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TEG and TEC Battery Cooling System

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Abstract: In various industries and applications, maintaining optimal operating temperatures for batteries is important to ensure performance, longevity, and safety. Traditional methods of battery cooling often involve complex and energy-intensive systems. In this paper, we propose a Thermoelectric Generator (TEG) and Thermoelectric Cooler (TEC) battery cooling system as an innovative solution to address this challenge. By harnessing the thermoelectric effect, this system offers a compact, efficient, and environmentally friendly approach to regulate battery temperatures. Through a comprehensive review of relevant literature and the design and implementation of our TEG and TEC cooling system, we explore its potential advantages and limitations. Experimental results demonstrate the system's effectiveness in maintaining desired battery temperatures while highlighting opportunities for further optimization. This research contributes to the advancement of battery cooling technology and opens avenues for future research and practical applications in various fields, including electric vehicles, renewable energy systems, and portable electronics.

I. INTRODUCTION

In recent years, the demand for efficient and reliable battery systems has grown significantly across various industries, including automotive,renewable energy, and consumer electronics. One critical aspect of battery performance that often receives less attention is temperature management. Maintaining optimal operating temperatures is essential for maximizing battery efficiency, extending lifespan, and ensuring safety. Traditional methods of battery cooling typically rely on bulky and energy-intensive systems, which can be challenging to integrate into compact or portable applications. However, advancements in thermoelectric technology offer promising solutions to this challenge. Thermoelectric devices, such as Thermoelectric Generators (TEGs) and Thermoelectric Coolers (TECs), utilize the thermoelectric effect to control temperature without the need for moving parts or harmful refrigerants. This paper explores the potential of employing TEGs and TECs as a battery cooling system. By leveraging the unique capabilities of thermoelectric devices, we aim to develop a compact, efficient, and environmentally friendly solution for managing battery temperatures. Through a comprehensive review of existing literature and our own experimental work, we investigate the effectiveness of this approach and its implications for various applications. The following sections will delve into the background of thermoelectric technology, the importance of battery cooling, and the design and implementation of our TEG and TEC battery cooling system. Additionally, we will discuss experimental results, analysis, and potential future directions for research and practical implementation. The global transition towards renewable energy sources is driven by concerns over limited reserve volumes, uneven distribution, and the environmental impacts of traditional fossil fuel-based energy resources. This shift is further accelerated by predictions indicating a substantial increase in electricity generation from renewable sources by 2035, with estimates suggesting it could be 2.7 times larger than in 2010. As the world embraces sustainability, renewable energy based applications such as consumer electronics, vehicles, and buildings are gaining prominence. Electric vehicle (EV) and hybrid electric vehicle (HEV) technology, in particular, have emerged as green substitutes for conventional combustion vehicles, attracting significant attention globally and rapidly replacing internal combustion engine-powered vehicles. In this transition, batteries play an increasingly critical role in renewable energy usage and storage. The performance of EVs and HEVs is highly dependent on battery capacity, making battery thermal management systems (BTMS) essential for monitoring and optimizing battery temperature.

Battery temperature significantly impacts operating performance, with the charge/discharge capacity and lifespan of batteries being strongly influenced by temperature variations. Efficient temperature management systems contribute significantly to battery health and extend overall lifespan. With increasing capacity and charge/discharge rates, battery security issues require more attention, leading to the development of various BTMS to meet demand for higher power, faster charge rates, and improved driving performance. Modern BTMS are divided into two groups: active systems and passive systems, each with its own advantages and limitations. While traditional active methods often involve forced circulation and the circulation of specific cooling materials such as water and air, recent developments have seen the integration of thermoelectric coolers (TECs) into BTMS for electric vehicles. TECs offer strong cooling capacities and reliable working potential, making them increasingly attractive for integration into BTMS. TECs operate based on the Peltier- Seebeck effect, converting voltage to temperature difference, and offering advantages such as quiet operation, stability, and easy temperature control.

