Electric Vehicle Battery Heat Management using A Thermoelectric Cooler Powered by Solar PV with MPPT

Amber Negi[1]**, Risha Mal**[1*]

[1]National Institute of Technology Silchar, Assam, India
*Corresponding Author: risha@ee.nits.ac.in

Abstract. As environmental emissions and the oil shortage worsen, countries are concentrating their efforts on green energy. Electric cars, as part of the alternative energy sector, have drawn worldwide interest due to their environmental friendliness. As a safer alternative to traditional combustion engines, electric cars and hybrid electric vehicles (EV/HEV) have gotten a lot of recognition around the world and are fast becoming a great alternative to internal combustion engine-powered vehicles. Electric vehicles are a great alternative to traditional vehicles. However, various characteristics of electric vehicles, such as performance, cost, battery life, and battery safety, restrict their growth. As a result, battery management is required to get optimal performance. A Battery Heat Management System is used to remove heat geenrated by the battery pack. The cost of a battery pack used in Electric Vehicle is high, which makes research in this area substantial in order to increase the lifespan of the battery pack. A battery heat management system that is powered by solar power from Photo-Voltaic with implementation of Maximum Power Point Tracking (MPPT) can be very substantial. The paper aims to do the same i.e. show the results of a simulation done to observe the effectiveness of the use of a Battery Thermal Management System, employing a Thermoelectric Cooler that is powered by a Photo-Voltaic with implementation of Maximum Power Point Tracking. The paper further proposes an arrangement of a copper casing outside the battery pack which consists of four Peltier devices, cooling the battery pack from four sides, and observe the effectiveness of the same via simulation.

Index Terms: Thermoelectric cooler, Peltier effect, Solar PV, Electric vehicle

I. INTRODUCTION

An electric vehicle uses an electric motor for propulsion. The Electric Vehicle can be powered through a battery, fuel cell, solar panels, etc. EVs first came into picture in the 19th century. Modern IC engines have been the primary choice for almost 100 years now. However, electric power has remained the choice for other types of vehicles such as trains and other smaller vehicles. Electric Vehicles are a great alternative to conventional vehicles; features such as immediate torque, silent ride, and premium performance make EVs a better option. Other than this, EVs also have lower fuel and maintenance costs; they also have fewer moving parts which means less maintenance. In today's car industry, various levels of hybrid electric vehicle and pure electric vehicle mixing are available. Various shapes, forms, and numbers of battery cells are installed in respective EVs depending on the blending level. There are many types of battery reactions available. Li-ion remains the most popular battery reaction in the EV field. In comparison to fossil petrol, battery cells as an energy source provide more stringent requirements in the workplace. However, they are very vulnerable to changes in temperature. The basic components of an EV are:

1. **Lithium-ion battery**: Charge is stored in the battery as DC and the battery acts as supply to run the EV after conversion to AC with the help of a power inverter. A Li-ion battery is rechargeable and is widely used in portable electronic devices.
2. **Power Inverter**: Converts the energy from DC to AC to power the electric motor and hence, drive the car. These are used in electrical power applications where conversion of high voltage and current is needed.
3. **Electric Motor**: Motor is turned by the AC current to run the car. It works by converting electrical energy into mechanical energy.
4. **Battery Charger**: Charger takes 230 V single phase mains supply as input and converts it into DC to charge the battery.
5. **Battery Management**: Manages the output, charging and discharging, and temperature of the battery.

The performance of electric vehicles (EVs) and hybrid electric vehicles (HEVs) is heavily reliant on the battery. Battery Thermal Management Systems (BTMS) are used to keep track of a battery's temperature.

Amber Negi, Risha Mal – "Electric Vehicle Battery Heat Management using A Thermoelectric Cooler Powered by Solar PV with MPPT", Pg no: 5 – 15. 2022
doi.org/10.36647/978-93-92106-02-6.2

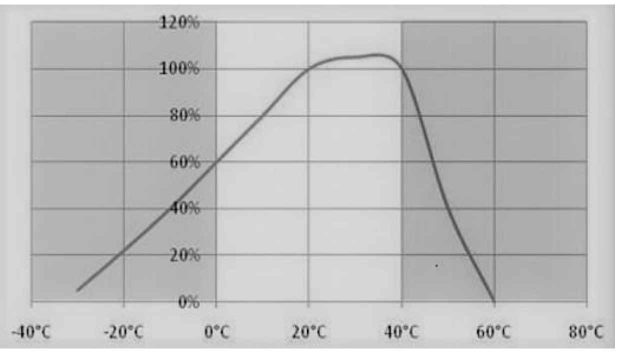


Fig. 1. Battery power vs temperature [1]

The working. performance of a battery is largely determined by its temperature. Even though the battery's rated temperature is -30°C to 60°C, the battery's performance fluctuates with temperature. According to studies, operating at temperatures above 50°C might shorten the battery's life. It was observed in Fig. 1 that the temperature range between 20°C-40°C provides the battery with the best conditions and the power is maximum in this range [1], in which batteries such as such as NiMH, Li-ion, lead-acid, etc get the best conditions for operation. Temperature management systems for batteries are a must, as they help in achieving an optimal range of temperature, take care of battery health and help increase the overall lifespan.To implement BTMS, different types of cooling are implemented:

1. **Air-cooling**: A method of heat dissipation which uses air as the medium of heat transfer.
2. **Liquid-cooling**: A method of heat dissipation which uses liquid as the medium of heat transfer which may be a refrigerant, distilled water, etc.
3. **Thermoelectric Cooling**: A method of heat dissipation which uses a Peltier device to dissipate heat, which is a semiconductor device that consists of n-type and p-type thermoelectric legs that are connected electrically in series.

