ENERGY HARVESTING USING THERMOELECTRIC GENERATOR

A PROJECT REPORT

Submitted by

MEGASREE B	**715515105031**
LAKSHMANAN A N	**715515105307**
KARTHICK R	**715515105305**

in partial fulfillment for the award of the degree

of

BACHELOR OF DEGREE

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

PSG INSTITUTE OF TECHNOLOGY AND APPLIED RESEARCH

COIMBATORE - 641062

ANNA UNIVERSITY: CHENNAI 600 025

APRIL 2019

ANNA UNIVERSITY: CHENNAI 600 025

BONAFIDE CERTIFICATE

Certified that this project report **"ENERGY HARVESTING USING THERMO ELECTRIC GENERATOR"** is the bonafide work of **"MEGASREE B, LAKSHMANAN A N** and **KARTHICK R "** who carried out the project work under my supervision.

HEAD OF THE DEPARTMENT

Dr. C L Vasu
Professor and Head
Department of Electrical and
Electronics Engineering
PSG Institute of Technology and
Applied Research

SUPERVISOR

Mr. M Sathiyanathan
Assistant Professor (Sr. Gr.)
Department of Electrical and
Electronics Engineering.
PSG Institute of Technology and
Applied Research

Certified that the candidates was examined in the viva voce examination held on 1-4-2019

INTERNAL EXAMINER EXTERNAL EXAMINER

ABSTRACT

This project aims to develop electric power using Thermoelectric Generators (TEGs). In this project a boost converter is designed to develop an output voltage of 13.5 V to charge the battery. The TEG converts heat energy to electrical energy based on "Seebeck Effect". The hot water pipeline is connected to hot surface and water inlet pipeline is connected to cold surface of TEG module. The temperature difference in the TEG surface creates a continuous electron flow in the circuit. The output voltage of TEG increases, if the temperature difference increases. The DC output generated from the TEG is regulated into constant DC using P&O algorithm to charge a 12 V lead-acid battery. Thermoelectric power generators have emerged as a promising alternative green technology due to their distinct advantages. Thermoelectric power generation offer a potential application in the direct conversion of waste-heat into electrical power. In this work the cost of thermal energy input is not considered and it is economical and pollution free. It can also be used for many applications such as in urban and rural areas where solid waste is converted into heat and then converted into electric power.

ACKNOWLEDGMENT

We would like to express our gratitude to **Dr. P V Mohanram, Principal**, and **Dr. G Chandramohan**, Vice-principal PSG Institute of Technology and Applied Research, Neelambur, Coimbatore - 641062, for providing the opportunity to carry out our project work with the best infrastructure and facilities.

We extend our sincere thanks to **Dr. C L Vasu**, Professor and Head, Department of Electrical and Electronic Engineering for providing valuable suggestions and continuous encouragement throughout the project.

We express our sincere thanks to **Mr. M Sathiyanathan**, Assistant Professor (Senior Grade), Department of Electrical and Electronics Engineering for giving his unfailing support throughout the project work and special thanks to **Mr. S Ravikrishna,** Assistant professor (Senior Grade) and the staff members Electrical and Electronics and Mechanical Engineering for helping in the hardware development of our project.

We express our gratitude to all the faculty and staff members, friends and our parents.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

In recent years, an increasing concern of environmental issues of emission, in particular global warming and the limitations of energy resources has resulted in extensive research into novel technologies of generating electrical power. Thermoelectric power generators have emerged as a promising alternative green technology due to its distinct advantages. Thermoelectric power generation offer a potential application in the direct conversion of waste-heat energy into electrical power where it is unnecessary to consider the cost of thermal energy input. The application of this alternative green technology in converting waste heat-energy directly into electrical power can also improve the overall efficiencies of energy conversion systems.

With the rapid development of technologies and industrialization, energy demand will keep increasing. The modern economy relies largely on fossil fuels. This dependence is further fueled by the advancement in the industrial sector and the adoption of new technologies. However, fossil fuels have unique limitations since their reserves are increasingly depleting. In addition, there are number of environmental issues related to fossil fuel production and use, at both local and global scales. Furthermore, a significant portion of energy from fossil fuels is wasted during the transformation process and use. Owing to the issues related to fossil fuels, energy experts around the world have expressed concerns about the future of energy generation.

Thermoelectric generator (TEG) has shown to offer a dependable and simpler way of thermo-electric energy conversion. Other advantages of TEG module include lack of moving parts, environmental safety, and silent operation. This generator can also be controlled in an accurate manner.

Researchers have shown increased interest using thermo-electric technology in improving waste recovery efficiency over the last three decades.

1.1 RECOVERY OF WASTE HEAT

There are various reasons for developing more efficient processes. These include the need to cut down on the budget, fossil resources coservation, restricted legal framework, and scarcity of renewable resources. By definition, waste heat includes sensible and latent forms of heat which leak out of a system or which is not used by the system. The sources of waste heat include waste water derived from washing, cooling or drying, refrigeration systems, furnaces or automobiles as well as exhaust air emitted from production halls. The recovery of waste heat losses offers an opportunity of low-cost and emission-free energy. Consequently, the industrial sector has continued to put more efforts in improving energy efficiency in its operation. About 25 percent of fuel energy is used in automobiles and accessories used in traditional combustion engines powered by gasoline. The remaining 75 percent is largely lost as waste heat.

It is clear that the wasted energy will need to be harnessed and put to full utilization in order to save the energy and protect the environment. A novel device was developed to directly produce electrical power from heat. An example of such technologies is TEG which can produce electricity while their power cycles are well established. Temperature originating from the source of waste heat is dispensable to ensure efficiency in generating power. In general, the generation of power from waste heat has remained limited to only high and medium temperatures of the source of waste heat.

1.2 THERMO-ELECTRIC MODULES

1.2.1 Peltier Effect

Peltier effect, the cooling of one junction and the heating of the other when electric current is maintained in a circuit of material consisting of two dissimilar conductors; the effect is even stronger in circuits containing dissimilar semiconductors. In a circuit consisting of a battery joined by two pieces of copper wire to a length of bismuth wire, a temperature rise occurs at the junction where the current passes from copper to bismuth, and a temperature drop occurs at the junction where the current passes from bismuth to copper. This effect was discovered in 1834 by the French physicist Jean-Charles-Athanase Peltier.

1.2.2 Seebeck Effect

Thermo-electricity is the phenomenon of producing electricity from heat, and vice-versa. The phenomenon is referred to as “Seebeck effect”, having been named after a German scientist, Thomas Seebeck. In 1821, Seebeck heated one end of two twisted wires made of different metals. Thomas observed a small current flow through the wires. Such flow is enhanced by the electrons which move from one end to another hence determining the direction of flow of the current. He concluded that electricity could be generated from heat. Peltier discovered the reverse phenomenon later in 1834. Peltier found that when direct current went through the twisted wires, cooling and heating effect was observed from each side.

1.2.3 Thomson’s Effect

Thomson effect, the evolution or absorption of heat when electric current passes through a circuit composed of a single material that has a temperature difference along its length. This transfer of heat is superimposed on the common production of heat associated with the electrical resistance to currents in conductors. If a copper wire carrying a steady electric current is subjected to external heating at a short section while the rest remains cooler, heat is absorbed from the copper as the conventional current approaches the hot point, and heat is transferred to the copper just beyond the hot point. This effect was discovered (1854) by the British physicist William Thomson (Lord Kelvin).

1.3 TEG STRUCTURE

In this project, TEG peltier module is used for generation of electrical energy. The TEG internal structure illustrated in Fig. 1.1 is made up of two unique semiconductors, one being p-type and another being n-type and they are static in nature. The working operation is based on Seebeck effect (conversion of heat into electricity) which occurs inside the Peltier modules.