Despite their potential benefits, the use of TECs in BTMS has been limited due to concerns over low thermal efficiency and the novelty of their application. However, recent research has shown promising developments in utilizing TECs for battery cooling, with advancements in design and optimization. This study focuses on the thermal management of batteries in state of electric vehicles and proposes an advanced hybrid BTMS design. This novel design incorporates solid-state TECs and a combination of forced air and liquid cooling, offering enhanced thermal management capabilities. The experimental design, setup, and preliminary results of this innovative BTMS are presented in the following sections, filling a gap in the literature regarding TEC- liquid-based battery thermal management systems. The global transition towards renewable energy sources and the urgent need to mitigate environmental impacts have accelerated the adoption of electric vehicles (EVs) and hybrid electric vehicles (HEVs) as alternatives to traditional combustion engine vehicles. Central to the performance and longevity of EVs and HEVs are their battery systems, which rely heavily on effective thermal management. In recent years, there has been a surge in research and development efforts focused on enhancing battery thermal management systems (BTMS) to optimize battery performance, longevity, and safety. Traditional cooling methods, such as air and liquid cooling, have been widely employed, but their limitations in efficiently managing battery temperatures under various operating conditions have prompted the exploration of alternative approaches. One promising avenue is the integration of thermoelectric coolers (TECs) into BTMS. TECs offer distinct advantages, including quiet operation, stability, reliability, and the ability to both heat and cool depending on the application requirements. However, the utilization of TECs in BTMS for electric vehicles is still relatively novel, and there is a need for innovative designs that maximize their effectiveness. This paper presents a novel hybrid BTMS design that combines the benefits of TECs with forced air cooling and liquid cooling. Unlike traditional approaches, this hybrid system leverages the use of battery shells to protect the batteries from direct contact with the coolant, enhancing safety and efficiency. Additionally, environmentally friendly solid-state TECs are employed as a versatile cooling medium, capable of adapting to varying environmental conditions by simply switching the current polarity. The experimental design, setup, and preliminary results of this innovative BTMS design are detailed in the following sections, providing valuable insights into the potential of hybrid cooling systems for advancing the performance and reliability of electric vehicle batteries. Through this research, we aim to contribute to the ongoing efforts towards sustainable transportation and the widespread adoption of electric vehicles.

II. PROBLEM CONCEPT

The increasing adoption of electric vehicles (EVs) brings to light several critical challenges associated with battery temperature management:

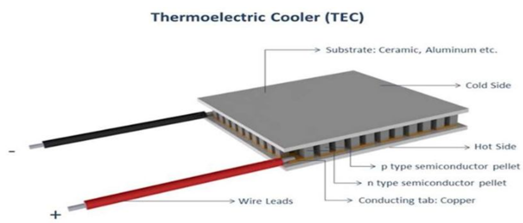
1) Rise in Temperature: As EV batteries undergo charging and discharging cycles, they generate heat due to internal resistance and chemical reactions. Without proper thermal management, this heat accumulation can lead to a substantial increase in battery temperature.
2) Melting of Battery Components: Elevated temperatures within the battery increase the risk of thermal runaway, where the electrolyte can vaporize,and battery components, such as electrodes and separators, may melt. This not only compromises the structural integrity of the battery but also poses safetyhazards due to the potential release of toxic gases andflammable materials.
3) Short-Circuit and Burning Possibility: High temperatures exacerbate the likelihood of internal short circuits, which can trigger thermal runaway andresult in fires or explosions. These events not only endanger the vehicle occupants but also pose risks to surrounding property and individuals.
4) Risks to Passenger Safety: The thermal hazards associated with overheating batteries pose significantrisks to passenger safety, especially in the event of a vehicle collision or malfunction. Ensuring the safe operation of EVs under various driving conditions isparamount to maintaining passenger well-being.
5) Wastage of Battery Charging: Excessive heat during charging and discharging processes leads to energy losses and decreased charging efficiency. This inefficiency results in wastage of battery capacity and compromises the overall energy utilization of the vehicle, thereby reducing its range and efficiency.
6) Effect on Battery Life: Elevated temperatures accelerate the degradation of battery materials, leading to a reduction in battery life expectancy. Premature battery failure due to thermal degradation necessitates costly replacements, adding to the overall ownership costs of EVs.
7) Costly Battery Replacement: The need for frequent battery replacements due to thermal degradation significantly contributes to the total cost of ownership of EVs. High replacement costs pose financial challenges for EV owners and hinder the widespread adoption of electric vehicles. Addressingthese challenges is crucial for enhancing the safety, reliability, and cost-effectiveness of electric vehicles,thereby accelerating their adoption and contributing to sustainable transportation solutions.

III. THEORETICAL CONCEPT

A Thermoelectric Cooler (TEC) operates based on the conversion of voltage to a temperature difference, known as the Peltier effect. This effect facilitates the transfer of heat between two electrical junctions when a voltage is applied across joined conductors. Consequently, heat is removed at one junction, inducing cooling, while heat is deposited at the opposite junction. Despite its advantageous properties such as noise-free operation, absence of internal chemical reactions, and low maintenance costs, TECs suffer from limitations like low efficiency and additional power requirements, which impede their widespread commercial application.

