Design of a waste heat recovery system in an Electric Vehicle by using thermo-electric generator

Vivek Raghav [1], Hari Om Patel [2], Aryan Malik[3],Abdullah Asif Toukir [4], Shivam s verma[5]

[1]School of mechanical engineering, Lovely Professional University, Phagwara, India, viv.rghv@gmail.com, +91- 8427971414
[2]School of mechanical engineering, Lovely Professional University, Phagwara, India, patelhariom795@gmail.com, +91-7999905002
[3]School of mechanical engineering, Lovely Professional University, Phagwara, India, aryanmalik2811@gmail.com +91-8273505137
[4]School of mechanical engineering, Lovely Professional University, Phagwara, India, toukirabdullah1@gmail.com, +91-6284246771
School of mechanical engineering, Lovely Professional University, Phagwara, India,shivam19473@lpu.co.in, +91-8558903647

Abstract

The project is to design a waste heat recovery system in an electric vehicle by using thermoelectric generator. Range of electric vehicles is low because the electric vehicle not uses its, whole generated power during driving some energy is waste in heat form from the electric motor, battery pack, etc. so to utilize this waste heat energy Thermo-electric generator (TEG) is used over the battery pack to increase the power output. The project aims in designing ofboth the geometries and comparing them on the basis of advantages provided by them. The project provides the TEG geometries that can be employed in vehicles according to their operating conditions. The employment of these geometries yields good results for the vehicle.

The purpose of the project is to design the TEG geometries that are specified earlier for a vehicle, designing the required parts, conducting the study over the electric vehicle parts, manufacturing of the parts, assembling TEG on the battery pack and then compare with the actual power generated values.

The project is being finalized by following various steps. The project initialized by finalizing the dimensions of the battery pack of an electric vehicle in which the TEG geometry is to be installed. Then we came up with the heat generated by a battery used in electric vehicle (li-ion, nickel hydride, lead acid batteries). Using these values and considerations we employed the TEG (thermo-electric generator) over the battery pack of an electric vehicle. The Thermo-electric generator that will be installed in the vehicle need to be designed so that it will be in accordance with the vehicle and to increase the power output of the vehicle. The calculations for power generated by a TEG or efficiency are done doing manual calculation with the help of formulas.

Things we learned in this project are the TEG how it works the battery thermal management system and how a lithium-ion battery work to produce energy to run the vehicle. It should with stand harsh working conditions of the vehicle.

The conclusion for the project is to increase the range of the electric vehicle by decreasing the load falling on the battery pack of the vehicle. Load considers the energy used to run the auxiliaries of the vehicle so the energy generated by the TEG is sufficient to run the auxiliaries and in this way the range of the electric vehicle increases. Then comparing both the geometries and specifying where the geometries if installed give good performance of the vehicle.

Introduction –

Since the world took the turn of its 21stcentury we have noticing and facing a lot of climate emergencies. Prominent scientists of the world blame almost half a part of it to the emissions from vehicles which are used on daily basics around the world. The smoke coming out of the silencer of the vehicle contains greenhouse gases which traps the sun's heat and don't let it escape thus increasing the temperature of the earth.

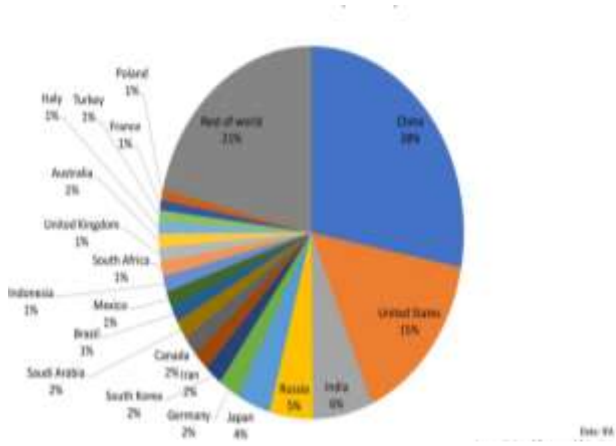

Figure 1*- share of global carbon dioxide emissions*

The following pie chart shows the 2015 annual carbon-dioxide emissions of different countries from same source. The data considers the carbon-dioxide emissions from the burning of fossils fuels.

