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Battery Thermal Management System for Lithium-ion Cells by using thermoelectric module

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Abstract - *Battery thermal management system (BTMS) Control and maintain the temperature of a battery cell at Different weather conditions. The range can be decided by BTMS. Thermal management is very important in the EV automobile sector, for the safety & performance of the vehicle. Battery performance decreases with increase in heat inside the battery cell whenever load on battery increases. Even when atmospheric temperature changes battery temperature increases which may cause thermal runaway in the battery, also in different cold conditions battery ability to deliver power effectively will reduce. Various methods use for BTMS such as Active, Passive, Phase change material (PCM), thermal insulation, thermal monitoring & control system. During this paper the thermos-electric module is used to control the temperature in various environmental conditions. Thermo electric coder is a solid state device that utilizes the peltier effect to transfer heat when an electric current flows through it. The battery temperature is controlled in the range of 10°C to 30°C. Which is very necessary for to improve the battery efficiency in the electric vehicle*

Key Words: BTMS- Battery Thermal Management system, TEC – Thermoelectric coder, SoC- State of Charge, SoH- State of Health, BTM- Battery thermal Model.

1. INTRODUCTION

Liquids have higher heat capacity than air, so they can absorb more heat per unit volume. This makes liquid cooling systems more effective at removing heat from batteries. Liquid Cooling systems can help to prevent thermal runaway and extend battery lifespan. (1) A study found that PCM/copper foam can be used to cool battery modules and maintain a uniform temperature. The most efficient arrangement was found to be a staggered arrangement with a 50% fill factor. (2) Battery state estimation methods are used to estimate the internal state of a battery. This is important for operating a battery-powered system effectively, sustainably, and safely. (3) A flexible approach to obtain reliable electrical and thermal design of LIB systems for automotive applications is proposed. The approach is suitable for identifying promising concepts and general design recommendations. (4) It is important to keep lithium-ion batteries at temperatures below 50°C and rapidly heat or self-heat them prior to operating at cold temperatures. (5) Traditional air cooling is not effective for battery thermal management. Direct immersion in a single-phase, non-conductive cooling fluid is the most efficient and reliable way to cool batteries.(6) The scheme uses active thermal controls to cool or heat battery cells based on the power requirements and temperature variation. The scheme can significantly improve the efficiency and reliability of the BMS. (7) To keep lithium-ion batteries (LIBs) operating within their safe temperature range and ensure their performance and safety, researchers have developed various battery thermal management systems (BTMSs). The most common BTMSs are air cooling, liquid cooling, and phase change material (PCM) cooling. (8) The development of an advanced integrated BMS is challenging due to the need for accurate physics-based models, effective charging and cell balancing algorithms, and thermal models. (9) A model of thermal dynamics in battery packs was developed to improve safety and reduce weight and cost. The model is a simplification of the full CFD/FEM model, but it is still accurate enough for real-time implementation. (10) Early models of lithium batteries were simplified to fit the computational power available at the time. Today's computers can simulate the entire cell sandwich, so there is no need for these simplifications. This paper presents the full-cell-sandwich model in its most developed form, and discusses its applications, such as interpreting experimental data and optimizing geometric parameters. (11) Lithium-ion batteries are widely used in consumer electronics due to their high energy density, high power density, long service life, and environmental friendliness. However, lithium-ion batteries for vehicles have high capacity and large serial-parallel numbers, which pose challenges in terms of safety, durability, uniformity, and cost. To ensure the safe and reliable operation of lithium-ion batteries in vehicles, a battery management system (BMS) is needed to control and manage the batteries. (12)Thermal management systems are essential for battery packs in electric vehicles to prevent overheating and safety hazards. This paper reviews the three main types of thermal management strategies: air management, fluid management, and phase-change materials. Parallel air management is the most efficient and cost-effective, while liquid management is more complex and expensive. Phase-change materials also guarantee excellent heat dissipation. (13) Electric vehicles (EV) develop fast and become popular due to their zero emission and high tank-to-wheels efficiency. However, some factors limit the growth of the electric vehicle, especially performance, cost, lifetime and safety of the battery. Therefore, the management of batteries is important in order to reach the maximum performance when operating at various conditions. Battery Thermal Management is one among the key functions of the BMS system of batteries. During this the various thermal aspects of the battery such as Heating, Cooling, Ventilation and Vibrations of battery is regulated to take care of the constant battery temperature at required level during the battery Charging and Discharging process to ultimately improve its Life Cycles and efficiency. The cycle life goes down slowly below 10°C due to anode plating causing sluggish chemical reactions and drops off quickly above 60°C due to the breakdown of electrode materials. Thus, generally the temperature must be controlled between 20°C and 40°C to make sure the performance and cycle life for the chemical batteries like Lithium-ion. Thermo-electric modules can convert electric voltage to temperature difference and vice-versa. Here the previous effect is adopted. Meaning it transfers heat through the module by consuming electricity directly. Some fans with cooling and heating tubes are installed to enhance heat transfer by forced convection. It's easy to modify between cooling and heating operations. To realize that, the poles of electrodes have to be reversed and also the temperature is maintained by regulating the voltage supply to the modules in four stages, with the assistance of a PIC18F458 microcontroller. Which makes this technique universal and can be adopted in any EV at any atmospheric conditions. The combine a passive liquid cooling system with thermo-electric module, the combined system is in a position Cool-down the battery even lower than the intake air temperature, but the facility is still limited to around some hundreds of watts and less than one