Components Use:

1) *TEG & TEC Plate:*



Peltier elements, also known as Thermoelectric Coolers (TECs) and Thermoelectric Generators (TEGs), are utilized as thermoelectric power generators in this study. While TECs are conventionally employed for cooling applications or heat pump uses, they can also function as generators. The efficiency of thermoelectric materials for the low-temperature sector (0 °C to 200 °C) is relatively modest, but the costs associated with TEGs are lower. Therefore, a critical consideration in this research is determining the temperature range and conditions under which expensive TEGs can be replaced by cost-effective TECs. Consequently, the study involves testing and comparing TECs and TEGs under uniform conditions to ascertain their performance characteristics.

2) *Temperature Sensors:*

Temperature sensors play a crucial role in monitoring and controlling the thermal conditions within the battery cooling system. In this study, LM35 temperature sensors are employed for their precision and reliability. The LM35 series, supplied by leading manufacturers, represents a class of precision integrated-circuit temperature sensors characterized by their linear output voltage proportional to the Centigrade temperature. Unlike sensors calibrated in Kelvin, the LM35 eliminates the need for subtracting a constant voltage to achieve convenient Centigrade scaling. Key advantages of the LM35 include its inherent calibration, low output impedance, and linear output, simplifying interfacing with readout or control circuitry. The LM35 device's robust performance characteristics, including its accuracy, wide operating temperature range, and low power consumption, make it well- suited for temperature monitoring applications within the battery cooling system.

3) *Battery:*

Batteries serve as the primary power source for various electrical devices, including those utilized in electric vehicles (EVs). As depicted in Fig 3.5, a battery typically consists of one or more electrochemical cells, each with specific external connections [1]. During power delivery, the positive terminal of the battery functions as the cathode, while the negative terminal serves as the anode [2]. Electrons flow from the negative terminal, through an external circuit, to the positive terminal, enabling the battery to supply electrical energy to connected devices. When a battery is connected to an external electric load, a chemical reaction known as a redox reaction occurs within the battery. This process converts high-energy reactants into lower-energy products, releasing the free-energy difference. The released energy is then delivered to the external circuit in the form of electrical energy. Historically, the term "battery" referred specifically to a device composed of multiple cells. However, over time, its usage has expanded to include devices consisting of a single cell. In the context of this study on TEG & TEC Battery Cooling System, understanding the fundamental principles of battery operation is crucial for assessing the effectiveness of the cooling system in maintaining optimal battery performance and prolonging battery life.

4) Electric Heater

Electric heating, is achieved by utilizing a known resistance within an electric circuit. This resistance impedes the flow of electrons, resulting in the generation of heat. The process of electric heating is highly efficient but can be costly due to the substantial amount of electrical energy required. The expense arises from the relatively high price of electricity compared to other energy sources such as water, gas, and fossil fuels. Despite the higher operational costs, electric heaters are favored for their ease of installation and relatively low purchase price. In domestic applications, electric heaters are often insulated with plastic materials to ensure user safety by minimizing the risk of electric shocks. Additionally, insulation helps to optimize energy efficiency by reducing heat dissipation. Electric heaters play a significant role in various applications, including residential heating, industrial processes, and heating systems for electric vehicles. Understanding the principles and characteristics of electric heaters is essential for evaluating their performance and efficiency in different contexts, including their integration within thermal management systems for batteries in electric vehicles.

5) Metal Plate

The Metal Plate, commonly referred to as the metallic or heat sink plate, serves a crucial role in the thermoelectric system by facilitating efficient heat dissipation. Typically constructed from materials like aluminum or other thermally conductive metals, this block acts as a medium for transferring heat away from the thermoelectric plates (TEG & TEC) to the surrounding environment. One of the primary functions of the M.S Plate is to provide a stable and uniform surface for the TEG & TEC plates to make contact. This ensures optimal thermal conductivity between the thermoelectric modules and the heat sink block, enabling efficient heat transfer across the system. By maximizing the surface area available for heat dissipation, the M.S Plate enhances the overall cooling efficiency of the thermoelectric system. Moreover, the M.S Block helps in maintaining the temperature stability of the thermoelectric modules by absorbing and dissipating excess heat generated during operation. This prevents thermal fluctuations and ensures consistent performance of the thermoelectric cooling system over extended periods. Additionally, the design and configuration of the M.S Block play a significant role in determining the overall thermal performance and reliability of the thermoelectric system. Factors such as the shape, size, and surface finish of the heat sink block influence its ability to dissipate heat effectively and maintain thermal equilibrium within the system. Overall, the M.S Plate serves as a critical component in thermoelectric cooling systems, facilitating efficient heat transfer and thermal management to ensure optimal performance and reliability. Its design and functionality are essential considerations in the development and optimization of thermoelectric- based cooling solutions for various applications.

