International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

Thermal Management System in Electric Vehicles

Varunsai B[1], P P Kumar P[2], Hasini K[3] , Sneha Latha G[4] , Sinduja K[5]

[1,3,4,5] B. Tech Students, Department of Electrical and Electronics Engineering, GMR Institute of Technology, Rajam, A.P, India

A B S T R A C T

This paper describes about an innovative Thermal Management System and the cooling system to maintain the safety and durability of electric vehicle. The thermal management in electric vehicle powered by the batteries is more important in that it affects the performance, reliability, and the toughness of these cars. Electric vehicles need optimal temperatures (neither warm nor cold) to run efficiently. The temperature control of the battery and power electronics plays just as important a role as the heating and cooling of the vehicle interior. The liquid coolant has indirect contact with the battery and acts as the medium to remove the heat generated from the battery during operation. Forced air assisted heat removal is performed from the condenser side of the thermoelectric liquid casing. Detailed experimental analysis is carried out and the results are revealing the cooling effect which regulates the thermal effect.

Keywords – Battery, EV, BTMS, Temperature

1. Introduction

The primary source of air pollution in the 21st century, particularly in cities, is the transportation industry. All studies agree that using electric vehicles is the best way to reduce pollution. Due to their zero emissions, great efficiency, and quiet operation, EVs have attracted a lot of attention. This equipment must operate at an optimal temperature to retain its excellent performance and durability, which means that in order to achieve optimal performance and a long service life, the Li-operating battery's temperature range must be kept at 15 -35°C, motor operating temperature range is 10–70°C, DC/DC converter operating temperature range is 10–55°C. As the central system driving the vehicle, the electrical components cannot achieve both high efficiency and durability until each of them under the appropriate operating temperature.[1] The liquid coolant has indirect contact with the battery and acts as the medium to remove the heat generated from the battery during operation.[2] The batteries play an important role in the thermal management of electric vehicle. Charging and discharging of battery involve many electric-chemical reactions sensitive to temperature. The heat produced during charge and discharge causes the batteries to overheat or possibly catch fire. Air cooling, liquid cooling, phase change materials, heat pipes, and thermos electric cooling are common cooling techniques created for then battery thermal management systems[3]. Air cooling-based BTMS is no longer suitable for EVs with high Due to reduced heat transmission, there are considerations for safety and endurance. Compared with the above, liquid cooing has a wide range of applications in battery thermal management system[4].

2. Battery thermal runaway

Thermal runaway results from exothermic reactions that become uncontrollable when the battery temperature exceeds 353.15 K. For big battery packs, the risk of thermal runaway increases due to the constant temperature increase[5]. Three steps make up the thermal runaway process. Due to separator faults that cause an increase in internal temperature, Before the battery overheats, it must first undergo a state change from normal to abnormal[3], [4], [6]. The second stage of a battery's life is marked by an exothermic reaction since the internal temperature rises quickly during this time. At the third stage, flammable electrolyte combustion results in explosion.

2.1 Lithium-ion battery working

A separator separates the positive and negative electrodes in a lithium-ion battery to create a rechargeable battery. [6]. The Li-ion batteries use electrolytes such as $LiPF6$, $LiBF4$, $LiCIO4$, etc. For the movement of electrons, it acts as a conducting medium[7], [8]. In a lithium-ion battery, the positive electrode releases its lithium ions into the electrolyte, where they can then travel to the negative electrode. Therefore, external circuits exhibit synchronous electron flow. When the capacitor is discharged, the opposite occurs.

In the constant current mode of operation, the current remains constant while the voltage increases during charging, resulting in a greater charging capacity[4]. As the voltage approaches its saturation point, it begins to drop fast. The discharge capacity keeps the voltage and current steady while discharging, and after a period the voltage drops and the current through the load rises very slightly[1], [5], [9] It is capable of supplying power up to the manufacturer-set voltage cutoff value.