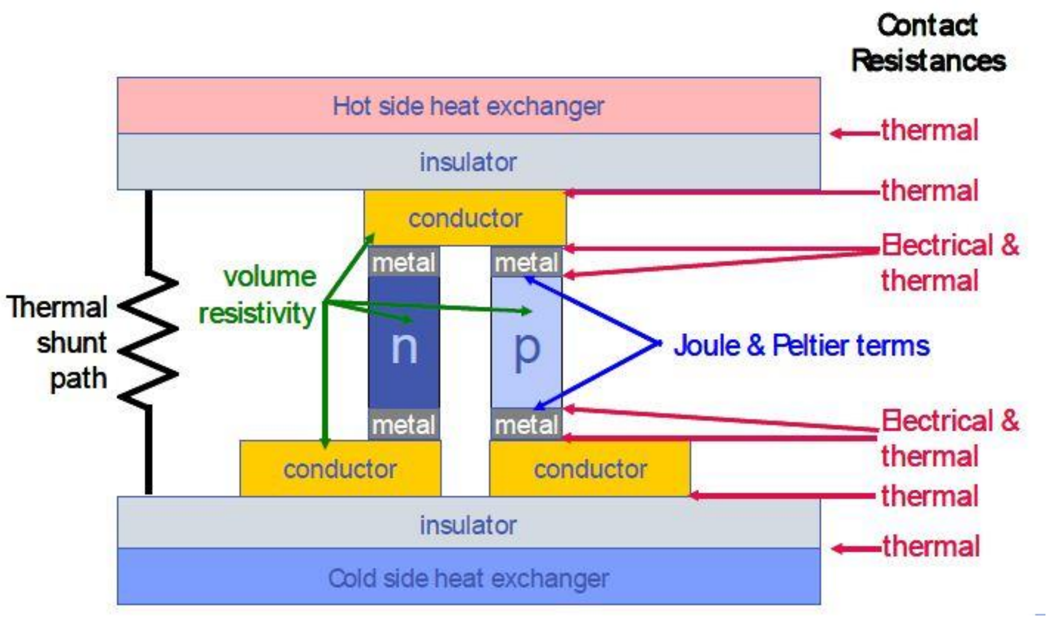

Fig. 1.1 TEG Internal Structure

As the heat spreads and starts flowing so does the free charge carriers from the hot side to the cold side. The end voltages are proportional to the temperature difference and the system keeps on generating voltage as long as the temperature difference remains intact. Generated voltages from each Peltier module increases with respect to time and temperature difference. They are connected in series so that the end voltages will be high. The temperature keeps on changing so instability occurs which may damage the connected load. Hence DC chopper is connected before connecting the TEG output to the load which provides constant dc voltages. The device is not only useful for isolated areas but it can also be used in the industrial sector, where latent heat is produced which can be used as the source of heating and extra amount of energy can be produced with it.

1.4 LITERATURE REVIEW

TEGs require heat as an energy source and can generate power as long as there is a heat source such as gas or oil flame, stove, camp fire, industrial machinery and furnace. There are many research attempts presented to increase efficiency of the TEGs and to determine the potential applications. The number of TEG based applications will be used in most energy projects in the future where low power is required.

A suggested application of thermo-electric generator is to exploit the natural temperature difference between air and soil to generate small amounts of electrical energy. By providing a constant heat input to various heat sinks, field tests of their thermal conductance in the soil and in air were performed. Theoretical considerations for design and selection of improved heat sinks are also presented. In particular, the method of shape factor analysis is used to give rough estimates and upper bounds for the thermal conductance of a passive heat sink buried in soil. (E.E Lawrence, 2002)

Thermoelectric generator (Peltier element) is a device in which thermoelectric effects (thermoelectric power generation) are used for the direct conversion of heat into electricity. Unlike the traditional dynamic thermal engine, thermoelectric generators contain no moving parts and they are completely muted. The main part of the generator is a thermo element (or thermocouple) formed of a pair of distinct conductors or a semiconductor P-N with a conductivity of electron 'n' and hole 'p', where the temperature of the hot and cold junction are different. (Pasek 2006, Langman et al. 2007)

Thermoelectric enable the collection of a very small amount of heat for low-power applications such as wireless sensor networks, mobile devices and for medical applications because they are smaller and lighter than conventional batteries. An example of the thermoelectric energy generation is a wristwatch. The watch is powered by body heat converted into electricity by thermoelectric. Under normal operating conditions using thermoelectric modules the watch generates 22 μW of electricity with only 1.5 K temperature drops. (Snyder, 2008)

The paper describes a Solar Heat Pipe Thermo Electric Generator (SHP-TEG) unit comprising an evacuated double-skin glass tube, a finned heat pipe and TEG module. The system takes the advantage of heat pipe to convert the absorbed solar irradiation to a high heat flux to meet the TEG operating requirement. The simulation has been carried out to study the performance and design optimization of the SHP-TEG. (W He, Y Su, JX Hou, 2011)

The paper investigates the three-dimensional turbulent flow in a chimney used for venting flue gas from either a boiler or stove. The thermo electric generator (TEG) modules are embedded in the chimney walls. To understand the power output performance of the TEG module, three-dimensional numerical simulations combining convection and radiation effects, including the chimney tunnel, TEG modules, plate-fin heat sinks and cold plates, based on water cooling are developed and solved simultaneously. It is worthy of note that the net electric power of the TEG module was obtained using the ideal electric power minus the extra pumping power. (J Yu, 2013)

The thermoelectric based energy harvesting will convert the heat energy into electrical energy when there is a temperature difference between the hot side and cold side. It is found that the higher the difference in temperature, higher the voltage produced. During the experiments, the maximum temperature difference produced was at 10.8˚C which generated the voltage output of 0.92 V when the motor cycle was running at a constant speed of 60 km/h. It can be concluded that the temperature at the hot side influences the output voltage produced by the TEG. (FarisyamilJfri, 2015)

Thermoelectric based on Seebeck effect an important technique that used as a renewable energy to produce electricity. The thermoelectric application could be classified based on average power which generated as low power generation (human applications) and high power generation (internal combustion engine applications). The voltage generated from thermoelectric generator as a result of heat harvesting from engine application is more than that generated as a result of heat harvesting from human body application. Usually thermoelectric generator used in medical application which is need of low power. As a result of development of material technology the thermoelectric promising perfect future. (Hanaa Kadhim Alsabahi, 2015)

Thermo-electric generators (TEGs) are semiconductor – based devices that harvest heat to produce electricity. This was made possible with the use of Seebeck effect. The researchers devised a generator which uses alternative source of energy that can be used to harness and store electricity. The energy that will be stored can be used in different applications such as to power and recharge mobile devices. (Albert Patrick Joson David, 2017)

Thermoelectric is the science dealing with both low- temperature and high-temperature thermal to electrical energy conversion systems. By using principle of thermoelectric automotive thermoelectric generator is implemented to recover waste heat from automobile. It presents a review of the state of the arc of current research of exhaust waste heat recovery systems utilizing thermoelectric generators (TEG). The number of TE modules to be used for electric conversion will also be high and connection of the TE modules depend also on their placement on the heat exchanger. Analysis in reveals that the efficiency loss could be in series connection at 9% and in parallel connection at 12%. (Pratiksha Pohekar, 2018)

1.5 PROBLEM STATEMENT

Some developing countries and most populated industrialized countries like India, China, Mongolia and Korea etc. have an average of 3 to 10 hours of daily power-cuts because the increase in demand of consumer utilization electricity exceeds the production of electrical energy and also shortage of fossil fuel and coal. There is about 60% of electricity generated from fossil fuels (oil and gas) are imported from Arabian countries. Due to the combustion of this fossil fuel pollution may also occur. And also generating power from these conventional sources may lead to harmful environment and pollute the nature. Nowadays, consumer demand is more than the power production which is the major difficulty to overcome.