6) Cooling Fans

Fans are integral components in thermoelectric cooling systems, playing a vital role in heat dissipation and air circulation. These devices facilitate the removal of hot air generated during the cooling process and contribute to enhancing the overall efficiency of the cooling system. One of the primary functions of fans is to assist in the dissipation of heat from the heat sink or M.S Block. As thermoelectric modules absorb heat from the target area, thetemperature of the heat sink block increases. The fan helps in expelling this heat by blowing air across the surface of the heat sink, promoting convective heat transfer and dissipating the thermal energy into the surrounding environment. Furthermore, fans aid in maintaining a consistent airflow within the cooling system. By circulating air over the heat sink and thermoelectric modules, fans ensure that thetemperature gradient across the system remains uniform, preventing localized hot spots and optimizing cooling performance. In addition to heat dissipation, fans also play a crucial role in preventing the buildup of stagnant air within the cooling system. Stagnant aircan hinder the efficiency of heat transfer and lead to temperature fluctuations, affecting the overall performance of the thermoelectric cooling system. By promoting air circulation, fans mitigate this issue and help maintain stable operating conditions. Moreover, fans can be strategically positioned to direct airflow towards specific areas of the cooling system, optimizing cooling efficiency in critical zones. Byadjusting the speed and direction of the fan, it is possible to fine-tune the cooling process and achieve optimal thermal management for different operating conditions. Overall, fans are essential components in thermoelectric cooling systems, contributing to efficient heat dissipation, air circulation, and temperature control. Their role in enhancing cooling efficiency and maintaining thermal stability makesthem indispensable for various applications, ranging from electronics cooling to automotive thermal management.

7) SMPS (Switched-Mode Power Supply):

The Switched-Mode Power Supply (SMPS) serves asa critical component in thermoelectric cooling systems, providing electrical power to various systemelements, including the TEG & TEC plates, fans, andother electrical components. Its primary function is to convert and regulate electrical energy from the input power source into stable and controlled output voltages required for the operation of the coolingsystem. One of the key advantages of SMPS over traditional linear power supplies is its high efficiency and compact design. Unlike linear power supplies, which dissipate excess energy as heat, SMPS utilizes switching regulators to efficiently control the voltage conversion process, resulting in reduced power lossesand improved energy efficiency. This efficiency is particularly important in thermoelectric cooling systems, where minimizing power consumption is essential for optimizing overall system performance and energy utilization. Moreover, SMPS offers flexibility in voltage regulation, allowing for precise control over the output voltage levels required bydifferent components within the cooling system. This ensures that the TEG & TEC plates, fans, and other electrical devices receive the correct voltage levels necessary for their proper operation, thereby enhancing the reliability and performance of the cooling system. Additionally, SMPS incorporates advanced features such as overvoltage protection, overcurrent protection, and thermal protectionmechanisms to safeguard the system against voltage spikes, current surges, and overheating conditions.These protective measures help prevent damage to thesystem components and ensure safe and reliable operation under various operating conditions. Furthermore, SMPS designs can be customized to meet the specific power requirements and operating characteristics of thermoelectric cooling systems. By selecting appropriate SMPS configurations and parameters, designers can optimize power delivery, efficiency, and performance to suit the unique needs of different applications and environments. In summary, SMPS plays a crucial role in thermoelectric cooling systems by providing stable and efficient electrical power to drive the operation of the system components. Its high efficiency, precise voltage regulation, and built-in protection features contribute to the overall reliability, performance, and safety of the cooling system, making it an essential componentfor various cooling applications.

