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Battery Thermal Management System for Electric Vehicles

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***Abstract:** Electrical vehicles (EVs) as a result of their rapid evolution and growing popularity, zero-emission, and high tank-to-wheelefficiency. Though, some features, particularly those relating to battery performance, cost, lifetime, and protection, restrict the development of the electrical car. In order to operate at peak efficiency under various circumstances, battery management is therefore required. The BTMS is essential for controlling the thermal performance of the battery. The BTMS technologies include heating, air conditioning, liquid cooling, direct refrigerant cooling, phase change material (PCM) cooling, and thermoelectric cooling. Performance, weight, size, cost, dependability, safety, and energy consumption are trade-offs analyzed for these systems. According tothe analysis the system is made up of two coolant loops, one refrigeration loop, and one cabin HVAC loop. The batteries, drivetrain, and cabin all contribute to the thermal burden. The model of these system is been built in the software MATLAB/SIMULINK. Based on the outcomes of the simulation, BTMS is crucial for regulating battery thermal behavior. Through the integration of thesimulation model with battery thermal and ML models, next research might be more thorough and precise.*

Index Terms: Battery Thermal Management System (BTMS), Refrigeration Loop, Cabin Loop, MATLAB/SIMULINK Model, EV

I. INTRODUCTION

The current automobile market offers a variety of HEVs and pure electric vehicle mixing levels. Numerous sizes, kind, and many battery cells are installed in EVs depending on the level of blending. Battery cells as an energy source have more stringent requirements for the working environment than conventional fuel. Temperature sensitivity is extremely acute in them. BTMS will naturally be combined with battery cells to guarantee a good thermal effective environment. Thus, understanding the necessary conditions for a battery's correct operation and the types of management systems capable of meeting these conditions is crucial. The performance and longevity of the battery pack in an EV can be maximized with this foundation [1]. Additionally, the vehicle's range on electricity.

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As environmental laws on greenhouse gas (GHG) emissions have been strengthened, interest in electric vehicles (EVs), including - hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and battery electric vehicles (BEVs), has increased. Finding the right energy source is the main obstacle for EVs. High mileage, quick charging, and high-performance storage system. Rechargeable Li-ion Batteries are said to be the best energy storing option owing to their greater energy density and specific power, Ev's higher recyclability, greater lightness, self-discharge rates are less compared to other rechargeable batteries like lead-acid, have a longer cycle life They also benefit from having no memory impact [3]. However, These Li-ion batteries are extremely temperature-sensitive in terms of performance, life, and safety. It is challenging to create a clear and comprehensive system that reduces the effectiveness and safety of Li-ion batteries because commercial batteries employ a variety of electrode materials and electrolyte mixes. However, it is evident Ni-Cd and Ni-MH batteries are made of nickel and cadmium that Li-ion battery performance and stability decline at the Almost all cell materials experience an aberrant temperature range. Batteries typically experience temperature changes because they are impacted by ambient factors and emit heat through a variety of Charge and discharge-related chemical reactions. Consequently, it is necessary to have an effective battery thermal management system (BTMS) to prevent negative effects from temperature, these batteries should be kept within the recommended temperature range and their temperature gradient should be kept to a minimum.

II. LITERATURE SURVEY

There are many papers that have major contributions to the battery system construction and development of a cooling system for the battery system. The battery thermal management system deals with the continuous monitoring of the Charge, Health, and thermal model of the battery system [4]. The cooling system for the battery is a major role in order to reduce the temperature level of the battery and helps to run within its operating range. In this battery thermal management system, the major emphasis is given to the air cooling, passive, and active cooling system and the observation made from this project allows us to develop an efficient cooling system for the battery.

III. LI-ION BATTERY

A. Mechanism

Anode, cathode, electrolyte, and separator are the components of a lithium-ion battery (Figure 2.1).

The oxidized electrode known as the anode is responsible for removing electrons from the internal circuit during discharge. The oxidizing electrode that accepts electrons from the external circuit is the cathode, which is equivalent.

The separator is used to isolate the electrodes, while the electrolyte is utilized to move ions between the electrodes inside the cell [5]. Additionally, the carbon anode's surface forms a thin passivation layer, known as the solid electrolyte interface (SEI), during the initial charge. It lowers the current and slows down the reaction rate (2014's Electropedia).