1.6 OBJECTIVES OF THE PROJECT

The main objective of the project is

- To develop 100 W electric power generating unit using Thermo-Electric Generators (TEG's)

- To charge a 12 V lead-acid battery through the power obtained from the TEG system.

1.7 SCOPES OF THE PROJECT

The scopes of the project study are

- By connecting thermoelectric generator in series / parallel can generate the power for maximum level.
- Implementing thermoelectric generators on vehicle exhaust manifolds would help reduce fuel consumption, which in turn would help preserve the world natural resources and reduce carbon emissions.

1.8 ORGANIZATION OF THE REPORT

This project report is formulated with five chapters. They are as follows:

Chapter 1 - provides an introduction of the project along with the theoretical explanation of Thermo Electric Generator and the literature survey.

Chapter 2 - provides in-depth details about TEG structure and its different array configurations.

Chapter 3 - explains the working of boost converter in its different operational modes and its design configuration of the project.

Chapter 4 - provides the hardware and simulation results of the project.

Chapter 5 - concludes the report with the summary of the project, recommendations for the optimum working of the project.

CHAPTER 2
TEG SYSTEM STRUCTURE

2.1 INTRODUCTION

A thermoelectric module is used for both heating and cooling purposes. Thermoelectric (TE) materials are semiconductor materials that can convert waste heat to electrical energy or utilizing electrical energy can cause a cooling/heating effect. A TEG is for power generation is maintained where the temperature difference across the module to generate a current. It mainly contains n and p-type doped semiconductor materials which are connected thermally in parallel and electrically in series. They are mounted between two ceramic layers that keep the overall structure together mechanically. It insulates the individual elements from one another electrically and from external mounting surfaces. Most TEM comes in size of approximately 2.5-50 mm (0.1 to 2.0 inches) square and 2.5-5 mm (0.1 to 0.2 inches) in height. Both of these types that is N-type and P-type Bismuth Telluride thermoelectric materials are used in a TEG. N-type material is highly doped so that it will have an excess of electrons and P-type material is doped so that it will have a deficiency of electrons. By varying temperature the output voltage generated across the module can be controlled. The key material parameters, namely Seebeck coefficient, electrical conductivity, and thermal conductivity are all interdependent material properties. Due to this, designing a high performance TE material is not a straight-forward matter of material choice, but involves smart design of material interfaces. A thermoelectric generator has many advantages over the various heat engines considered. Thermoelectric modules make no noise when they run, the loudest component of the system would be a small fan used for cooling. Similarly, the only moving part in the system would be the cooling fan, which typically runs for thousands of hours without failure on most personal computers. The thermoelectric generator converts heat directly into electricity, eliminating the need for an electric generator as would be needed by the engines considered.

The selection of proper TEG module, may increase the power from half a watt, to a hundred watts. All of the components necessary for the system can be purchased, making cost estimating and prototyping very straightforward. The working operation is based on Seebeck effect (conversion of heat into electricity) which occurs inside the Peltier modules. As the heat spreads and starts flowing so does the free charge carriers from the hot side to the cold side. The end voltages are proportional to the temperature difference and the system keeps on generating voltage as long as the temperature difference remains intact. Generated voltages from each Peltier module increases with respect to time and temperature difference. They are connected in series so that the end voltages will be high. The temperature keeps on changing so instability occurs which may damage the connected equipment so a chopper is connected before connecting the device to the system which provides pure and stable dc voltages. The device is not only useful for isolated areas but it can also be used in the industrial sector where latent heat is produced which can be used as the source of heating and extra amount of energy can be produced with it.

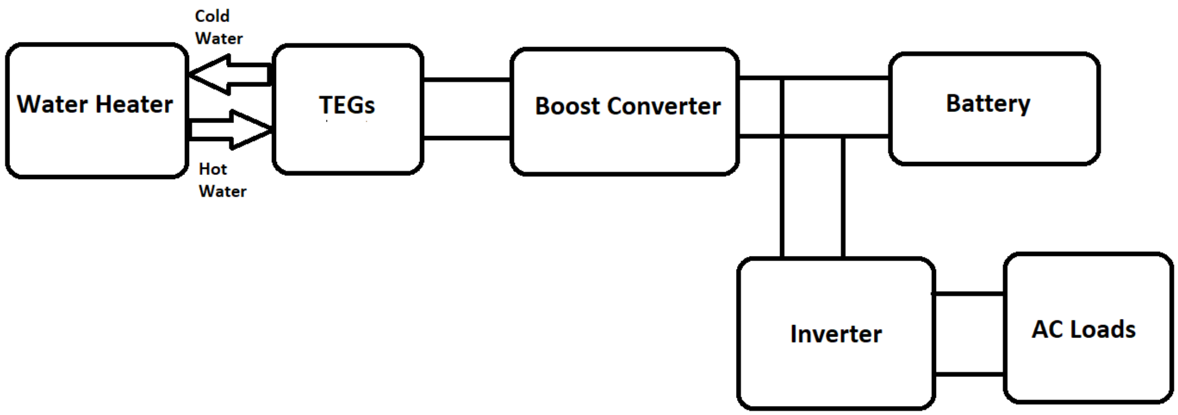

Fig. 2.1 Block diagram of the system

The system uses 12 numbers of thermoelectric power generator (TEPG) TEC12706 modules of 72 W each. In Fig. 2.1, the hot water pipeline is connected to hot surface and water inlet pipeline is connected to cold surface of TEPG. The temperature difference in the TEPG surface creates a continuous electron flow in the circuit. The output voltage of TEPG increases, if the temperature increases. The change in output voltage of TEPG should be made constant to connect a load. The DC output generated from the TEPG is regulated into constant DC to charge a 12 V lead-acid battery. Similarly, the single-phase inverter circuit may also be used for DC to AC power conversion to feed AC loads.

2.2 SEEBECK EFFECT

Thomas Johann Seebeck discovered the phenomenon in the 1800s. More recently, in 2008, physicists discovered what they are calling the spin Seebeck effect. The spin Seebeck effect is seen when heat is applied to a magnetized metal. As a result, electrons rearrange themselves according to their spin. Unlike ordinary electron movement, this rearrangement does not create heat as a waste product. The spin Seebeck effect could lead to the development of smaller, faster and more energy-efficient microchips.

The Fig. 2.2, shows the Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductors or semiconductors produces a voltage difference between the two substances. When heat is applied to one of the two conductors or semiconductors, heated electrons flow toward the cooler one. If the pair is connected through an electrical circuit, direct current (DC) flows through that circuit. The voltages produced by Seebeck effect are small, (millionths of a volt) per kelvin of temperature difference at the junction.