8) Voltmeter/MultiMeter

In thermoelectric cooling systems utilizing thermoelectric generator (TEG) functionality, a voltmeter serves as a crucial instrument for measuring the voltage generated by the TEG plates. This measurement is essential for monitoring the electricity generation process and assessing the performance of the TEG modules within the system. The voltmeter istypically connected in parallel to the TEG plates, allowing it to measure the voltage difference or potential between the two electrical junctions of the thermoelectric module. As the TEG plates operate based on the Seebeck effect, which generates a voltage when a temperature gradient is applied across the module, the voltmeter provides real-time feedback on the electrical output of the TEGs. By accurately measuring the voltage output of the TEG plates, the voltmeter enables system operators to evaluate the efficiency and effectiveness of the thermoelectric energy conversion process. This information is crucial for optimizing system performance, maximizing energy harvesting capabilities, and identifying any potential issues or malfunctions within the TEG modules. Moreover, the voltmeter facilitates the characterization and testing of TEG modules under various operating conditions, such as temperature gradients, heat fluxes, and load resistances. This allows researchers and engineers to analyze the electrical performance characteristics of TEGs and develop strategies for enhancing their efficiency and reliability. Additionally, the voltmeter can be integrated into the control and monitoring system of the thermoelectric cooling system, enabling automated voltage measurement and data logging capabilities.
This enables continuous monitoring of TEG performance over extended periods, facilitating long term performance analysis and optimization. Furthermore, the voltmeter serves as a diagnostic tool for troubleshooting TEG-related issues, such as voltage fluctuations, output variations, or performance degradation. By detecting and analyzing changes in TEG voltage output, system operators can identify potential problems early on and implement corrective measures to maintain optimal system performance. In summary, the voltmeter plays a critical role in thermoelectric cooling systems utilizing TEG functionality by providing accurate and real-time measurements of the voltage generated by the TEG plates. Its monitoring capabilities enable efficient system optimization, performance evaluation, and troubleshooting, contributing to the overall effectiveness and reliability of the thermoelectric cooling system.

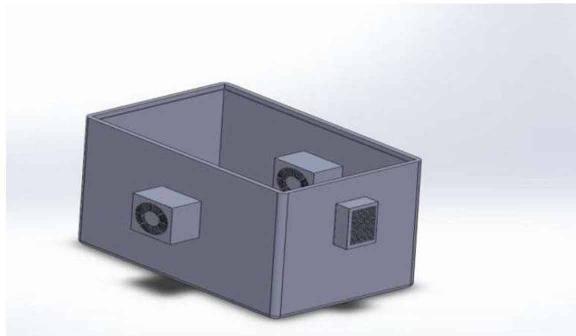
IV. FLOWCHART DESCRIPTION

TEG & TEC-Based Battery Cooling System:
The flowchart depicts the operational steps involved in a thermoelectric generator (TEG) and thermoelectric cooler (TEC)-based battery cooling system. This system is designed to regulate the temperature of a battery pack by employing thermoelectric modules for both heating and cooling purposes. Below is a detailed description of each step represented in the flowchart:

1) Temperature Monitoring and Heater Activation: The system begins by monitoring the temperature of the battery pack. If the temperature exceeds a predefined limit indicating overheating, the heater is activated to provide additional heat to the battery pack, thus maintaining it within the optimal temperature range.
2) Electricity Generation with TEG Plates: In parallel with the heater activation, the TEG plates start generating electricity from the temperature gradient between the battery pack and the ambient environment. This electrical energy is harnessed from the Seebeck effect, where a voltage is produced across the TEG plates due to the temperature differential.
3) Battery Charging and Energy Storage: The electricity generated by the TEG plates is directed to charge a 12V battery, serving as an energy storage device. This battery acts as a power source for various components of the cooling system and ensures continuous operation even when the temperature gradient fluctuates.
4) TEC Plate Activation for Cooling: Once the battery is sufficiently charged, the system activates the TEC plates to initiate the cooling process. The TEC plates utilize the Peltier effect to transfer heat from the battery pack to the surrounding environment, effectively lowering its temperature.
5) Blower Fan Activation for Heat Dissipation: Concurrently, the blower fan is turned on to facilitate the dissipation of heat generated during the cooling process. The fan helps in circulating air around the battery pack, enhancing the efficiency of heat transfer and promoting faster cooling.
6) Continuous Operation and Temperature Control: The system operates continuously, with the TEG plates generating electricity, the TEC plates providing cooling, and the blower fan ensuring proper air circulation. The temperature of the battery pack is continually monitored, and the cooling process persists until the temperature reaches the desired limit or drops below the predefined threshold.

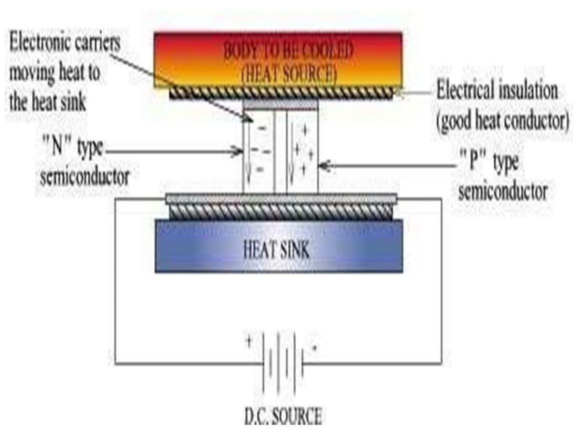
7) Temperature Control and System Shutdown: Upon reaching the desired temperature or if the temperature drops below the set limit, the system shuts down to prevent overcooling or unnecessary energy consumption. This ensures that the battery pack remains within the optimal operating temperature range, maximizing its performance and longevity. This comprehensive flowchart outlines the sequential steps involved in the operation of a TEG & TEC-based battery cooling system, emphasizing the integration of thermoelectric technologies for efficient temperature regulation and energy management.