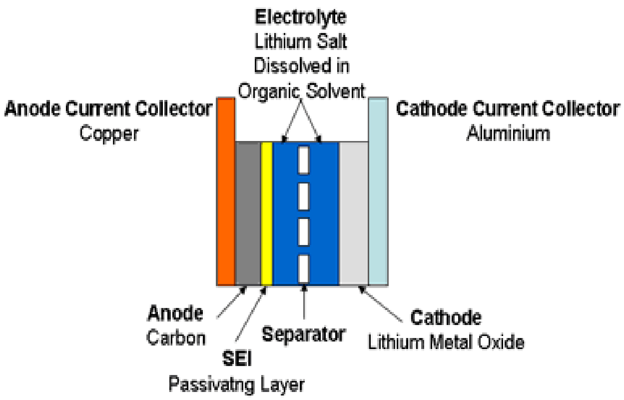

Fig: 2.1. The Physical Structure of li-ion battery (electropaedia, 2014)

Additionally, a Li-ion battery's electrochemical reactions can be reversed because it is rechargeable. When discharging, lithium ions spread from the negative to the positive, and when charging, they do the opposite. Instead of using metallic lithium as the electrode, lithium-ion batteries use intercalated lithium compounds [8]. The following is an expression for the electrochemical reactions for Li-cobalt in the positive electrode and negative electrode:

Following is the positive electrode reaction:

$$\mathrm{Li}COO2 \Leftrightarrow Li1{-}xCOO2 + xLi{+} + xe{-} \quad (2.1)$$

The adverse electrode response:

$$xLi{+} + xe{-} + xC6 \Leftrightarrow xLiC6 \quad (2.2)$$

Other lithium batteries' positive electrode and negative electrode electrochemical processes are comparable.

There are numerous cathode oxide-named lithium-ion battery types, each with its own set of characteristics, which are as follows:

Table 2.1 Reference names for Li-ion batteries

Chemical name	Material	Short form	Note
Lithium Cobalt Oxide	LiCoO2	Li- cobalt	High capacity; for cell phone laptop,
Lithium Manganese Oxide	LiMn2O4	Li- manganese	Most safe; lower capacity than Li- cobalt but high specific power and long life. Power tools, e-bikes, EV, medical
Lithium Iron Phosphate	LiFePO4	Li- phosphate	
Lithium Nickel Manganese Cobalt Oxide	LiNiMnCoO2	NMC	
Lithium Nickel Cobalt Aluminium Oxide	LiNiCoAlO2	NCA	Important in electric powertrain and grid storage
Lithium titanate	Li4Ti5O12	Li- titanate	

B. Li-ion Battery Thermal Issues

The performance of lithium-ion cells is affected by both temperature and operating voltage. Lithium -Ion cells perform well when voltage and temperature are limited. Otherwise, irreversible damage will be done to the cells.

Over-voltage occurs when the charging voltage exceeds the allowable cell voltage, resulting in excessive current flows and two problems. At high currents, lithium ions are deposited faster than intercalation to the anode layers, and the lithium ions are then deposited as metallic Lithium on the anode's surface. This is called lithium plating. It causes a decrease in free lithium ions and irreversible capacity loss. 2014 (Electropaedia). Metal lithium plating is classified into two types: homogeneous lithium plating and heterogeneous lithium plating, but the lithium plating is dendritic in nature. It may eventually result in a short circuit between the electrodes. Under-voltage, like over-voltage, causes problems that lead to the breakdown of the electrode materials [5]. The copper current collector for the anode fails. It increases the battery's discharge rate and voltage, but the copper ions precipitate as metal copper, which is irreversible. The scenario is dangerous because a short circuit between the anode and cathode might occur. After numerous cycles at low voltage, the cobalt oxide or manganese oxide in the cathode will disintegrate. Meanwhile, oxygen will be released, and the battery's capacity will deplete. The battery's temperature should be regularly checked. Both too much and too little heat may cause issues. Chemical reaction rates are proportional to temperature. When the working temperature is reduced, the response rate and current carrying capacity are reduced while charging or discharging. In other words, the battery's capacity is reduced. Furthermore, the slower reaction rate makes inserting lithium ions into intercalation gaps more difficult. As a result, power and lithium plating are reduced, resulting incapacity loss. High temperatures accelerate the response rate with increased power production, but they also enhance heat dissipation and produce even higher temperatures. The temperature will rise unless heat is released faster than it is created, resulting in a thermal runaway. Thermal runaway is divided into numerous phases, each of which results in irreparable cell damage First, the SEI layer is dissolved in t h e electrolyte at around 80 degrees Celsius.