2.2 Battery Management System

An essential part of electric cars that exemplifies sustainable transportation is the energy storage device (Batteries)[9]. Lithium-ion technology, the preferred choice for electric car batteries, has recently gained popularity[5]. This involves things like choosing the right cells, materials, and electronic circuitry, as well as making optimal use of batteries. The battery must be maintained carefully for the EV system to operate safely and to increase battery efficiency. It also carries out tasks including state monitoring,[8] data monitoring and analysis, battery package temperature control, and cell balancing. [2], [10] The BMS keeps the battery healthy and ensures that the cells are constantly available for usage while also protecting it from degeneration.

3. Electric Vehicle Thermal Management System

System Description

An electric vehicle thermal management system refers to the set of components and technologies that are used to regulate the temperature of various elements in an electric vehicle (EV). The system helps to ensure that the battery, power electronics,[1] motor, and other components are operating within their safe and efficient temperature ranges. [6]There are two main aspects to the thermal management of EVs: heating and cooling. The heating system is used to raise the temperature of the battery, power electronics, and other components when they are too cold. [3]This is especially important in cold weather conditions, as low temperatures can reduce the performance and efficiency of these components.[4] On the other hand, the cooling system is used to lower the temperature of these components when they are overheating, [2], [8]for example during high-speed driving or charging.

The parts of a thermal management system for an electric vehicle could be:

Cooling system: To remove heat produced by the power electronics and battery, a cooling system is used. [6] The cooling system may rely on a heat exchanger or radiator and may use air or liquid cooling.

Heating system: A heating system is used to warm up the battery and power electronics when they are too cold.[3] This can be done through electrical heating elements, or by using waste heat from the power electronics or the motor.

Thermostats: Thermostats are used to control the temperature of the components in the system. [4]They can be used to activate the heating or cooling system as needed, and can also be used to shut down the vehicle if the temperature exceeds a certain threshold.

Sensors: Sensors are used to measure the temperature of the various components in the system, and to provide data to the control unit.

Control unit: The control unit is the brain of the thermal management system, and is responsible for coordinating the different components and making decisions based on the temperature data from the sensors.

The thermal management system is an important aspect of the overall design of an electric vehicle, [1], [4]and can play a significant role in determining the vehicle's range, efficiency, and reliability.

4. Cooling System

In an electric vehicle (EV), the cooling system plays a crucial role in maintaining the temperature of various components such as the battery, motor, and electronics. [5], [9]This helps to ensure their optimal performance and extend their lifespan. The battery cooling system helps to regulate the temperature of the battery pack, which can generate a lot of heat during charging and discharging cycles. [7]This is particularly important for EV batteries, which are typically more temperature-sensitive than their internal combustion engine counterparts.[8] A battery cooling system typically consists of a cooling fluid, a heat exchanger, and a pump that circulates the fluid through the battery pack to absorb and dissipate heat. The motor cooling system helps to regulate the temperature of the electric motor, which can generate a lot of heat during operation. [2]This is a particularly important for high-performance EV motors, which can generate a lot of heat due to their high-power density.[10] A motor cooling system typically consists of a cooling fluid, a heat exchanger, and a pump that circulates the fluid through the motor to absorb and dissipate heat. Finally, the electronics cooling system helps to regulate the temperature of the various electronic components in the EV, such as the power electronics and control electronics. This is important because high temperatures can shorten the lifespan of these components and reduce their performance.[11] Electronics cooling system typically consists of air cooling and/or liquid cooling, depending on the specific requirements of the components being cooled. Overall, the cooling system is an important component of an EV and helps to ensure that the vehicle's various components are operating at optimal temperatures for maximum performance and longevity.