Country	Emission in 2017(MtCO2)	%of Global Emissions
China	9,839	27.2%
United States	5,269	14.6%
India	2,467	6.8%
Russia	1,693	4.7%
Japan	1,205	3.3%
Germany	799	2.2%
Iran	672	1.9%
Saudi Arabia	635	1.8%
South Korea	616	1.7%
Canada	573	1.6%
Mexico	490	1.4%
Indonesia	487	1.3%
Brazil	476	1.3%
South Africa	456	1.3%
Turkey	448	1.2%
Top 15	26,125	72.2%
Rest of World	10,028	27.7%

Figure 2*- Rank wise nation emissions*

So, to overcome this problem of emissions electric vehicle comes to take place because as the time move forward a lot of oil wells running dry. And we have to admit that fossils fuels are available in a limited amount. Hence, one day there will be a scarce supply of it.

Electric vehicle is also known as electrics which means that a device which uses extra electric motor (traction motor) for the momentum. Electric vehicle power-driven through a collector system by using electricity from off-vehicle sources, or may be independent with a battery, or solar panels.

In the mid of the nineteenth century electric vehicle came into existence. Modern engines have been the leading propulsion method for motor vehicles for nearly about 100 years, but electric power has persisted in common place in other vehicle types,such as trains and smaller vehicles of all types.

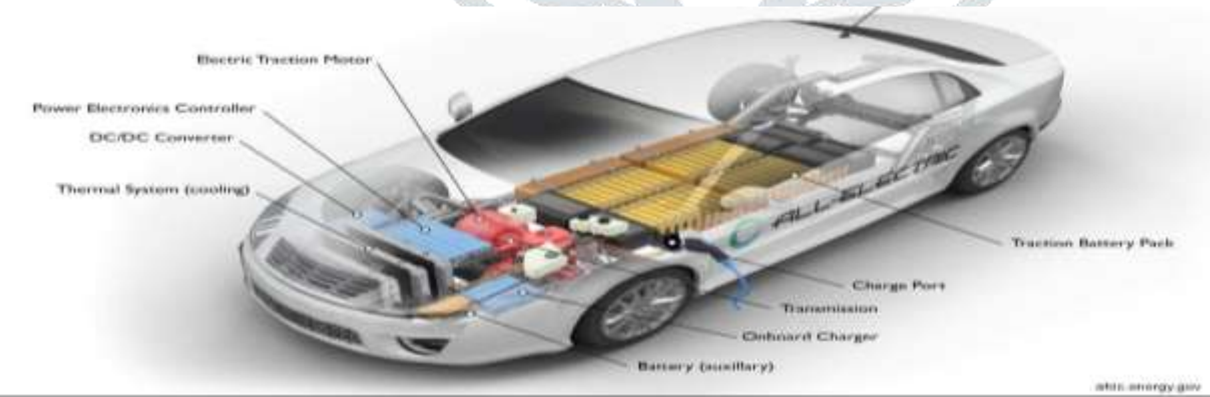

Figure 3*- components of an electric vehicle*Li-ion batteries –

These, batteries are used by most of the electric vehicles. Very few other Practical batteries have as high energy , long life and high power than most other Lithium-ion batteries. Protection, robustness, thermal failure and price are complicating factors. For operating safely and efficiently safe temperature and voltage range are necessary for Li-ion batteries. If the batteries lifespan increases then effective cost will decrease operating a subset of the battery cells at a time one technique.

In before EV cars which is made by general motor used Nickel Metal Hydride batteries but because of Self-discharging problem, these battery types are considered to be out dated in the market. Chevron, Creating, a problem for their extensive growth hold the batteries patent. Due to these factors and high- cost Lithium-ion batteries has the major battery for EVs.