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Primary overheating can be caused by excessive current or a high ambient temperature. Following the collapse of the SEI layer, the electrolyte begins to react with the anode. This is an exo- thermal process that causes the temperature to rise. Second, the increased temperature degrades organic solvents, resulting in theproduction of hydrocarbon gases. This usually starts at 110° c. The gas has raised the pressure inside the cells and raised the temperature over the flashpoint.

The gas, however, does not ignite due to a lack of oxygen [3]. A vent is essential to expel the gas in order to keep the cells at proper pressure and avoid rupture. The separator melts and short circuits occur between the anode and cathode at 135 ° c [6] . Finally, around 200 degrees Celsius, the metal-oxide cathode degrades and emits oxygen, allowing the electrolyte and hydrogen gas to burn. This reaction is also exo-thermal, which raises the temperature and pressure even higher. Coefficient of Total Heat Transfer Heat transfer can generally be expressed using the overall heat transfer co-efficient by the following equation to predict the performance of the heat exchange:

$$q = UA\Delta TM \quad - (2.3)$$

where

q Heat transfer rate [W]

U Overall heat transfer coefficient [W/ (m²·K)]

A Heat transfer surface area [m²]

ΔTM Approximate mean temperature different [K]

This equation accounts for both convective and conductive heat transfer between hot and cold fluids in a heat exchanger. The radiation component of heat transfer, as well as heat transfer between the heat exchanger and the atmosphere, are insignificant.

IV. BATTERY THERMAL MANAGEMENT SYSTEMS (BTMS)

Different types of battery thermal technologies are as follows:

A. Air Conditioning and Heating

Air serves as the heat medium in air systems. The intake air might come directly from the environment or the cabin, or it could be conditioned air from the heater or evaporator of an air conditioner. The former is referred to as a passive air system, whereas the latter is referred to as an active air system. Active systems might provide additional cooling or heating capacity. An active system is restricted to 1 kW of cooling or heating power, but a passive system can offer hundreds of watts. They are also known as forced air systems since the air in both situations is provided by a blower. A schematic depiction of systems is depicted in the diagram below [6].

B. Heating and cooling with liquids

Aside from air, the liquid is another heat transfer fluid that can be used to transfer heat. There are two types of liquids used in thermal management systems. One type of dielectric liquid (direct-contact liquid), such as mineral oil, can directly contact the battery cells. The other type is conducting liquid (indirect-contact liquid), which can only make indirect contact with the battery cells, such as a mixture of ethylene glycol and water. Different layouts are designed based on the different liquids. The standard layout for direct-contact liquid is to submerge modules in mineral oil. Heating and air conditioning Liquid systems can also be classified as passive or active based on the heat sink used for cooling. A radiator serves as the heat sink for cooling in a passive liquid system. This system is incapable of producing heat. The systematic scheme of a passive liquid system is depicted below. The pump circulates heat transfer fluid within a closed system. The circulating fluid absorbs heat from the battery pack and dissipates it through a radiator. The cooling power is highly dependent on the temperature difference between the ambient air and the battery. Fans behind the radiator can improve cooling performance, but if the ambient air temperature is higher than the battery temperature or the difference is too small, the passive liquid system becomes ineffective. A jacket around the battery module, discrete tubing around each module, placing the battery modules on cooling/heating plates, or combining the battery module with cooling/heatingfins and plates are all possible layouts for indirect-contact liquid. (2001, Pesaran) In between these two groups, indirect contact systems are preferred for improved isolation between the battery module and its surroundings, and thus for improved safety performance [3].

C. Direct Refrigerant Heating and Cooling

A direct refrigerant system (DRS) is an A/C loop that, like active liquid systems, uses refrigerant directly as heat transfer fluid circulating through the battery pack. The systematic design is as below

D. PCM (Phase change materials)

Heat is absorbed by PCM during melting and stored as latent heat until the latent heat reaches its maximum. The temperature is held at the melting point for an extended period of time, and the temperature rise is delayed. As a result, PCM is used in battery thermal management systems as a conductor and buffer. The graph depicts the PCM working mechanism on battery cells. A PCM is also always combined with air or liquid cooling system to manage the battery temperature.