Air cooling

Electric vehicles (EVs) use air conditioning as a technique to control the temperature of various parts, including the battery, electronics, and control units. Utilizing fans and other devices to move air across the cooling components, air cooling works by absorbing heat from the components and transporting it elsewhere.[3], [4], [6] In an EV, air cooling is used to regulate the temperature of components that do not generate large amounts of heat or that are located in areas that are difficult to access for liquid cooling. For instance, air cooling can be used to cool the power electronics and control electronics in an EV. A fan, air ducts, and heat sinks are the typical components of air cooling systems.The fan circulates air over the components being cooled,[1] absorbing heat and carrying it away from the components. The air ducts direct the air flow over the components, and the heat sinks are used to transfer the heat from the components to the air. Air cooling has several advantages in EV design.[5] For example, air cooling systems are generally less complex and less expensive than liquid cooling systems, and they can be more reliable because they have fewer moving parts. In addition, air cooling systems are more tolerant of leaks and other failures, making them a good choice for applications where maintenance is difficult or impossible. [11]However, air cooling has some disadvantages compared to liquid cooling. For example, air cooling is typically less effective at regulating temperature than liquid cooling because air has a lower thermal capacity and cannot transfer heat as efficiently as liquids.[2] This means that air cooling systems may need to be larger and more powerful to achieve the same cooling performance as liquid cooling systems.

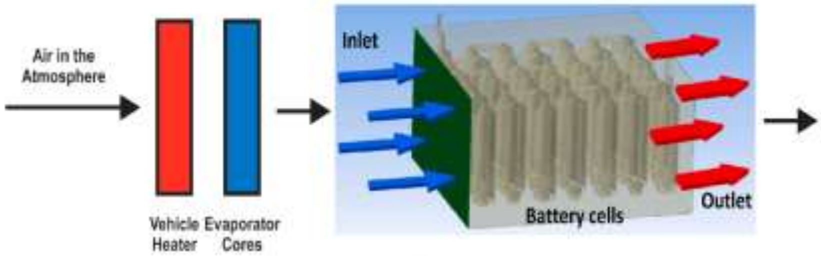

Fig 1. Air cooling System: Gang Zhao (2021)[8]

Liquid cooling

Liquid cooling is a method used in electric vehicles (EVs) to regulate the temperature of various components, such as the battery, [3]motor, and electronics. Liquid cooling is typically more effective than air cooling because liquids have a higher thermal capacity and can transfer heat more efficiently than air. In a liquid cooling system, a cooling fluid,[4] such as water or a specialized coolant, is circulated through the components being cooled. The fluid absorbs heat from the components and carries it away to a heat exchanger, where the heat is transferred to the ambient environment. This process helps to regulate the temperature of the components, ensuring that they are operating within a safe and optimal temperature range.[1] Liquid cooling is particularly useful in EVs because many of the components in these vehicles generate a lot of heat. For example, the battery pack in an EV can generate a lot of heat during charging and discharging cycles, and high-performance EV motors can generate a lot of heat due to their high-power density. Liquid cooling can help to regulate the temperature of these components, ensuring that they are operating at optimal temperatures for maximum performance and longevity. In addition to its thermal benefits, liquid cooling can also help to reduce the size and weight of the cooling system compared to air cooling. [9]This is because liquid cooling systems can be designed with smaller, lighter components that can transfer heat more efficiently than air cooling systems. Overall, liquid cooling is an important aspect of EV design, as it helps to regulate the temperature of various components, ensuring their optimal performance and longevity. battetivarun@gmail.com Describe the air conditioning system of an EV. Electric vehicles (EVs) employ the technique of air cooling to control the temperature of a number of parts, including the battery, electronics, and control units. Air cooling works by using fans and other components to circulate air over the components being cooled, absorbing heat and carrying it away from the components.[11] In an EV, air cooling is used to regulate the temperature of components that do not generate large amounts of heat or that are located in areas that are difficult to access for liquid cooling. For instance, air conditioning can be used to cool the electronics in an EV, such as the control and power electronics. Heat sinks, air ducts, and fans are the common components of air cooling systems.The fan circulates air over the components being cooled, absorbing heat and carrying it away from the components. [2]The air ducts direct the air flow over the components, and the heat sinks are used to transfer the heat from the components to the air. Air cooling has several advantages in EV design. For example, air cooling systems are generally less complex and less expensive than liquid cooling systems, and they can be more reliable because they have fewer moving parts. In addition, air cooling systems are more tolerant of leaks and other failures, making them a good choice for applications where maintenance is difficult or impossible. [1], [3], [6]However, air cooling has some disadvantages compared to liquid cooling. For example, air cooling is typically less effective at regulating temperature than liquid cooling because air has a lower thermal capacity and cannot transfer heat as efficiently as liquids. This means that air cooling systems may need to be larger and more powerful to achieve the same cooling performance as liquid cooling systems[12-25].

