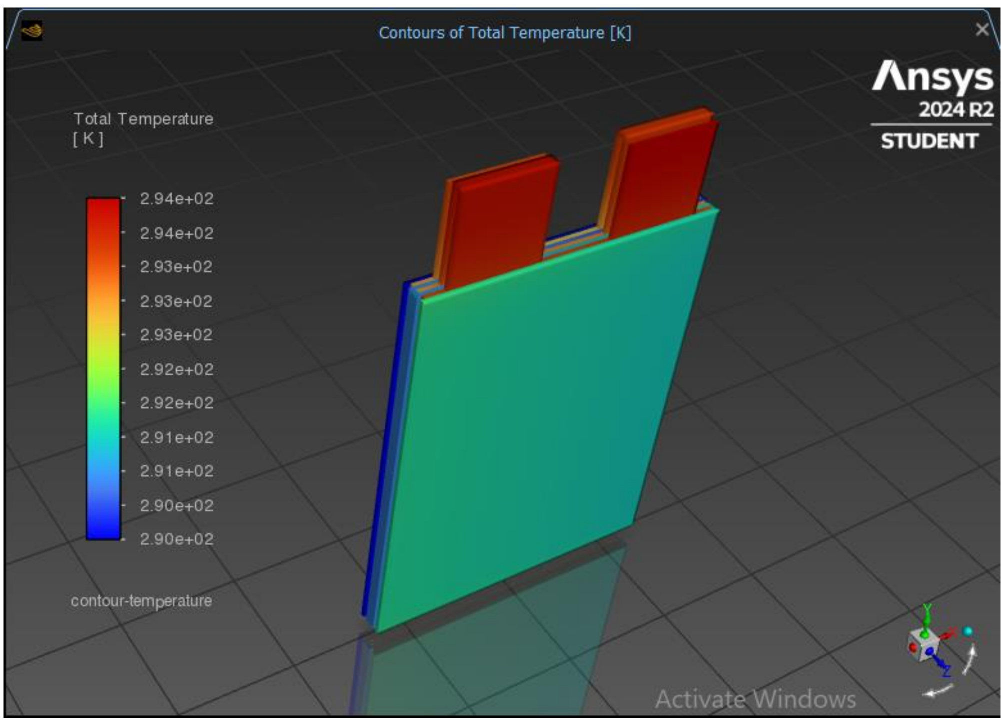

Figure 4.20 Temperature contour for dual pack with active cooling

Analysis of Results

Without active cooling	Single pack	Dual pack	Percentage change (Dual compared to Single)
State of Charge	0.3253013 (32.53%)	0.5507243 (55.07%)	69.3% Increase
Average Temperature	541.1166K	541.5001K	0.07% Increase

Table 4.25 Analysis of Results Without Active Cooling

With active cooling	Single pack	Dual pack	Percentage change (Dual compared to Single)
State of Charge	0.3253013 (32.53%)	0.5507243 (55.07%)	69.3% Increase
Average Temperature	292.9649	291.7718	0.45% Decrease

Table 4.26 Analysis of Results With Active Cooling

The simulation results provide a comprehensive comparison of the performance of single and dual battery configurations in terms of **State of Charge (SoC)** and **average temperature**, both with and without active cooling.

1. State of Charge (SoC) Performance

The **State of Charge (SoC)** indicates the efficiency of the charging process. Without active cooling, the dual battery configuration achieved an SoC of **55.07%**, whereas the single pack reached only **32.53%**. This represents a **69.3% increase** in SoC for the dual battery setup, showing a significant improvement in charging speed compared to the single pack.

With active cooling, the SoC remained unchanged for both configurations, with the dual pack still at **55.07%** and the single pack at **32.53%**. This suggests that the introduction of cooling does not impact the charging efficiency of the battery systems, as both configurations maintained the same charging performance.