Since the price is continuously decreasing (li-ion) on the market. In these, batteries electrolyte helps for the transformation of Li-ion from the negative electrode to the positive electrode at discharged state this also helps to back to the negative electrode during charging. Positive electrode material and negative electrode graphite called intercalated lithium compound is used by Li-ion batteries. High energy density, no memory effect (other the LFP cells) and low self-discharge contain in the batteries. For containing flammable electrolytes, they can however be a safety hazard and damaging or improper charging can lead to explosions and fires. Chemistry, Performance, cost and safety characterizes can be differed for LIB types. Lithium polymer batteries (with electrolytic polymer gel) are used by handheld electronics with lithium. Cobalt inside (LicO2) which is used as cathode material. These, type of batteries are useful for tools (Run by electricity), Vehicles widely use NMC and its derivatives. Extend duration, increase energy density, improving protection, reducing price and increase in the charge speed among other are experimental areas for Li-ion batteries. As a pathway research being done on non-flammable electrolytes for, increasing the safety.

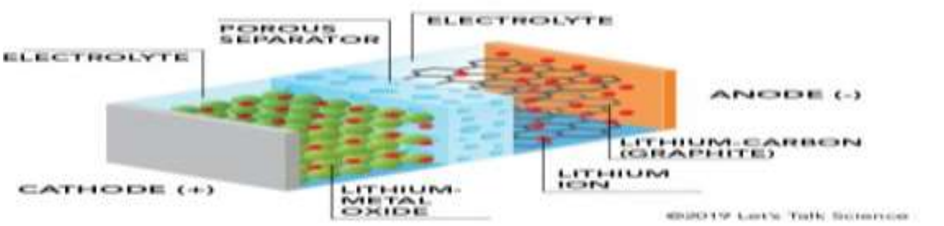

Figure 4*- parts of a li-ion battery*

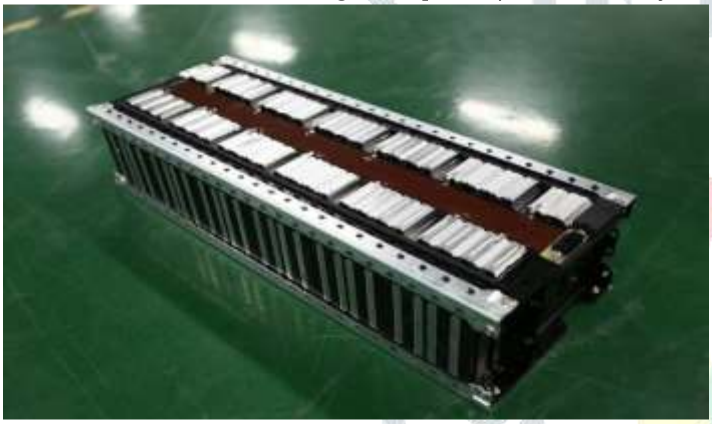

Figure 5*- Battery pack mounted in electric vehicle*

A Single Lithium-ion cells is charged in two stages: Constant Current (CC) and Constant voltage (CV). Lithium-ion battery is charged in three stages: Constant current, Balance, Constant voltage.

A steady current is applied on li-ion battery at a steadily increasing voltage by the charger at the time of the constant current phase. To reach the voltage limit Per cell. The charging current is reduced by the charger at the time of balance phase (The charge are Paid and stopped which reduces the average current). When, a complementary circuit brings the state of charge of individual cells to the identical level to balance the battery. This stage is avoided by some first chargers. The balance is accomplished by some chargers to charge cell independently.

At the time of constant voltage phase a equivalent voltage is applied to the maximum, cell voltage times the number of cells in series to the battery. Because of gradual declination of the current to 0 the current is under a set of threshold of about 3% of initial persistent charge current.

500 hours maximum charge on one occasion. It is advisable to start top charging when the voltage goes below 4.05V/cell.

Extreme Temperatures –

Li-ion batteries offer good charge Performance at cooler temperature and also might be allowed fast charging inside a temperature collection of 5 to 45°c (41 to 113°F).This temperature rate is required for charging. Though temperature from 0 to 5°C charging is achievable, the charge current must be reduced. At the time of a low-temperature charge, the minor temperature rise above ambient as the internal cell resistance is helpful. Battery degradation occurs when charging at high temperatures and At 45°C or above battery performance is degraded..As low temperatures may increase the internal resistance of the battery the outcome is slow charging and therefore longer charging periods.

