

Modeling and Simulation of a Line Integrated Parabolic Trough Collector with Inbuilt Thermoelectric Generator

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Abstract: The concept of power generation using parabolic trough and inbuilt thermoelectric generator interconnected with grid is presented in this paper. The proposed set up consists of parabolic trough collector, absorber tube, thermo electric module, DC-DC converter and an inverter. The thermo electric module placed on the parabolic trough collector surface directly convert thermal energy from the solar radiation to electric energy. This electric energy (voltage) is step up into a suitable voltage level by using DC-DC boost converter. The boosted output voltage is converted and synchronized to main grid .An algorithm is employed for controlling the converter system. The output of boost converter is connected to the grid through an inverter. Different configurations of thermo electric modules, performance of converter and inverter are described.

Keywords: Parabolic Trough Collector, Thermo electric Generators, Boost Converter, Three Phase full bridge inverter.

1. INTRODUCTION

The thermo electric is solid state energy converting device working with Seebeck effect .Thermal electric power generation is clean energy from direct solar power generation. Electricity is produced by the concentrator thermo electric generator. Thermoelectric module produces energy by converting difference in temperature between two parts using semi conductors.

The parabolic trough collector with variable focus compared with cylindrical heat pipe receiver pipe. The receiver tube focal length varies as function of vertical displacement with respect to horizontal central line. Skew ray tracing method is used for analysis. To optimize irradiance uniformity in heat distribution in pipe surface to optimize concentrator geometry. This approach improve the irradiance uniformity and heating efficiency of parabolic trough collector. [1]

A modified integration method with new model applied to parabolic trough collector with vacuum tube receiver. The optical efficiency is calculated at each point of the reflector by integration algorithm. By using this method the net heat energy can be easily calculated. The errors such as tracking error, optical error, position error, transmittance and absorptivity of vacuum tube is also simulated. [2]

Sealing failure is the major problem in receiver tube in the trough collector. The collector efficiency is reduced due to loss of vacuum inside the tube with sealing failure. After conducting series of test the result shows that excellent performance in glass to kovar alloy ends. [3]

A metal black pipe covered with a glass tube to reduce heat losses is placed along the focal line of the collector. Thermal analysis of parabolic trough collector using convection, conduction and radiation. [4]

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Parabolic trough collector wind flow analysis around a under real working condition is performed. The variation of heat transfer coefficient around the heat collector element with Reynolds number is presented and compared to the circular cylindrical in cross flow. [5]

The above analysis prove that advantages of thermal analysis of parabolic trough and its absorber tube. But in the proposed system absorber tube is replaced with number of thermo electric modules are arranged in parallel or series depends upon the requirement of voltage. The DC output voltage of thermo electric module boost into required voltage level using boost converter then connected to the grid through an inverter. The detailed analysis of working and output waveforms are discussed below.

2. THERMOELECTRIC GENERATOR

Thermoelectric generators are converting thermal energy into electric energy. The electrical voltage is generated between two ends of two different metals they welded together maintaining at different temperature.

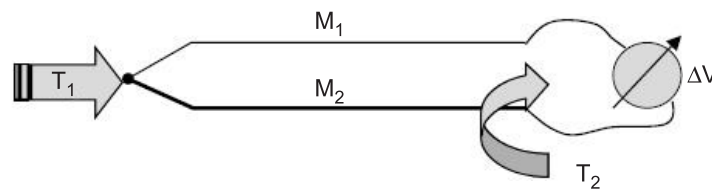


Figure 1: Principle of Seebeck effect [6]

Voltage developed

$$\Delta V = \alpha_s \Delta T \quad (1)$$

Where: α_s – Seebeck coefficient

ΔV – voltage difference in Volts

ΔT – absolute temperature difference in Kelvin

Seebeck coefficient describes a bulk effect, determined by the following effects: Temperature difference generates a difference in Fermi level, Bandgap distance changes with temperature. The gradient of charge carriers changes for n and p type as a function of temperature. Diffusion coefficient is a function of temperature. Charge carriers move from the heated side to cold side by thermo diffusion. Electric field will be generated due to the transport of charge carriers. Seebeck effect is used mainly in thermocouples used for temperatures ranging from -200 to 1600°C .