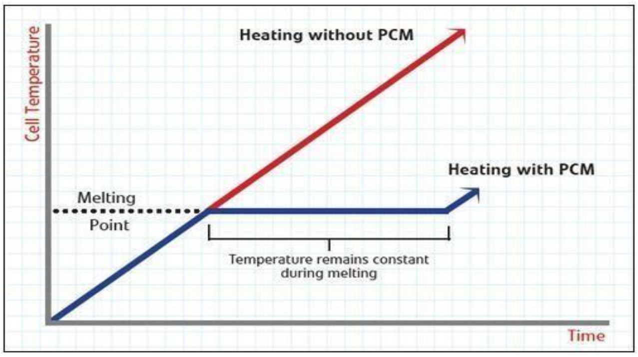


Figure 3.1 The working mechanism of PCM on battery cells

E. Module Thermoelectric

There are two possible upgrades to improve the cooling/heating power of passive air systems. One method is to use thermo- electric modules, which will be discussed further below.

Thermoelectric modules are capable of converting electric voltage to temperature difference and vice versa. The former effect is used here. That is, it transfers heat through the module by directly consuming electricity. The diagram structure is shown below. Two fans are installed to improve forced convection heat transfer. When a passive air system is combined with a thermo-electric module, the combined system can cool the battery even lower than the intake air temperature, but the power is still limited to hundreds of watts and less than one kW. (Valeo, 2010) It is simple to switch between cooling and heating modes. To accomplish this, the electrode poles must be reversed [4].

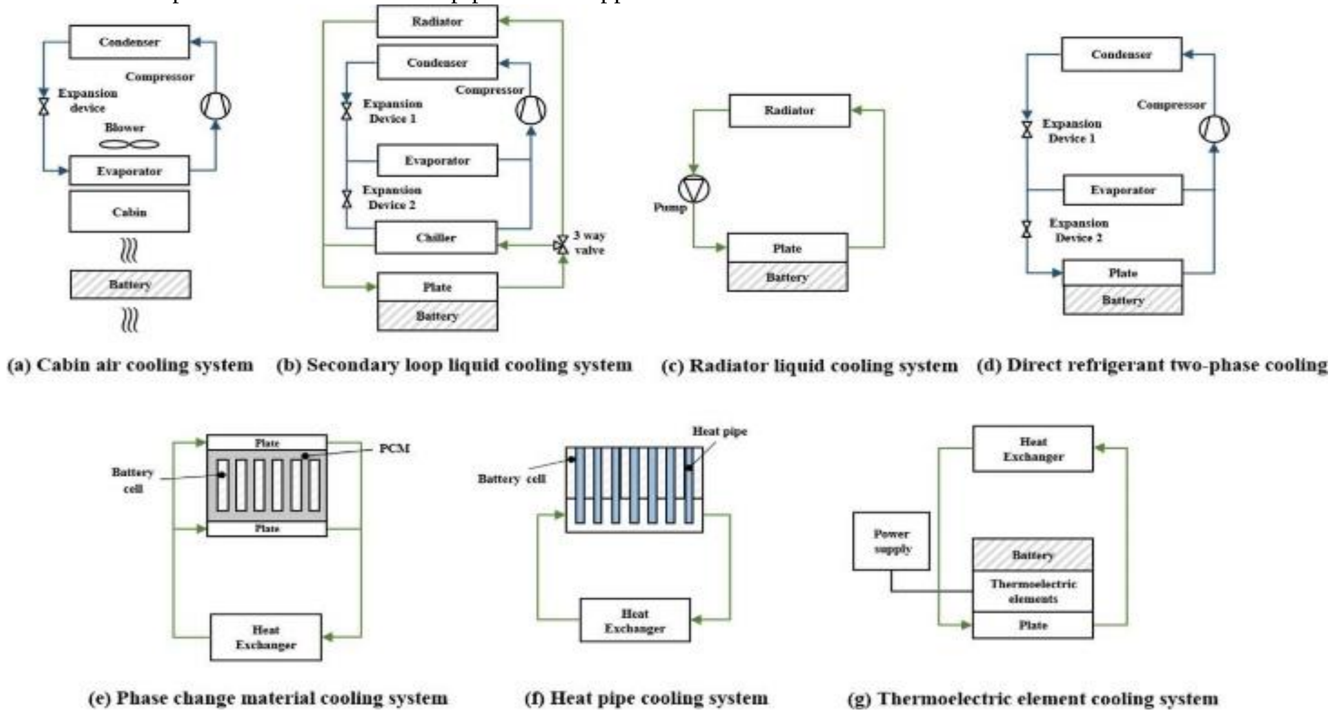
F. Heat Tube

A heat pipe, in addition to thermo-electric modules, is another way to improve passive air systems. A heat pipe's structure is depicted below. The heat pipe's flat copper envelope was partially vacuumed. Sintered copper powder is used to make the capillary structure [2].

