

TEG Assists Performance Enhancement on Solar Roof-Top System

Ashwin Padole^[1], Aniket Tidke, Saurav Pillai, Aashay Mohite, Kundan Wath, Antariksh Derkar

Department of Electrical Engineering
Yeshwantrao chavan college of engineering
Wanadongri, Nagpur, India

Abstract - Solar is most commonly used form of Renewable energy. Solar energy is used nowadays for different purposes and the main use of solar energy is for production of electricity. There are many solar panels invented but they all are used when there is sunlight. Solar panel can be used with TEG (Thermo-electric generator) to improve the overall performance of the solar roof top system. Thermoelectric generators (TEG's) are energy conversion devices. This device is extremely reliable, safe, simple, compact and eco-friendly. The main aim of this paper is to implement and verify the mathematical modelling of thermoelectric generators with the help of MATLAB Simulink.

Key Words: Renewable energy, Thermoelectric Generators, TEG characteristics, MPPT of Thermoelectric module, MATLAB Simulink, Insulation Co-ordination.

1. INTRODUCTION

At recent years, one of the most important problems at the world is lack of supplying energy in a continuous way due to increase in use of devices that mostly uses electrical energy. Nowadays the electrical energy which is being used is because of conventional sources like coal, diesel and nuclear. It is well known that this conventional sources are limited in nature and because of this environment is polluted. Therefore, it needed to use clean and non-enforceable energy which is "renewable energy" such as tidal energy, solar energy, wind energy, geothermal energy. And one of the easiest method to convert renewable energy into electrical energy is solar energy. But use of solar energy as compare to its presence is very less. Mostly solar panel is used for conversion of heat energy into electricity. Solar panel is used in the presence of sunlight. And this is the main drawback of solar panel, due to which the efficiency of solar panel is less, nearly less than 14%. And thus it must have to deal with this problem. Brief drawbacks of the current renewable energy sources have been tabulated below.

Table -1: Renewable Sources and Its Drawbacks

Sr. No.	Renewable Sources	Drawbacks
1	Solar Panel	Night time charging.
2	Wind Energy	Location Dependent
3	Tidal energy	Construction Cost
4	Bio-gas	Global warming.

For increasing the efficiency of solar panel, it must be used during blackouts. With the help of TEG, efficiency can be increased of solar panel system. TEG is thermoelectric generator. Basically with the help of temperature difference it convert energy from sunlight into electricity.

Thermoelectric generator is based on the principle of Seebeck effect. Seebeck effect is a phenomenon in which a temperature difference between two dissimilar electrical conductor of semiconductors produces a voltage difference between two substances. In this paper how electricity can be extracted from heat using thermocouples is explained.

The hardware model which is explained in this paper is THERMOGENERATOR, having more focus on energy generation by TEG during blackouts.

During day time when sun is having its light as well as heat energy with the help of a converging lens the heat energy provided by the sun is focused on heat exchanger and the fluid present in the heat exchanger gets heated up. Due to this transfer of energy the liquid which is also present in the thermos gets heated up to certain temperature during daytime. TEG's are already installed on thermos one side of the TEG is in contact with the hot liquid and another surface of TEG will be exposed to the atmospheric temperature. In this way the temperature difference is generated and electrical power is produced. The nature of electrical power generated is not constant because of temperature change hence it is necessary to extract Maximum Power Point. The MATLAB simulation of the MPPT using Perturb and observe, incremental conductance algorithm can be applied to the TEG's.