Above 0°c(32°f) temperatures is obviously required for charging of consumer grade lithium ion batteries. A battery set can appear to be charge normally but electroplating of metallic lithium can arise at the negative electrode through a sub-freezing charge and repeated cycling cannot be able to remove it.

Electric Motor –

The kilowatts (kw) is the measurement unit for the Power of a vehicles motor and also other vehicle's. Though 100 kw almost same as 134 hours power. Electric motor can deliver their maximum torque over a wide RPM range.

By converting electrical energy to mechanical energy, energy is lost. Engine converts approximately 90% of the energy to mechanical energy, damage is to the motor and drive train normally, direct current (DC) electricity is feed into a DC/AC inverter and converts into alternating current (AC) electricity and connects this AC electricity to a 3-phase AC motor. The vehicle's often use DC motor for electric trains, forklift trucks and some electric cars. For employing AC&DC motors, vehicle's use universal motor In some cases. At present production vehicle's implement various types of motor ,for example: Tesla Motor uses induction motor in their vehicle's

.

Figure 6 *- parts of an electric motor*

THERMOELECTRIC GENERATOR –

TEG is a device which is used to change waste heat into electricity. It works on the principle of seebeck effect. In this phenomenon temperature difference between two different conductors or semi -conductors generate a voltage difference between the two material.

Now's today our vehicle is running over fuel like(petrol, diesel, CNG) fuel gives power to IC engine but it makes a lot of air pollution. Graph of emissions from cars is increasing day by day after some time these fuel resources is going to be deplete.

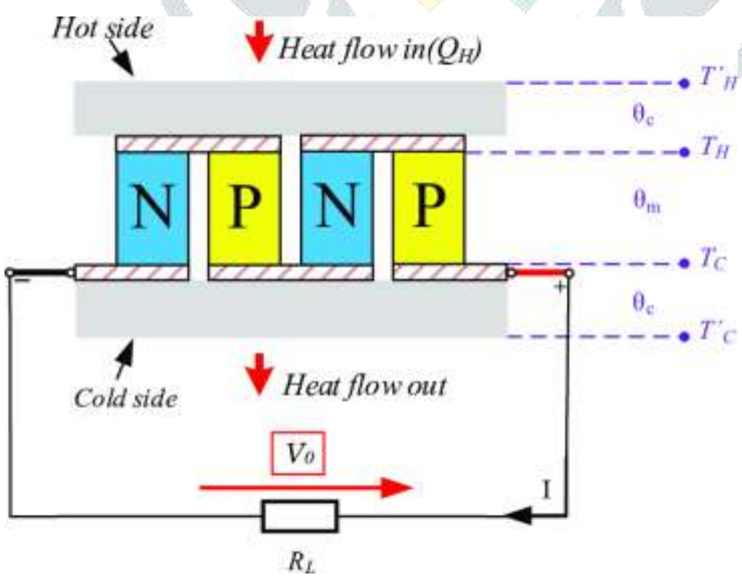

Figure 7 *-Thermoelectric generator*

SEEBECK EFFECT –

In 1821 Thomas John Seebeck who is the German physicist revealed that, though two strips of different electrically conducting materials were separated lengthwise, combined together by two "legs" at their were developed around the legs for Providing a temperature difference occurred among the two junctions. His observations were published by him this year and the name of the phenomenon was the Seebeck effect. But the cause of the magnetic field was not identified by Seebeck. Though this magnetic field outcomes from equal, contrary electric, currents in the two metal-strip legs. An electrical potential difference causes these currents and thermal differences induce across the junction between the materials. By opening one junction the temperature difference is sustained. Though current no longer flows in the legs, a voltage can be measured across the open circuit. This produced voltage (v) is the Seebeck voltage which is correlated to the difference in temperature (ΔT) among the heated junction and the open junction by a Balance factor(α) called Seebeck efficient, or v= α ΔT. The types of material at the junction determine the value for α.