A Peltier device, also known as a Thermoelectric Cooler, operates on the Peltier effect, which states that when current travels between the junctions of the device's two conductors, heat is evacuated at one junction and cooling occurs, while heat is deposited at the other junction. The electrons absorb energy, in this instance heat, when they transit from the p-type (low energy) semiconductor element to the n-type (high energy) semiconductor element at the cold junction. The energy necessary to transport the electrons is provided by the electricity supply. At the hot junction, energy i.e. heat is transferred to a heat sink as electrons move from an n-type to a p-type. A Peltier device works on DC supply.

Researches implementing different types of cooling are under research. Chuan-Wei Zhang [2] stated that the pefor- mance of a battery is easily affected by temperature. They suggested a new cooling system with a control unit and a modified cooling structure. They developed a basic heat generation model for a single cell as well as a cooling model based on a battery's heat generation mechanism and a thermoelectric chip's heat generation mechanism. They did this in ANSYS 17.0 and studied the effects of inlet velocity on the performance of different heat exchanger structures. They discovered that the U-loop configuration performed best and that the flow distribution was the most uniform at 1 m/s inlet velocity. They discovered that combining liquid cooling with thermoelectric cooling improved efficiency. They also designed the software and hardware that was needed for the control system. It is important to improve the methods that are being used traditionally or to find an alternative modern approach to increase the battery's overall performance and function They compared the efficiency of two separate systems for the liquid cooling process. They discovered that the U-shape structure's flow field distribution was much more uniform than the Z-shape structure's.

Hongguang Sun [3] aimed to suggest a method for designing a cooling strategy for a lithium-ion pouch cell battery pack in a hybrid electric vehicle's air-cooled battery pack (HEV). They also wrote about the problems with battery pack temperature uniformity, as well as temperature uniformity in different lithium-ion pack cells and the battery's cooling efficiency. They used the Optimal Latin-hypercube methodology to construct a DOE design model, a correlated battery pack thermal model, and a morphing model using the analytical method of experiments (DOE) method. These DOE studies were carried out to determine the results of various cooling techniques for the cooling tube, cooling duct, cooling plate, and thermal behaviour, as well as to determine the best design principle for a battery pack with air cooling to improve reliability and range. They concluded that it was necessary to apply an air cooling system to make sure that the operation of the battery cells occur in an optimal controlled temperature range and uniformly across cells to get maximum capacity and durability. They found that the mathematical modeling of thermal behavior of the battery for cooling technique can be a cost effective and effective tool to achieve good performance and good lifespan.

Zhongming Liu [4], provided a computational shortcut for calculating the flow and thermal studies of a parallel airflow-cooled battery pack in a short amount of time. To compute the thermal dispersal in the battery as impacted by airflow and also among cell packs, the suggested technique employs a flow resistance network design as well as a transient heat transfer design. They presented a short-crosscut approach for approximating the flow and thermal profiles in a large battery with parallel airflow cooling. A flow network model and a transient 18 heat transfer m`odel were used in the process. The fl`ow network model's function is to imitate the air-coolng system's flow feld whereas the transient heat transfer model calculates the increase in temperature of every unit of battery. The non-uniform distribution of airflow and uniformity in temperature was considered for the simulation. Then, the method was applied to stress on structure parameters which aim to improve uniformity of temperature in the battery pack. They concluded that the scattering of non-uniform airflow was inevitable even if wedge-shaped structures are employed for distribution of air. From the flow resistance network model, they concluded that the scattering of air flow is affected by c`oefficients of pressure loss, which in turn depend on the construction of system and the status of flow. As, the pressure loss coefficient is much smaller than that of the air convergence plenum which is the reason why the velocities of airflow and the pressure differences in the cooling channels increase as we go from the first channel to the ninth. Therefore, the solution was to slow the growth of the pressure losses in the plenums which would in turn improve the uniformity of the distribution of the airflow. This effect could be possible in we adjust the structural parameters of the parallel air-cooling system. The results they obtained proved that the shortcut method and the CFD method results are closely approximate. The maximum temperature difference calculated only has a difference of 0.5°C. However, the shortcut method saves a ton of time, where the CFD method took about 10 hours to get the solution; the shortcut method proposed took about 2-3 seconds. Both methods were implemented using the same desktop computer.

Yuqun Zeng [5] investigated the performance at overcharge for Li-ion polymer batteries. This was done by analyzing the generated heat and monitoring variation in temperature during overcharge. While most researches are being focused on the battery management system and its improvement, some relevant papers found how big an impact this research is likely to cause. Different battery reactions are also considered as an option for EV. Michael R. Giuliano [6] saw that Lithium-titanate batteries are becoming a considerable option for EV as it fulfills the need of storing large amounts of energy while also keeping large amount of charge and discharge currents without taking a toll from the life of the battery. They have the ability to be charged very fast due to high current thresholds and also to supply the required power to operate the EV. However, they discovered a significant quantity of waste heat, which they attributed to loss processes resulting from the cell’s internal chemistry and ohmic resistance. It was mentioned that an active cooling mechanism is necessary to keep the cell at a safe operating temperature. The study used laboratory settings to conduct thermal analysis of lithium-titanate cells. To monitor surface temperature, they used thermochromic liquid crystals. The information was then utilised to determine how efficient the active cooling mechanism was in managing heat in lithium-titanate cells.

Rami Sabbah [7] analyzed the efficacy of cooling (passive) using phase change materials with active cooling (forcd air). The PCM coolng here used a micro composite graphite PCM matrx which was surrounding the array of cells whereas, the active cooling mode here, used air blasted was between the cells through the gaps. It was found that the air coolng is not a dependable method to retain the temperature in the desired range. On the other hand, the passve coolng system was successful in providing the desired operation range without any need of an additional fan.

Shahabeddin K. Mohammadian [8] in his paper, analysed the thermal performance of an air-cooled battery module using a new type of aluminium pin fin heat sink. The height of these pins rose linearly in the direction of air flow through the channel’s width. Even while heat sinks with the same pin fin heights increased the standard deviation of the temperature field, the results showed that utilising this pin fin helped not only reduce the bulk temperature but also the standard deviation of the temperature field. They also discovered that increasing the input air temperature reduced the standard deviation of the temperature field while increasing the battery’s maximum temperature. The standard deviation of the temperature field grew as the input air velocity was raised further until it reached its maximum point, after which it decreased.