2] Objective:

1. To develop a BTMS model for balancing the different cooling and heating circuits within the battery pack to fulfil the performance requirements.

2. Use different mode to cool the battery temperature within specified range

3] Methodology:-

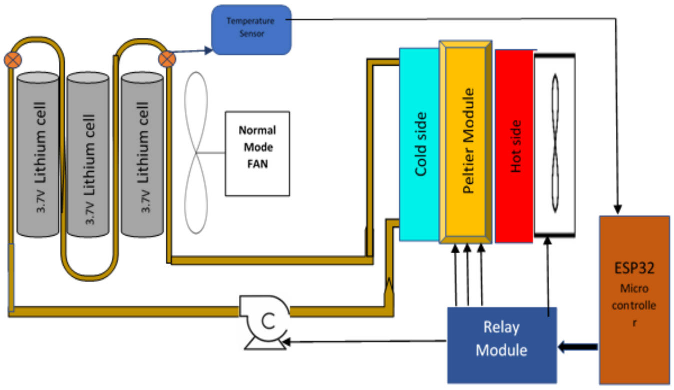


Fig no.3.1 Block diagram of overall BTMS system using thermoelectric module

3.1) Battery Thermal Management Systems (BTMS) :

The BTMS is a system that manages the heat generated by the battery cells in an electric vehicle. It helps to keep the battery cells within their optimal operating temperature range, which improves their performance and lifespan. The BTMS typically includes heat dissipation, temperature uniformity, insulation, and monitoring features.

Here are some of the key benefits of a BTMS:

Improved battery performance: A BTMS can help to improve the performance of the battery by keeping it within its optimal operating temperature range. This can lead to longer range, faster charging, and better overall performance.

Extended battery lifespan: A BTMS can help to extend the lifespan of the battery by preventing it from overheating or freezing. This can save you money on replacement batteries.

Improved safety: A BTMS can help to improve the safety of the battery by preventing thermal runaway and other safety hazards.

If you are considering buying an electric vehicle, it is important to make sure that it has a BTMS. This will help to ensure that your battery performs well and lasts for many years.

Here are some additional things to keep in mind about BTMS:

The specific features and design of a BTMS will vary depending on the type of electric vehicle and the battery technology used.

BTMSs are becoming increasingly sophisticated as battery technology continues to evolve.

The cost of BTMSs is also decreasing, making them more affordable for electric vehicle manufacturers.

Thermal Issues of Li-ion battery

Over voltage: Can cause lithium plating, which is a process where lithium metal is deposited on the surface of the anode. This can cause a short circuit between the electrodes, which can lead to a fire or explosion.

Uneven temperature distribution: Can cause local deterioration, which can lead to a loss of capacity and performance. It can also lead to thermal runaway, which is a chain reaction that can occur in a lithium-ion battery if it gets too hot. This can cause the battery to catch fire or explode.

To prevent these problems, it is important to operate lithium-ion batteries within their safe operating range and to keep the batteries cool.

Here are some tips:

Use a battery management system (BMS) to monitor the voltage and temperature of the batteries.

Charge the batteries to the correct voltage.

Do not discharge the batteries too deeply.

Keep the batteries cool.

Avoid uneven temperature distribution.