2. ANALYSIS OF TEG

2.1 Introduction of TEG

A Thermoelectric generator device consists of multiple thermocouple elements that are connected electrically in series and thermally in parallel. The basic structure of a thermocouple element in the Fig 2. The TEG structure consists of two heavily doped semiconductors with their edges connected to conductors, thus creating an electrical loop. During operation, different temperatures are applied on these junctions [i.e. T_h and T_c] causing electrons and holes in the n-type and p-type semiconductors, respectively, to flow from the hot to the cold side. This process results in the development of an electric field across the p and n semiconductors, due to the Seebeck effect. Thermoelectric generators (TEGs) are devices that employ Seebeck effect in thermocouple to convert temperature gradient (temperature difference) heat into electrical power. Recently, TEGs have been getting increasing attention as green and flexible source of electricity able to meet wide range of power requirements. One TEG can be electrically represented by a dc voltage source with internal resistance and then it is connected to a load. A single unit of TEG can be represented through a simple equivalent electrical circuit as shown in Fig 1. The circuit is assumed to be resistive in nature in order to simplify the model. The circuit contains a voltage source V_{TEG} in series with the internal resistance of TEG. R_{TEG} is the equivalent internal resistance of all the thermocouples and junctions formed by them. R_L is the load resistance connected across the TEG or in this case across the combination of TEG's.

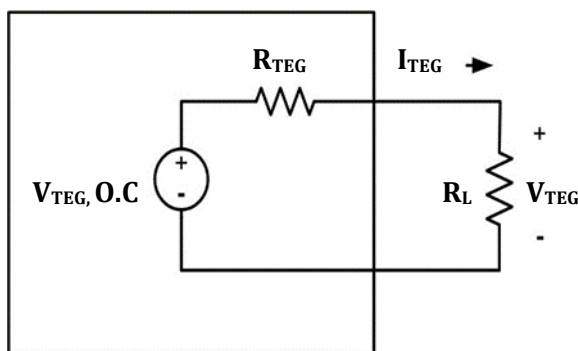


Fig -1: Electrical equivalent circuit of TEG

2.2 Seebeck Effect

Seebeck effect describes the induction of voltage, when junctions of two different conducting materials are subject to different temperatures. Seebeck effect increases in magnitude, when Seebeck coefficient of conducting materials increases. As shown in Fig.2 the temperature difference is applied to the thermoelectric module, the because of the

temperature difference between two heavily doped semiconductors, we can the direction of flow of electrons and holes in the module. Because of the movement of the electrons and the holes the close loop is formed and current flows in the circuit. [3]

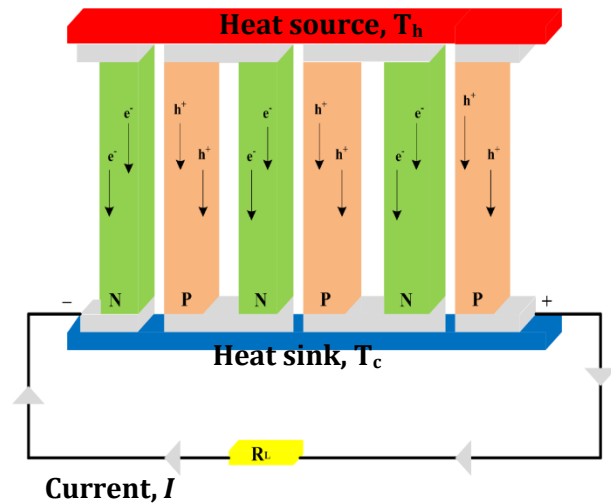


Fig -2: A basic TEG

2.3 Specification of TEG.

For our purpose we are using the TEG model TEP1-24156-2.4.

Table -2: Specifications of TEG.

Sr. no.	Specifications	
1.	Hot side temperature($^{\circ}C$)	300
2.	Cold side temperature($^{\circ}C$)	30
3.	Open circuit voltage(V)	17.7
4.	Match load resistance(ohms)	4.4
5.	Matched load output voltage(v)	8.8
6.	Matched load output current(A)	2.0
7.	Matched load output power(W)	17.6
8.	Heat across module(W)	≈ 301
9.	Heat flow density($W\ cm^{-2}$)	≈ 9.6

The max operating temperature is 300 $^{\circ}C$ and life expectancy of 200,000 Hours with a failure rate based on long Time testing of 0.2%

The stated model contains nearly 241 thermocouples which is able to generate a net output voltage of 8.8V along with the net current of 2.0A. For improvement in the output voltage level we have used 6 TEG in series.

