Analysis on Power Generation through Thermoelectric Generators

Parth Shah
Department of Mechanical Engineering,
Lokmanya Tilak College of Engineering, Koparkhairane, Navi Mumbai (India)

Dr. Chandra Babu. D
Professor Department of Mechanical Engineering,
Lokmanya Tilak College of Engineering, Koparkhairane, Navi Mumbai (India)

Vaibhav Deshpande
Asst. Professor Department of Mechanical Engineering,
Lokmanya Tilak College of Engineering, Koparkhairane, Navi Mumbai (India)

Abstract- Discovery of electricity has changed everyone's life. As advancement of technology has taken place, the need of electricity has also increased. Electricity can be generated through various energy sources such as wind energy, hydroelectric energy, fossil fuels, non-renewable sources etc. As we know that, globally, the consumption of power is very high as compared to its production, generation of power on a large scale has become a global phenomenon. Generation of power through non-renewable sources has now become a severe issue for mankind considering its present use. Depletion of these resources is taking place at a rapid rate. Hence, to meet the needs of such high power demand, many alternative methods of generating power are available. One of them being the use of TEG (thermoelectric power generators). A study has shown that the amount of heat energy wasted is far more than it is consumed. This heat wastage can be prevented by using the waste heat to generate power for various domestic and industrial purposes through the use of TEG. This paper focuses on the use of waste heat energy to generate power through TEG (thermoelectric generators). The heat source having high temperature flows across the sink of the TEG (thermoelectric generators) and converts it into electric energy by a phenomenon called as seebeck effect. The components used in TEG are of low maintenance, cheap etc. Also the power generation through TEG is affordable, easy and can be used even in the remote areas thus solving the problem of energy crisis to some extent.

Keywords- TEG (thermoelectric generators), Seebeck effect, heat source, heat sink, waste heat energy

I. INTRODUCTION

Power is the most important part of our life. Almost all the activities require power, from small cellphones to large aero planes. The work that we do regularly also requires power such as watching television, using an elevator, driving a vehicle etc. Without power, our life would be like dead flower. All the discoveries were done with the help of power. If power was not there, the humanity would have had to face several hardships. Hence it becomes important for us to generate power in ample quantity. Generation of power has now become a challenge for us as the usage of power is very high compared to its production.

This has forced us to find alternative methods to generate power using renewable resources. One such method is generating power with the help of TEG (Thermoelectric generator) by using heat energy. It converts the heat energy into electric energy.

Waste heat is produced by several processes that make use of energy as well as machines which do work. The releasing of heat from various sources is based on the laws of thermodynamics. Several sources that produce heat are day to day activities, ecosystems etc. This waste heat energy can be utilized for generation of power with the help of TEG. TEGs have low initial cost and efficiency of these devices is high, hence they can be used in various places to solve the problem of power generation.

II. SEEBECK EFFECT

An effect in which a voltage difference is produced between two dissimilar conductors because of their temperature difference is known as SEEBECK EFFECT. A scientist called Thomas Johann Seebeck made this discovery. When application of heat takes place on one of the two conductors, the movement of heated electrons is from hot side to cold side.

This effect produces small voltages. They are only a few microvolts per Kelvin of a temperature difference. The output voltage can be increased by connecting large number of devices in series or parallel. Effective, small scale power can be provided by large array of these devices if temperature difference across their junction is very large.

In 2008, another discovery was made, what the physicists called it as SPIN SEEBECK EFFECT. When application of heat is done to a magnetized material, this effect is seen. Rearrangement of electrons takes place according to their spin. Heat is not created as a waste product in such arrangements.

2.1 SEEBECK CO-EFFICIENTS: -

SR NO	METAL USED	FERMI LEVEL AT 0 K (eV)	S (theoretical) (μV/K)	S (calculated) (μV/K)	h (W/m^2K)
1.	Au	5,50	4,40	6,50	1,48
2.	Ag	5,50	4,40	6,50	1,48
3.	Cu	7,00	3,45	6,50	1,88
4.	K	2,00	12,09	-9,00	-0,74
5.	Al	11,60	2,08	3,50	1,68
6.	Na	3,10	7,80	-2,00	-0,26

III. TEG (THERMOELECTRIC GENERATOR)

The device that converts heat energy into electric energy is called a thermoelectric generator. Their working is based on thermoelectric effect. It consists of a heat source and a heat sink. The high temperature of the heat source allows the heat to flow through the converter to the heat sink that has a lower temperature as compared to the source. In a thermoelectric generator, the energy flow direction is reversible. Electrical power can be converted into thermal power and vice versa.