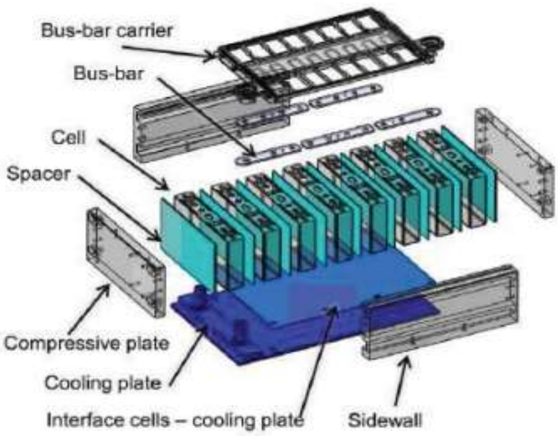

Fig 2. Liquid Cooling: M M. Rahman (2016)[8]

Analysis of Cooling Strategies

Liquid cooling is generally considered to be a better option than air cooling for regulating the temperature of components in an electric vehicle (EV) for the following reasons: Higher thermal capacity: Liquid has a much higher thermal capacity than air, meaning that it can absorb and transfer heat more efficiently than air. [5]This makes liquid cooling a more effective way to regulate temperature than air cooling. Improved heat transfer: Liquid cooling allows for more efficient heat transfer from the components being cooled to the cooling fluid, and then from the fluid to the environment. This improved heat transfer helps to regulate temperature more effectively than air cooling. [9]Compact design: Liquid cooling systems can be designed to be more compact than air cooling systems, making them a good choice for applications where space is limited. This is because liquid cooling systems can be designed with smaller, lighter components that can transfer heat more efficiently than air cooling systems. [10]Better temperature control: Liquid cooling provides more precise temperature control than air cooling because it can be more easily regulated and monitored. This precise temperature control is particularly important in EVs, where components such as the battery and motor generate a lot of heat and require precise temperature control to ensure optimal performance and longevity. [2]Improved reliability: Liquid cooling systems can be designed to be more reliable than air cooling systems because they have fewer moving parts and are less susceptible to leaks and other failures. This improved reliability is important in EVs, where maintenance is often difficult or impossible.[3] Overall, liquid cooling [26-35]is generally considered to be a better option than air cooling for regulating the temperature of components in an EV because of its higher thermal capacity, improved heat transfer, compact design, better temperature control, and improved reliability[45-50].

TABLE1: VARIOUS COOLING STRATEGIES

Features	Air cooling	Liquid cooling
Thermal conductivity	Medium	High
Structure complexity	Low	Medium
compactness	High	Low
Weight	Low	High
Uniform temp distribution	Low	Medium
Coolant viscosity	Low	Medium
Cost	Low	Medium