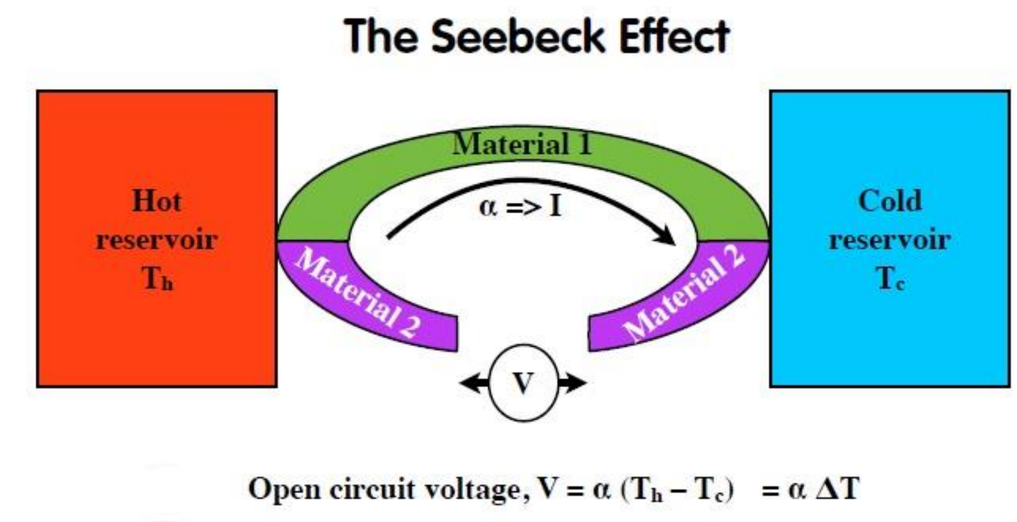

Fig. 2.2 Seebeck Effect

If the temperature difference is large enough, some Seebeck-effect devices can produce a few millivolts (thousandths of a volt). Numerous such devices can be connected in series to increase the output voltage or in parallel to increase the maximum deliverable current. Large arrays of Seebeck-effect devices can provide useful, small-scale electrical power if a large temperature difference is maintained across the junctions and Seebeck coefficient is presented in equation (2.1)

$$\text{Seebeck coefficient, } \alpha = \frac{dV}{dT} \quad \text{units: } \frac{V}{K} \tag{2.1}$$

The Seebeck effect is responsible for the behavior of thermocouples, which are used to approximately measure temperature differences or to actuate electronic switches that can turn large systems on and off. This capability is employed in thermoelectric cooling technology.

2.3 CAD DESIGN

The optimum mechanical design of the system is shown in the Fig. 2.3. It has been done using AUTOCAD and the aluminum material was chosen for the fast energy transfer and for long lasting time

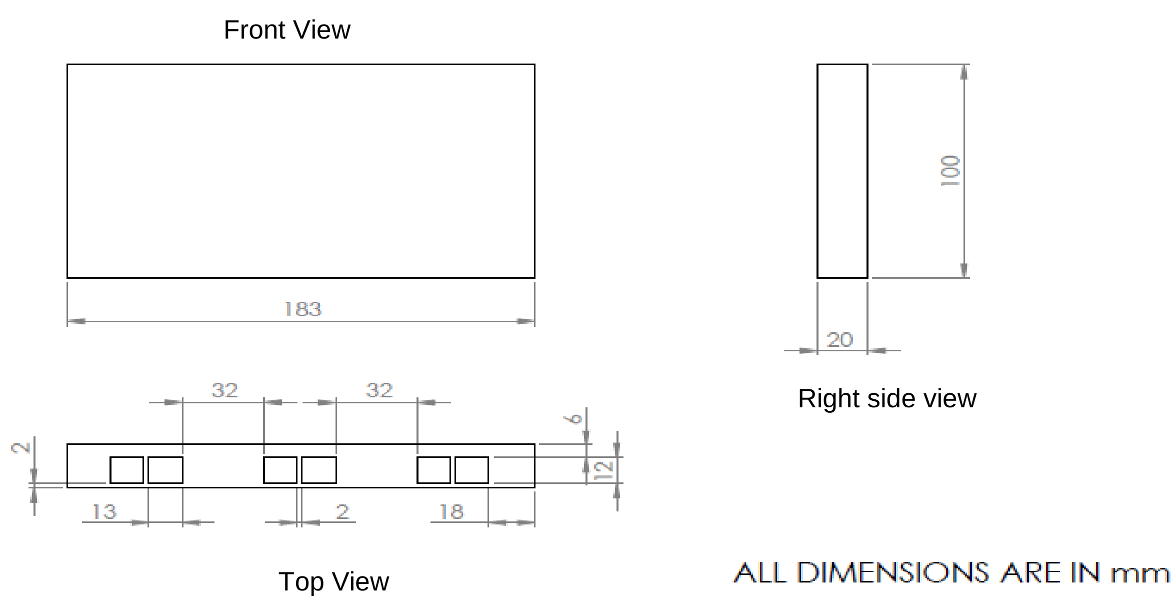

Fig. 2.3 CAD Design

2.4 TEG Circuit Connection

It is possible that the exact calculations be based on a particular application of the generator where each module provides the exact power in demand. As a result, most thermoelectric generators (TEG) contain a certain number of individual modules connected either in series or in parallel or in a combination of both.

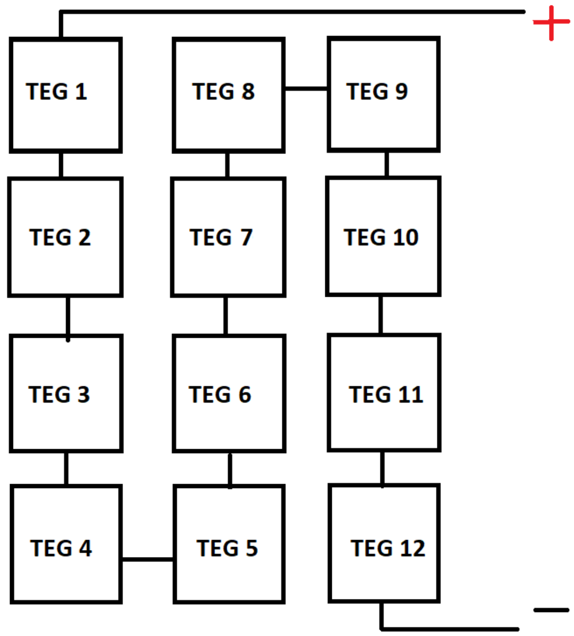

Fig. 2.4 Basic series configuration

Fig. 2.5 Series configuration of the system

A typical TEG configuration is presented in Fig. 2.4, Fig. 2.5. This generator has a total number of modules is the number of modules connected in series is the number of modules connected in parallel.

The Thermo electric generator coupling modules connected to one and another in series this shows the characteristic features with respect to the generation of voltage.

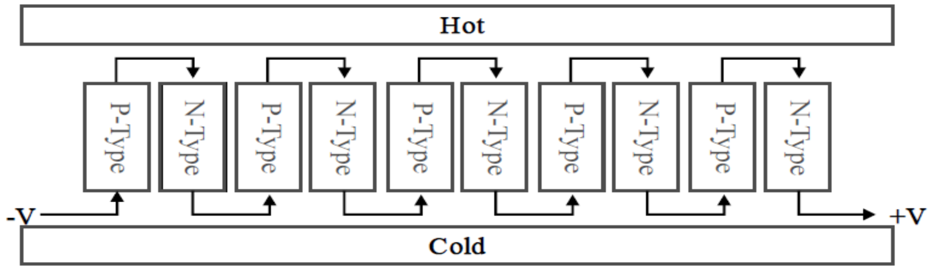

Fig. 2.6 Internal series and parallel combination of TEG

The p- type and n-type semiconductors which make up the thermoelectric module are arranged in series electrically, and in parallel thermally, as shown in Fig. 2.6

2.4.1 Series Array Configuration

As per the Fig. 2.7, the series connection of three TEGs, each of them represented by a voltage source V_1-V_3 in series with an internal resistance R_1-R_3. Under ideal operating conditions, each module within the array will experience an equal DT and therefore all modules will produce an equal output voltage VOC and the array will be in a balanced thermal condition.

