Battery Thermal Management for Sustainable Electric Vehicles

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Abstract- **Battery thermal management is a critical aspect of electric vehicle (EV) design, as it directly impacts the performance, safety, and longevity of the battery pack. This project aims to investigate and develop effective battery thermal management systems (BTMS) for electric vehicles. The project will focus on designing and optimizing a BTMS that utilizes phase-change materials (PCMs) to regulate battery temperature and prevent overheating. The system will be designed to maintain optimal operating temperatures, reduce thermal stress, and improve overall battery performance. The project will involve simulation, experimentation, and testing to validate the effectiveness of the proposed BTMS. The results of this project will contribute to the development of more efficient and reliable electric vehicles.**

I. INTRODUCTION

The increasing demand for sustainable transportation solutions has led to a significant growth in the adoption of electric vehicles (EVs). As EVs continue to gain popularity, the importance of efficient battery thermal management systems (BTMS) cannot be overstated. Batteries in EVs are sensitive to temperature fluctuations, which can impact their performance, safety, and longevity. Effective BTMS are crucial to maintaining optimal battery temperatures, preventing overheating, and ensuring the overall efficiency and reliability of EVs. This project aims to design and develop an innovative BTMS using phase-change materials (PCMs) to regulate battery temperature and prevent overheating, thereby improving the performance, safety, and adoption of electric vehicles. The current automotive market offers a wide range of HEVs, Pure electric car mixing level. Many sizes, friendly, many battery cells are installed according to the EV Mixed level. Battery cells as energy sources There are more stringent requirements for the work The traditional fuel environment. Temperature sensitivity They are very serious. Of course, BTM is combined Use battery cells to ensure excellent heat effect environment. Therefore, they understand the necessary conditions for correct operation and type of battery Management systems that can meet these conditions are Definitive. Battery performance and life span This foundation allows you to maximize your EV. Additionally, there is an electrical vehicle area. As part of the Environmental Act on Greenhouse Gas Emissions (GHG) Interest in electric vehicles (EVs) has been strengthened, - hybrid electric vehicle (HEV), plugin - Includes hybrid Electric Vehicles (PHEVs) and Battery Electric Vehicles (BEV) is increasing. Find the right energy source Major obstacles to EVs. High mileage, fast charging, and high-performance storage systems. Rechargeable li-ion Batteries are said to be the best energy storage option unpaid for their larger energy density and specific forces, EVs are higher Recyclability, greater lightness, and lower self-emission rate Compare with other rechargeable batteries such as lead acids Longer cycle life, you also benefit from no memory Effect. However, these Li-ion batteries are extreme Sensitive to temperature in terms of performance, life and safety. Creating clear and inclusive creations is difficult Systems that reduce the effectiveness and security of Li-ion Commercial batteries use a variety of applications, so Electrode material and electrolyte mixture. But that's true Clear Ni-CD and Ni-MH batteries made of nickel Cadmium li Ion Battery Performance with almost all cellular materials experience one an abnormal temperature range.

II. LI-ION BATTERY

Li-ion batteries operate on the principle of intercalation, where lithium ions move between the cathode and anode during charging and discharging. When a Li-ion battery is charged, lithium ions are extracted from the cathode and inserted into the anode. During discharge, the process is reversed, and lithium ions flow back to the cathode, releasing electrons that flow through the external circuit.

The Key Components of Lithium -ion batteries are as follows;

Cathode (Positive Electrode): Typically made from lithium metal oxides (e.g., lithium cobalt oxide), the cathode is a critical component that determines the battery's capacity and voltage.

Anode (Negative Electrode): Usually composed of graphite, the anode stores lithium ions during charging and releases them during discharging.

Electrolyte: A lithium salt dissolved in an organic solvent, the electrolyte facilitates the flow of lithium ions between the cathode and anode.

Separator: A thin, porous membrane that separates the cathode and anode, preventing electrical shorts while allowing ions to pass through. Thermal issues in lithium-ion battery.