2. Thermal Performance

Thermal management is critical in maintaining battery performance and safety. Without active cooling, the average temperature of the dual battery configuration was slightly higher at **541.5001 K**, compared to **541.1166 K** for the single pack, reflecting a **0.07% increase**. This minor rise in temperature indicates that the faster-charging dual battery setup does not significantly exacerbate thermal conditions.

When active cooling was applied, both configurations experienced a considerable drop in temperature. The single battery pack reached an average temperature of **292.9649 K**, while the dual pack dropped to **291.7718 K**, showing a **0.45% decrease** in temperature for the dual battery configuration compared to the single. This highlights the effectiveness of active cooling in managing heat, especially in the dual configuration, which showed a slight but notable improvement in thermal performance.

3. Comparison with and without Active Cooling

Without cooling, the dual battery configuration demonstrated a marked increase in SoC without a substantial rise in temperature. The **69.3% improvement** in SoC highlights the efficiency gains from the dual battery system, while the **0.07% temperature increase** shows that the thermal impact is minimal.

With active cooling, the dual configuration maintained the same SoC advantage but showed an improved thermal response. The **0.45% decrease in temperature** with cooling indicates that the dual battery system, combined with active cooling, offers a favorable balance between charging efficiency and thermal management.

In essence, the simulation results suggest that the dual battery configuration enhances charging performance while maintaining manageable thermal levels, particularly when active cooling is used to regulate temperatures effectively.

Mathematical Validation

The SOC of a battery during charging can be expressed as:

$$SOC(t) = SOC_{\text{initial}} + \frac{I \cdot t}{C}$$

Where:

- SOC(t) = State of charge at time ttt.
- SOCinitial = Initial state of charge.
- I = Charging current.
- t = Time.
- C = Battery capacity.
-

Single Battery Configuration:

For the single battery configuration:

$$SOC_{\text{single}}(t) = SOC_{\text{initial}} + \frac{I \cdot t}{C_{\text{single}}}$$

Dual Battery Configuration:

For the dual configuration, where the total capacity is halved ($C_{dual}=0.5C_{single}$):

$$SOC_{\text{dual}}(t) = SOC_{\text{initial}} + \frac{I \cdot t}{C_{\text{dual}}} = SOC_{\text{initial}} + \frac{I \cdot t}{0.5C_{\text{single}}}$$

This simplifies to:

$$SOC_{\text{dual}}(t) = SOC_{\text{initial}} + \frac{2 \cdot I \cdot t}{C_{\text{single}}}$$

Hence;

$$\Delta SOC_{\text{single}} = \frac{I \cdot t}{C_{\text{single}}}$$

While

$$\Delta SOC_{\text{dual}} = \frac{2 \cdot I \cdot t}{C_{\text{single}}}$$

Therefore;

$$\Delta SOC_{\text{dual}} = 2 \cdot \Delta SOC_{\text{single}}$$

This shows that the dual configuration ought to achieve twice the increase in SOC compared to the single configuration within the same charging time. However this is not the case due to inefficiencies arising from energy loss to heat.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

The study investigated the impact of a dual battery configuration on optimizing the charging time of electric vehicles (EVs), comparing it to a single battery pack in both cooled and non-cooled environments. The simulation results showed a significant improvement in the **State of Charge (SoC)** for the dual battery configuration, which demonstrated a **69.3% increase** in charging efficiency compared to the single pack. Thermal performance, while slightly affected in non-cooled conditions, was well-managed under active cooling, with the dual pack experiencing a **0.45% decrease** in temperature when cooling was applied.

These findings suggest that adopting a dual battery configuration could considerably reduce charging times without substantially compromising thermal stability, especially when paired with active cooling systems. However, several limitations and challenges were encountered during the study that could affect its real-world application.