The current flowing into the load is

$$I = \frac{V_{OC} - V_S}{R_1 + R_2 + R_3} \qquad (2.2)$$

Where V_s = Voltage at the array's terminal

V_{oc} = Open Circuit Voltage

R_1, R_2, R_3 = Resistance of the TEG module under OFF state

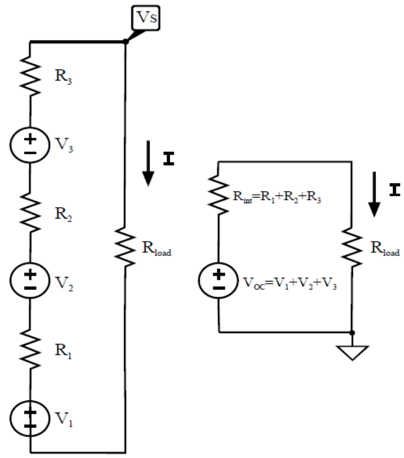

Fig. 2.7 Series array configuration

2.4.2 Parallel array configuration

The Fig. 2.8, shows three TEGs in a parallel configuration. For ideal operating conditions, the TEG modules in the array operate at the same DT. Hence each TEG produces the same voltage and operates at maximum power, with $I_1 = I_2 = I_3$. Under non-ideal thermal conditions the different temperature gradient across each TEG unit will lead to a mismatch in the currents magnitude.

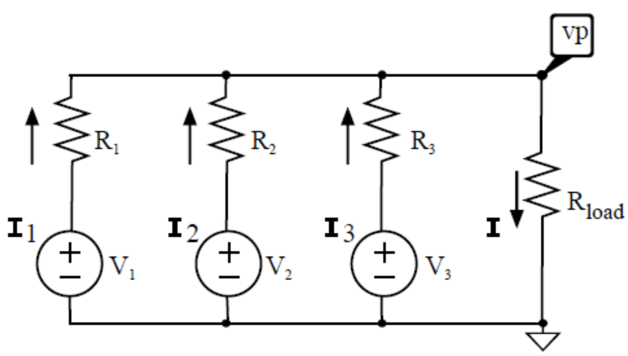

Fig. 2.8 parallel array configuration

$$I_1 = \frac{V_1 - V_p}{R_1} \quad (2.3)$$

$$I_2 = \frac{V_2 - V_p}{R_2} \tag{2.4}$$

$$I_3 = -I_1 - I_2 c \tag{2.5}$$

Where V_p = the voltage at the arrays terminals.

2.5 RESULTS AND DISCISSION

By connecting thermoelectric generator in series or parallel, it is able to generate the power for maximum level as shown in the Table 2.1. Even body heat can be utilized by TEG to generate power to charge the portable equipment like laptop, mobile etc. By installing the TEG in the vehicle above the radiator means the vehicle battery will charge self.

Table 2.1 Output results of TEG

Hot side (˚C)	Cold side (˚C)	Voltage per module (V)	Voltage from 12 modules (V)
96	25	1.7	15.3
71	22	1.5	13.5
60	24	1.2	10.8
53	23	0.7	6.3
40	24	0.5	4.5

CHAPTER 3
DC – DC BOOST CONVERTER

3.1 INTRODUCTION

The DC-DC converters are electromechanical devices which change one level of direct current / voltage to another (either higher or lower) level. It is a type of electric power converter. Power levels range from very low (small batteries) to very high (high-voltage power transmission). They are primarily of use in battery-powered appliances and machines which possess numerous sub circuits, each requiring different levels of voltages. A DC-DC converter enables such equipment to be powered by batteries of a single level of voltage, preventing the need to use numerous batteries with varying voltages to power each individual component.

In its simplest form, a DC-DC converter simply uses resistors as needed to break up the flow of incoming energy – this is called linear conversion. However, linear conversion is a wasteful process which unnecessarily dissipates energy and can lead to overheating.

A more complex, but more efficient, manner of DC-DC conversion is switched-mode conversion, which operates by storing power, switching off the flow of current, and restoring it as needed to provide a steadily modulated flow of electricity corresponding to the circuit's requirements. This is far less wasteful than linear conversion, saving up to 95% of otherwise wasted energy

DC to DC converters are used in portable electronic devices such as cellular phones and laptop computers, which are supplied with power from batteries primarily. Such electronic devices often contain several sub-circuits, each with its own voltage level requirement different from that supplied by the battery or an external supply (sometimes higher or lower than the supply voltage). Additionally, the battery voltage declines as its stored energy is drained. Switched DC to DC converters offer a method to increase voltage from a partially lowered battery voltage thereby saving space instead of using multiple batteries to accomplish the same thing. Most DC to DC converter circuits also regulate the output voltage.

3.2 BOOST CONVERTER

A Boost converter is a switch mode DC to DC converter in which the output voltage is greater than the input voltage.

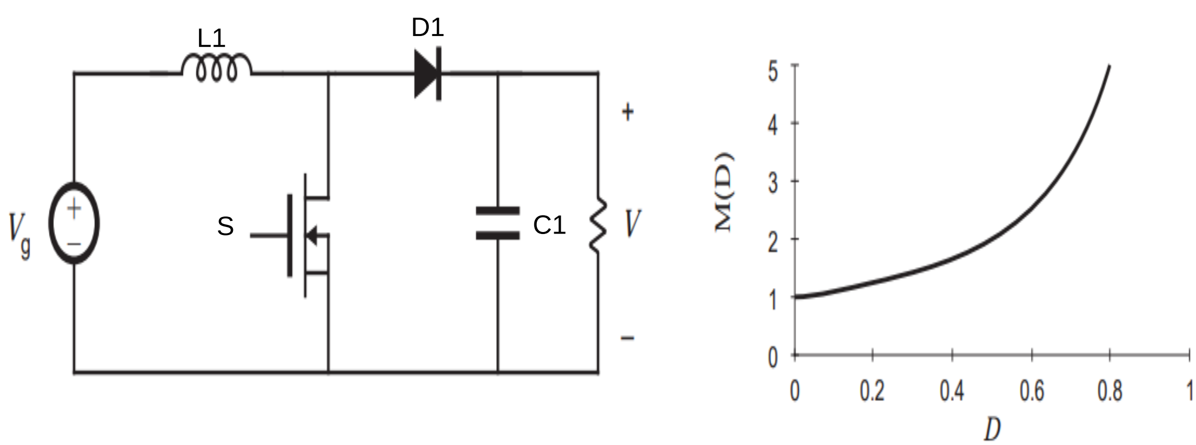

Fig. 3.1 Basic boost converter circuit and Graph B/W Duty cycle and efficiency

It is also called as step up converter as shown in the Fig. 3.1. It is a class of switched-mode power supply (SMPS) containing at least two semiconductors (a diode and a transistor) and at least one energy storage element: a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter). By law of conservation of energy the input power has to be equal to output power (assuming no losses in the circuit).Input power (P_{in}) = output power (P_{out}) Since $V_{in} < V_{out}$ in a boost converter, it follows then that the output current is less than the input current. Therefore in boost converter $V_{in} < V_{out}$ and $I_{in} > I_{out}$.

Mode 1: The Fig. 3.2, says when the switch is closed the inductor gets charged through the battery and stores the energy.