3.1 BLOCK DIAGRAM OF TEG WITH SEEBECK EFFECT

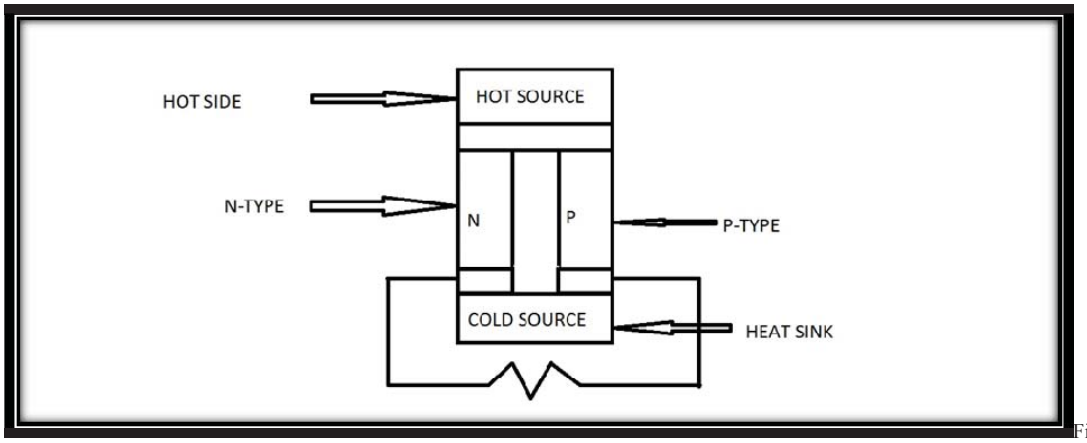
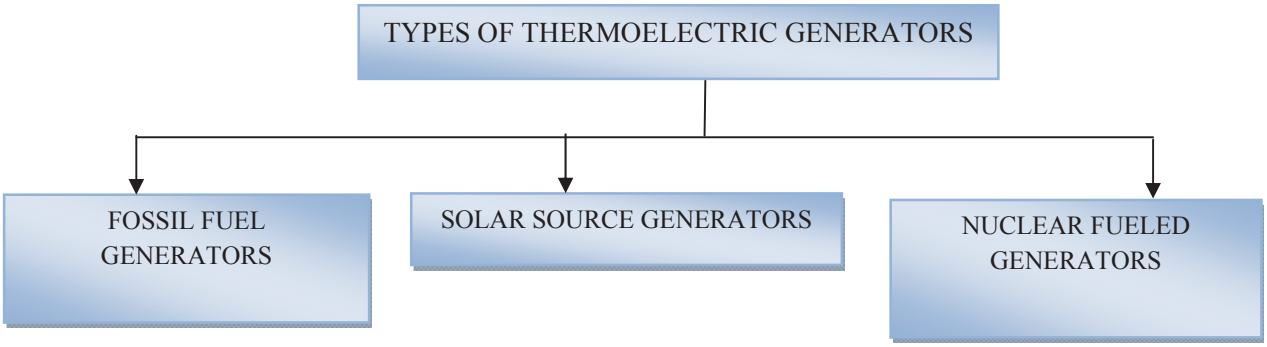


Figure 3.1- Thermoelectric generator

3.2 TYPES OF TEG (THERMOELECTRIC GENERATORS)



3.2.1 Fossil fuel generators –

The generators that use butane, kerosene etc are called FOSSIL FUEL GENERATOTRS. They range between 10 to 100 watts output power. Such generators have their application in remote areas.