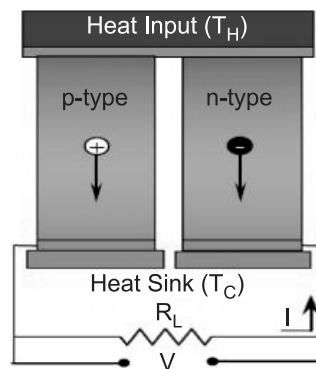


Figure 2: Power generation by Seebeck effect [6]

It is possible that the precise conditions will exist within a given generator application whereby one module will provide the exact output power desired. As a result, most thermoelectric generators contain

a number of individual modules which may be electrically connected in either series, parallel, or series/parallel arrangement. A typical generator configuration is illustrated in Figure 3. This generator has a N_T total number of modules with N_S number of modules connected in series and N_P number of modules connected in parallel. The total number of modules in the system is

$$N_T = N_S \times N_P \quad (2)$$

Where N_T = Total number of modules

N_S = Number of modules connected in series

N_P = Number of modules connected in parallel

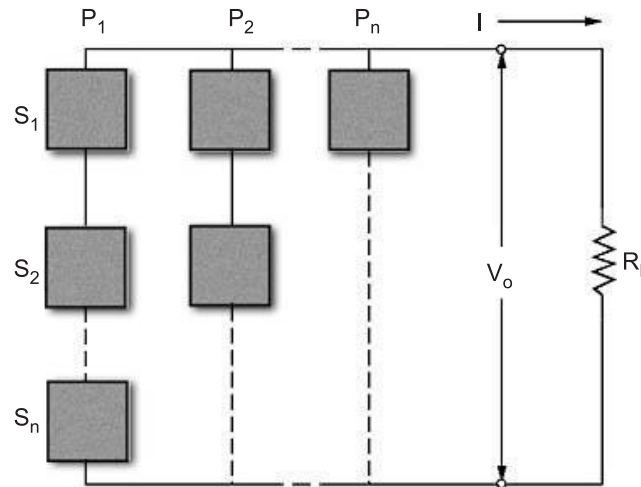


Figure 3: Typical Thermoelectric Generator with a Series-Parallel Arrangement of Modules [7]

Hot side is rated to a maximum of 320°C continuous

Cold side is rated to a maximum of 180°C continuous

Both sides of the TEG have a graphite foil pre-applied as a thermal interface material (TIM). There is no need to add any additional thermal grease or compounds.

The current (I) in amperes passing through the load resistance R_L is

$$I = \frac{N_S \times S_M \times D_T}{\frac{N_S \times R_M}{N_P} + R_L} \quad (3)$$

Where S_M = Seebeck coefficient in volts/°K

D_T = Temperature difference across the couple in °K

R_L = Load resistance in ohms

R_M = Average internal resistance of the thermoelectric couple

The Output Voltage (V_O) from the generator in volts is:

The Output Power (P_O) from the generator in watts is:

$$P_O = V_O \times I = \frac{N_T \times (S_M \times D_T)}{4 \times R_M} \quad (4)$$

The total heat input (Q_h) to the generator in watts is:

$$Q_h = (S \times T_h \times I) - (0.5 \times I^2 \times R_c) + (K_c \times DT) \quad (5)$$

The efficiency (E_g) of the generator is:

$$E_g = \frac{P_o}{Q_h} \times 100\% \quad (6)$$

Maximum efficiency occur when the internal resistance of the generator (R_{GEN}) equals the load resistance (R_L). The generator resistance is:

$$R_{GEN} = \frac{N_s \times R_M}{N_p} \quad (7)$$

3. BLOCK DIAGRAM

A boost converter (step-up converter) is a DC-to-DC power converter that steps up voltage from its input supply to its output load and regulates the output voltage. The input current is same as inductor current, so it rises above the load current when the switch is closed and falls zero when the switch is closed.

The duty ratio of boost converter is

$$\frac{V_{out}}{V_{in}} = \frac{1}{1-D} \quad (8)$$

Where

V_{out} = Output voltage in volts

V_{IN} = Input voltage in volts

D = Duty ratio

Voltage Source Inverter (VSI) has stiff DC source voltage that is the DC voltage has limited or zero impedance at the inverter input terminals.