Yutao Huo [9] built a BTMS based on a mini-channel cold plate to handle the thermals of a rectangular Li-ion battery The goal was to ensure safety while also prolonging the battery life cycle in electric vehicles. They created a three-dimensional thermal model and tested various parameters. Number of channels, inflow mass flow rate, flow direction, and so on were among the characteristics. During the discharge procedure, these parameters were recorded. According to their findings, the maximum temperature of the battery lowers as the number of channels and the incoming mass flow rate rise. They also discovered that when the mass flow rate increased, the influence of flow direction on cooling performance reduced. With the increase in intake mass flow rate, they found an improvement in cooling performance. The findings of their simulations will be beneficial in improving the design of mini-channel cold plate based BTMS. Jingzhi Xun [10] in his research, created an analytical and numerical model for lithium ion battery stack heat control. The goal was to learn more about the thermal behaviour of cylindrical and flat plate stacks as they were being discharged. When the number of channels and channel size were modified with the same volume ratio of cooling channel and battery of flat plate type design, equal average battery temperatures were achieved. It was also discovered that, while increasing channel size improves cooling energy efficiency, it also results in more unequal temperature distribution. As for the cylindrical stacks that were used, they were found to be better in terms of energy efficiency and were less compact. However, the thermal behaviors of these two designs were found to be similar. They also suggested that the cooling tubes be arranged in a counter-flow configuration.

Kuahai Yu [11] aimed to dissipate generation of heat while also trying to keep the temperature distribution as uniform as possible.It was attempted utilising two types of air ducts with separate intake and exhaust channels and fans. They served slightly different purposes. The first was to use the usual channel to cool the batteries, while the second used jet cooling to reduce heat accumulation in the centre of the battery pack. An anisotropic three-dimensional heat transport model was also created to better understand the thermal behaviour of the batteries, and it was confirmed by tests and simulations. It was found that the minimum temperature attained was 33.1°C with improve in temperature uniformity. This field of research has even been looked from the aspect of arrangement of the battery modules.

Tao Wang [12] considered a new battery module design to take care of temperatures of batteries in operation. The study looked at the thermal performance of batteries in a variety of cell layouts, including 1 x 24, 3 x 8, and 5 x 5 rectangular arrays, 19 cells hexagonal arrays, and 28 cells circular arrays. Aside from that, they looked at alternative air conditioning tactics, such as positioning fans in different parts of the battery module to promote temperature uniformity. They observed the best results for the 5 x 5 cubic structure in terms of cooling capacity as well as cost. TEC coooling is getting more and more involvement in our daily lives. For e.g. - use in PC-processors, small storages for food and beverages and TEC air-conditioners. There are certain reviews that show the advance in thermoelectric materials [13], bulk thermoelectric materials [14] and low dimension materials [15]. The estimation of the future of EV has also been shed light upon by Tianshi Zhang [16]. They proposed a heating ventilation air conditioning (HVAC) system and estimated the near future of the vehicle market. All over the world, EVs are seen as a great alternative and the research is being supported everywhere. In Europe, the French government has set up an EV coordination committee specially to support the research. The German government estimated that there will be more than one million new energy vehicles in 2020.

Abdul Muhaimin Ismail [17] wrote about the current scenario of global energy and how fu´els play a crucial part and the problems in environment we are facing. Feed in Tariff (FiT) policies are being implemented all over the world in order to increase renewable energy contribution. We need to reduce our dependence on non-renewable energy. To make this happen safety issues related to RE sources must also be addressed. Solar power is particularly a very promising part of RE.

Tulus. B. Sitorus [18] shed light on the capability of PV when they built and investigated a TEC that was powered by solar energy in Medan city. They found TEC systems to have lesser noise, lesser vibration, and their temperature could be controlled along with having lesser requirements for continuation. The solar TEC utilizes solar power as a proxy and can be applied to decrease the temperature of a room or an article. TEC modules, PV cells, a cooling box, insulating material, heat sinks, and cooling fans are all part of the system. PV cells produce electricity and send it to a thermoelectric cooling system. The TEC was powered by a pair of batteries in the cooler. A solar charge controller (SCC) with a rating of 12 V and 10 A was used to change the current during charging in order to avoid overcharging while also monitoring the battery’s thermal health.The cooling system’s box was then connected to a data acquisition system, the Cole Parmer 18200-40, through a thermocouple attached to the component. Weather parameters such as radiation intensity, air temperature, and relative humidity were also recorded using a data recording device. To seal the cooling box, the top cover had attached bolts that could be opened and closed. The testing were carried out in open areas with access to direct sun radiation. The weather was maintained under control because it has a direct impact on the PV cells utilised. Solar radiation was collected by the PV cells, which were then stored in batteries. This electricity was also utilised to power the Peltier component. The investigation lasted five days. The studies lasted eight hours, starting at 09.00 WIB and ending at 17.00 WIB. With shifting weather patterns, the temperature distribution was observed for five days. The best results were seen on the third day as the temperature distribution. Temperature, humidity, and solar radiation intensity were the variables considered. They arrived to the conclusion that solar radiation intensity and the temperature difference between the hot and cold sides of the TE component are critical to the device’s performance. The COP was found to be lesser than in a system that employs compressors but the PV scene with some improvements has great prospects.

In this paper, we plan to study and observe the effectiveness of a BTMS using a TEC that is powered by PV with MPPT. As seen in some of the papers, PV system is more than capable of running a Peltier device. Here, we aim to observe how effective the proposed cooling system turns out to be. Then, we propose a copper casing with four Peltier devices outside the battery pack to further study the effectiveness of the model which can be practically implemented at a later point of time.