5. Results and Discussion:

Thermal management of battery electric vehicle describes the battery Heat flow Rate, Vehicle Speed, Components Temperature, Cabin Temperature. This System consists of 2 coolant loops, one refrigeration loop and cabin hvac loop. The thermal loader batteries power train and cabins and the 2 coolant loops are joined together in serial mode or in parallel mode using four-way wealth system. In this system it mainly consists of scenario subsystem and control subsystem. The scenario subsystem setup's the environmental conditions and inputs of the systems for the selected scenario. Based on the tabulated data the vehicle speed, battery current demand and power train heat load. It also consists of environmental block, cabin hvac system, power demand and vehicle speed. Environmental block consists of pressure, temperature, relative humidity and Co2 in tabulated data. Vehicle speed shows the drive cycle values by using signal filter in un its of km/Hour. In power demand subsystem there is time iq i.e., battery, inverter motor, charger current and blocks. Control subsystem: The Control subsystem consists of all the controllers for pumps, compressors, fan, blower and valves in terminal management system. Fan controllers has condenser requirement, inverter requirement, motor requirement all are working together with control subsystem. Scope: Scope is used to find the output signals. Parallel mode flow path & Serial mode flow path: In this subsystem there is a parallel mode flow path that is port A to D and port C to B and serial mode flow path is port A to B and port C to D. Here, A to B, C to D, A to D, C to B means the four-way valve subsystem control the coolant loop operates in series or parallel mode. Motor pump subsystem: The pumps in the motor pump subsystem operate the coolant loops that keep the chargers, motor, and inverter cool. Charger subsystem: The charger is surrounded by a coolant jacket that simulates the heat flow rate, source, and thermal mass. Motor subsystem: The motor subsystem simulates the coolant jacket that surrounds the motor as a source, rate, and thermal mass of heat. There are numerous subsystems in an inverter, such as a cabin subsystem, a blower subsystem, etc. This subsystem displays the same valves and data as before. Environmental recirculation flap, a blower, and moisture air characteristics make up the blower subsystem.There are four valves they are chiller expansion valve, evaporator expansion valve, radiator bypass valve, chiller bypass valve to construct the electric vehicle thermal management system. There are three modes in this subsystem: drive cycle mode, cool down mode, and cold weather mode. According to the modes, the required outside temperature for the drive cycle mode is 30°C, the required outdoor temperature for the cool down mode is 40°C, and the required outdoor temperature for the cold weather mode is -10°C. Moreover, a battery heater, ptc heater, and cabinet are needed.

Ptc heater: ptc heater is more useful to protect the battery from high temperature. Condenser subsystem: It consists of condenser and refrigeration loop, liquid receiver, exchange expansion valves, chiller, evaporator and its own compressor. Chiller: Chiller is used to cool the coolant in hot weather condition as radiator alone is insufficient. Evaporator: Evaporator is used to cool the vehicle cabin when the air condition is turned on. There are hvc loops in the condenser it consists of blower, evaporator, ptc heater with vehicle cabin. PTC heater: It provides heating in cold weather. As the blower is controlled to maintain the specified cabin temperature at set point. Now we can run the simulation from the workspace as we can see all the parameters and can modify the data when required. The stop timer is 3600sec.

A. Vehicle Speed:

The speed of an electric vehicle can also be influenced by driving conditions and the way the vehicle is driven. For example, driving at high speeds or in hilly terrain can reduce the range of a battery electric vehicle due to the increased energy consumption. Similarly, the use of air conditioning and other electrical systems can also impact the speed and range of the vehicle. The vehicle depends on the road and by the data input.

