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Electrically Powered Vehicles Battery Management System: Cooling for Parked Vehicles

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For electrically powered vehicles Battery Management Systems are responsible for protected charging of the batteries. Different switches like MOSFETS, transistors are used to control the charging current of the batteries. While charging the batteries with 48A/11KW or 16A/45 KW the switches generate heat up to 150 W. The air environment in parked vehicles is not sufficient to cool the BMS. As a result the temperature rises up to 230°C, which in turn can change the nominal value of different components like resistors, semiconductor switches, inductances, capacitances, and the system could behave abnormally. Therefore, a reliable system must be appointed here to cool the BMS. The main goal of this paper is to propose and develop a system which can be a perfect choice for BMS cooling. There are many cooling systems which can be considered for this purpose. However, the Thermoelectric Cooler (TEC): Peltier cooler is the best option, which we have analysed from different point of views. The solution approaches included for evaluation are a physical model proposition, from that model designing a MATLAB simulator and after that various perspectives are elucidated using this simulator. Another important utilisation of the MATLAB simulator is that any TEC system independent of sizes can be simulated here and the performance of the system can also be realised visually.

Keywords: BMS; MOSFET; TEC; MATLAB; Heat Sink

I. INTRODUCTION

Electrical energy is the most convenient form of energy. It can be converted to another form without too much efforts and high efficiency. Other natural energy sources like oil, gas, coal are limited, and after 20-30 years later there will be scarcity of these resources. In modern world, the car vehicles are dependent on oil or gas. As the scarcity of these kind of energy resources are being approached day by day a new technology electrically powered car vehicles are being popular day by day. With the advent of modern battery efficiency and higher energy rating the vehicles are designed. With a single charging the car can run several hundred kilometres now. Some car companies like Tesla, BMW, Nissan, Ford, Volkswagen, and Kia are manufacturing electrically powered vehicles efficiently.

Charging of the batteries is the refuelling system of the Car vehicles. Various battery chargers are designed according to the Ah (Ampere-hour) rating of the batteries. These chargers are designed in such a way that the power losses through charging are minimum. In this charging process MOSFET, transistors, diodes, resistors, and capacitors play the driver's role.

MOSFET, transistors, diodes, and resistors generate heat in the charging process. As the charging time increases this total amount of heat also rises resulting in a temperature rise up to 230°C in the circuit board. The value of the resistance, and semiconductor devices is dependent on temperature. The rise in temperature causes a rise in resistance according to $R=R_0*(1+\alpha\theta)$, while the conductivity of the semiconductor increases with the rise in temperature based on this relation $R=R_0*\exp[-\beta(1T_0-1T_1)]$. If these parameters change, then the whole circuit behave

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abnormally. So, a proper cooling system must be involved to avoid such situation.

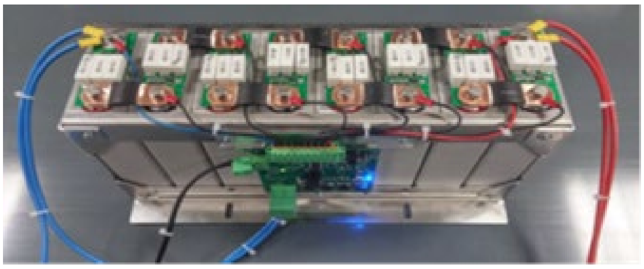

Figure 1. Battery Management System charging circuit

While charging the batteries in the parking lot the airstream in the lot cannot exchange the heat with the environment and as a result the air gets warmer, and it cannot perform the essential task to cool. So, a proper cooling system must be involved to do this task. However, space, costing is also important factor to choose any kind of cooling system.