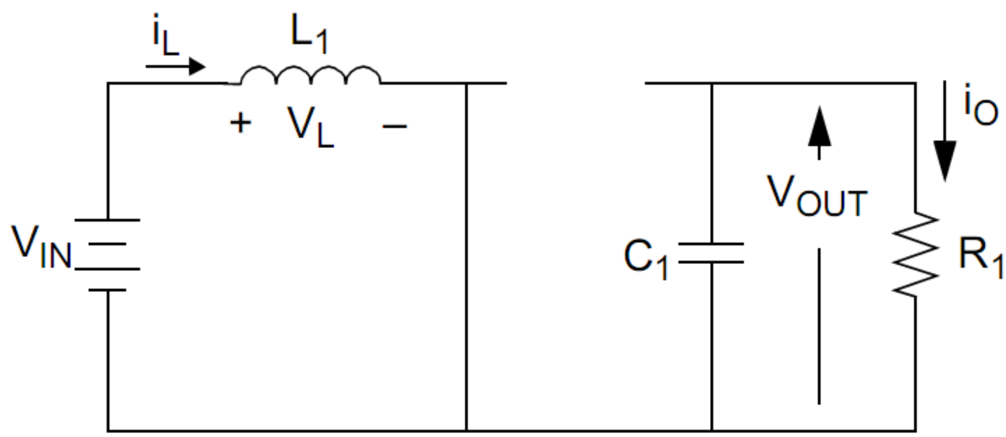

Fig. 3.2 Mode 1 operation of boost converter

In this mode inductor current rises (exponentially) but for simplicity it is assumed that the charging and the discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor.

Mode 2: This says when the switch is open and so the diode becomes short circuited. The energy stored in the inductor gets discharged through opposite polarities which charge the capacitor. The load current remains constant throughout the operation.

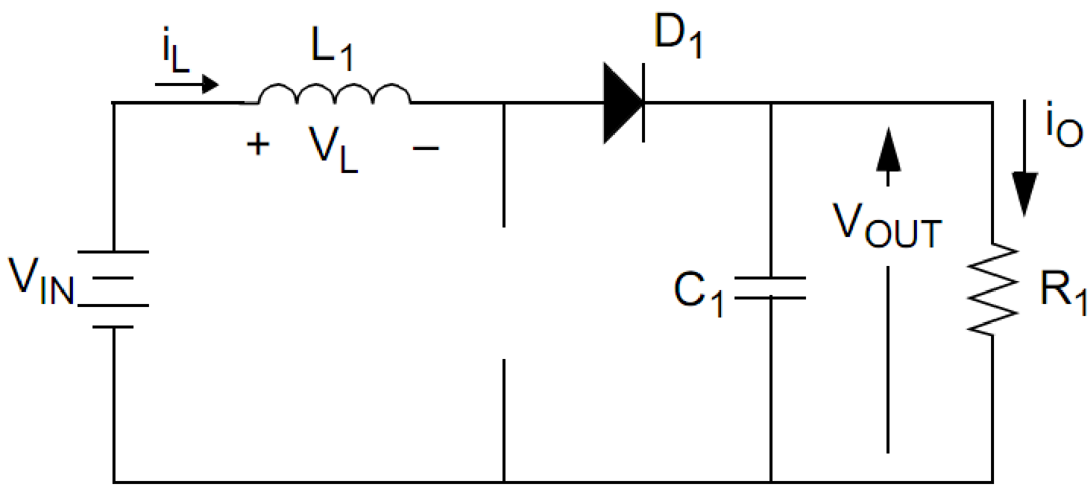

Fig. 3.3 Mode 2 operation of boost converter

3.3 DESIGN OF PASSIVE ELEMENTS

The passive elements such as inductor and capacitor are calculated and presented as follows.

3.3.1 Calculation of Inductor (L)

Boost inductor can be selected in order to minimize the output current ripple in input current. It maintains the output continuously and boost the voltage and current when the converter switch is operated at higher switching frequency. From minimum inductance value is obtained as

$$D = 1 - \frac{V_{in} * \eta}{V_{out}} \quad (3.1)$$

From the equation (3.1)

$V_{in} = 6$ V

$V_{out} = 12$ V

$\eta = 85$ %

Duty cycle is obtained as = 57. 5 %

$$\Delta I_L = (0.2\ to\ 0.4) * I_{out(\max)} * \frac{V_{out}}{V_{in}} \quad (3.2)$$

$$\Delta I_L = 0.4 * 2 * \left(\frac{12}{6}\right) = 1.6\ A$$

$F_s = 4$ kHz

$$L = \frac{V_{in}(V_{out} - V_{in})}{\Delta I_L * F_S * V_{out}} \quad (3.3)$$

From the equation (3.3)

$$L = \frac{6 * (12 - 6)}{1.6 * 4 * 10^3 * 12} = 0.468mH$$

3.3.2 Calculation of Capacitor(C)

The certain minimum value for the input capacitor is necessary to stabilize the input voltage due to the peak current requirement of a switching power supply. The best practice is to use low equivalent series resistance (ESR) ceramic capacitors. Otherwise, the capacitor can lose much of its capacitance due to DC bias or temperature.

$I_{out(\max)} = 2$ A

$$\Delta V_{out(ESR)} = ESR * \left(\frac{I_{out\,(\max)}}{1-D} + \frac{\Delta I_L}{2}\right) \quad (3.4)$$

From the equation (3.4)

$$\Delta V_{out(ESR)} = 0.12 * \left(\frac{2}{1 - 0.575} + \frac{1.6}{2}\right) = 0.452\ V$$

$$C = \frac{I_{out(\max)} * D}{f_s * \Delta V_{out}} \quad (3.5)$$

From the equation (3.5)

$$C = \frac{2*0.575}{4*10^3*0.452} = 636.06\ \mu F$$

The value can be increased if the input voltage is noisy. With external compensation, this can be used to adjust the output capacitor values for a desired output voltage ripple.

3.4 PERTURBATION AND OBSERVATION (P&O) Algorithm

Perturbation and observation (P&O) method is one of the most efficient methods among all the MPPT strategies. In general, P&O algorithm uses a fixed step size, which is determined by the accuracy and tracking speed requirements. However, As per the (Fig 3.4) if the step size is increased for tracking speed-up, the accuracy is decreased because P&O fails to track the power under fast varying atmospheric conditions resulting in a comparatively low efficiency and vice versa. These drawbacks of traditional P&O algorithm can be eliminated by varying the step size under varying atmospheric conditions. It will effectively reduce the power losses in the system and operate the PV system close to MPP.

In this system, stepped P&O algorithm is proposed for the MPPT method and is dedicated to find a simple, effective way to improve tracking accuracy and to overcome the drawbacks in traditional MPPT algorithms.