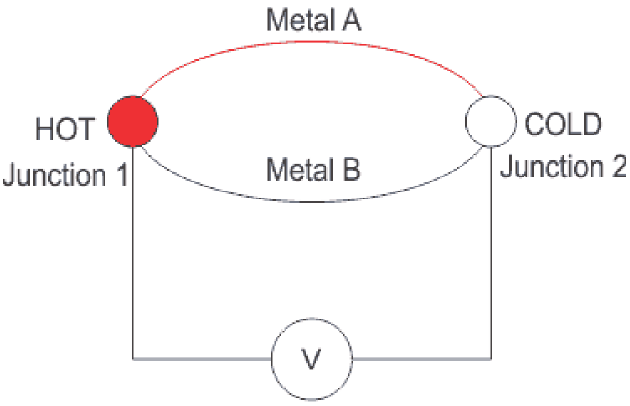

Figure 8 *-Seebeck effect*

OBJECTIVE

The objective of this research paper is to utilize the waste heat that is comes from the battery while it is in operating condition. Because, nowadays our dependency on the foosils fuels like (petrol,diesel,CNG,etc)isincreasingdaybydayaftersometimeitmaybedepleted.Anddue to this greenhouse gases (CO, methane, carbon-dioxide, etc) and global warming increasing day by day. So, we switch to electric vehicle which is powered by a battery pack and battery pack consists of many battery or cells. So,the weight of the electric vehicle id needed to be less so there is not enough load to be bear by the battery of the vehicle. We only utilize 60%-70% power of the battery rest 30% is released in waste heat form which reduces the efficiency of our battery. So, to overcome this problem we use a thermoelectric generator to convert the waste heat from the battery into energy which leads to increase in the efficiency of the battery and the vehicle. As we know the efficiency of the thermoelectric generator is very less with the waste heat energy, we run the auxiliaries of the vehicle.so we placed the thermoelectric generator over the battery pack of the electric vehicle. Because maximum heat generated is at the centre of the battery pack. After this placement of the TEG over the battery pack the efficiency of the battery increase , life of the battery increases because there is less load falling on the battery.

Research methodology

Electric cars have recently been dominate the international scene, with cars across the entire nation. Still customers show some amount of dishonor – saying that the cars are not well smoothed for on a daily basis use. In cities or on highways extra electric charging stations is going to be open to power the electric vehicles.

An electric car is one of the most excellent ways to help out the environment because by having it in fact decrease carbon-emissions by up to take three tons per annum. If electric vehicle is there. It is useful to join the fight next to the global warming.

The reason for their increasing prominence is that electric cars are;

- Efficient in nature.
- No noise is there.
- Much easier to operate.
- Reduce the air pollution.
- Do not emit any type of gases.
- Give better performance than usual petrol or diesel cars and.
- carbon dioxide emissions is less.

Challenges with EV'S –

The main challenges for battery electric vehicles (BEVs) is their high costs, driving range, battery issues and charging.

- In electric vehicle battery plays an important role because waste heat in electric vehicle is come from the battery pack. Only 60-80% efficiency is used as a power output and rest 20% is wasted. So, to utilize the waste energy we use thermoelectric generator. These generators are used at that place where energy is wasted in the vehicles. This helps in increasing the battery life and efficiency of the battery. Power generation and heating/cooling applications are equally attractive.

Battery thermal management system(BTMS) –

A BMS is an embedded system that protects safety host application operator, protects battery from abuse, prolong battery life, maintains battery in a functional state, and informs host application how to make the best use of the pack right now.

The BMS functional requirements fall into five general categories –

(1) Protection – over-charge, over-discharge, short circuit, over-current

(2) Interface – Data recording, range estimation, reporting

(3) Diagnostics - state of health (SOH), state of life estimation

(4) Performance management –power-limit computation, balance/equalizing cells

(5) Sensing, high-speed voltage control - measure current, voltage, temperature

CALCULATIONS –

Aim is to convert waste heat from the battery of an electric vehicle by means of thermoelectric generator (TEG) modules as given away in Figure 9. Specifications of a thermoelectric generator is given as-

No. of TEG modules (N) = 24

No. of thermocouples (n) = 98

Hot junction temperature (th) = 230°C

Cold junction temperature (tc) = 50°C

Cross-sectional area of the thermo-element (for p type and n type) $An = Ap = 12\ mm^2$

Leg length of the thermo-element (for p type and n type) $Ln = Lp = 4.6$ mm An array substance properties for the *p*-type and *n*-type thermo-elements are understood to be as$ap = -an = 168$ mV/K, $rp = rn = 1.5 \times 10^{-3}$ W cm, and $kp = kn = 1.1 \times 10^{-2}$ W/cmK. which is shown in the figure.