II. EXISTING METHOD

Currently various types of cooling systems are used in different systems. It depends upon the overall cooling cost and requirements, which cooling method has to be utilised in a particular location. Space is also an important factor to determine the cooling system. Conduction cooling where the heated body is connected with a heat sink and the heat sink emits the heat in the environment is not possible to implement here. Because circulating open airstream is not available here to cool the heat sink. Because of having no proper capable circulating airstream convection cooling is also not possible here in battery management system cooling. Refrigerant cooling might be an option for cooling purpose, but it has also some limitations. This system requires a complex management system and space, which is not feasible in this case. Liquid cooling where special kinds of liquid like 3M florescent are applied very closely to the heated body to extract heat but this system also requires complex maintenance system and costs.it is also not suitable for this defined task. So, none of the systems discussed above are not suitable for battery management system. Here comes the thermos electric cooler proposition. The problems mainly faced in the methods mentioned before: complex management system, costs, requirement of free airstream are handled tactically by thermoelectric cooling method. Firstly, this system does not require too much maintenance. Once it is established, then no need to change the accessories or other parts. Second thing is that this method does not require too much cost comparing to the other methods. The space problem of the cooling system is also minimised here.

III. PHYSICAL MODEL

In the physical model the Peltier effect cooling mode is implemented. A DC current is passed through the p-type and n-type semiconductors. When the current passes through the p- and n-type semiconductors then the electrons from the lower energy level of the p-type moves to the higher energy level of the n-type. In this process the electrons absorb heat in one end and pass it to the other end (Figure 2).

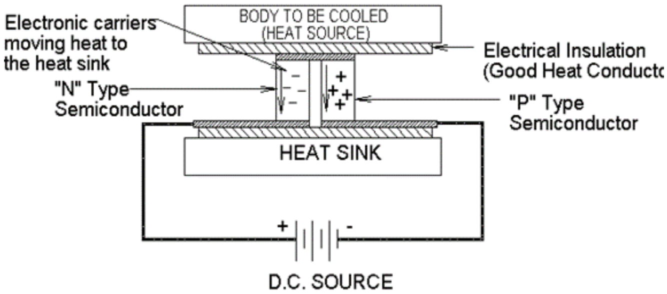

Figure 2. Schematic diagram of Thermoelectric Cooler (TEC)

The practical TEC module consists of n (n is an integer) number of pairs of the thermocouples connected in series, which are kept between two ceramic plates like a sandwich (Figure 3). Even the number of TEC modules can be arranged in several stages (single, double and so on) in parallel but it actually depends upon the capacity of the TEC module. As soon as the current is flowed heat is transmitted from one plate to the other end.

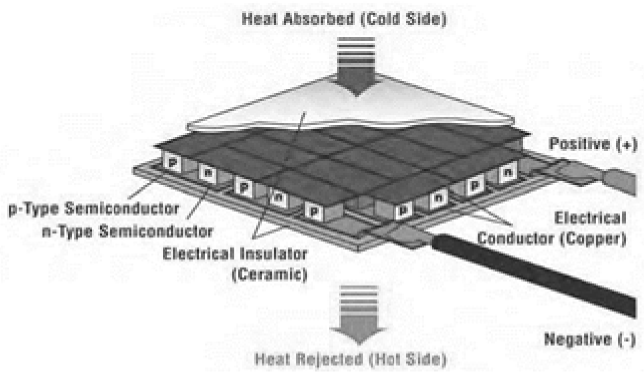

Figure 3. Schematic diagram of Thermoelectric Cooler array

IV. MATHEMATICAL MODEL

The Physical model will be represented in a mathematical equivalent model. To simulate this physical model, MATLAB Simulink simulator is used, and the virtual thermoelectric cooler is built. Basically, the whole process of cooling mechanism passes through some stages, which can be expressed by mathematical functions. Some key parameters like the p-type and n-type Seebeck materials, heat sink materials, current, cross-sectional area of thermoelectric generator, numbers of p-n pairs are responsible for cooling. These parameters are controlled, and the performance of the physical model is tested. In the left side of the virtual cooler various inputs are changed like the P- & N-type materials, temperature difference, current, no of PN cells and the outputs (cooling power, consumed power, COP) are observed in the right side.