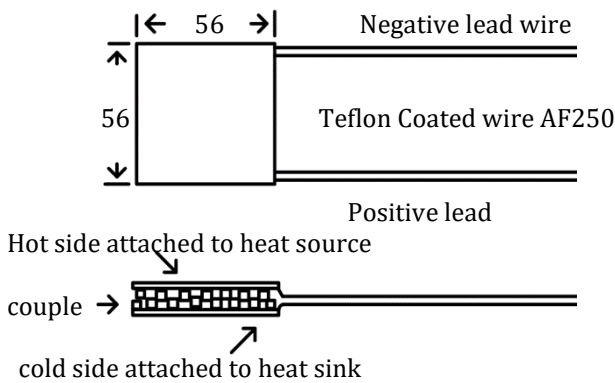


Fig -3: TEG Specifications

2.4 Theoretical modelling of TEG

For the simulation of different parameter of thermoelectric module, it need different mathematical relationships. The output voltage of the TEG (a single unit) can be calculated using the following formula. [2]

$$V_0 = \frac{\alpha N(T_h - T_c)}{(1 + 2rL_c/L)} \quad (1)$$

The output current of TEG unit is calculated using

$$I_0 = \frac{\alpha A(T_h - T_c)}{(2\rho(L+n)(1 + \frac{2rL_c}{L})^2)} \quad (2)$$

The output Power of TEG unit is given by

$$P_0 = \frac{\alpha^2 NA(T_h - T_c)^2}{2\rho(L+n)(1 + \frac{2rL_c}{L})^2} \quad (3)$$

Where,

α =Seebeck constant.

T_h =Temperature of the hotter side of the module.

T_c =Temperature of the cooler side of the TEG module.

N =Number of thermocouples=241

$r = \lambda/\lambda_c$

L =Length of thermoelement (mm).

L_c =Thickness of the contact layer (mm).

λ =Thermal conductivity of thermoelement.

λ_c =Thermal conductivity of the contact layer.

A =Cross-sectional area of thermoelement (mm)².

$n = 2\rho_c/\rho$

ρ =Thermal resistivity (Ω cm) of the module.

ρ_c =Electrical contact resistivity.

All constants are from [4].

2.5 Simulation of TEG

Simulation of TEG is needed to obtain the characteristics, to study the voltage, current and power waveform with respect to time and with respect to temperature changes. Simulation of the mathematical model of TEG in MATLAB Simulink by using equations (1), (2), (3). And the input characteristics is as shown in the Chart -1 and the output characteristics is as shown in the Chart -2.