II. THEORETICAL FUNDAMENTALS

1. **Lithium-ion Battery**:A Li-ion battery is a power source with an anode, cathode, and electrolyte, as well as a separator. The positive electrode in lithium-ion batteries is made of a lithium compound, whereas the negative electrode is generally made of graphite. The energy density of these batteries is great, and they have a low self- discharge rate.The separator is used to segregate electrodes while the electrolyte is utilised to move ions between electrodes inside the cell. The electrochemical processes occurring inside a Li-ion battery are reversible, making it rechargeable. When Li-ions are discharged, they disperse from negative to positive, and when they are charged, they disperse from positive to negative. The electrode of a Li-ion battery is comprised of intercalated lithium compound rather than metallic lithium. The performance of a Li-ion battery is determined by the operating voltage and temperature. When they run within a given voltage and temperature range, they tend to perform at their best. Temperature has a direct effect on the rate of chemical reactions inside the battery. When the temperature drops below a specific degree, it has an immediate effect since it decreases

the response rate and hence the carrying current capacity during both charging and discharging. This reduces the battery's power capacity. The reduced rate of reaction also makes it difficult for lithium ions to reach the intercalation gaps. As a result of the lithium plating, there is a drop in power and a loss of capacity. On the other hand, when the temperature rises, the rate of response rises, meaning a larger power output. This process, however, promotes heat loss, resulting in even greater temperatures. Thermal runaway will occur if the heat created is not dispersed quicker than the heat generated after a given period of time. Research is already being done on different aspects of the battery, such as performance at overcharge for Li-ion batteries [19]. Thermal runaway gives irreversible damage to cells. The battery temperature should be maintained by a management system to improve the performance and avoid thermal issues. With the increase in capacity and charge and discharge rate, security and health of battery becomes more important and requires more attention [20].

2. **Battery Thermal Management System**:The Battery Thermal Management System is critical for removing the heat created by the battery pack and ensuring that the battery pack operates at the proper temperature. [21]. The performance of a battery is easily affected by temperature [22]. The BTMS is expected to perform these four functions to make sure of the best operating conditions for the battery/battery pack:

(a) **Cooling**: The battery cells generate electricity as well as heat. When the temperature of the battery pack surpasses the ideal temperature, this heat is meant to be eliminated. Hence, cooling function is necessary in BTMS.

(b) **Heating**: For the same reasons, in colder climates the battery temperature needs to be increased in order to reach the optimal temperature range. For the battery to achieve the ideal temperature range, a heating function, such as a PTC heater, is required.

(c) **Insulation**: The temperature differential between the interior and exterior of the battery pack is quite high in regions where the weather is excessively cold or hot. Battery temperature is influenced, and effective insulation is a vital function that may slow down the fast fall or rise in battery temperature. The effect is greatest when the car is parked outside, which is true in the majority of situations.

(d) **Ventilation**: To exhaust the harmful gases inside the battery pack ventilation is a necessary function. Different types of cooling arrangements are used, many are being researched upon. The aim is to dissipate heat from the battery pack, which can be done through many techniques. Different technologies for heat management are being researched. Air cooling, liquid cooling, phase change material cooling, and thermoelectric cooling are all used by researchers.

The cooling medium in air-cooled BTMS is air, which removes the heat created by the battery cell/pack. The cooling performance of the system is determined by the airflow pattern; the flow pattern is regulated by the BTMS settings. Because of its advantages, such as its simple form and inexpensive cost, air cooling is quite popular.

There are three basic types of liquid cooling systems: passive cooling, active cooling, and refrigerant cooling. In a passive cooling system, heat is dissipated by the radiator, which uses the temperature differential between the liquid and the ambient temperature to accomplish so.

3. **Thermoelectric Cooler**:A thermoelectric cooler is a solid-state semiconductor device built up of n-type and p-type thermoelectric legs that are electrically coupled in serial and thermally coupled in parallelism. The Peltier effect asserts that when current is conducted through a thermocouple's circuit, heat is created at one junction and absorbed at the other. As seen in Fig. 2, this effectively generates a temperature differential between the two sides. The device has two sides, and when DC current passes through it, heat is transferred from one side to the other, making one side cooler and the other hotter. The "hot" side is linked or hooked to a heat sink to maintain it at room temperature, while the "cool" side is kept below it.Materials with a mix of low heat conductivity and strong electrical conductivity are ideal for high-efficiency TEC systems. When the effects are merged, the combined effect is compared using the ZT figure of merit. Some of the benefits of a Peltier device are:

(a) Low maintenance

(b) Long lifespan

(c) Can be used in extreme environments

(d) Capable of cooling far below room temperature

Peltier devices can be a good choice in applications where there is a need to cool an object below ambient tem- perature or to maintain a specific temperature. They are available in different dimensions such as 15mm, 20mm, 25mm, 30mm, 45mm and 62mm.

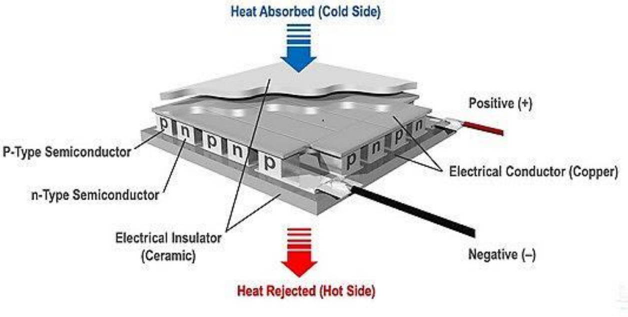


Fig. 2. Thermoelectric cooler
(Reference: Laird Thermal Systems)

4. **PV**: PV stands for Photovoltaic. It is the conversion of sunlight into electricity. Photons from the sun, strike the surface and ionize the semiconductor material on the PV panel which consists of photovoltaic cells that possesses photovoltaic effect.