Inspect the batteries regularly for signs of damage.

3.3 Operating Requirements:

The battery temperature should be controlled within temperature limits to avoid the thermal issues and improve the performance. The temperature range affects the battery power and battery cycle life, as shown table no. 1. At the identical time, the temperature distribution should be even to make sure the battery performance and lifetime. That's also the rationale why the battery thermal management system is necessary to the battery system.

	Volumetric flow rate(L/s)	Average heat transfer coefficient (W/m^2K)
Air	43	25
Mineral Oil	0.057	57
Water	0.049	390

Table No. 1 The volumetric flow rate and average heat transfer co-efficient at the same mass flow rate 50g/s

When temperature ranges from 20°C to 40°C, battery power reaches maximum. The cycle life goes down slowly below 10°C thanks to anode plating and drops off quickly above 60°C due to the breakdown of electrode materials. Generally, the temperature must be controlled between 20°C and 40°C to ensure the performance and cycle life. Moreover, the temperature distribution is controlled under 5K to maintain the safety and lifetime of the battery (Pesaran, 2002). Additionally, ventilation is additionally essential to the battery system and will be taken into account.

3.4) Liquid cooling: The next Table shows that at the same flow rate the air volume is much bigger than the water volume, while the air heat transfer coefficient is way lower than water heat coefficient. So for air cooling to dissipate heat the utmost amount as water cooling, it requires higher volumetric flow which suggests more space and more power. Air cooling systems take up larger space and consume much more energy compared to liquid cooling systems.

There are three sorts of cooling systems, namely passive cooling system, active cooling system, and refrigerant cooling system.

The passive cooling system is suffering from the ambient temperature, because the warmth dissipation is dependent on the radiator and the radiator dissipates heat through the temperature difference between liquid and the ambient temperature. Under normal circumstances, it works well, but under high ambient temperature it's insufficient.

Active cooling systems have good thermal performance which may keep the battery pack within the operating temperature and keep temperature distribution between cells even because of the high heat coefficient of the coolant. Thanks to many auxiliaries and moving parts, the structure is complicated and difficult to take care of. It also has the tendency of leaking out.

Compared to active cooling systems, direct refrigerant cooling systems are more efficient because they use refrigerant to cool the system instead of using refrigerant to cool coolant first and then using coolant to cool the system. The weaknesses of refrigerant cooling systems are complicated structure and difficult maintenance, also potential to leak out and so on.

3.4 Thermoelectric System:

The thermoelectric effect as shown in Fig. 3.2 is the direct conversion of temperature differences to electric voltage and vice versa via a thermocouple. A thermoelectric device creates a voltage when there's a different temperature on each side. Conversely, when a voltage is applied thereto, heat is transferred from one side to the opposite, creating a temperature difference. At the atomic scale, an applied gradient causes charge carriers in the material to diffuse from the hot side to the cold side. The term "thermoelectric effect" encompasses three separately identified effects: the Seebeck effect, Peltier effect, and Thomson effect. When an electrical current is passed through a circuit of a thermocouple, heat is generated at one junction and absorbed at the opposite junction. This is often known as the Peltier effect: the presence of heating or cooling at an electrified junction of two different conductors. This principle of peltier effect is employed in this system

To improve cooling/heating power of passive liquid systems, there are two possible upgrades. One is through thermo-electric modules, which can be introduced here. Thermo-electric module can convert electric voltage to temperature difference. Here the previous effect is adopted. Meaning it transfers heat through the module by consuming electricity directly. The schematic structure is presented in Figure.

Two fans with cooling and heating tubes are installed to enhance heat transfer by forced convection. To mix a passive liquid cooling system with thermo-electric module, the combined system is in a position to cool down the battery even lower than the intake air temperature, but the facility is still limited to around some hundreds of watts and less than one kW. It's easy to modify between cooling and heating operation. To realise that, the poles of electrodes have to be reversed. Thermo-electrics have small and light-weight structures and can turn a heating element to an efficient cooling element by reversing the polarity. Without moving parts to wear, thermo-electrics are reliable, durable and of low maintenance. And also easy to exchange in case of failure. In addition, operation is quiet and vibration-free. The performance is related to the required temperature difference. The greater the temperature difference is, the lower the pumping capacity is, until it stops performing at 70K.