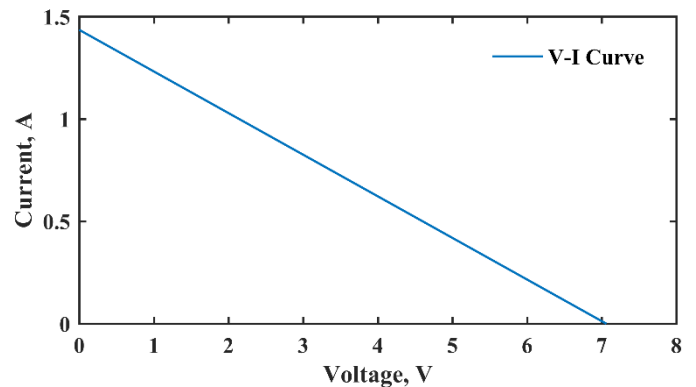


Chart -1: V-I characteristics of TEG

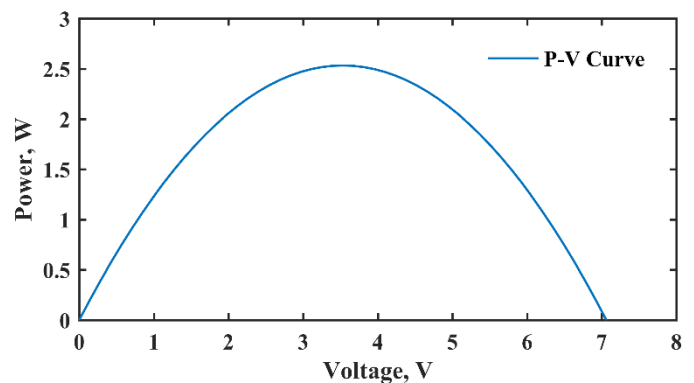


Chart -2 P-V characteristics of TEG

For obtaining this characteristics one ramp input consisting of variable temperatures is given to the simulation module. With the variation in the temperature the voltage and current values are changing and the V-I characteristics of this change is obtained accordingly as shown in the Chart -1 Similarly, due to variation the voltage and current the P-V characteristics is obtained accordingly as shown in the Chart -2 From the above characteristics it is concluded that the V-I characteristics is linearly decreasing in nature, that indicates when the voltage increases, the value of current starts decreasing with the increase in temperature. Similarly, from the P-V characteristics maximum power is obtained.

3. SIMULATION OF TEG WITH PRACTICAL CONDITIONS

Typically, in the practical scenario, when sun rises the ultraviolet rays of the sun are not that much effective therefore the heat energy that can be extracted from the sun is less. As the time goes on the heat energy that can be extracted is also increases gradually. During this period the temperature of the liquid increase gradually. Extraction of the heat is maximum during 12pm to 3pm and during this period the temperature of the liquid has reached to its maximum value and it cannot be further increased, so temperature of the liquid remains constant for some time. In the evening, solar radiations from the sun are not available to heat up the liquid again. So the temperature of the liquid starts falling. Due to the insulation provided to the tank the decrease in the temperature is not rapid and does not reach to room temperature and its minimum value maintained to certain level.

Considering this practical scenario, input temperature signal that can be given to the simulation model is developed as shown in the Fig 4.

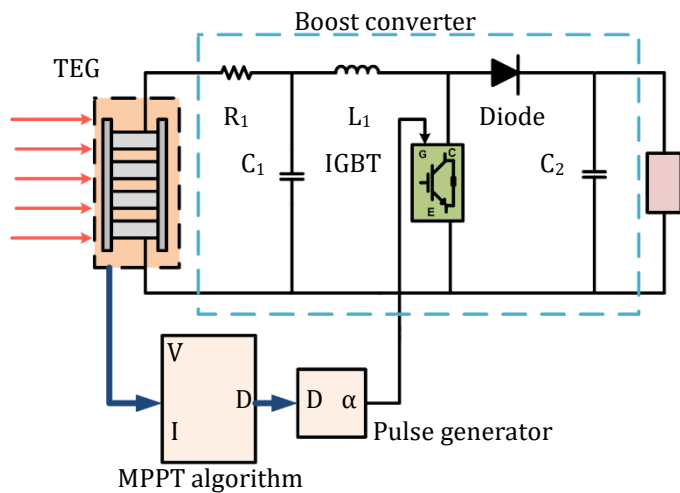


Fig -4: Conceptual Circuit diagram of Simulation model

3.1 Steady state condition

Steady state condition is the condition where the temperature given to the simulation model is constant and not varying according to the proposed conditions. The temperature given is 225°C or 498 K, then the steady state results obtained are as follows in Chart -3.

In Chart -3 the steady state temperature is shown which is given as input to the simulation model. And the steady state values of the voltage, current and power are obtained are as follows. As the given input temperature is constant to the simulation model, the values obtained are also constant.