Drawbacks of the Study

1. **Computational Limitations**: Due to limited computational resources, a complete model of a large battery pack consisting of numerous cells could not be simulated. Instead, the study was restricted to modeling a small set of **pouch cells**, which simplified the representation of the battery pack. This simplification likely affected the accuracy and scalability of the results, as real-world battery packs are much more complex and would require detailed modeling of thousands of cells to capture realistic behaviors.
2. **Assumptions and Simplifications**: The assumptions made during the mathematical and geometric modeling stages—such as the uniformity of the cells and thermal properties—could impact the validity of the results when applied to a more diverse and larger battery pack. Real-world battery packs experience non-uniform temperature distributions, variations in internal resistance, and different electrochemical reactions that were not fully accounted for in this simplified study.

Potential Drawbacks in Real-World Implementation

1. **Cost and Complexity**: Implementing a dual battery system in real-world EVs would introduce additional complexity and costs. This includes the need for dual charging ports, separate battery management systems for each pack, and potential redesigns of the vehicle's architecture to accommodate two battery modules. These modifications would increase manufacturing costs and potentially complicate maintenance and repairs.
2. **Thermal Management**: While active cooling was shown to effectively regulate the temperature of the battery packs in this simulation, implementing efficient cooling systems in real-world EVs is a challenge. The energy and resources required to cool two separate battery packs may offset some of the benefits gained in charging efficiency, as well as place additional demands on the vehicle's overall energy consumption.
3. **Space and Weight Constraints**: Adding a second battery pack may pose design challenges in terms of space and weight within the vehicle. Dual battery packs would require additional space, which could compromise passenger or cargo capacity, and the increased weight could negatively affect the vehicle's overall performance, especially in terms of range and handling.

Areas for Further Study

1. **Full Battery Pack Modeling**: Future studies should focus on modeling a complete battery pack with all its cells to more accurately capture the thermal and electrical behavior during charging. This would provide a more realistic assessment of the dual battery configuration's performance in actual EVs.
2. **Long-Term Performance Analysis**: Further research is needed to assess the long-term performance of dual battery systems, including their effects on battery degradation, lifespan, and thermal cycling under various operating conditions. Understanding these factors will be crucial for determining the feasibility of implementing dual battery systems in commercial EVs.
3. **Thermal Management Systems**: Additional studies should explore advanced thermal management solutions for dual battery configurations. Investigating the integration of passive cooling technologies or more efficient active cooling methods could help mitigate the potential thermal challenges posed by dual battery systems.

4. **Cost-Benefit Analysis**: Conducting a comprehensive cost-benefit analysis is essential to determine whether the gains in charging efficiency are worth the additional costs and complexities associated with a dual battery setup. This analysis should consider manufacturing, maintenance, and energy consumption impacts.

Recommendations

Based on the findings of this study, the following recommendations are made:

1. **Explore Dual Battery Configurations in EV Prototypes**: Vehicle manufacturers should consider experimenting with dual battery configurations in prototype EVs to evaluate their real-world performance. Such experiments should include detailed testing of charging speed, thermal performance, and vehicle range to determine the viability of this approach.
2. **Invest in Advanced Cooling Technologies**: As thermal management is critical to maintaining battery health, investments should be made in developing more efficient and lightweight cooling systems tailored to dual battery configurations. Exploring materials and technologies that improve heat dissipation will be key to overcoming thermal challenges.
3. **Optimize for Space and Weight**: When designing EVs with dual battery systems, careful consideration must be given to space and weight distribution. Advanced materials and compact design strategies should be explored to mitigate the impact of additional battery packs on vehicle performance and capacity.
4. **Investigate Hybrid Approaches**: Future research could explore hybrid battery systems, where one pack is dedicated to fast charging while the other is optimized for energy storage and range extension. This could balance the trade-offs between charging efficiency, energy density, and overall vehicle performance.

In conclusion, while the dual battery configuration offers promising improvements in charging efficiency, the real-world implementation of such systems presents challenges that require further investigation. Nonetheless, this study provides valuable insights into the potential benefits and limitations of dual battery setups, paving the way for more advanced research and development in the pursuit of faster and more efficient electric vehicle charging systems.

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