3.2.2 Solar source generators –

Solar source generators can be used in underdeveloped and developing regions of the world where heat energy is available in ample amounts. These generators have been used for electric supply in orbiting spacecrafts but have not been able to match with solar cells made up of silicon that have better efficiency and lower weight as compared to SOLAR SOURCE GENERATORS.

3.2.3 Nuclear fueled generators –

The generators that use decayed products of radioactive isotopes to provide high temperature are called NUCLEAR FUELED GENERATORS. These generators are effective as they can last for longer duration of time and are immune to nuclear radiations. NUCLEAR FUELED GENERATORS deliver power in the range of 0.00001-100 watts.

3.3 MATERIAL SELECTION CRITERIA - Materials for TEG are selected based on the following few factors-

3.3.1 Semiconductors –

They are usually used in TEG (Thermoelectric generators) because of their band structures and other properties. Efficiency of the device is given by ZT, so at high temperature ideal materials have larger Z values.

3.3.2 Electrical conductivity –

The electrical conductivity is given by K=K(electron)+K(photon).

According to WIEDEMANN-FRANZ law, as the electrical conductivity increases, K(electron) also increases. Hence, K(photon) should be minimum.

3.3.3 State density –

Thermoelectric effect is better for Band structure of semiconductors in comparison with metals. As the Fermi energy is below conduction band, state density is asymmetric. Hence, electron energy required for conduction of band is always higher than Fermi energy, due to which conduction of system is carried out lower energy state.

3.4 APPLICATIONS OF TEG (Thermoelectric generators)

- They are used in gas pipelines.
- Generation of electricity by space probes like MARS CURIOSITY ROVER is done by TEG.
- The efficiency of a vehicle can be enhanced to a greater extent by using the waste heat with the help of TEG.

3.5 SOME DISADVANTAGES OF TEG (Thermoelectric generators)

- Thermoelectric generators have low efficiency and set up cost is high.
- They have very high output resistance.
- Adverse thermal characteristics- Since the working of a TEG takes place at a low thermal conductivity, it affects the heat dissipation of such devices. These devices are economical when high temperature is available with a need of small amount of power.

IV. REVIEW ON FEW EXPERIMENTS

4.1 Wei zhu et al [1]: - In recent times, the development in the performance of STEGs have shown their ability of converting solar energy into light. They use the principle of effect. In STEGs, firstly, conversion of solar energy takes place into thermal energy that further gets converted into light energy. The performance of a STEG can be increased by increasing the temperature difference across the thermoelectric legs. In this experiment the researcher aims at increasing the performance of a thin film STEG (Solar thermoelectric generator). Analysis and testing of STEGs performance due to the effect of air convection was carried out. In STEG, solar radiation helps in achieving the required temperature difference. The absorber is used to convert the light energy into heat. In the circular area, the temperature is high. This helps in conduction of heat through the device. This work was done in order to increase the temperature difference between the thermoelectric legs. The results obtained showed that the performance was increased by a significantly large margin.