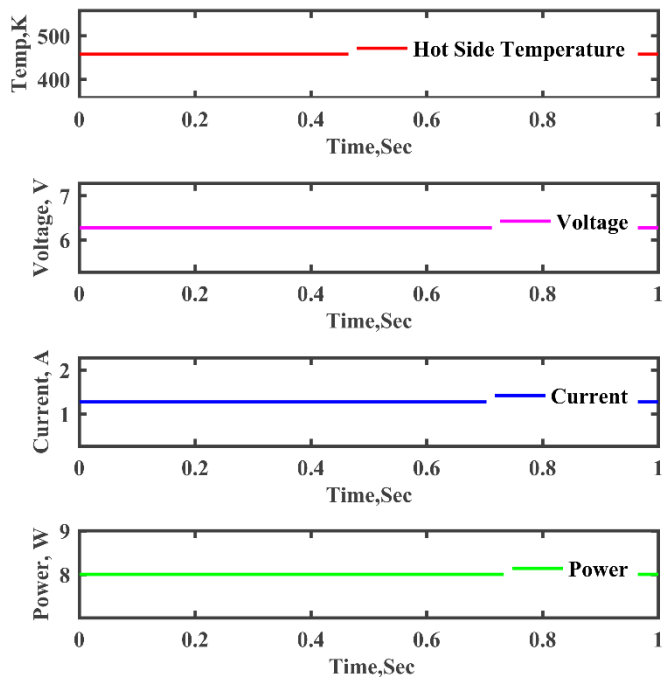


Chart -3: Steady state output.

3.2 Dynamic state condition

Dynamic state condition is the condition where the temperature input given to the simulation model is of dynamic nature i.e. similar to the practical conditions which are stated above in the paper. The temperature is variable in nature according to the availability of sun during whole day.

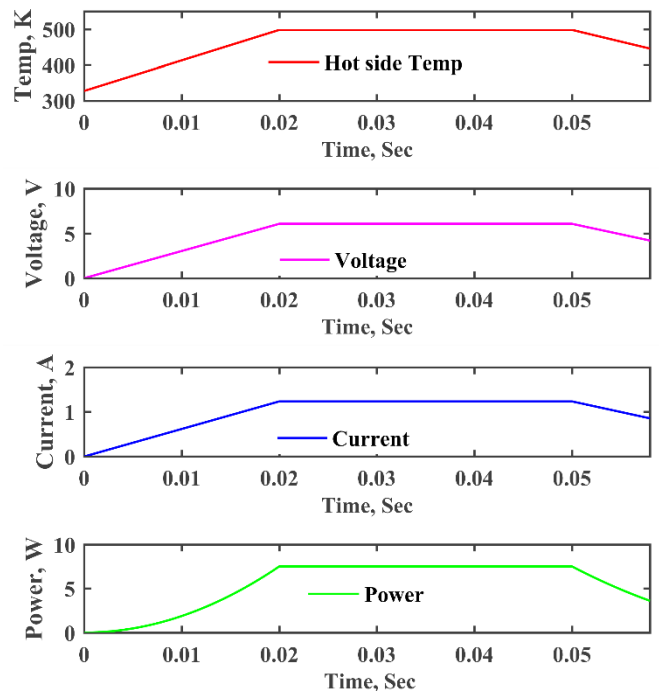


Chart -4: Dynamic state output

In Chart -4 The dynamic state temperature is given as an input to the simulation model. And the dynamic state values of the voltage, current and power are obtained are as follows. As the given input temperature is variable to the simulation model, the values obtained are also variable in nature.

With the dynamic nature of input, it is seen that the values of voltage and current are varying according to the availability of sun. So output characteristics that is P-V characteristics will not be same as the obtained P-V characteristics that is obtained by using standard formulas as shown in Chart -2 Therefore, the output characteristics obtained with the dynamic input is as shown in the Chart -5.

In the P-V characteristics shown, it is increasing and then reached to its maximum point and this is the point needed for the charging of the battery or supporting other dc loads. This maximum point can be tracked by using proper maximum power point tracking system, after reaching maximum point its starts decreasing.