Water serves as the working fluid in the heat pipe. Due to the low pressure inside, water on the evaporator side will absorb heat and turn into vapor at temperatures below 100°C. Water on the condenser will dissipate heat to the surrounding environment and revert to liquid. This cycle is repeated indefinitely.

G. PTC Heater

PTC thermistors have a wide range of self-heating applications due to their unique voltage-current or current-time characteristics. One of the applications is as a PTC heater, which is a self-regulating heater [3]. The temperature of a PTC heater can be kept constant by automatically adjusting the resistance of the PTC heater.



(a) Cabin air cooling system (b) Secondary loop liquid cooling system (c) Radiator liquid cooling system (d) Direct refrigerant two-phase cooling

(e) Phase change material cooling system (f) Heat pipe cooling system (g) Thermoelectric element cooling system

Fig. 3.2. Schematics of the various battery cooling system.

V. MODELLING OF BTMS

The system is comprised of two coolant loops, a refrigeration loop, and a cabin HVAC loop, as constructed by the MATLAB modelling based on the examination of the various BTMS technologies. The thermal load is made up of the batteries, powertrain, and cabin. Using the 4-way valve, the two coolant loops can be joined in serial mode or kept separate in parallel mode. In cold weather, the coolant loops operate serially, allowing heat from the motor to warm the batteries. A heater can be used to provide additional heat if necessary [1]. In hot weather, the coolant loops remain serial, and the batteries and powertrain are both cooled by radiators. The coolant loop switches to parallel mode and separates in hot weather. The radiator is used in one loop to cool the powertrain. The chiller in the refrigeration loop is used to cool the batteries in the other. A compressor, a condenser, a liquid receiver, two expansion valves, a chiller, and an evaporator comprise the refrigeration loop. When the radiator alone is insufficient to cool the coolant in hot weather, the chiller is used. When the air conditioning is turned on, the evaporator cools the vehicle cabin. The compressor is set so that the condenser can dissipate the heat absorbed by either the chiller or both the evaporator and the chiller. A blower, an evaporator, a PTC heater, and the vehicle cabin comprise the HVAC loop. In cold weather, the PTC heater provides heating; in hot weather, the evaporator provides air conditioning. The blower is programmed to maintain the cabin temperature setpoint. Three situations are included in this model. The drive cycle scenario replicates driving conditions in 30°F with the air conditioner turned on. The NEDC determines the vehicle speed, which is followed by 30 minutes of high speed to boost the battery heat loa d. In the cool down scenario, a stopped car in 40 -d e g r e e temperatures with the air conditioner turned on is simulated.

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Finally, the cold weather scenario replicates driving in -10-degree weather, necessitating the usage of the battery heater and PTC heater, respectively, to warm up the batteries and cabin.

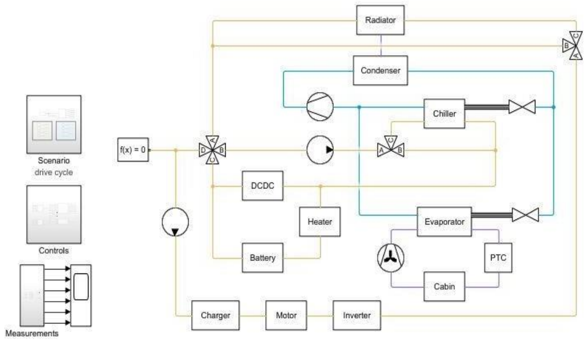

Fig. 4.1. modelling of BTMS in MATLAB

VI. RESULTS

The model is been checked in three different situations based on the environmental condition and the vehicle