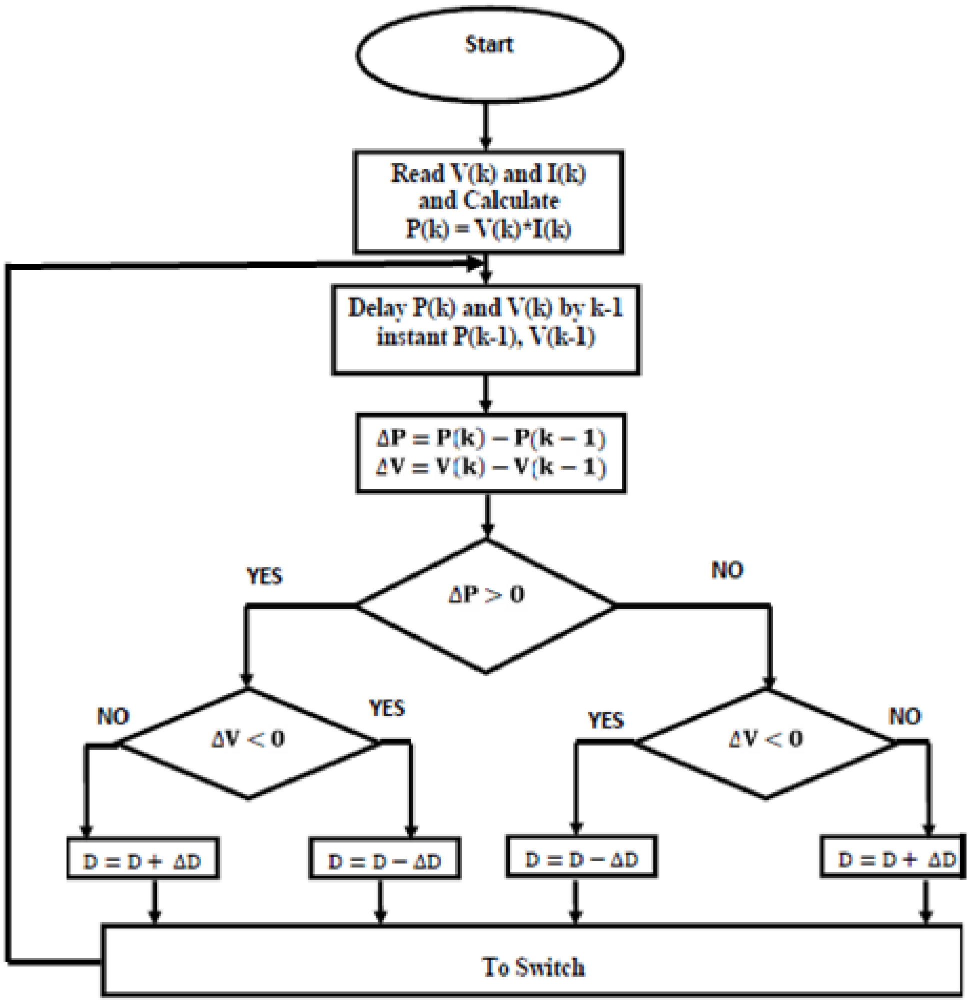

Fig. 3.4 Flow chart of P&O algorithm

The flowchart of the stepped P&O MPPT algorithm is shown in Fig. 3.4, where the step size is automatically tuned according to the PV array operating point. When a step change in the solar irradiance occurs, the step size is automatically tuned according to the operating point. If the operating point is far from the MPP, it increases the step size which enables a fast tracking ability.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 SIMULATION RESULTS

The DC output generated from the TEG is regulated into constant DC by boost converter to charge a 12 V lead-acid battery and simulation results are presented in Table 4.1. By connecting thermoelectric generator in series or parallel able to generate the power for maximum level. Even body heat can be utilized by TEG to generate power to charge the portable equipment like laptop, mobile etc. By installing the TEG in the vehicle above the radiator means the vehicle battery will charge self.

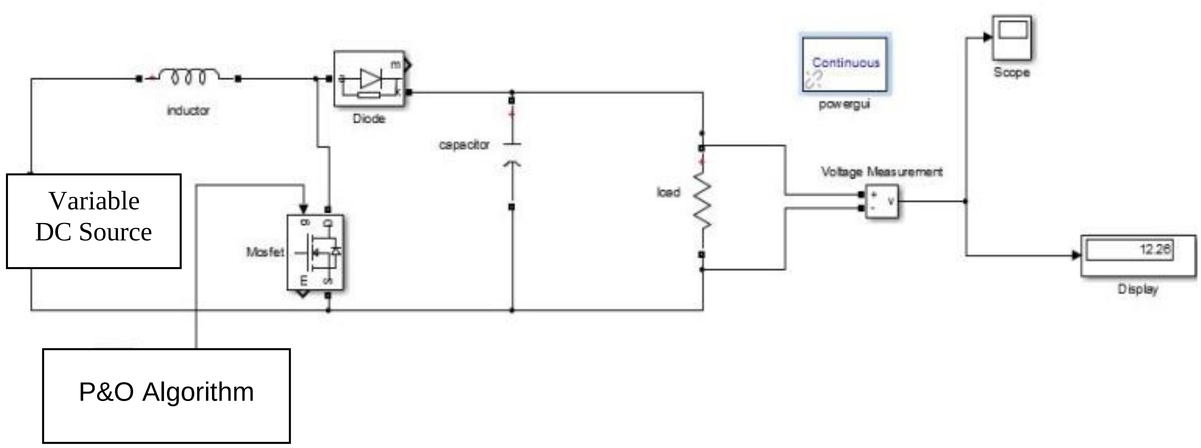

Fig. 4.1 Modeling of BOOST converter using MATLAB

Output Voltage Waveform of BOOST Converter

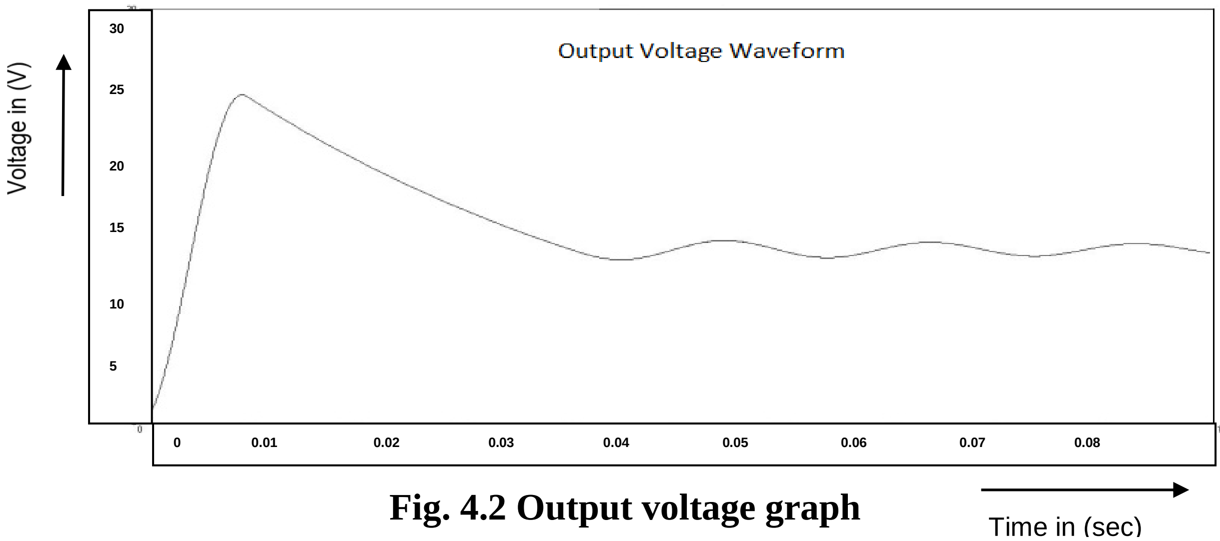

Fig. 4.2 Output voltage graph

By this boost converter circuit design shown in Fig. 4.1, the input voltage is given as 6 V and the output voltage is obtained as 12.26 V and the duty cycle is kept as 54%. The output voltage waveform is shown in the Fig. 4.2.

Table 4.1 Simulated output voltage of the system

Hot side (˚C)	Cold side (˚C)	Voltage per module (V)	Voltage from 12 modules (V)	Boost converter output (V)
60	24	1.2	10.8	13.5
53	23	0.7	6.3	13.5
40	24	0.5	4.5	13.5

Using boost converter the output voltage is maintained or regulated to constant voltage of 13.5 V as shown in the Table 4.1

4.2 MECHANICAL SETUP OF TEG

Fig. 4.3 Mechanical setup of TEG

The mechanical setup is shown in the Fig. 4.3, and it is made using Aluminum pipeline and the TEG modules are fixed on the hot side of the pipeline and not fixed on the cold side. The glass wool is used as an insulating substance between hot and cold side pipe line and also from the external atmosphere.