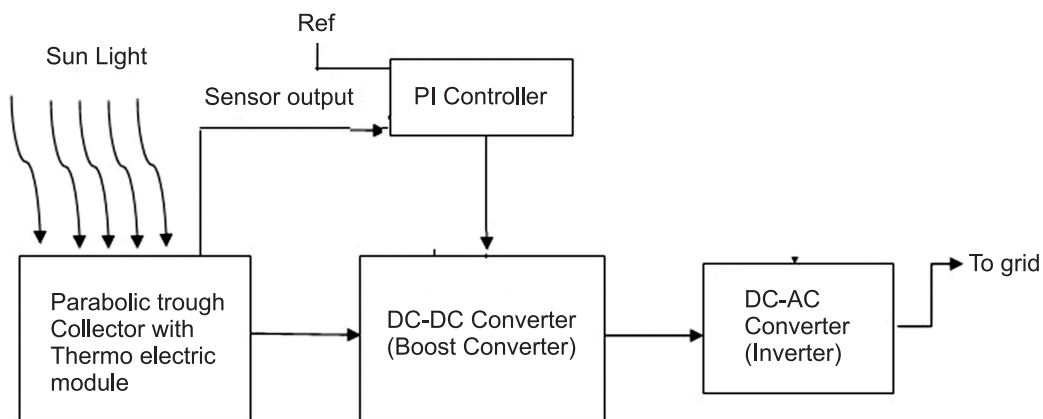


Figure 5: Block diagram of proposed system

This inverter circuit converts DC to AC. It achieves this by closing and opening the switches in the right sequence. It has four different operating states which are based on which switches are closed.

The output voltage of three phase full bridge inverter

$$V_{out} = \frac{4V_s}{n\pi} \quad (9)$$

Where V_s is the input voltage. In a PI controller constants are found out by using Ziegler Nichols method. The value of K_p is 0.0001 and K_i is 1. The components and their specifications are given in Table 1

Table 1
Components specification

Components	Specification	Voltage rating/ Module (Volts)	Current rating/ Module (Amps)	Power rating/ module (watts)
Thermo Electric Generator	1261G-7L31-05CQ	4	2	2.5
Parabolic Trough	Length: 1.2192 m Focal Length: 0.606 m Material: SS			
MOSFET	IRFP840	500	8	
IGBT	FGA25N120	1200	50	
Capacitor	C = 2.034 mF	500		
Inductor	L = 870 mH		5	

4. SIMULATION DIAGRAM

The simulation has been carried out by using MATLAB/SIMULINK. In the simulation the output voltage of thermo electric generator is 40 V. For generating 40V at the output of TEG four modules are connected in series and this series connected module connected in parallel with other three series connected modules. 1261G-7L31-05CQ thermo electric module used for this. TEGs will deliver the maximum power output (Power = Volts \times Amps) when the load resistance equals the TEGs internal resistance. If you cannot match the load, then always try to keep the load resistance slightly higher than the TEG resistance rather than lower. The graph is shown in Figure 7. In thermo electric generator hot temperature is taken as 100° and cold temperature is taken as 50°. The variation of output power, current, voltage and PTC temperature versus time graph shown in Figure 8, 9, 10, 11

This 40 V is the input of boost converter, convert this voltage into 400V by using IRFP840 MOSFET. This output voltage is given to the input of three phase full bridge inverter using 6 FGA25N120 IGBT switches.