Figure 9- thermoelectric generator used in vehicle

SOLUTION -

Th = 503K AND Tc = 323K

Material properties: $\alpha = \alpha p - \alpha n = 336\times 10^{-6}$V/K, $\rho = \rho p + \rho n = 3.12\times 10^{-5}$ohm meter, and k=kp+kn=2.36W/mK

$$Z=\frac{\alpha^2}{\rho k} = \frac{(336\times10^{-6})^2}{3.1\times10^{-5}\times2.36} = 1.533\times10^{-3}$$

And,

$$ZT=Z\frac{(tc+th)}{2} = 1.533\times10^{-3}\,\frac{(503+323)}{2} = 0.633$$

We apply the condition of R_L/R =1 for power output (maximum). The internal resistance R is,

$$R = \frac{\rho L}{A} = \frac{(3.1\times10^{-5})\times4.6\times10^{-3}}{12\times10^{-6}} = 0.012 \text{ Ohm}$$

The electric current per module is

$$I = \frac{\alpha(th-tc)}{RL+R} = \frac{336\times^{10-6}(503-323)}{0.024} = 2.528\ Ampere$$

Voltage of each module is,

$$V = \frac{n\alpha(th-tc)}{R+\frac{Rl}{1}}\left(\frac{Rl}{R}\right) = \frac{98(336\times10^{-6})(180)}{2} = 2.964 \text{ V}$$

Now, the maximum power output is,

$$W = \frac{n\alpha^{2(th-tc)^2}}{R}\left(\frac{\frac{RL}{R}}{1+\left(\frac{RL}{R}\right)^2}\right) = \frac{98(336\times10^{-6})\text{^}2(180)\text{^}2}{0.048} = 7.493 \text{ Watt}$$

for the entire TEG device:

The power output is (maximum),

W maximum = N× W = 24× 7.493 = 179.8W

The maximum power efficiency is given by,

$$\eta = \frac{1-\frac{tc}{th}}{2-\frac{1}{2}\left(1-\frac{tc}{th}\right)+\frac{2}{ZT}\left(1+\frac{tc}{th}\right)} = \frac{1-\frac{323}{503}}{2-\frac{1}{2}\left(1-\frac{323}{503}\right)+\frac{2}{0.633}\left(1+\frac{323}{503}\right)} = 0.051$$

total absorded heat is :

$$Q = \frac{W}{\eta} = \frac{7.493}{0.051} = 3{,}525\ W$$

Table 1: rate of heat generation of li-ion battery

Temp [k]	0.25C	0.5C	1C	2C	3C
283k	0 to 2.09	0 to5.29	0 to 10.82	0 to 24.71	-
273k	-0.33 to 2.05	0 to 5.20	0 to10.21	0 to 19.52	0 to 29.93
263k	-0.24 to 1.43	0 to 4.37	0 to 8.87	0 to16.72	0 to 24.79
253k	-0.44 to 0.87	0 to 3.32	0 to 4.92	0 to 13.78	0 to 4.92
243k	-0.46 to 0.85	-0.33to1.86	0 to4.56	0 to10.39	0 to 16.48
233k	-0.43 to 0.71	-0.44 to 1.62	0 to3.70	0 to 7.88	0 to 14.21

Here, C= discharge rate,

LiFePo4 40Ah lithium-ion battery, Maximum heat generation at 40 degree Celsius taken, Rate of discharge (2C) /recharge,
Heat generation for 20Ah battery at 40 degree Celsius with, rate of discharge 2C = 7.88
Heat generated for 160 Ah battery = $\frac{160\times7.88}{4}$ =31.52 W