When a photon of a sufficient wavelength strikes these cells, the photon's energy is transmitted to an electron in the semiconducting material, causing it to move to a higher energy state known as the conduction band. These electrons are free to flow through the material while they are in their excited condition in the conduction band, and their travel causes an electric current in the cell. As an output, a PV generates DC. Solar modules, which are made up of solar cells that assist create electricity, make up the system. These solar cells are comprised of a variety of semiconductor materials and are typically quite thin. These cells are sandwiched between protective layers made of glass and polymers to resist the harsh outside environment for a long time. PV systems may be designed to handle any load, large or little. 1000 watts (W) of light per cubic metre at a temperature of 25°C are considered ideal solar conditions. Solar PV has a variety of advantages including, no pollution and no greenhouse gas emissions.

5. **MPPT**: Maximum Power Point Tracking is a technique that is implemented in PV systems to extract maximum power. MPPT is the process of finding the maximum power power point (MPP) in the load characteristic to improve the system's efficiency. To maintain the power transmission as efficient as possible, the load characteristic is altered. This is necessary because the operating point of a load directly linked to a solar panel is rarely at peak power. MPPT uses algorithms to sample the panel voltage and currents and alter the duty ratio appropriately. The following strategies may be employed to optimize the power output of PV:

(a) Perturb and observe
(b) Incremental conductance
(c) Current sweep
(d) Temperature method
(e) Constant voltage

All of them have different advantages and disadvantages. However, Perturbation & Observation (P&O) algorithm is the most widely used algorithm. It is considered to have a good balance between simplicity and performance.

Now, when PV is implemented along with MPPT, the gating pulse to the DC-DC boost converter is obtained from MPPT function block, in which different MPPT algorithms may be employed. For our simulation we employed the P&O algorithm. When PV is integrated with MPPT, it ensures maximum power output which increases the efficiency of the system as a whole. A new casing arrangement is further proposed that uses a copper casing outside the battery pack. Copper is used because of its high thermal conductivity.

III. METHODOLOGY

Fig. 3 shows the block diagram of the proposed system. PV system with MPPT is modeled using MATLAB Simulink. The model consists of a PV panel that is connected to a DC-DC boost converter. The gating pulse for this DC-DC boost converter comes from the MPPT function block which contains the MPPT algorithm to ensure maximum power.

It is further connected to an R-load which is a Peltier device in our case. This is further connected to a Li-ion battery via a bi-directional converter. This is done to guarantee that the load receives consistent power. When PV-generated power is less than the load's necessary power, the battery will provide the load, while PV-generated power is greater than the load's consumption, the battery will charge. The PV findings prior to and after MPPT are compared. As seen from previous researches, PV system is more than capable of supplying a load as small as a Peltier device. The ouput from the PV system i.e. 5.2A is then fed to a Peltier device for cold side temperature readings. The supply to the Peltier device is varied to get more readings in order to better observe the effectiveness of the cooling system. A 4x4 18650 three-dimensional Li-ion battery pack is modeled using SolidWorks at 38˚C. The Peltier device is then used to cool the battery pack and reduction in temperature at different temperatures of the Peltier device is observed. The heat simulation part is performed on SolidWorks. After observing the obtained results, the effectiveness of the system is discussed along with future research scope.

Going a step further, a cooling system arrangement is proposed that employs a copper casing of thickness 2mm, outside the 4x4 Li-ion battery pack which consists of four Peltier devices on the outer walls of the casing as shown in Fig. 4.

IV. SIMULATION & RESULTS

The simulation for PV with MPPT is done using Simulink in MATLAB. The model in Fig. 5 shows a PV panel that is connected to a boost coverter. The gating pulse for the boost coverter comes from the PWM generator. The duty signal for the PWM generator comes from the MPPT function block which contains the MPPT algorithm. The algorithm works to determine the Maximum Power Points by searching for dP/dV=0 derivative. The point at which the power and voltage are not changing, the derivative will be zero which will be the Maximum Power Point. For this simulation, Perturbation & Observation (P&O) theorem has been employed. This algorithm works to change the duty cycle, which changes the gating pulse, and finally the voltage, to ensure maximum power. Futher, an R-load is connected which is a Peltier device in our case. This is now connected to a bi-directional converter which is connected to a Li-ion battery. This is done to ensure continuous supply to the Peltier device. When PV-generated power is less than the load's necessary power, the battery will provide the load, while PV-generated power is greater than the load's consumption, the battery will charge. For a 6A rated 45mm Peltier device, when a supply of 5.2A is supplied, the cold side of the device gets to 281.1K i.e. 11.35˚C.

For thermal study, a 4x4 18650, three-dimensional Li-ion battery pack was modeled in SolidWorks at 38˚C ambient temperature as shown in Fig. 6. As the model name of the battery suggests, the dimension of each battery is 18x65mm. They are usually connected in arrangements of 4x4, 5x5 to form battery packs. For simulation purpose a 4x4 battery pack is considered as it is close to the size of a 45mm Peltier device.