A. Charging state
B. Drive mode
C. Cold weather
D. Hot weather

A. The result of the charging state is shown below:

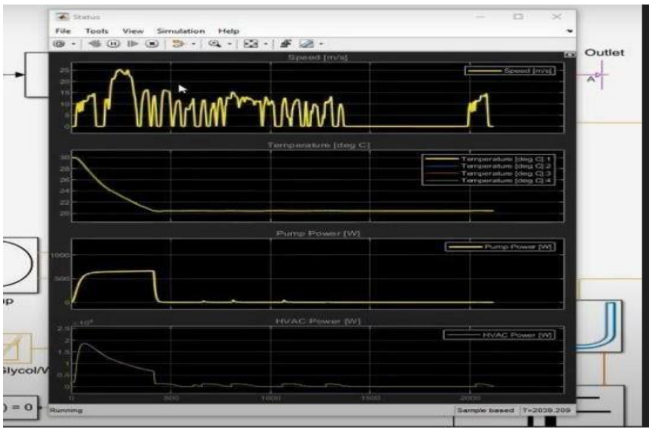

Fig. 5.1. Simulation Output of Charge Cycle

B. Results Of Drive Cycle Under Different Environmental Conditions

- *During Cold Weather Conditions*

The scope below depicts the drive cycle cold weather scenario's vehicle speed, heat degeneracy, cabin temperature, component temperature, and control orders. The coolant loop is initially in serial mode. It switches to parallel mode after roughly 2500 seconds, and the chiller is utilized to keep the batteries above 20 degrees Celsius.

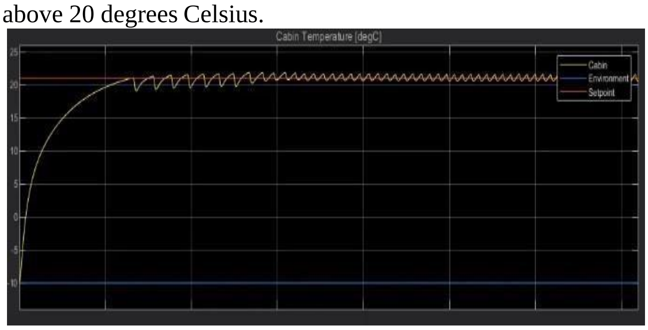

Fig 5.2 Cabin Temperature

- *During Hot weather conditions*

The scope below depicts the drive cycle scenario's vehicle speed, heat dissipation, cabin temperature, component temperatures, and control orders. The coolant loop is initially in serial mode. It switches to parallel mode after roughly 1100 seconds, and the chiller is utilised to keep the batteries below 35 degrees Celsius.

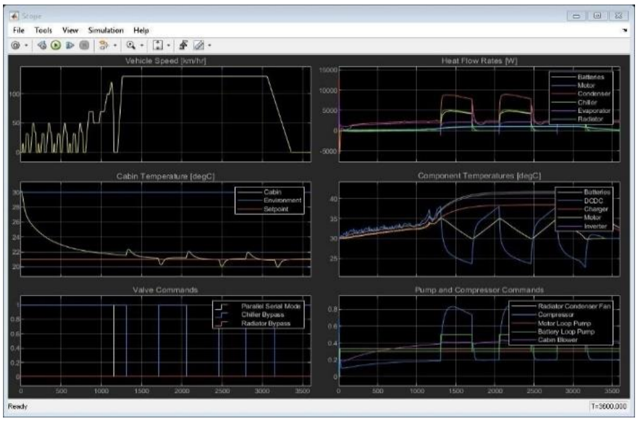

Fig 5.3 Output during Hot Weather Condition

VII. CONCLUSION

In general, the two cooling systems have been constructed to meet nearly all of the initial requirements. Under various weather, control, and driving conditions, numerical results with figures have been generated. The predicted electric energy consumption makes logic and had the correct propensity.

Furthermore, the modelling demonstrated its adaptability to novel systems with minor variations. The simulation findings demonstrated the impact of driving style, battery starting temperature, and ambient temperature on the BTMS and related power consumption.

The results showed that the BTMS feature was strongly affected by different driving cycles in hot weather but not as much in cold weather. The ambient temperature was the most crucial factor for the BTMS. Energy usage was greatly impacted by the battery's starting temperature, which represented pre-conditioning treatment, especially in extremely hot and cold climates.

FUTURE SCOPE

Despite the creation of a Simulink model, much more research might be conducted on the subject of battery temperature management systems. This model presently can only process stationary data from files.

As a result, the model interface must be enhanced so that it can communicate with other battery pack or car component models using machine learning algorithms and ANN. With the pre-and post-conditions, alternative control tactics, consumer behavior, and other aspects may all be used to optimize the thermal management system by building an ANN model which can be combined with this model.

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Authors Contributions	Both authors have the equal participation in the article with the domain they are strong.

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