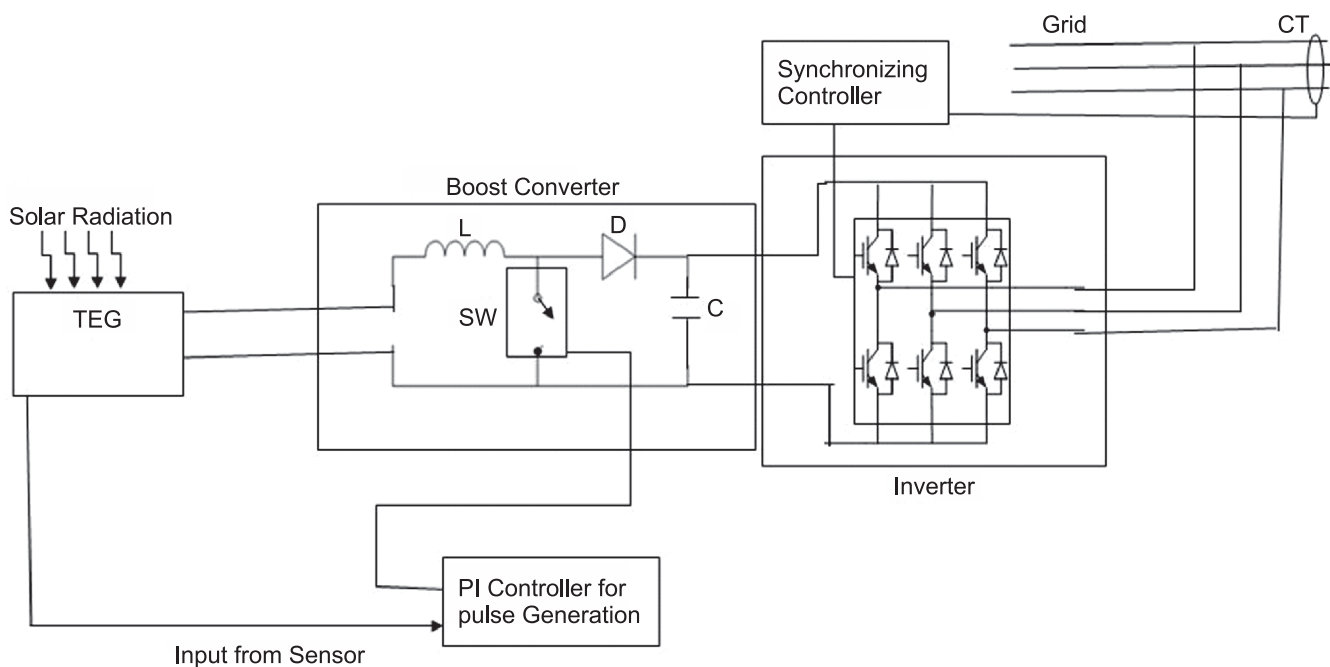


Figure 6: Circuit diagram of proposed system

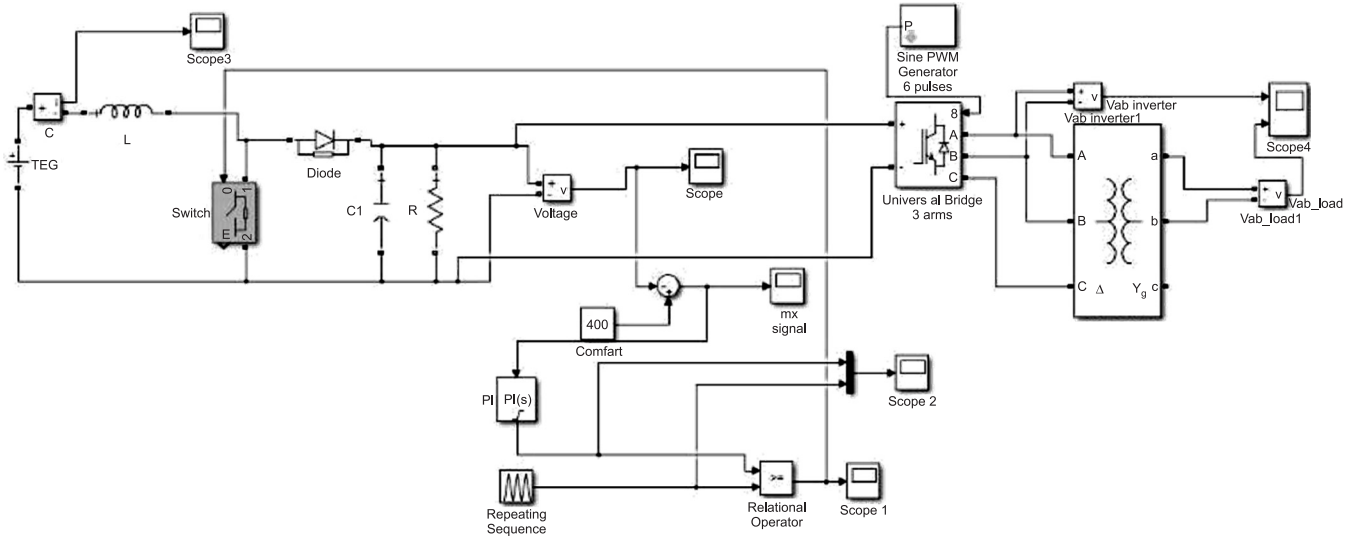


Figure 7: Detailed Simulation diagram of proposed system

5. SIMULATION RESULT

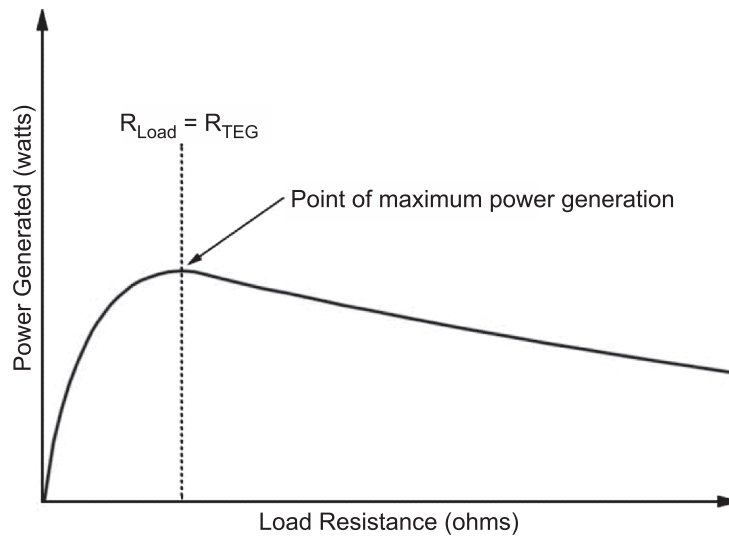