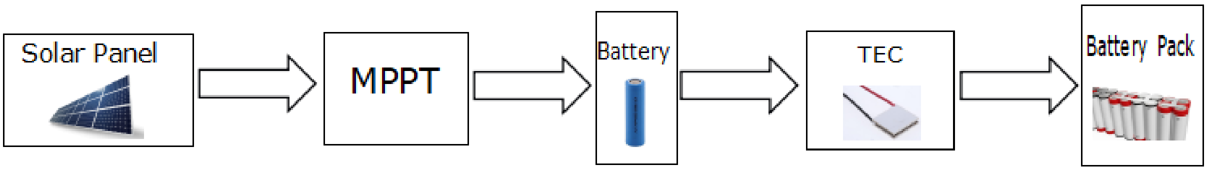


Fig. 3. Block diagram for the proposed cooling system

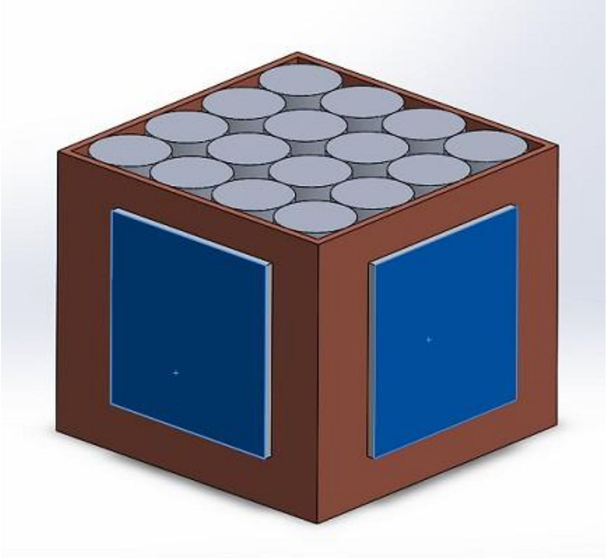


Fig. 4. Proposed copper casing arrangement

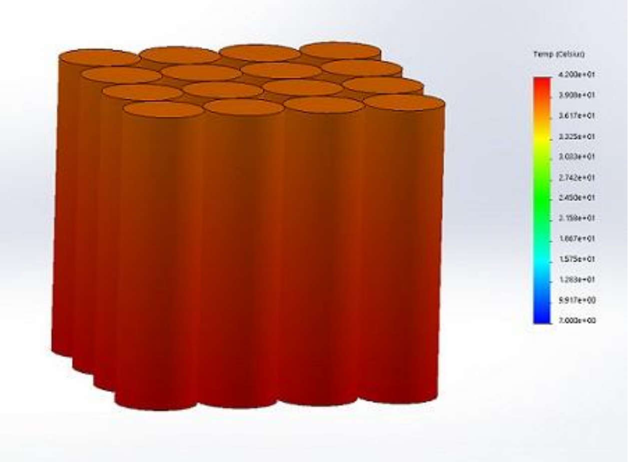


Fig. 6. A 4x4 Li-ion battery pack

The results show the voltage and current from PV before MPPT and after MPPT. The voltage and current is recorded before MPPT and after MPPT, power is also observed after MPPT as shown in Fig. 8-Fig. 10. The current was 4.7A before MPPT, and is observed to be around 5.2A after MPPT which is then fed to the 45mm, 6A rated Peltier device. For a single 213W rated PV panel that was used for simulation, 210W power ouput was observed after MPPT from the results of the simulation. For observational purposes, when the supply to the Peltier device is varied, we get a variety of temperature readings on the cold side and is used to better note the effectiveness of the thermal management system. Fig. 7 shows the various temperature readings got from the Peltier device. Note that the readings are in K, and are converted to ˚C before thermal simulation. The thermal simulation, done in SolidWorks shows results at various temperatures of the cold side of the Peltier device. Table 1 shows the reduction in temperature. For different temperature of the Peltier device. Fig. 11 shows all four thermal simulations and reduction in temperature for different temperatures of the Peltier device that were chosen from the temperature readings of the Peltier device in Fig. 7. For different temperatures of Peltier device, a significant difference in reduction of temperature was observed. As the temperature of the Peltier device decreased, the heat reduction increased which is the expected behaviour.

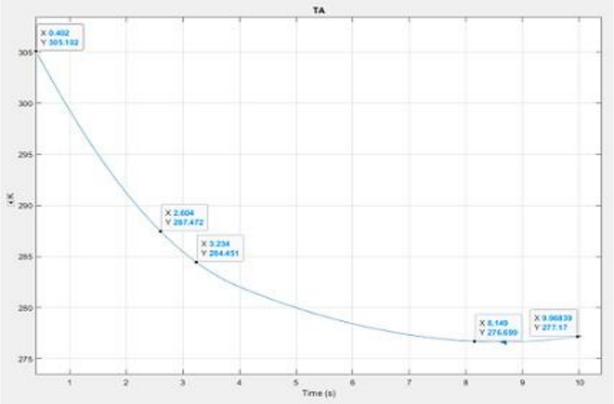


Fig. 7. Temperature graph from TEC when supply is variedat 38˚C ambient temperature