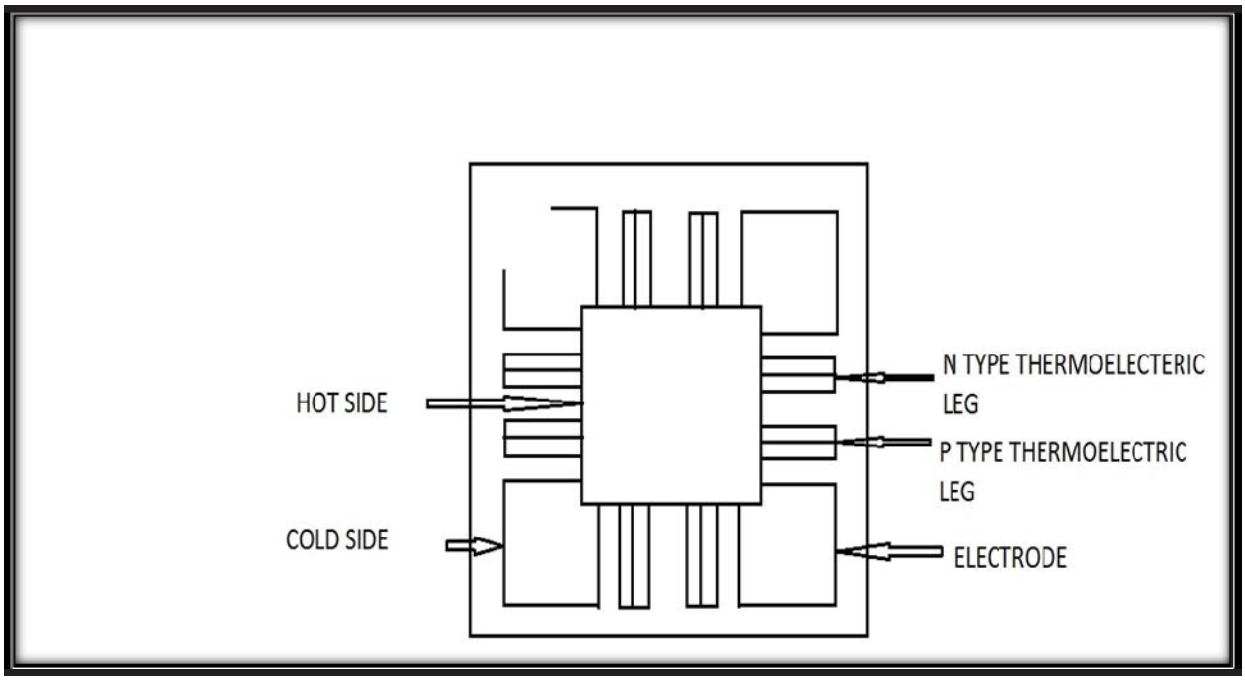
4.1.1 System description

System under study is a STEG having following main parts and other systems: -

- P-type thermoelectric leg: - Bi0.5Sb1.5Te3 was used as P-type thermoelectric leg

- N-type thermoelectric leg: - Bi2Te2.7Se0.3 was used as N-type thermoelectric leg
- Electrode
- ANSYS: - This is used for calculation of rate of flow of heat, temperature difference etc.

4.1.2 Solar thermoelectric generator setup



4.1.3 Procedure

- Thermoelectric leg is fixed at a particular distance.
- The substrate's thickness and length of TE (Thermoelectric leg) are kept variable.
- To obtain the output power, a load resistance is connected to the circuit.
- The area at the center (circular) is treated with a solar irradiation.
- An assumption is made that absorption of solar energy takes place which finally leads to conversion into heat.
- Air temperature is adjusted and consideration of convection heat loss is neglected.

4.1.4 Result

- The fabrication and designing of a thin film STEG was carried out.
- It was seen that the results obtained from simulations and infrared measurements were almost equal.
- Under light irradiation, the voltage response of STEG was also carried out.
- It was seen that when the light is switched on, there was a rapid increment in the voltage in the initial period which after some time got stable.
- When light was switched off, the voltage started decreasing rapidly and then became zero.

4.1.5 Conclusion

- This experiment tells us about the effect of geometry of the device and their properties on various factors like temperature, efficiency of STEG etc.
- In order to increase the temperature difference, the substrate should have low thermal conductivity.
- The temperature in the center can be reduced by using heat conductive layers of heat. Simultaneously it will maintain difference in temperature.

4.2 Andrea montecucco et al [2] :- In this, the researcher has done a complete study on how a solid fuel stove can be used to heat water for household and other purposes. Fuel stoves are easily available and are cheap, hence can be used on a small scale or in remote areas. Also the efficiency of these stoves is very high. He has explained how the heat released from a solid fuel stove is used to charge a battery with the help of TEG (Thermoelectric generator). This battery then supplies power to heat the water. The system under study is a CHP system. The following experiment involved four thermoelectric devices. These devices were placed on the heat exchanger made of aluminum. The top of the stove was covered by the exchanger. A water tank was used in which the water used to flow to and from the tank by a dc pump. The working of a CHP system is explained in this experiment.

4.2.1 Materials Specification

- MPPT converter: - They are used for increment in the power of TEGs
- Solid fuel stove
- TEG (Thermoelectric generators): - They convert the heat energy into electrical energy
- heat exchanger

4.2.2 Result

- The experiment consisted of four thermocouples.
- All the thermocouples displayed identical values. The temperature difference was found to be variable across the thermoelectric legs.
- However, the operation was carried out at maximum power by the MPPT converter.