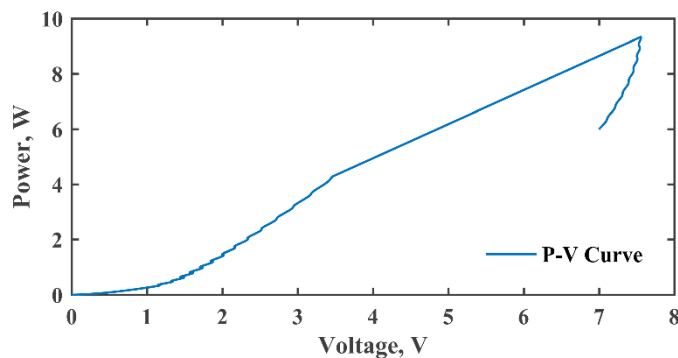


Chart -5: Dynamic P-V characteristics.

4. INSULATION CO-ORDINATION

4.1 Power loss

The power output generated by thermoelectric module is proportional to the amount of heat flowing through the module. The amount of heat will be input power. The heat flowing is given by

$$Q_H = K_{TEG} (T_H - T_C) + S_{TEG} * T_H * I - 0.5 * I^2 R_{TEG} \quad (4)$$

$$\eta = \frac{P_{OUT}}{Q_H} \quad (5)$$

The amount of heat flowing through the module and the efficiency of the module for different temperatures is shown in the table given below

Table -3: Efficiency for Corresponding Temperature Difference.

Different temperatures	40	60	80	100	120	140	160
Q_H	26.7	40.0	53.	66.0	78.9	91.63	104.25
$\eta(\%)$	1.86	2.81	3.7	4.81	5.7	6.69	7.68

4.2 Insulation co-ordination

According to the Newtons law of cooling the rate of fall of temperature is constant.

$$T(t) = T_s + (T_o - T_s) e^{-kt} \quad (6)$$

Where,

t = time(sec)

T_s = Surrounding temperature $k_{water} = 0.0015175 \text{ sec}^{-1}$

T_o = temperature of liquid $k_{oil} = 0.00005175 \text{ sec}^{-1}$

k = Cooling constant(sec^{-1})

With the passage of time the heat is lost and after some time tank will reach room temperature, so the time available of the extraction of power will be less. Hence there is a need of insulation to be provided for the tank. The power loss is given by

$$P = \frac{k * A * \Delta T}{d} \quad (7)$$

Where,

A = area of con

k = thermal conductivity(W/mk)

d = Thickness

the power loss can be avoided by providing an insulation with proper thickness and material. The heat loss which can be avoided by providing different kind of materials with 5cm thickness is shown in the Table -4.

Table -4: Power Loss with Various Insulation Material

Insulation material	Vacuum	Polystyrene	Wood	Silica aerogel
Thickness	5 cm	5 cm	5 cm	5 cm
Power loss	2.352 J	194 J	235.2 J	17.64 J

From the Table -4 we can conclude that with the help of various kind of insulating materials we can minimize the power in terms of heat which is going to be lost from the thermal tank in order to obtain more and more temperature difference to obtain more power from the thermoelectric modules.

5. HARDWARE MODEL

The hardware model derived from the above description has following circuit diagram shown in the Fig -5