Figure 8: Point of maximum power generation characteristics

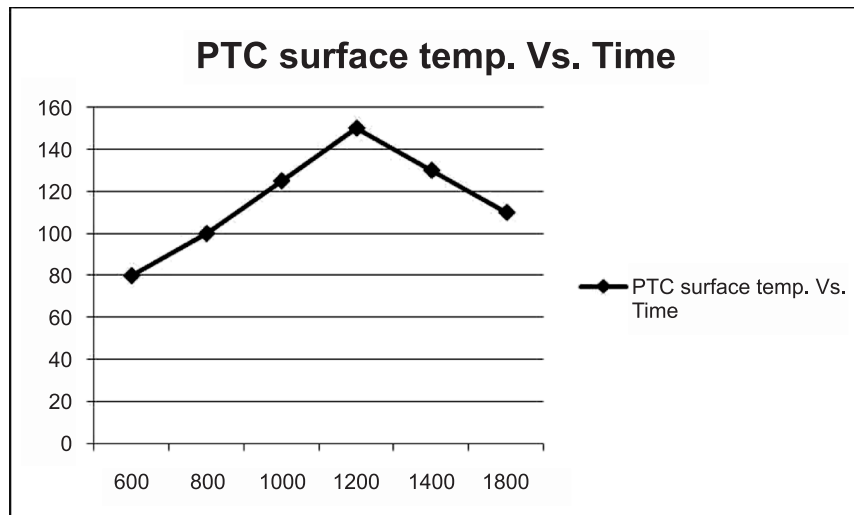


Figure 9: TGE power output Vs Time

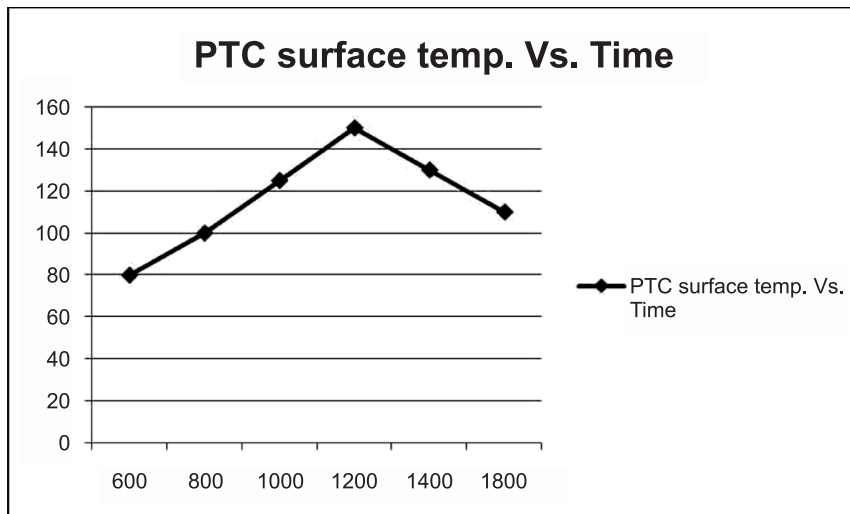


Figure 10: PTC surface temp. Vs Time

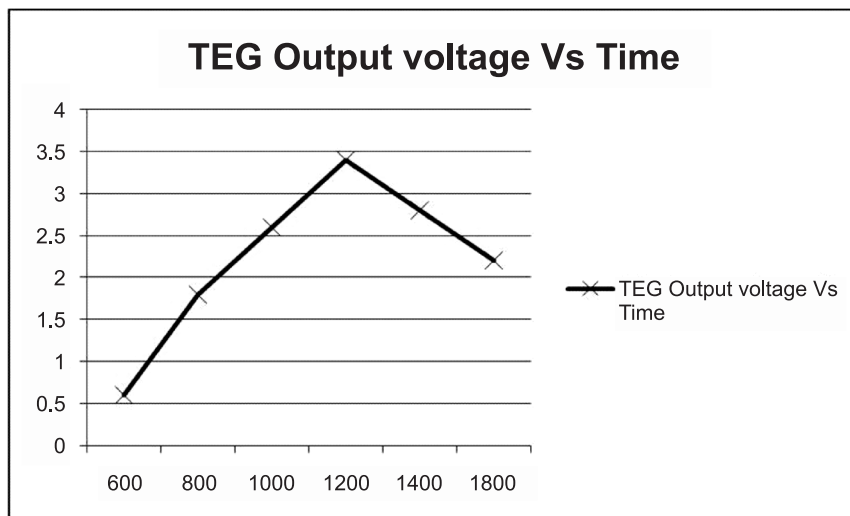