4.2.3 Conclusion

- This experiment has shown the working of a CHP system for supplying heat from a solid fuel stove to heat the water for various purposes.
- As the setup cost of the system is low, it can be used on a larger scale in many developing countries of the world.

4.3 Andreas patyk et al [3]: - In this study, the researcher aims at focusing on various environmental issues caused due to pollution, natural calamities etc. and the costs required to reduce these effects. As we know, in present times as the rate of pollution is increasing to a greater extent, a tremendous amount of heat energy is generated. More than 75% of this heat energy is wasted. Many improvements can be made if this waste heat energy is used for various significant purposes. The researcher tells us how the use of this heat energy in thermoelectric generators and steam expanders can be helpful in dealing with various environmental issues. He has also made a comparison between TEGs and steam expander systems. The experiments show that TEGs play a vital role in reducing environmental issues and help to save energy cost. However when power demand is high, steam expanders are better than TEGs in terms of production of electricity and efficiency.

4.3.1 Materials Specification

- TEG (Thermoelectric generators):- They convert the heat energy into electrical energy
- steam expander
- base Pus

4.3.2 Result

- Power generation by steam expanders and TEGs was compared.
- For small amount of power generation, TEG was found to have greater efficiency than steam expanders.
- However, as the amount of power generation increased, efficiency of steam expanders was found to be more as compared to TEGs.
- Cost of production of TEGs is less as compared to steam expanders.
- However steam expanders provide more advantages than TEGs.

4.3.3 Conclusion

- The above study tells us that use of TEGs should be done in small power plants as they have higher efficiency.
- However, the efficiency of TEGs decrease as the size of power plants increases.
- Hence, TEGs should be used when power plants are small while steam expanders should be used when large power plants are considered.

4.4 M.F Remeli et al [4]:- In this study, the aim of the researcher is to generate power by using heat energy that is wasted with the help of TEG (Thermoelectric generator) and heat pipes. TEGs have higher efficiency and set up cost is also low, hence they can be used in generation of power in many places where power is not easily available especially in remote and underdeveloped areas. For performing the experiment in the lab, the researcher has made use of a heat exchanger of counter flow air duct type. 8 TEGs modules were sandwiched between 2 blocks of copper. 6 TEGs and 4 heat pipes were placed in each of the modules. Stable state data of electrical power generated by the system and air temperature were recorded by a data logger. The experiment was carried out at different airspeeds in the upper duct. The external resistance was changed gradually for obtaining maximum output of electrical power.

4.4.1 Materials Specification

- TEG (Thermoelectric generators)
- Variable speed fan
- Heat pipes

4.4.2 Result

- The total power is directly proportional to the external load resistance.
- As the load resistance increases, the power also increases.
- The maximum power and the rate of heat transfer will increase if the ratio of mass flow rate of upper duct to that of lower duct is high.

4.4.3 Conclusion

- The experiment shows a useful method of generating power using TEG and heat pipes.
- The ratio of mass flow rate of upper duct to that of lower duct has a significant effect on the system performance.

- Maximum power and rate of heat transfer will be high if the ratio of mass flow rate of upper duct to that of lower duct is high.

4.5 N.Wojtas et al [5] :- The researcher has explained how the efficiency of a µTEG (Micro thermoelectric generator) can be increased using µHTS (Micro heat transfer system). In this experiment, fabricated structures of µHTS and µTEG were used. Fabrication of µHTS was carried out with respect to its performance and heat transfer rate. For homogeneous heat distribution, the devices were mounted on a heat source consisting of a copper block and resistive heater. At the center of the copper block an integrated thermocouple was placed that controlled the temperature of the block. The thermal losses due to convection were neglected. For reduction of thermal losses due to convection, area of block in contact with ambient air was kept minimum. A differential pressure sensor meter is used for the measurement of pressure drop over the heat sink.