Hybrid combination

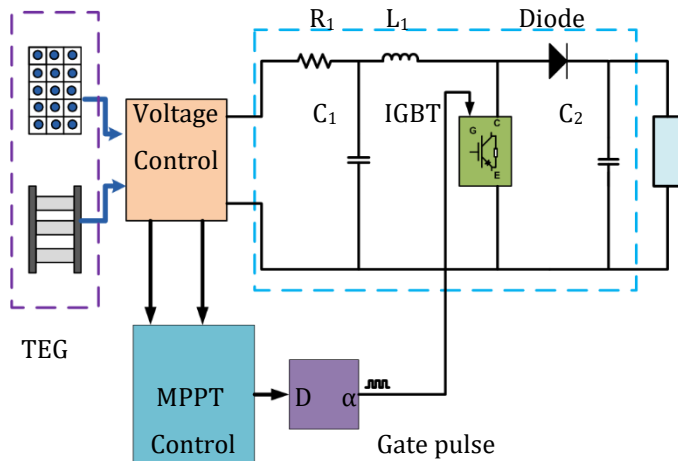


Fig -5: Hardware circuit diagram

The proposed hardware model consists of one tank on which the thermoelectric modules are installed and one concentrating dish is installed which will concentrate the sun's radiation at one point. At that point, there is a heat exchanger, in which the liquid is present which will be heated when the temperature increases. This heat exchanger is equipped with two pipes, one at top which is hot liquid pipe and other pipe is at bottom which is cold liquid pipe. This two pipes are connected to the thermal container. In this container, liquid is present and the heated liquid is circulated by the laws of thermodynamics.

The hardware includes 6 TEG's installed, one heat exchanger, one tank insulated with polystyrene and EPE foam, concentrating dish, circulating pipes. The insulation provided to the tank has three layers. First layer is thermal blanket. Second layer is polystyrene. Third layer is EPE foam which provide better insulation to avoid heat loss in the tank. So the actual model will look like Fig -5.

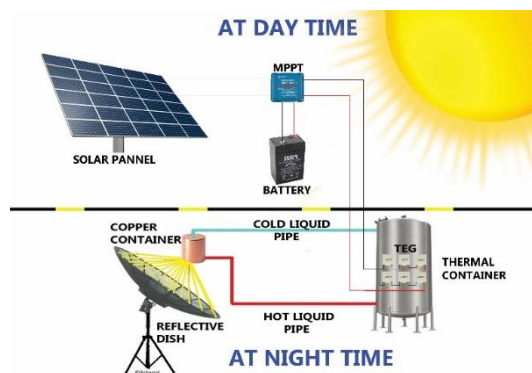


Fig -5: Hardware Model

The actual hardware results are with 300⁰ C at concentrated point the maximum temperature reached by

the liquid is 150⁰ C. The voltage generated by 6 Teg is around 6V and current 0.5A and this output is given to a 6V 4.5ah battery and the time taken to charge the battery is 10hours.

6. CONCLUSIONS

In this paper we have investigated and thought about the possibility of employing TEG's in order to make solar roof top systems more efficient. We have seen in detail the theoretical model of TEG and its various physical attributes as well as its input and output characteristics have been studied in detail. And MATLAB Simulink model is generated to obtained the desired characteristics.

The effect of environment has also been kept in mind and necessary calculations were carried out in order to incorporate the heat loss due to lack of insulation. It was later seen that with appropriate and sufficient level of insulation the loss of heat energy can be reduced and thus in turn the efficiency can be raised, this was illustrated using a sample case. Finally, a hardware model was proposed and built which can be used along with the solar panels so that the maximum utilization of the solar energy can be done to have higher duty cycle of the equipment, along with the complete and organized details.

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BIOGRAPHIES



Ashwin Padole was born in Nagpur, India, in year 1997 and received his bachelor's degree in Electrical Engineering from RTMNU university. His current area of interest is security system technology integrated with renewable energy.



Aniket Tidke was born in Nagpur, India, in year 1997 and received his bachelor's degree in Electrical Engineering from RTMNU university.



Saurav Pillai was born in Kollam, India, in year 1996 and received his bachelor's degree in Electrical Engineering from RTMNU university.



Aashay Mohite was born in Nagpur, India, in year 1997 and received his bachelor's degree in Electrical Engineering from RTMNU university.



Kundan Wath was born in Sausar (M.P), India, in year 1997 and received his bachelor's degree in Electrical Engineering from RTMNU university.



Antariksh Derkar was born in Chandrapur, India, in year 1997 and received his bachelor's degree in Electrical Engineering from RTMNU university.