Thermo-electrics have small and light-weight structures and can turn a heating element to an efficient cooling element by reversing the polarity. Without moving parts to wear, thermo-electrics are reliable, durable and of low maintenance. And also easy to exchange in case of failure. In addition, operation is quiet and vibration-free. The performance is related to the required temperature difference. The greater the temperature difference is, the lower the pumping Fig 3.2 capacity is, until it stops performing at 70K. So under heat the temperature difference is great and thermo-electrics perform badly.

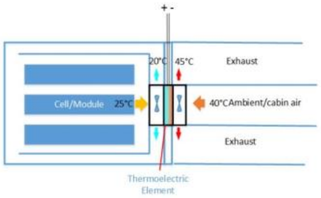
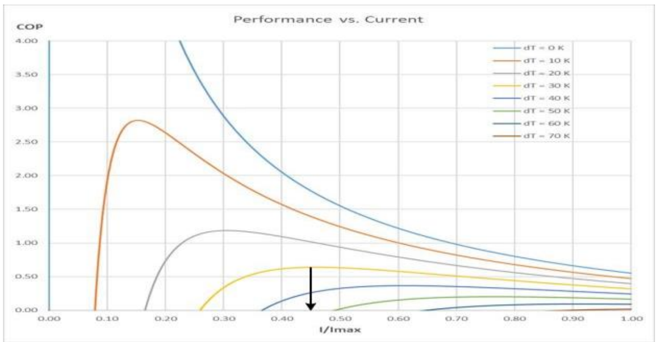


Fig no.3.2 thermoelectric element

4. Result & Discussion:

As shown in fig no. 3.3 the following steps are necessary when designing a thermoelectric cooling application:



Estimate heat load of the object to be cooled: - 10 Watt on each Peltier

Fig no. 3.3 Graph of Battery Performance Vs Current

Define temperature working range of object and heat sink :- Cold Side Temp = 15°C ; Hot Side Temp. = 45°C

Choose a Peltier element that satisfies the requirements: - Peltier TEC12704

Choose a TEC controller with suitable power range :- Vmax=12V ; Imax=4Amp

Choose a heat sink for the Peltier element: - Al Heat sink (40×40×20)mm

Choose a fan to air the heat sink (optional) :- 12V DC Fan

Choose the object temperature sensor and the optional sink sensor

Choose a power supply for the TEC controller: - 16 Watts

This is an iterative process. Test your experimental setup, improve it and repeat the above steps.

There are two thermal parameters which are necessary to select a Peltier element.

Maximum cooling capacity Qmax

Temperature difference dT

4.1 Estimate Heat Loads and Define Temperatures

We assume a Lithium ion battery pack with a heat load of **Q_C = 10 W** to be cooled to 10°C degrees Celsius. (T_0 = 15 °C) Let's say that the battery temperature is 35 °C and the heat sink temperature T_S is expected at 40 °C. Thus, the temperature difference between the cold side and the hot side of the Peltier element dT is 30 K. It's important to remember that it would be incorrect to calculate dT as difference between ambient air temperature and desired battery temperature.4.2 Choosing a Peltier/TEC Module our goal is to find a Q_{max} that is large enough to cover the needed Q_C and yields the best COP. In the performance vs. current graph we locate the maximum of the dT = 30 K curve at a current of **I/I_{max} = 0.45**. In general, this ratio should not be higher than 0.7. using that factor for the current we find in the heat pumped vs. current graph the value **Q_C/Q_{max} = 0.25** for the given temperature difference dT = 30 K and relative current of 0.45.

Now we can calculate the Q_{max} for the Peltier element.

Q_{max} = Q_C / 0.25 = 10 W / 0.25 = **40 W**

In the performance vs. current graph we find **COP = 0.6** for our previously read out I/I_{max}. This allows us to calculate

P_{el} = Q_C / COP = 10 W / 0.6 = **16.7 W**.

Peltier element manufacturers offer a wide range of elements. In their product line we look for an element with a Q_{max} of 40 W. As we have a temperature difference of dT = 30 K, a single stage Peltier element is sufficient.

As an example, we choose a Peltier element with Q_{max}=41 W, dT_{max}=68 K, I_{max}=5 A and V_{max}=15.4 V.