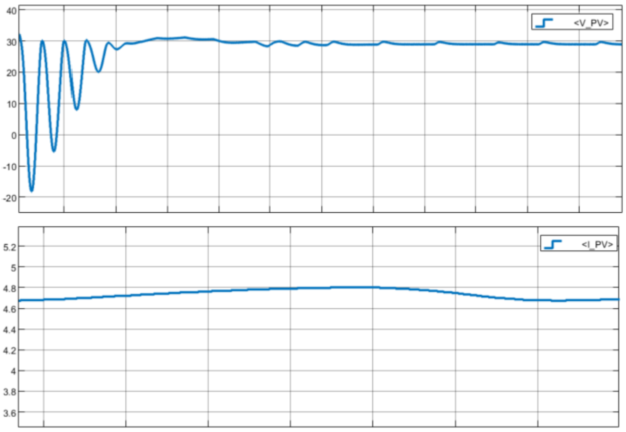


Fig. 8. Voltage and Current output from PV

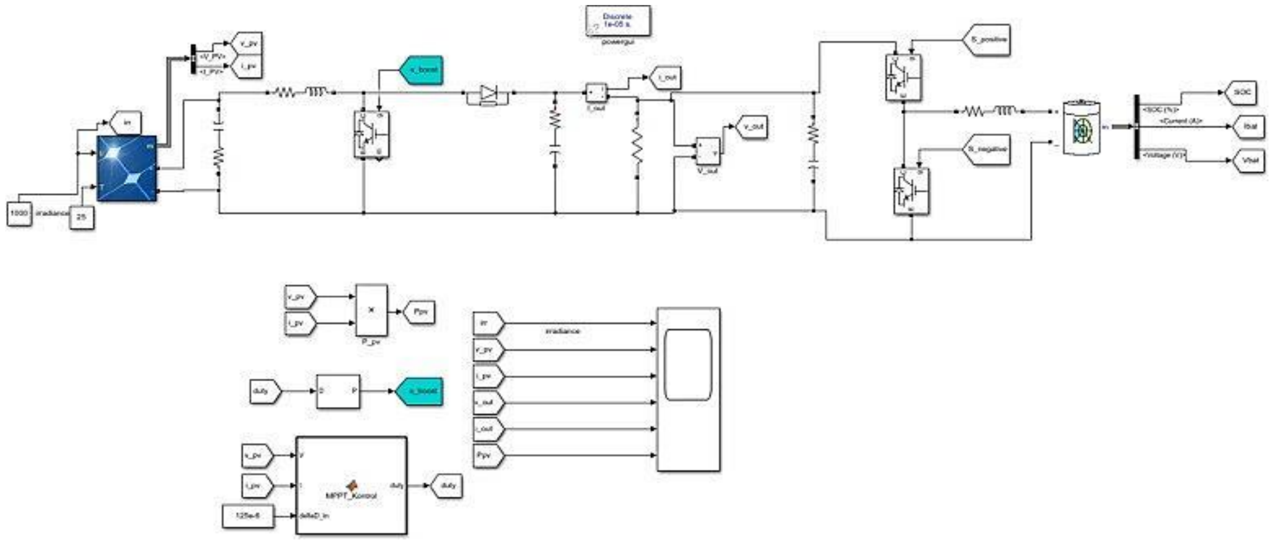


Fig. 5. PV model with MPPT

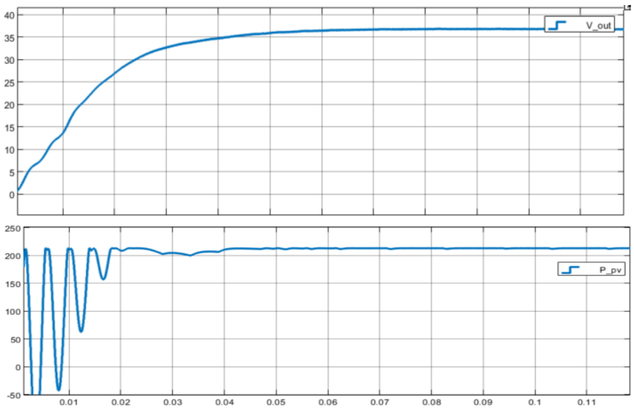
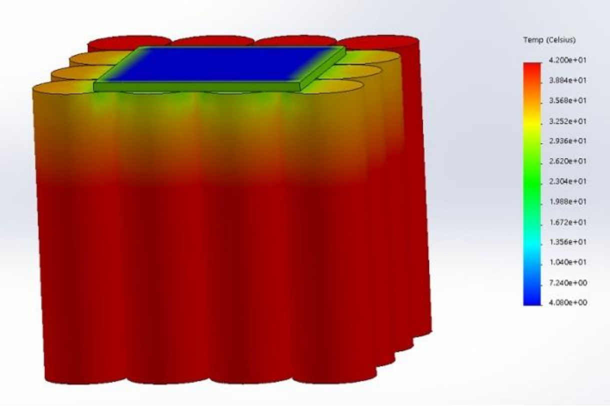


Fig. 9. Power output from MPPT



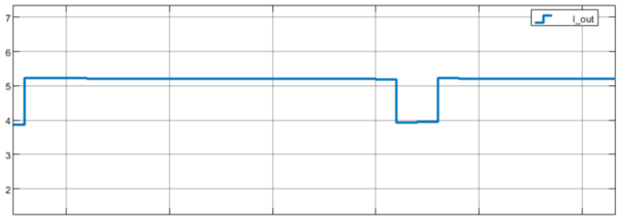
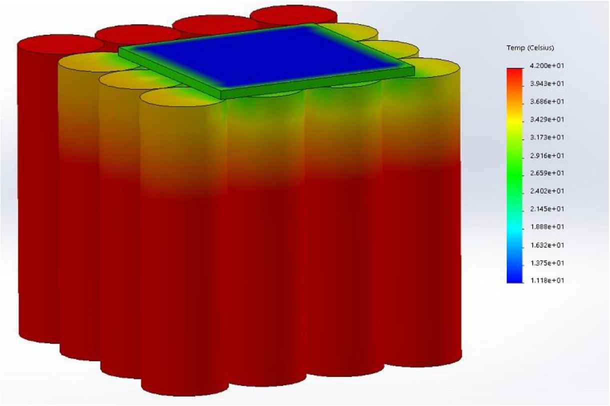
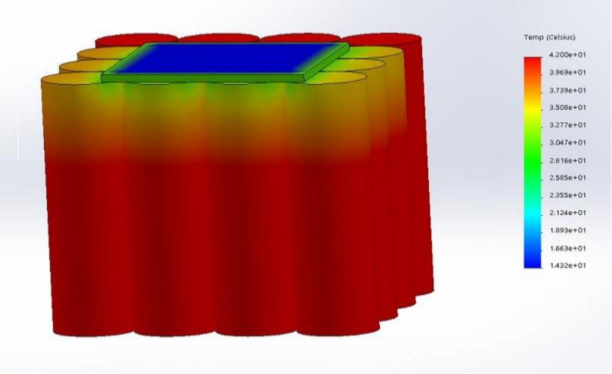