Design of Components:



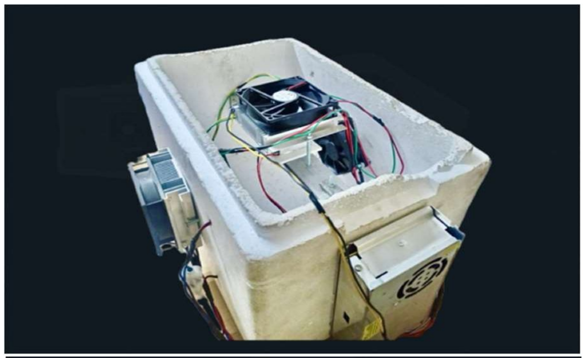
Assembly of Model

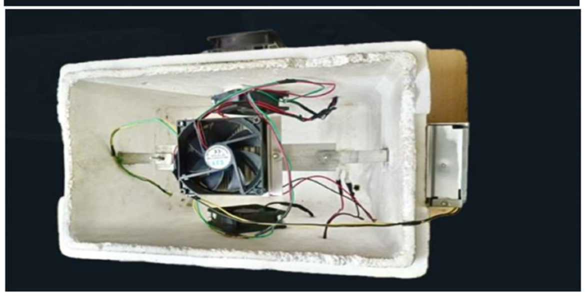
a) Cooling Fans with TEG/TEC Plates: Three cooling fans are connected to Thermoelectric Generator (TEG) or Thermoelectric Cooler (TEC) plates. The TEG/TEC plates are responsible for transferring heat away from the battery or metal plate to maintain optimal temperature conditions.
b) SMPS (Switched-Mode Power Supply): The three cooling fans with TEG/TEC plates are connected to an SMPS. The SMPS converts alternating current (AC) to direct current (DC) and provides power to the cooling fans.
c) Temperature Monitor Switch: A temperature monitor switch is provided to control the temperatureof the metal plate. When the temperature monitorswitch is turned on, it activates the heating process.
d) Heater Connections: Heater connections are established between the metal plate and the TEG/TEC plate. These connections facilitate the transfer of heatfrom the metal plate to the TEG/TEC plate.



e) Peltier Effect: When the temperature monitor switch is activated, the metal plate heats up. The TEC plate, based on the Peltier effect, cools down by absorbing heat from the metal plate. This cooling process helps maintain the desired temperature of the metal plate.
f) Heat Sink: A heat sink is used to dissipate excess heat generated by the TEG/TEC plates during the cooling process. It ensures efficient heat transfer and prevents overheating of the system components.
g) Readings & Observation: Readings of temperature and other relevant parameters are observed and monitored during the operation of the cooling system. These readings provide valuable insights into the performance and efficiency of the system.

Project Model:



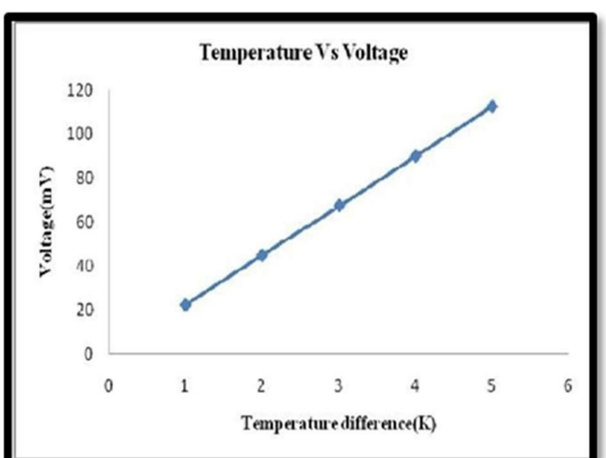


V. RESULT AND OBSERVATION

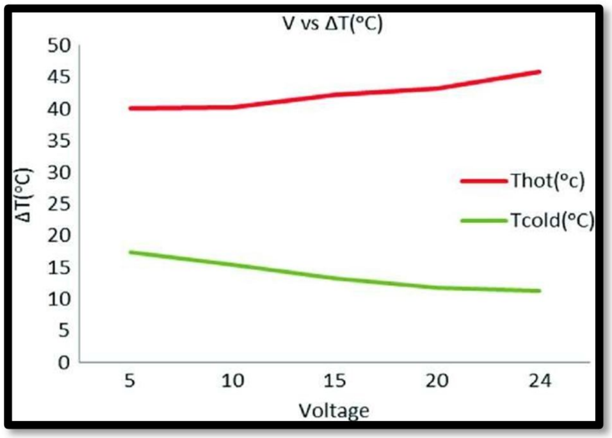
Observation Table:

Heater Temperature (°C)	Voltagefrom Peltier Plate (V)	Battery Cooling Temperature (°C)
36.7	0.24	26.9
37	0.48	23.9
38	0.50	22.6
40	0.53	22.3

1) Heater Temperature vs. Voltage from Peltier Plate: The voltage output from the Peltier plate increased as the heater temperature rose. This indicates a direct relationship between the temperature of the heating plate and the voltage generated by the TEG.



2) **Battery Cooling Temperature:** As thevoltage from the Peltier plate increased, the temperature of the battery cooling system decreased. This demonstrates the effectiveness of the TEC-based cooling system in maintaining lower battery temperatures.



VI. CONCLUSION

In conclusion, the development and implementation of TEG & TEC-based battery cooling systems represent a significant advancement in the pursuit of efficient and sustainable energy solutions. Through the integration of Thermoelectric Generators (TEGs) and Thermoelectric Coolers (TECs), this project has demonstrated the potential to address critical temperature-related challenges across various applications, including electric vehicles (EVs), energy storage systems, and electronics. The project's findings underscore the numerous advantages offered by TEG & TEC-based cooling systems. By effectively regulating battery temperatures within optimal ranges, these systems contribute to improved battery performance, extended lifespans, and enhanced safety. Moreover, their energy-efficient operation and eco- friendly characteristics align closely with the growing demand for sustainable energy solutions in today's world. Furthermore, the success of this project highlights the versatility and adaptability of thermoelectric technologies in meeting the evolving needs of modern industries. From mitigating thermal issues in EVs to enhancing the reliability of energy storage systems, TEG & TEC-based cooling systems present a viable and promising solution for a wide range of applications. As research and development in this field continue to progress, further innovations and optimizations can be expected, paving the way for even more efficient and cost effective cooling solutions. With ongoing advancements in material science, engineering techniques, and system integration, TEG & TEC-based cooling systems are poised to play an increasingly prominent role in shaping the future of energy management and sustainability. In summary, the successful implementation of TEG & TEC-based battery cooling systems represents a significant milestone in the quest for sustainable energy solutions. By harnessing the power of thermoelectric technologies, this project has demonstrated the potential to revolutionize how we address temperature-related challenges in various industries, ultimately contributing to a more sustainable and resilient energy ecosystem.

REFERENCES

[1] Kevin Wang Jonathan Ripheden "Thermalmanagement system for lithium-ion batteries"TRITAITM-EX 2022:185.
[2] Y. Lyu a , A.R.M. Siddique a , S.H. Majid b , M. Biglarbegian a , S.A. Gadsden a , S. Mahmud a,∗ "Electric vehicle battery thermal management systemwith thermoelectric cooling" June 2019
[3] Chaitanya Pandya1, Dhrunil Timbadia2 "A Detailed Review on Cooling System in Electric Vehicles" e-ISSN: 2395-0056 Volume: 08 Issue: 06 |June 2021 www.irjet.net p-ISSN: 2395-0072
[4] A.R.M. Siddique, S. Mahmud, B. Van Heyst, Areview of the state of the science onwearable thermoelectric power generators (TEGs) and their existing challenges, Renew. Sustain. Energy Rev. (2017)
[5] W. He, J. Zhou, J. Hou, C. Chen, J. Ji, Theoreticaland experimental investigation on a thermoelectric cooling and heating system driven by solar, Appl. Energy (2013)
[6] M. Al-Zareer, I. Dincer, and M. A. Rosen, "Electrochemical modeling and performance evaluation of a new ammonia-based battery thermal management system for electric and hybrid electric vehicles," Electrochimica Acta, vol. 247, pp. 171– 182, 2017.
[7] H. Fathabadi, "High thermal performance lithium-ion battery pack including hybrid active–passive thermal management system for using in hybrid/electric vehicles," Energy, vol. 70, pp. 529–538, 2014.
[8] B. Mortazavi, H. Yang, F. Mohebbi, G. Cuniberti,and T. Rabczuk, "Graphene or h-BN paraffin composite structures for the thermal management of Li-ion batteries: a multiscale Investigation," Applied Energy, vol. 202, pp. 323–334, 2017.