The operating current and voltage are calculated as follows:

I = I_{max} * (I/I_{max}) = 5 A * 0.45 = **2.25 A**
V = P_{el} / I = 16.7 W / 2.25 A = **7.42 V**

4.3 Battery Temperature effect with BTMS by outside temperatures

A battery initial temperature Variation with respect to surrounding temperature and voltage are verified earlier. It was found that battery Temperature is mainly affected by the surrounding environment temperature. While, the dynamic operation of the battery in this environment for continuously long hours also results in potential temperature rise, which may result in disturbing discharge electrochemistry of the battery and also further affecting the life of the battery. Here in the below table no.4.1 battery temperatures at various environmental temperatures were tested and it was found that the battery temperature is mainly affected by the outside temperature which is variable according to the climate and daily environmental conditions. Dynamic working of batteries in such harsh environments nearly tackling at 40°C to 45°C may even damage the cell electrochemistry and reduce its performance and life. Also we have seen at temperatures below 10°C battery chemical reactions get sluggish again reducing its performance.

In next table no.4.2, 4.3, 4.4, 4.5 the separate behavior is shown for the BTMS. There are total 4 modes shown in the next tables which will give a clear idea about the behavior of the battery cell at various temperature

Outside Temperatures in Degree Celsius	**Battery Temperature without BTMS from temperature sensor 1st**	**Mode of Operation** **1st mode :- Normal Mode** **2nd Mode :- Cooling Mode** **3rd Mode :- Boost Cooling Mode** **4th Mode :- Heating Mode**	**Battery Temperature with BTMS from 2nd temperature sensor reading.**
20°	20	BTMS Not operational	20
24°	24	1st Mode	20
26°	26	1st Mode	21
28°	27	1st mode	22
29°	28	2nd mode	15
30°	28	2nd mode	16
32°	30	2nd mode	17
34°	32	2nd mode	18
35°	34	2nd mode	18
36°	35	2nd mode	20
38°	38	3rd mode	18
40°	40	3rd mode	19
42°	42	3rd mode	20
45°	46	3rd mode	22
48°	50	3rd mode	24
52°	54	3rd mode	26
56°	58	3rd mode	28
60°	62	3rd mode	30
15°	15	BTMS Not Operating	15
10°	12	BTMS Not Operating	12
5°	6	4th mode	20
2°	2	4th mode	18
0°	0	4th mode	16
-2°	-2	4th mode	16
-5°	-5	4th mode	15
-10°	-10	4th mode	12
-20°	-20	4th mode	8

Table no. 4.1 Battery Temperature effect with BTMS by outside temperature at various modes

Sr. No.	Outside Temperatures in Degree Celsius	Battery Temperature without BTMS from temperature sensor 1st	1st mode :- Normal Mode	Battery Temperature with BTMS from 2nd temperature sensor reading.
1	20°	20	BTMS Not operational	20
2	24°	24	1st Mode	20
3	26°	26	1st Mode	21
4	28°	27	1st mode	22

Table no. 4.2 Battery Temperature effect with BTMS by outside temperature at Mode 1

Sr. No.	Outside Temperatures in Degree Celsius	Battery Temperature without BTMS from temperature sensor 1st	2nd Mode :- Cooling Mode	Battery Temperature with BTMS from 2nd temperature sensor reading.
1	29°	28	2nd mode	15
2	30°	28	2nd mode	16
3	32°	30	2nd mode	17
4	34°	32	2nd mode	18
5	35°	34	2nd mode	18
6	36°	35	2nd mode	20

Table no. 4.3 Battery Temperature effect with BTMS by outside temperature at Mode 2

Sr.No.	Outside Temperatures in Degree Celsius	Battery Temperature without BTMS from temperature sensor 1st	4th Mode :- Heating Mode	Battery Temperature with BTMS from 2nd temperature sensor reading.
1	5°	6	4th mode	20
2	2°	2	4th mode	18
3	0°	0	4th mode	16
4	-2°	-2	4th mode	16
5	-5°	-5	4th mode	15
6	-10°	-10	4th mode	12
7	-20°	-20	4th mode	8

Table no. 4.4 Battery Temperature effect with BTMS by outside temperature at Mode 3

Sr.No.	Outside Temperatures in Degree Celsius	Battery Temperature without BTMS from temperature sensor 1st	4th Mode :- Heating Mode	Battery Temperature with BTMS from 2nd temperature sensor reading.
1	5°	6	4th mode	20
2	2°	2	4th mode	18
3	0°	0	4th mode	16
4	-2°	-2	4th mode	16
5	-5°	-5	4th mode	15
6	-10°	-10	4th mode	12
7	-20°	-20	4th mode	8