A. Cooling Power

It is defined as the resultant thermal power, which is transmitted from one plate to the other end. When a current is circulated in the circuit consisting the p-type and n-type semiconductors, then the transmitted heat can be represented by the following equation:

Transmitted thermal power=(αp-αn)*I*dT, where αp,αn are the Seebeck coefficients of the two branches, dT is the temperature difference between two ends and I is the current. Conversely, some other factors which act in the reverse direction of the cooling is heat conduction rate. Heat conduction rate mainly depends upon the temperature difference and the thermal conductance.

Heat conduction rate = (T2-T1)*(Kp+Kn)

Additionally, Joule heating of the thermal elements, which also act in the opposite direction of cooling is represented by the following equation:

Joule heating = (1/2) I^2*(Rn+Rp)..........(1)

So, finally the cooling power can be expressed as:

Q1=(αp-αn)*I*dT-(1/2)I^2*(Rn+Rp)-(T2T1)*(Kp+Kn)..........(2)

B. Power Consumed

The electrical power, which is consumed in the system is divided into two portions: Joule resistance heating and the power to crate the temperature deviation.

W=(αp-αn)*I*dT + (I^2)*(Rn+Rp)..........(3)

C. COP (Coefficient of Performance)

The ratio of the heat extracted from the source to the expenditure of electrical energy is defined as COP. If the cooling capacity is Q1, the electrical power consumption W and coefficient of performance is denoted by COP then,

COP=Q1/W..........(4)

D. MATLAB Simulink Model

At first the subsystem model of the TEC module is represented (Figure 4). In the left side of the TEC module different inputs (αp,αn=p-, n-type Seebeck coefficients; Kp, Kn=the thermal conductance of p- & n-type; Rp, Rn=thermal resistances of p- & n-type; dT=Temperature difference; Cells = No of p- & n-pairs) are inserted and the corresponding outputs (consumed power, COP and Cooling power) of the inputs are observed in the right side of the model. In the subsequent figure of the subsystem model the in-detail Simulink model (Figure 5) is represented.