Result & discussion

This project deals with the improvement in the range(km) of electric vehicle by using the thermoelectric generator over a lithium ion battery pack. The heat generated by the lithium ion battery is 31.52Watt, capacity of the battery is 160Ah, the specification of the thermoelectric generator that is used over the battery pack has cross-sectional area 12mm^2, leg length of the generator is 4.6mm, the power generated by the thermoelectric generator is 179.8Watt and the efficiency that obtained by this generator is 0.051 or5.1%. Figure merit table of different materials of the thermoelectric generator is give below-

Table 2 - Figure of merit of thermoelectric materials

Material	*ZT* Value
PbTe	0.8
PbSe	1.2
Pb_2Te_3	1.2
Bi_2Te_3	1.0
SiGe	0.8
TeAgGeSb	1.2
$CeFe_4Sb_{12}$	1.1
PbTe-SrTe	1.7
$(BiSb)_2Te_3$	3.3

Lithium ion battery is used in the electric vehicle for power production because it is having a high power to weight ratio, energy efficiency and high-quality high temperature performance. Lithium ions batteries also not have a good "self-discharge" speed, which means that they are better than other batteries at maintaining the ability to hold a full charge over time. Furthermore, large number of lithium ion batteries part is eco-friendly making these batteries a first-class preference for the environmentally conscious. Nickel metal hydride batteries are also use it is having good life existence than the lithium ion batteries but their high price, high self-discharge rate and high heat at elevated temperatures that is why it is mostly used in electric means of transportation.

Conclusion

After getting the results, it was concluded that after using the thermoelectric generator over a lithium ion battery pack that the energy which is generated by the generator is suitable to run the auxiliaries of the electric vehicle. Auxiliaries, includes power steering pump, power window, air conditioning compressor, wiper, sunroof, ABS (anti-locking braking system). Because of this the efficiency of the battery increases which leads to increase in the range(km) of the electric vehicle. Load over the battery decreases which helps in improving the life or ageing of the battery. Thermoelectric generator is having efficiency between4-10%. Battery heating problems is going to be degraded lot more because the thermoelectric generator uses that heat. The generated energy can also used in increasing the range of the vehicle only if the generated energy is little bit more than the energy used to run the auxiliaries of the electric vehicle.

Reference –

(1) Nesrine jaziri, Jensmuller, Fares Tounsi, Mohammed Ismail, a comprehensive review of thermoelectric generator: technologies and common applications. Energy reports(2019,https://doi.org/10.1016/j.egyr.2019.12.011).

(2) Zhirong Wang, Kai Liu, Hao Wang, Xuang Tong, Chi-Min Shu, , calculation methods of heat produced by a lithium ion battery under charging discharging conditions. Fire and materials. 2018:1-8.https://doi.org/10.1002/fam2690

(3) Chan c. The state of art of the electric and hybrid vehicle.2002;90(2):247-275.

(4) Zhongao Rao, Yiping Wen, Jiateng Zhao, 2019, thermal performance of a battery thermal management system using composite matrix coupled with mini channel. Energy storage.2019;1;e59.https://doi.org/10.1002/est2.59.

(5) Hsiu Ying Hwang, Yi-Shi n Chen, 2014, optimizing the heat dissipation of an electric vehicle battery pack.

(6) Wissan Bou Nader, Thermoelectric generator optimization for hybrid electric vehicles.(2019),doi:https://doi.org/10.1016/j.applthermaleng.2019.114761

(7) Hicks, L.D, M.S, Dreesselhaus,1993, Thermoelectric generator figure of merit.

(8) V.G Choudhary, T.M Sathe, 2020, a review on heat generation and various thermal management systems for lithium ion battery used for electric vehicle. Journal of energy storage 32(2020),doi:https://doi.org/10.1016/j.est2020.101729.

(9) Mohan Naryana, Ravi kumar, Hanamant Yaragudri, 2018, Design and analysis of heat exchanger for battery thermal management system.(2018) journal of emerging technologies and innovative research:doi:https://jetir.org/j.est2018.2349-5162.