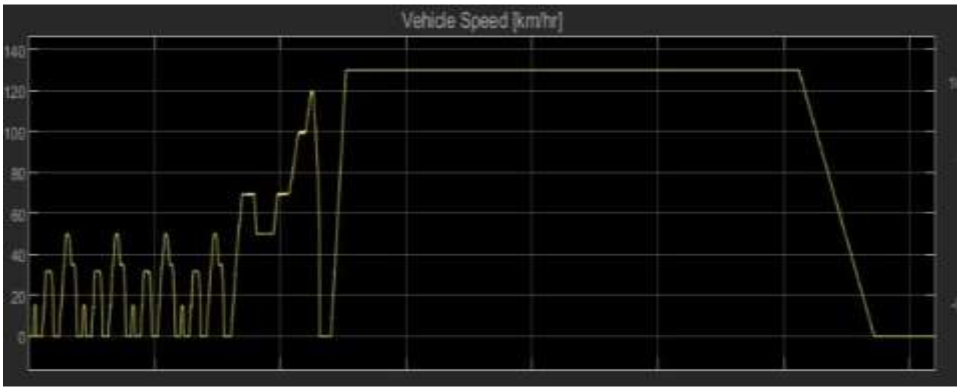

Fig 3. Vehicle Speed

B. Heat Flow Rate:

The heat flow rate in a battery electric vehicle depends on various factors, including the size and capacity of the battery pack, the charging and discharging rate, and the ambient temperature. The electrical resistance of the cells, the current flow rate, and the chemical reactions that take place inside the battery all have an impact on how much heat the battery produces while charging and discharging. Using cooling systems, such as air or liquid cooling systems, to remove heat from the battery and manage its temperature can control the heat flow rate. The performance and lifespan of a BEV battery can be impacted by the heat flow rate within the battery. Excessive temperatures might cause the battery to age more quickly and lose capacity and efficiency.

Fig 4. Heat Flow Rate

C. Cabin Temperature:

The outside temperature, the amount of insulation in the car, the amount of sun exposure, and the use of heating and cooling systems are just a few of the variables that affect the temperature within a car's interior. To guarantee optimum performance and lifetime, it is crucial to carefully monitor and adjust the heat flow rate in BEV batteries. Here, the outcomes are as follows Orange represents the set point (21°C), blue the environment temperature, and yellow the cabin temperature. Here, the thermal management system keeps the temperature constant when the cabinet temperature hits the threshold value under a certain circumstance.

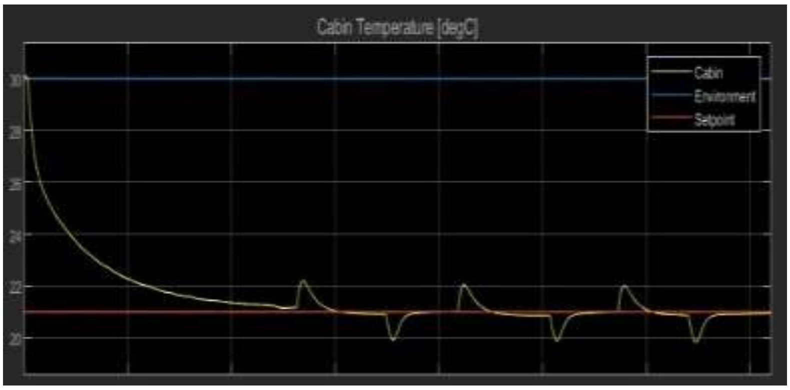

Fig 5. Cabin Temperature

6. Conclusion:

A well-designed thermal management system helps to regulate the temperature of these components, preventing overheating and other temperature-related issues that can negatively impact performance and reliability. There are several methods used for thermal management in EVs, including air cooling and liquid cooling. While both methods have their advantages and disadvantages, liquid cooling is generally considered to be the better option due to its higher thermal capacity, improved heat transfer, compact design, better temperature control, and improved reliability. Overall, thermal management is an important aspect of EV design, and the choice of cooling method will depend on various factors, such as component requirements, available space, and maintenance accessibility. The cooling system helps to regulate the temperature of various components, ensuring their optimal performance and longevity. Out of the two main cooling methods, air cooling and liquid cooling, liquid cooling is widely considered to be the better option. This is because liquid cooling has several advantages over air cooling, such as higher thermal capacity, improved heat transfer, compact design, better temperature control, and improved reliability. The ability of liquid cooling to precisely regulate temperature, combined with its improved heat transfer and reliability, make it an ideal solution for the thermal management of EVs.

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