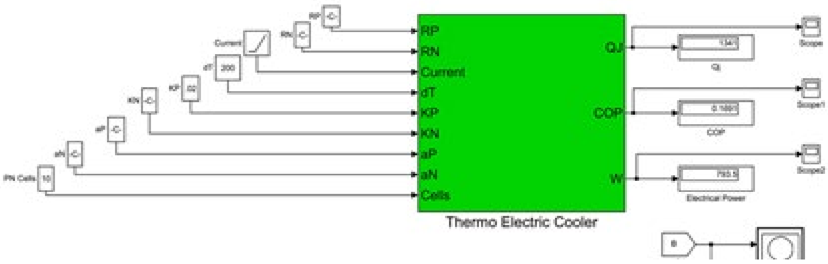

Figure 4. Subsystem Model. Left side is input, and right side is output section

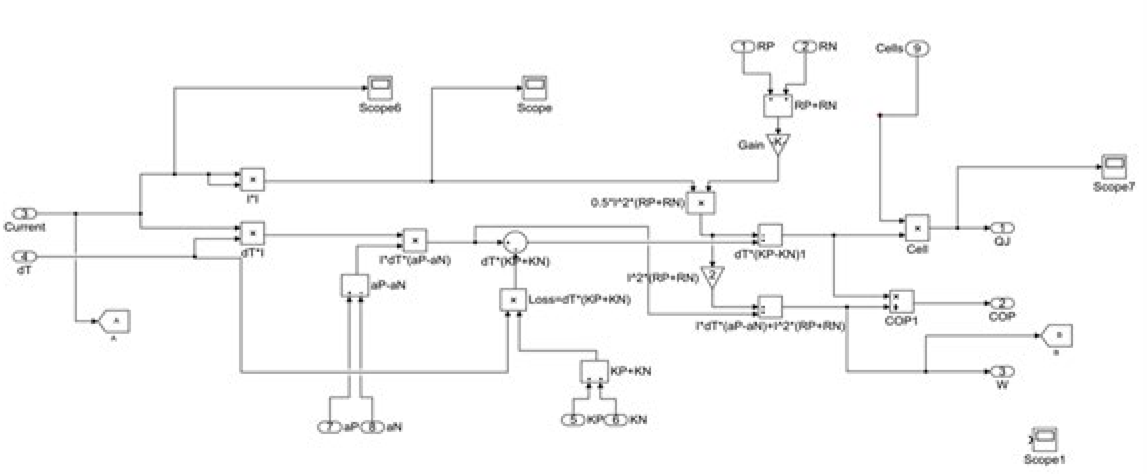

Figure 5. Full Simulink Model

V. MATERIAL SOLUTION

In order to implement the solution the whole system is divided into different parts. From the MOSFET heat is emitted in the heatsink. The heatsinks are connected with the p- and n-type semiconductor Seebeck materials. Through the circulation of current in the circuit heat is transferred to the outer portion. In this section these components will be discussed briefly.

A. *Heat Sink*

In this project heat sinks play a crucial role for the tec module. At first, the generated heat from the MOSFET is dissipated in the inner aluminium heat sink (Figure 6). Next, the tec module transmits this heat to the outer end where another heat sink of large cross-sectional area is connected. It is essential that there must be electrical insulation between the tec module and the heat sinks. Ceramic-type insulator is used here for the purpose of insulation. Aluminium-type metal is chosen for the outer heat sink (Figure 7). Since the outer heat sink has comparatively large cross-sectional area and has melting point of around 660°c, it can easily dissipate the heat in the environment.

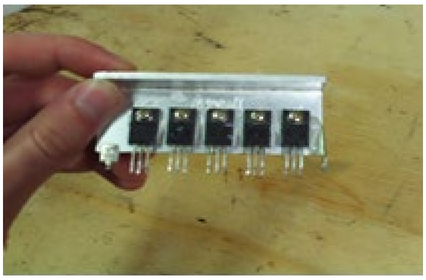

Figure 6. Aluminium-type inner heat sink connected with MOSFET

Figure 7. Aluminium-type outer heat sink connected with environment

B. Seebeck Materials

It is the heart of TEC modules upon which the performance of TEC module depends on. Electrons are responsible for the transmission of electricity and heat. Different metals have different Seebeck coefficients of different signs and of different values. The reason behind this fact is due to asymmetry of electrons arrangement around the Fermi level. In order to select the thermocouple it is kept in mind to choose the combination of maximum positive and minimum negative coefficients.

Table 1. Seebeck Coefficient of Semiconductors and Metals

Semi-conductors	**Coefficient (μV/K)**	**Metals**	**Coefficient (μV/K)**
Se	900	Antimony	47
Te	500	Nichrome	25
Si	440	Molybdenum	10
Ge	300	Cadmium	7.5
n-type Bi2Te3	-230	Tungsten	7.5
p-type Bi2.x SbxTe3	300	Gold	6.5
p-type Sb2Te3	185	Silver	6.5
PbTe	-180	Copper	6.5
Pb03Ge39Se58	1670	Rhodium	6
Pb06Ge36Se58	1410	Tantalum	4.5
Pb09Ge33Se58	-1360	Lead	4
Pb13Ge29Se58	-1710	Aluminium	3.5
Pb15Ge37Se58	-1990	Carbon	3
SnSb4Te7	25	Mercury	.6

C. Substrate Materials

The substrate has several functions. It provides the electrical insulations between different components, baseplates. It performs to remove the heat losses generated by the system. Different kind of materials could be selected for substrate like metal insulator semiconductor system, polymers, ceramic. Particularly which one should be selected depends upon several properties. To choose a material focus should be on thermal conductivity, thermomechanical ageing or physiochemical stresses, coefficient of thermal expansion, chemical stability of the materials, high resistivity to reduce leakage current, a high dielectric strength and mechanical strength. Keeping all requirements in mind the ceramic-type substrate is chosen for this project.