Table no. 4.5 Battery Temperature effect with BTMS by outside temperature at Mode 4

4.4 Result Explanation:

Here, for creating such environments, we have used the external heater and cooler to test the battery at various temperature conditions ranging from extremely harsh hot state of 60°C to extremely cold -20°C Temperature, and it was found that: For normal temperature range from 20° to 27°C the fan was alone enough to cool the battery temperature and easily bring it to 20° to 22°C using the 1st mode of our BTMS for Hot Temperatures may be in summers and during daytime ranging from 28° to 36°C the Fan would be not enough to cool down battery temperature and so one of the peltier sets is made ON here using 2nd Cooling mode of our BTMS. Here now liquid flowing through tubes which is chilled by peltier is used to cool battery and quickly bring down its temperature to our desired range i.e. between 15°C to 20°C. For Extreme hot conditions in harsh summers Daylight, the temperatures may reach 45°C and may even above and so here full cooling requirements are needed to bring down the battery temperature. So, here both peltier sets working with 3rd mode of Booster cooling of BTMS is used to bring down the battery temperature in desired temperature range from 18° to 24°C. Here now liquids flow through both peltier and get cooled faster and thus also cooling the battery. For Cold winter conditions temperatures ranging from 0° to 5°C or even below reduced the battery cell operation due to sluggish reactions. So here a single peltier set working in reversed polarity phase using 4th mode, creates the same heating effect as it was producing the cooling effect earlier on the same side through which liquid is flowing. Now due to faster heating of peltier, the liquid also gets heated and thus effectively also brings up the battery temperature to 15 to 20°C which is best for battery performance.

4.5 Dynamic Battery Thermal Performance with BTMS at various load

Here we have tested the different battery loading conditions to test its effects on the battery temperature. The temperature of the battery doesn't vary largely with respect to various loading cycles on it, for various conditions. From the Graph below Figure it was seen that battery temperature lies in the range of the outside environmental temperature, but there may be certain rise in temperature above the environment, if continuous dynamic operation of battery is made at heavy loading conditions. This may result in an increase of battery temperatures from 0-6°C temperature extra from the outside temperatures. We can see that loading on the battery above 80% of its total capacity results in a slight increase in temperature of the battery above its outside temperature. And when the load on the battery increases above its limit or total capacity, in dynamic conditions the temperature of the battery rises significantly affecting battery performance and its life. But with help of our BTMS operating in 2nd and 3rd modes we can cool down the battery temperature even below the maximum desired temperature value i.e 25° C shown by the yellow line. Thus the orange line of BTMS parallel to actual battery temperature before BTMS is the desired temperature range of the battery (15-25°C) maintained by the BTMS, which is the main objective of our project.

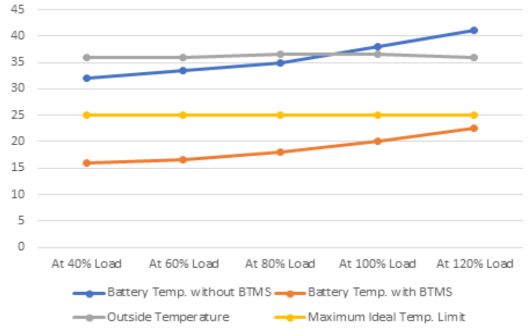


Fig no. 4.1 Battery Performance at different load

5. Conclusion

Battery management systems can be architected using a variety of functional blocks and design techniques. Careful consideration of battery requirements and battery life goals will guide you in determining the right architecture, functional blocks and related ICs to create your battery management system and charging scheme to optimise battery life. In electric vehicles, the necessity of designing a battery thermal management system was determined to keep the battery pack temperature in the optimum temperature range under hot and cold climatic conditions. Thus, the efficiency and lifetime of the battery increased. In the case of using a liquid cooled and heated system in the battery thermal management system high efficiency is achieved. But it is bad at keeping battery temperature within the optimum operating temperature. Therefore, it was determined that the electric vehicle thermal management system should consist of a liquid cooled and heated system for which Thermoelectric Peltier module is used here to provide the heat difference to the liquid. Due to the advantage of peltier to supply both heating and cooling by changing the polarity it had become easy to provide optimal temperature to the battery pack.

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BIOGRAPHIES

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