4.3 HARDWARE RESULTS:

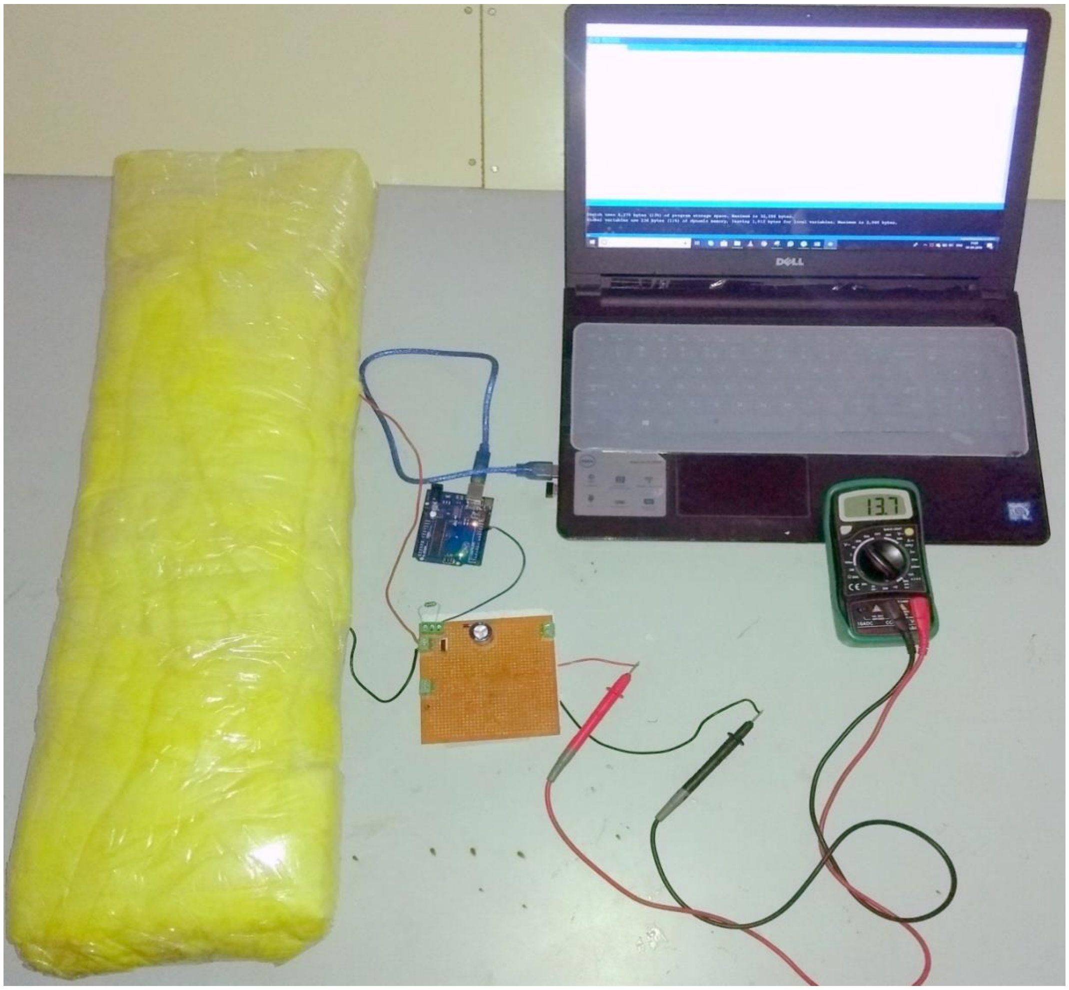

Fig. 4.4 Hardware setup

The output from the mechanical setup of TEG is obtained as 9 V (unregulated). This voltage is given to the input of the boost converter, so that the output is obtained as 13.5 V (regulated) with switching frequency of 4 kHz generated using arduino as shown in the Fig. 4.4.

Table 4.2 Measured output voltage of the system

Hot side (˚C)	**Cold side (˚C)**	**Voltage per module (V)**	**Voltage from 12 modules (V)**	**Boost converter output (V)**
60	24	1.2	10.8	13.7
53	23	0.7	6.3	13.7
40	24	0.5	4.5	13.7

As shown in Table 4.2 the measured output voltage of the system is obtained as 13.7 V

CHAPTER 5
CONCLUSION

The proposed system converts thermal energy into electrical energy which is economical and pollution free. The system considers thermoelectric generator module TEC12706 for 72 W power generation. The power generators are to be tested for various input conditions i.e., hot and cold side temperature using hot and cold water. The mechanical setup is developed for maintaining the water temperature. The TEG modules of 12 numbers are connected in series to generate 72 W (predicted using experimental data) with a temperature difference of about 100-150°C between hot and cold sides. This system stores the energy in a battery bank. This project may also be used for many applications such as urban and rural areas where solid waste is converted into heat and then converted into electric power.

Thermoelectric generators are an intriguing way to generate renewable energy directly from waste heat. However, their efficiencies are limited due to their thermal and electrical properties being dependent on each other. Nevertheless, their solid state scalable technology makes them appealing and even more efficient in selective applications. Implementing thermoelectric generators on vehicle exhaust manifolds would help reduce fuel consumption, which in turn would help preserve the world natural resources and reduce carbon emissions.

REFERENCES

1. Automotive Waste Heat Recovery System (E.E Lawrence,11May 2002)

2. Experiment on thermal uniformity and pressure drop of exhaust heat exchanger for automotive thermoelectric generator (Snyder,2008)
3. An effective Seebeck coefficient obtained by experimental results of a thermoelectric generator module(W He, Y Su, JX Hou, 2011)
4. The effect of temperature mismatch on the thermoelectric generators electrically connected in series and parallel(J Yu,2013)
5. Automotive applications of thermoelectric materials (HanaaKadhimAlsabahi, 2015)
6. Computer controlled test system for measuring the parameters of the real thermoelectric module(FarisyamilJfri, 2015)
7. Thermoelectrics: from space power systems to terrestrial waste heat recovery applications(Albert Patrick Joson David, 2017)
8. Engineering Scoping Study of Thermoelectric Generator Systems for Industrial Waste Heat Recovery(Pratiksha Pohekar, 2018)
9. International Energy Outlook 2010, (U.S. Energy Information Administration, 2010).
10. A. I. Hochbaum, "Enhanced Thermoelectric Performance of Rough Silicon Nanowires," Nature 451, 163 (2007).
11. G. J. Snyder, "Complex Thermoelectric Materials," Nature Materials 7, 105 (2008).

12. L. E. Bell, "Cooling, Heating, Generating Power, and Recovering Waste Heat with Thermoelectric Systems," Science 321, 1457 (2008).
13. A. Majumdar, "Thermoelectricity in semiconductor nanostructures," Science 303, 777 (2004)
14. A. I. Boukai, "Silicon Nanowires as Efficient Thermoelectric Materials," Nature 451, 168 (2008).
15. C. B. Vining, "An Inconvenient Truth About Thermoelectrics," Nature Materials 8, 83 (2009).
16. C. Yu, "Thermoelectric Automotive Waste Heat Energy Recovery Using Maximum Power Point Tracking," Energy Conversion and Management 50, 1506 (2009).