Different types of ceramic materials: Boron nitride, alumina, aluminium nitride, and silicon nitride, could be used. These ceramic materials have different physical, mechanical, and chemical properties. To select a particular type they are analysed from different point of views. While choosing a particular ceramic material these properties are taken into account: dielectric strength, mechanical strength, thermal conductivity, coefficient of linear thermal expansion, physicochemical stability, and thermal shock resistance.

However, for our targeted application Aluminium Nitride is chosen. The reasons behind this selection are excellent thermal conductivity, high mechanical stability, and coefficient of thermal expansion. Due to less thermal expansion, it puts less stress on power semiconductors and on thermal joints during thermal cycling.

VI. SIMULATION RESULTS

For simulation the P- and N-type materials are taken here are Pb15Ge37Se58 and Pb03Ge39Se58, respectively. The corresponding values of these two types of materials are rp=.52*10^-3, rn=10^-3, kp=.02, kn=.206, ap=1800*10^-6, an=-1900*10^-6, respectively. Where ap, an=p-, n-type Seebeck coefficients; Kp, Kn = the thermal conductance of p- & n-type; Rp, Rn = thermal resistances of p- & n-type; dT = Temperature difference; Cells = No of p- & n-pairs.

In Figure 8 it is seen that the COP increases with current at certain value, after that it decreases with the change of current. This is because when current flows in the circuit it causes some resistive power losses in the circuit. After reaching the peak value the losses in the resistance becomes higher, and the cooling performance is decreased downward.

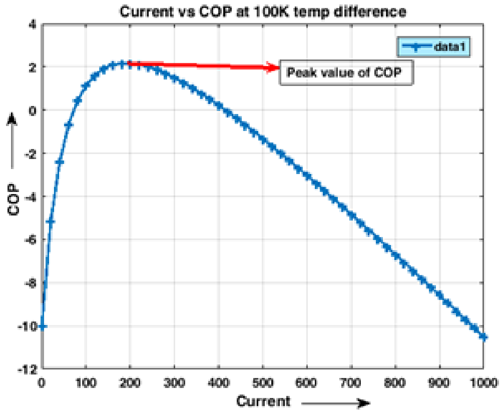

Figure 8. COP (Coefficient of performance) *vs* Current

Figures 9 and 10 reflect the effect of temperature difference in the performance of Thermoelectric Cooler. Referred to Equation 2, this is due to the fact that the cooling power is proportional with dT. It clearly shows that the performance of the cooling will be higher as the temperature difference between the cold and hot junction is increased.