Figure 11: TEG output voltage Vs Time

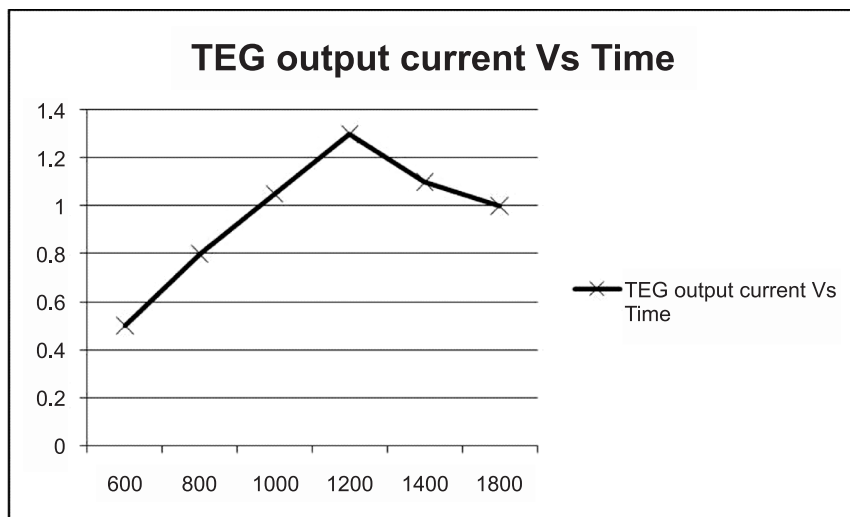


Figure 12: TEG output current Vs Time

Waveform of output voltage of inverter, error signal of PI controller, DC – DC converter output current are shown in simulation results