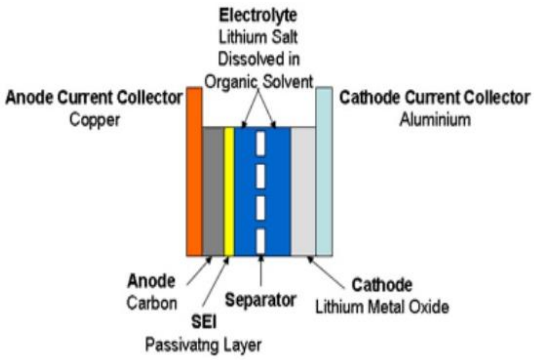

Fig: The Physical Structure of li-ion battery

III. LI-ION BATTERYTHERMAL ISSUES

The performance of lithium-ion cells is affected by both Temperature and operating voltage. Lithium - Ion Cells if tension and temperature are limited, take off often. Otherwise, the cells cause irreversible damage. If the charging voltage exceeds, an overvoltage will occur. Accepted cell tension leads to excessive power flow and two problems. In high flow, lithium ions are the anode layer and the lithium ions then accumulate as metallic lithium. Anode surface. This is called lithium coating. It causes a Reduction of free lithium ions and loss of irreversible ability. Metallic lithium coating is split into two types: uniform lithium coating and non-uniform It is a lithium coating, but lithium coating is naturally dendritic. Finally, this electrode. Under voltages such as over voltages caused Problems leading to electrode collapse material. The copper current collector on the anode fails. The battery discharge rate and voltage increase, Copper ions fail as metallic copper, but this is irreversible. The scenario is dangerous because there are shorts between them. Anodes and cathodes can occur. After many cycles at low voltages, cobalt oxide or oxide manganese and the cathode dissolves. In the meantime, it will become oxygen It will be released and the battery will run out of capacity. The battery temperature should be checked periodically. Both if the heat is too low, problems will arise. Chemicals The reaction rate is proportional to the temperature. in the case of the working temperature drops, and the return rate is the current load capacity decreases during load or Exhaust. In other words, the battery capacity is Decreased. Furthermore, the reaction speed is slower Inserting lithium ions into the intercalation gap is more difficult. As a result, performance and lithium coating decrease. Impossible loss. High temperature accelerates the reaction There is a rate when power generation increases, but they also increase the heat sector and generate even higher temperature. If no heat is released, the temperature will rise It leads to thermal outliers faster than it is created.

Thermal outliers are divided into many phases, each This leads to irreparable cell damage in the first place. This is a layer It is resolved with an electrolyte of approximately 80 degrees Celsius. The main overheating is excessive current or the ambient temperature is high. Continuing with the collapse of the layer, the electrolyte, begins to react with the anode. It is an additional thermal process that leads to increased temperature. Second, the rise in temperature affects organic solvents; It leads to the production of hydrocarbon gases. This is normal It starts at 110°C. Gas increased cell pressure. The temperature of the flash point has been increased. However, the gas will not ignite due to lack of oxygen. Ventilation is essential to eliminating and maintaining gas Prevent cells from breaking down with proper pressure.

IV. BATTERY THERMAL MANAGEMENT SYSTEM(BTMS)

Several thermal management technologies are employed to regulate the temperature of batteries. These can be broadly categorized as follows:

A. Air-Based Thermal Management

Air is utilized as the heat transfer medium in these systems. The air drawn into the system can be sourced directly from the surrounding environment or the vehicle cabin. Alternatively, it can be conditioned air that has been heated or cooled by the vehicle's heater or air conditioning unit. Passive Air Systems: These systems draw in ambient air directly without any additional conditioning. They are capable of providing cooling or heating in the range of hundreds of watts. Active Air Systems: These systems utilize conditioned air, offering enhanced cooling or heating capabilities, typically up to 1 kW. Both passive and active air systems rely on a blower to force the air across the battery pack, and are therefore also known as forced air systems.

B. Liquid-Based Heating and Cooling

Liquids serve as another effective heat transfer medium for battery thermal management. Two main types of liquids are used:

Direct-Contact (Dielectric) Liquids: These liquids, such as mineral oil, possess non-conductive properties, allowing them to come into direct contact with the battery cells. A common design involves submerging battery modules in the dielectric liquid.

Indirect-Contact (Conducting) Liquids: These liquids, such as a mixture of ethylene glycol and water, are conductive and can only make indirect contact with the battery cells. Various layouts are employed, including jackets around battery modules, discrete tubing around each module, placing modules on cooling/heating plates, or integrating modules with cooling/heating fins and plates. Indirect contact systems are generally favored for improved safety due to the enhanced isolation they provide between the battery module and its surroundings. Liquid-based systems can also be classified as passive or active based on the cooling mechanism:

Passive Liquid Systems: These systems utilize a radiator as a heat sink for cooling. A pump circulates the heat transfer fluid within a closed loop. The fluid absorbs heat from the battery pack and dissipates it through the radiator. These systems are unable to provide heating. Their cooling capacity is highly dependent on the temperature difference between the ambient air and the battery.