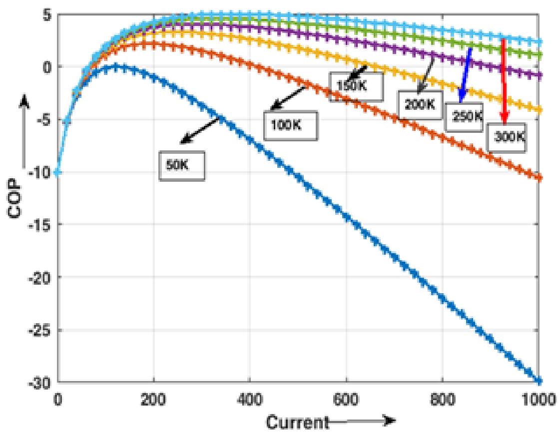

Figure 9. COP *vs* Current at different temperatures

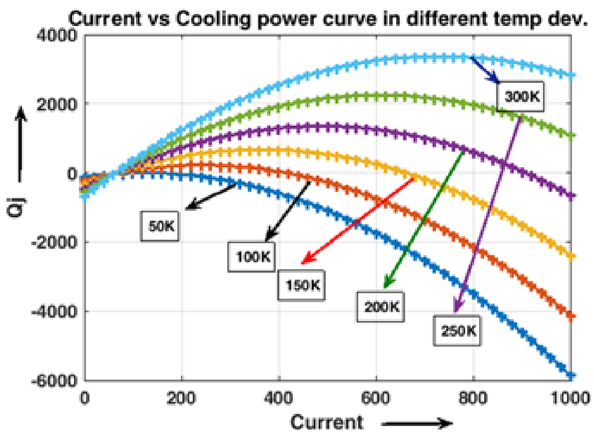

Figure 10. Cooling power (Qj) *vs* current curve

If the PN cells are augmented, then the performance of the system dramatically changes. Figure 11 and Equation 2 clearly explains the relation. So, if the cooling power is known and from this relation the number of cells required can be calculated easily.

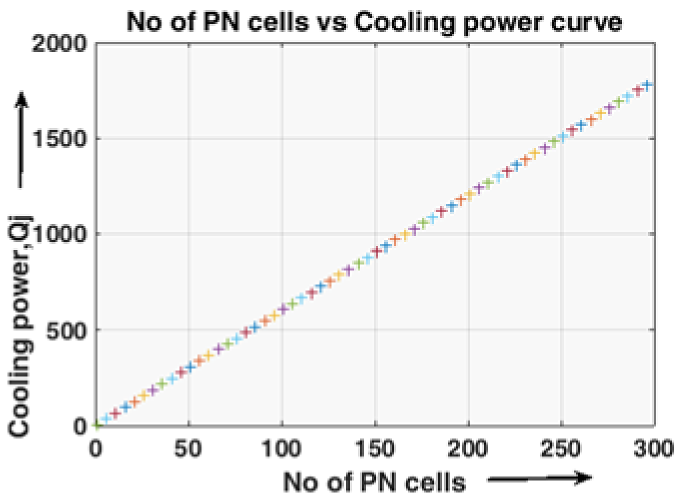

Figure 11. Cooling power *vs* number of PN cells

In Figure 12 cooling power change with respect to the temperature difference is shown. From 0A to 60 A the changes are negative. This is due to the fact that at these values of the current, the losses in the PN resistance and thermal coefficient are larger than the cooling power. But after 60A a sharp increase of the cooling power is found since after this marginal value the cooling power becomes larger than the losses due to current.

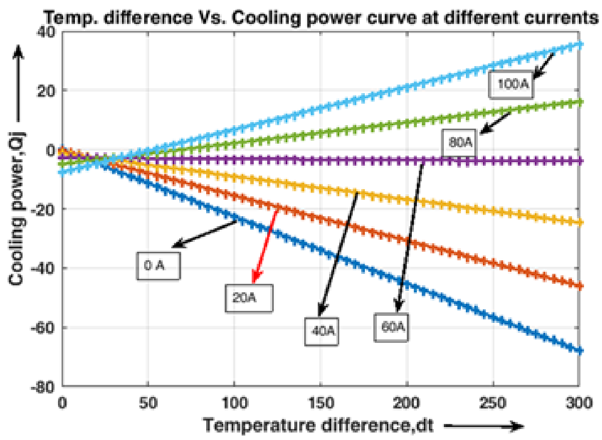

Figure 12. Cooling power *vs* Temp difference curve

The cooling power increases with the consumed electric power at certain values, and then it starts to fall as indicated in Figure 13. The losses due to the increase of current becomes higher after reaching the peak value. The system must be operated before reaching the peak point in order to get the maximum output from the system.