[9] K. Chen, M. Song, W. Wei, and S. F. Wang, “Structure optimization of parallel aircooled battery thermal management system with U-type flow for cooling efficiency improvement,” Energy, vol. 145, pp. 603–613, 2018. TEG & TEC Battery Cooling System ZCOER Narhe, Pune (Electrical Department)Page 20
[10] G. Jiang, J. Huang, M. Liu, and M. Cao, “Experiment and simulation of thermal management for a tube-shell Liion battery pack with composite phase change material,” Applied Thermal Engineering, vol. 120, pp. 1–9, 2017.
[11] S. Abada, G. Marlair, A. Lecocq, M. Petit, V. Sauvant-Moynot, and F. Huet, “Safety focused modeling of lithium-ion batteries: a review,” Journal of Power Sources, vol. 306, pp. 178–192, 2016.
[12] M. F. M. Sabri, K. A. Danapalasingam, and M.
[13] F. Rahmat, “A review on hybrid electric vehicles architecture and energy management strategies,” Renewable and Sustainable Energy Reviews, vol. 53, pp. 1433–1442, 2016.
[14] Z. J. An, L. Jia, Y. Ding, C. Dang, and X. J. Li, “A review on lithium-ion power battery thermal management technologies and thermal safety,” Journal of Thermal Science, vol. 26, no. 5, pp. 391– 412, 2017.
[15] C.-W. Zhang, K.-J. Xu, L.-Y. Li, M.-Z. Yang, H.-B. Gao, and S.-R. Chen, “Study on a battery thermal management system based on a thermoelectric effect,” Energies, vol. 11, no. 2, 2018.
[16] [15] Engineering, vol. 120, pp. 1–9, 2017. [35] Q. Wang, B. Jiang, B. Li, and Y. Y. Yan, “A critical review of thermal management models and solutions of lithium-ion batteries for the development of pure electric vehicles,” Renewable and Sustainable Energy Reviews, vol. 64, pp. 106–128, 2016.
[17] Ning, G., & Popov, B. N. (2004). Cycle Life Modeling of Lithium-Ion Batteries. Journal of The Electrochemical Society, 151(10), A1584. doi:10.1149/1.1787631
[18] Yang, X.-G., Zhang, G., Ge, S., & Wang, C.-Y. (2018). Fast charging of lithium-ion batteries at all temperatures. Proceedings of the National Academy of Sciences, 115(28), 7266–7271. doi:10.1073/pnas.1807115115
[19] Ouyang, D., He, Y., Chen, M., Liu, J., & Wang,
[20] J. (2017). Experimental study on the thermal behaviors of lithiumion batteries under discharge and overcharge conditions. Journal of Thermal Analysis and Calorimetry, 132(1), 65–75. doi:10.1007/s10973- 017-6888-x
[21] Bandhauer TM, Garimella S, Fuller TF. A critical review of thermal issues in lithium-ion batteries. J Electrochem Soc.2011;158(3):R1–25.
[22] M.A. Hannan, F.A. Azidin, A. Mohamed, Hybrid electric vehicles and their challenges: a review, Renew. Sustain. Energy Rev. 29 (2014) 135– 150.
[23] Jarrett, A.; Kim, I. Y. Design optimization of electric vehicle battery cooling plates for thermal performance. J. Power Sources 2011, 196, 10359– 10368, DOI: 10.1016/j.jpowsour.2011.06.090 [22] Jarrett, A.; Kim, I. Y. Influence of operating conditions on the optimum design of electric vehicle battery cooling plates. J. Power Sources 2014, 245, 644– 655, DOI: 10.1016/j.jpowsour.2013.06.114
[24] Rao and S.Wang, A review of power battery thermal energy management, Renewable & Sustainable Energy Reviews 15 4554-4571
[25] Mohapatra, S. and Loikits, D., “Advances in Liquid Coolant Technologies for Electronics Cooling,” Proceedings of the 21st IEEE Semiconductor Thermal Measurement and Management Symposium, San Jose, CA, 2005, pp. 354-360.
[26] Pesaran, A.A. (2001). Battery Thermal Management in EVs and HEVs: Issues and Solutions. Advanced automotive battery conference, Las Vegas, Nevada.
[27] Y. Deng, C. Feng, J. E, H. Zhu, J. Chen, M. Wen, H. Yin. Effects of different coolants and cooling strategies on the cooling performance of the power lithium ion battery system: A review, Appl. Therm. Eng.142(2018) 10-29.
[28] Kizilel, R., Sabbah, R., Selman, J. Robert & Al- hallaj, S., 2009. An alternative cooling system to enhance the safety of Li-ion battery packs. Journal of Power Sources, 194