4.5.1 Materials Specification

- µHTS (Micro heat transfer system)
- µTEG (Micro thermoelectric generators)
- copper

4.5.2 Conclusion

- It is seen that the heat transfer resistance of µHTS is high at low pumping power.
- The output power of µTEG was maximum at a temperature difference of about 50K.

V. REVIEW TABLE

SR NO	NAME OF RESEARCHER	MATERIALS USED	CONCLUSION
1	Wei zhu	STEG	Geometry and property of device effects the efficiency of STEG.
2	Andrea montecucco	Solid fuel stove and TEG	Heating of water can be done by solid fuel stove.
3	Andreas patyk	TEG with base PUs	Efficiency of TEG is higher in small plants.
4	M.F Remeli	TEG with heat pipes	Power can be generated by TEGs and heat pipes
5	N.Wojtas	µHTS and µTEG	Efficiency of µTEG increases by use of µHTS.

VI. CONCLUSION

In this review paper, analysis was carried out on how the power generation can take place with the help of TEGs (Thermoelectric generators) using waste heat energy. Generating power with the help of TEGs can play a vital role in the future. As a large amount of heat energy is wasted, this waste heat energy can be utilized in a right way for power generation through TEGs (Thermoelectric generators). Also TEGs can be used at small scale levels too as initial setup is cheap. But the current developed from a single TEG is of very small value. Hence, development should be made to improve the development of power generation through TEG. I personally feel that the heat that is

wasted from industries, vehicles etc should be used to generate power as many underdeveloped regions of the world are facing the problem of energy crisis.

REFERENCES

[1] Wei Zhu , Yuan Deng , Min Gao , Yao Wang , Jiaolin Cui , Hongli Gao :- "Thin-film solar thermoelectric generator with enhanced power output: Integrated optimization design to obtain directional heat flow". Energy 89 (2015) 106-117.

[2] Andrea Montecucco, Jonathan Siviter, Andrew R. Knox:- "A combined heat and power system for solid-fuel stoves using thermoelectric generators". Energy Procedia 75 (2015) 597-602

[3] Andreas Patyk:- "Thermoelectric generators for efficiency improvement of power generation by motor generators – Environmental and economic perspectives". Applied Energy 102 (2013) 1448-1457

[4] M.F Remeli, L. Kiatbodin, B.Singh, K.Verojporn, A.Date, A.Akbarzadeh :- " Power generation from waste heat using Heat Pipe and Thermoelectric Generator". Energy Procedia 75 (2015) 645-650

[5] N. Wojtas, E. Schwyter, W. Glatz, S. Kuhne, W. Escher, C. Hierold:- "Power enhancement of micro thermoelectric generators by microfluidic heat transfer packaging". Sensors and Actuators A 188 (2012) 389-395

[6] M.G. Molina, L.E. Juanico´, G.F. Rinalde:- "Design of innovative power conditioning system for the grid integration of thermoelectric generators". INTERNATIONAL JOURNAL OF HYDROGEN ENERGY 37 (2012) 10057-10063

[7] Camille Favarel, Jean-Pierre Bédécarrats, Tarik Kousksou, Daniel Champier:- "Experimental analysis with numerical comparison for different thermoelectric generators configurations". Energy Conversion and Management xxx (2015) xxx-xxx

[8] Ugur Erturun, Kaan Erermis, Karla Mossi:- "Influence of leg sizing and spacing on power generation and thermal stresses of thermoelectric devices". Applied Energy 159 (2015) 19-27

[9] Champier D, Bedecarrats JP, Rivaletto M, Strub F. Thermoelectric power generation from biomass cook stoves. Energy 2010;35:935–42.

[10] Chen M, Lund H, Rosendahl LA, Condra TJ. Energy efficiency analysis and impact evaluation of the application of thermoelectric power cycle to today's CHP systems. Appl Energy 2010;87:1231–8.

[11] Jang J-Y, Tsai Y-C. Optimization of thermoelectric generator module spacing and spreader thickness used in a waste heat recovery system. Appl Therm Eng 2013;51(1–2):677–89.

[12] Chen W-H, Liao C-Y, Hung C-I, Huang W-L. Experimental study on thermoelectric modules for power generation at various operating conditions. Energy 2012;45(1):874–81.