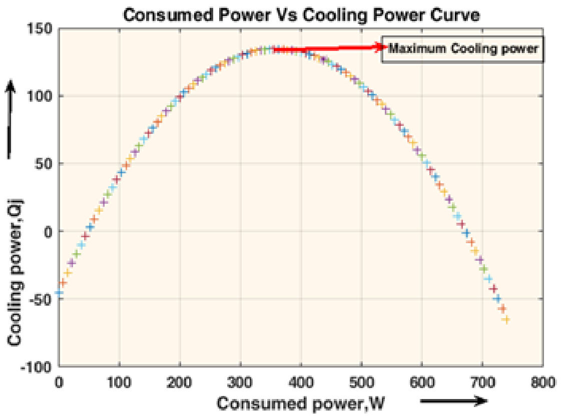

Figure 13. COP curve

Like Figure 13 the phenomenon is observed once more in Figure 14 when taking into account COP. COP is the ratio between Qj and consumed power. Qj has a peak value at certain point and then decreases so as the COP also with respect to consumed power.

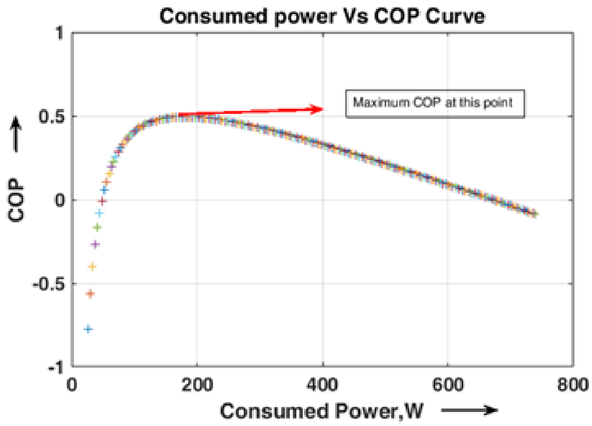

Figure 14. COP *vs* Consumed power curve

VII. COST CALCULATION AND COMPARISON

In particular, the proposed system requires these modules: a heat sink, TEC module and other accessories like nuts, bolts, and wires shown below.

Table 2. Price list of required materials

Item	Price
heat sink	7 €
TEC module	7 €
Ceramic Substrate	12 €
Accessories (nut, bolt, wires)	1 €
PCM (paraffin wax)	60 €
Total	27 €

There is no rotating bodies' here. For this reason, it does not require too much maintenance. Physical structure is compatible anywhere because of little space requirements. The cooling temperature can be controlled precisely. For example, a precision of 0.1°C can also be controlled. Another important benefit is it can cool a particular spot unlike the other the cooling systems. No gases or harmful liquids are used here. So, this cooling system is environmentally friendly. By utilising the temperature difference between the two ends of the cooler a small amount of electricity is possible to generate.

However, the proposed technique has some disadvantages compared to the other methods. It has lower COP (Coefficient of performance), advantageous only at lower capacity type cooling and it requires more power to run the system.

VIII. FUTURE DEVELOPMENT

The efficiency of a thermoelectric cooler depends upon Seebeck coefficients and the current mostly. However, it also depends on the resistance of the P- & N-types' semiconductor devices, and thermal conductance but in a negative way. The fewer amounts of these values of thermal conductance and PN resistances the better is the output. So, focus should be on semiconductor devices design from which a Seebeck coefficient of high value can be found. A lot of research works are currently going on to develop semiconductors to get a large Seebeck coefficient. Hopefully, when a better semiconductor device is devised of large Seebeck coefficient then a dramatic rise of the COP of the thermoelectric cooler would be visible.

IX. CONCLUSION

Finally, the main goal was to propose and develop a system, which can be a perfect choice for Battery management system cooling. Various cooling method can be implemented, but we found that the Peltier cooler might be a perfect choice through analysis keeping all conditions in mind. The analytical approach was to propose a physical model, then build a mathematical model according to the physical model, and after that, simulate the model with real data for perfect predictions of results.

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