Active Liquid Systems: These systems, unlike passive ones, incorporate a chiller or a heat pump to provide active cooling and potentially heating.

C. Direct Refrigerant Heating and Cooling (DRS)

A Direct Refrigerant System operates similarly to an active liquid system but uses refrigerant as the direct heat transfer fluid circulating through the battery pack. This system essentially integrates an air conditioning loop directly with the battery thermal management.

D. Phase Change Materials (PCM)

Phase Change Materials absorb heat by undergoing a phase transition, typically from solid to liquid (melting). During this process, a significant amount of heat is absorbed and stored as latent heat with minimal temperature change, effectively delaying temperature rise. Consequently, PCMs are utilized in BTMS as both a thermal conductor and a thermal buffer. It is important to note that PCM is typically used in conjunction with air or liquid cooling systems to provide comprehensive temperature management.

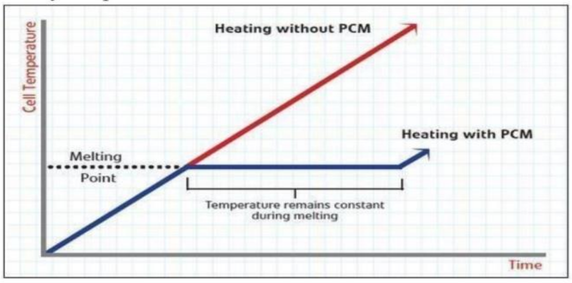

Fig: The working mechanism of PCM on battery cells

E. Thermoelectric modules

Thermoelectric Modules can convert electric voltage into a temperature difference and vice versa. This document focuses on the former effect, where electricity is directly used to transfer heat through the module. Combining a passive air system with a thermoelectric module allows for battery cooling to temperatures lower than the intake air temperature, although the power remains limited to hundreds of watts, not exceeding one kilowatt. The ability to switch between cooling and heating modes is easily achieved by reversing the electrode poles. Heat Pipes Heat pipes offer another method for improving passive air systems, in addition to thermoelectric modules.

F. PTC Heaters

PTC thermistors find widespread application in self-heating devices due to their unique voltage-current or current-time characteristics. One such application is the PTC heater, which is a self-regulating heater. The temperature of a PTC heater can be maintained at a constant level through automatic adjustment of the PTC heater's resistance.

V. MODELING OF BTMS

Based on an examination of various BTMS technologies, a MATLAB model was constructed, consisting of two coolant loops, a refrigeration loop, and a cabin HVAC loop. The thermal load is composed of the batteries, powertrain, and cabin. The two coolant loops can be connected in series or kept separate in parallel mode using a 4-way valve. In cold conditions, the coolant loops operate in series, allowing heat from the motor to warm the batteries. If necessary, a heater can provide additional heat. In hot conditions, the coolant loops remain serial, and both the batteries and powertrain are cooled by radiators. The coolant loop switches to parallel mode and separates in hot conditions. One loop uses the radiator to cool the powertrain, while the other uses the chiller in the refrigeration loop to cool the batteries. The refrigeration loop includes a compressor, a condenser, a liquid receiver, two expansion valves, a chiller, and an evaporator. The chiller is employed when the radiator alone is insufficient to cool the coolant in hot weather. When the air conditioning is activated, the evaporator cools the vehicle cabin. The compressor is configured to allow the condenser to dissipate the heat absorbed by either the chiller or both the evaporator and the chiller. The HVAC loop comprises a blower, an evaporator, a PTC heater, and the vehicle cabin. The PTC heater provides heating in cold conditions, while the evaporator provides air conditioning in hot conditions. The blower is programmed to maintain the cabin temperature set point. This model incorporates three scenarios: a drive cycle scenario simulating driving conditions at 30°F with the air conditioner on; the NEDC determines the vehicle speed, followed by 30 minutes of high speed to increase the battery heat load. The second scenario simulates a stopped car in 40-degree temperatures with the air conditioner activated

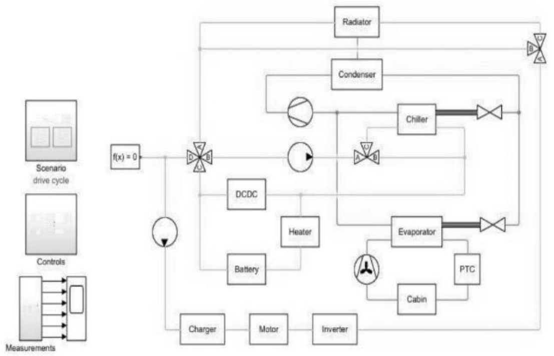

Fig: Modeling of BTMS in MATLAB

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:

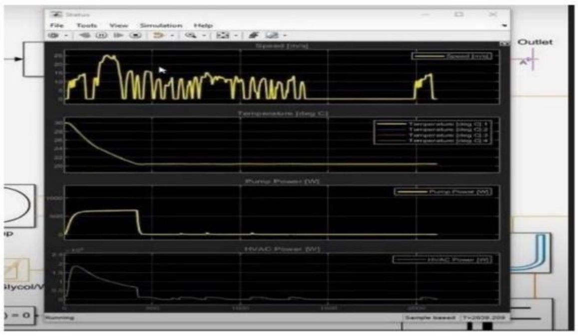

Fig: Simulation Output of Charge Cycle

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.

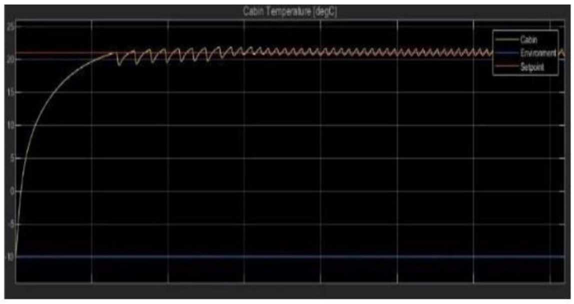

Fig: Cabin Temperature

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 utilized to keep the batteries below 35 degrees Celsius.

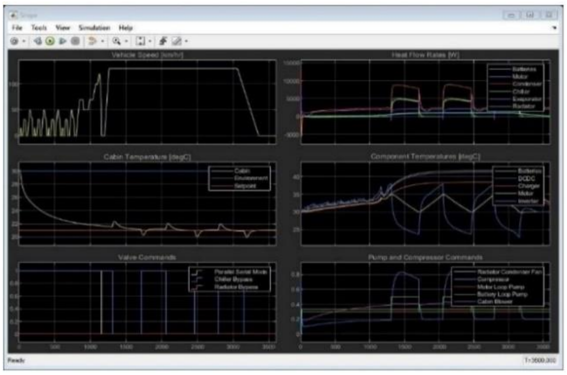

Fig: Output during Hot Weather Condition

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 modeling 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.

REFERENCES

[1] "Extreme rapid charging of electric vehicles: A technical review," H. Tu, H. Feng, S. Srdic, and S. Lukic, IEEE Trans. Transport. Electrify, vol. 5, no. 4, December 2019, pp. 861-878, doi: 10.1109/TTE.2019.2958709. [CrossRef]

[2] "Improved operation and management of single-phase integrated onboard charger system," IEEE Trans. Power Electron, vol. 36, no. 4, pp. 4752-4765, Apr. 2021.M. Huang, Y. Lu, and R. P. Martins,‘‘A reconfigurable bidirectional wireless power transceiver for batteryto-battery wireless charging,’’ IEEE Trans. Power Electron., vol. 34, no. 8, pp. 7745–7753, Aug. 2019 [CrossRef]

[3] Kumari SHIPRA, Rakesh MAURYA, and Shambhu N. SHARMA, CPSS TRANSACTIONS ON POWER ELECTRONICS AND APPLICATIONS, VOL. 6, NO. 1, MARCH 2021. [CrossRef]

[4] 10.1109/ACCESS.2021.3090763 Digital Object Identifier Study of Electric Vehicle Battery Charging Strategy Considering Battery Capacity June 21, 2021 / SEOUNG UK JEON / IEEE access journal

[5] S. Bandyopadhyay, P. Venugopal, J. Dong, and P. Bauer, "Multiobjective optimization of magnetic couplers for IPT-based EV charging," IEEE Trans. Veh. Technol., vol. 68, no. pp. 5416-5429, Jun. 2019. [CrossRef]

[6] Khaligh and M. D'Antonio, "Global Trends in High-Power OnBoard Chargers for Electric Vehicles," IEEE Transactions on Vehicle Technology, vol. 68, no. 4, April 2019, pp. 3306-3324. [Crossruff]

[7] Battery University (2014) University of the Battery [Online] Available at: http://batteryuniversity.com/learn/article/lithiu m ion types [Accessed on April 8, 2014].

[8] Binder (2014). Technology for thermoelectric cooling.