Fig. 10. Voltage and Current output from MPPT





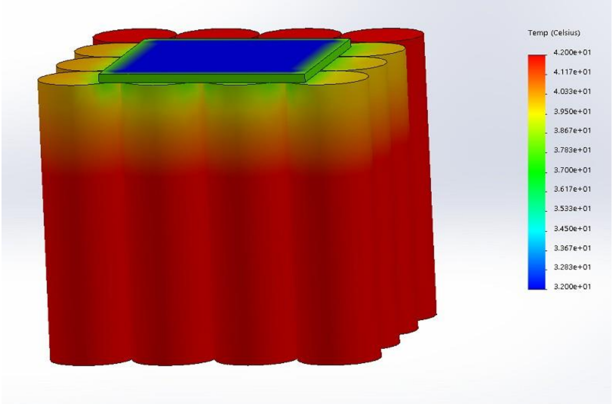
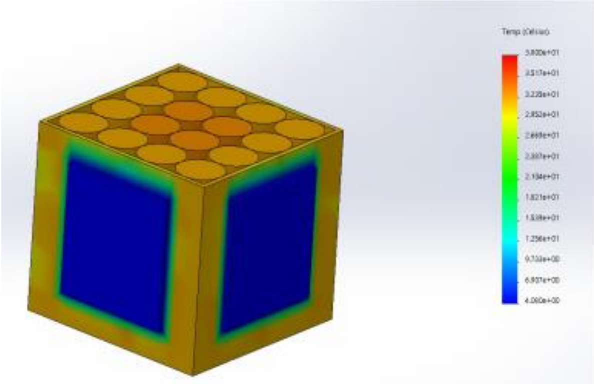
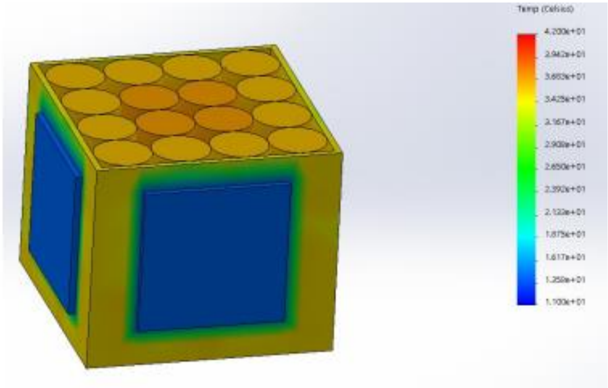
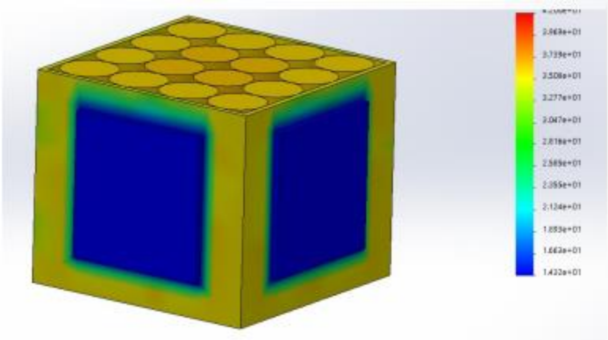


Fig. 11. Reduction in battery temperature when Peltier device is at 4.08˚C, 11.3˚C, 14.32˚C & 32˚C

The average reduction in temperature was observed to be 5.4˚C. However, this system only consists of one Peltier device and the cooling only takes place at the end closer to the cooling device. To tackle this, a copper casing outside the 4x4 Li-ion battery pack is proposed which helps increase the cooling as well as improve the uniformity of cooling.







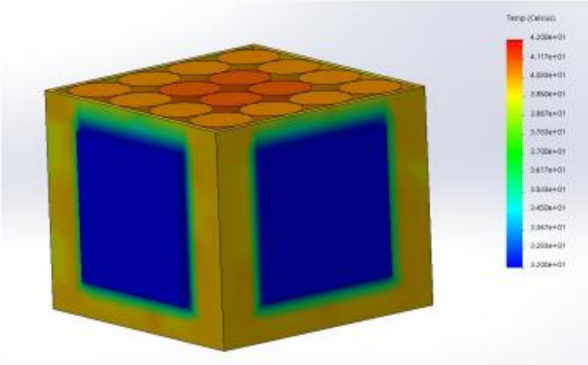


Fig. 12. Reduction in battery temperature with copper casing for the same temperatures of the Peltier device.

Across the whole battery pack as shown in Fig. 12. After addition of the casing, the average reduction in temperature was observed to be 6.1˚C. This shows the effectiveness of the system, results for a practical application may vary a little but there’s no denying that the system helps reduce the temperature of the battery pack.

Table 1. Comparison of temperature reduction at different temperature of TEC

Ambient Temperature	TEC temperature	Reduction in battery temperature	Reduction when with copper casing
38˚C	4.08˚C	8.1˚C	9.9˚C
38˚C	11.3˚C	5.9˚C	6.5˚C
38˚C	14.32˚C	5.5˚C	6.2˚C
38˚C	32˚C	2.1˚C	1.8˚C

V. CONCLUSION

Finite reserve bulk, disparity in distribution, and the rising demand of energy is resulting in an increase in the number of green energy replacements to supplement fossil-fuel-based energy supplies. Battery temperature has a significant effect on the battery pack's operating efficiency. A Battery Heat Management System is needed to keep a battery pack's temperature stable for optimum efficiency and longevity. TEC is infamous for having a low efficiency; however, it is a good selection for the given application. The project successfully observed the effectiveness of the proposed method of cooling that was done using Thermoelectric cooling that is powered by PV with MPPT. The PV with MPPT system simulation gave good results. Further, heat reduction for different temperatures of the Peltier device was observed. The average temperature reduction of the battery heat management system came out to be 5.6˚C. The paper also proposed a model that employed a copper casing with four Peltier devices at the four walls of the casing around the battery pack was simulated and observed. The average temperature reduction here was observed to be 6.1˚C. Results after a practical application may vary a little but the cooling system does help reduce the temperature of the battery pack. As a whole, the system proves to be effective. The next step could be an hardware implementation of the proposed model to identify any gaps that may or may not exist and also to observe the practical effectiveness of the system.

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