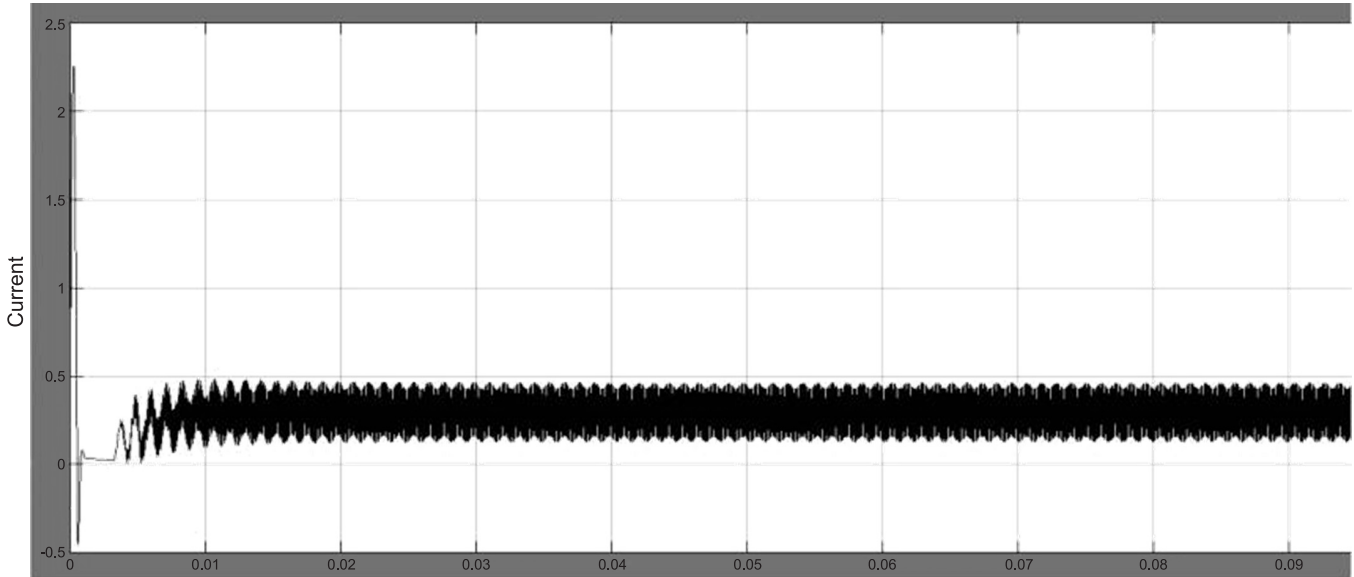


Figure 13: Waveform of DC-DC converter output current

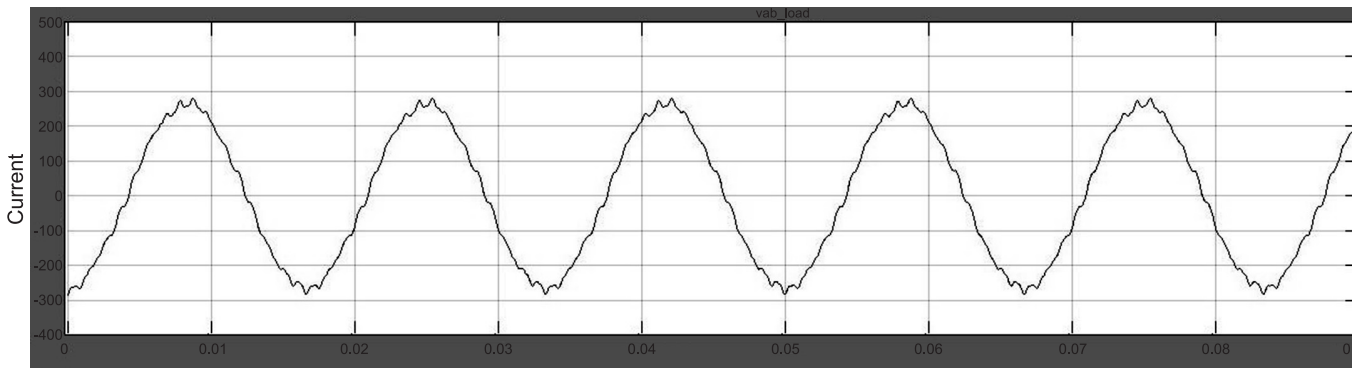


Figure 14: Waveform of inverter output current

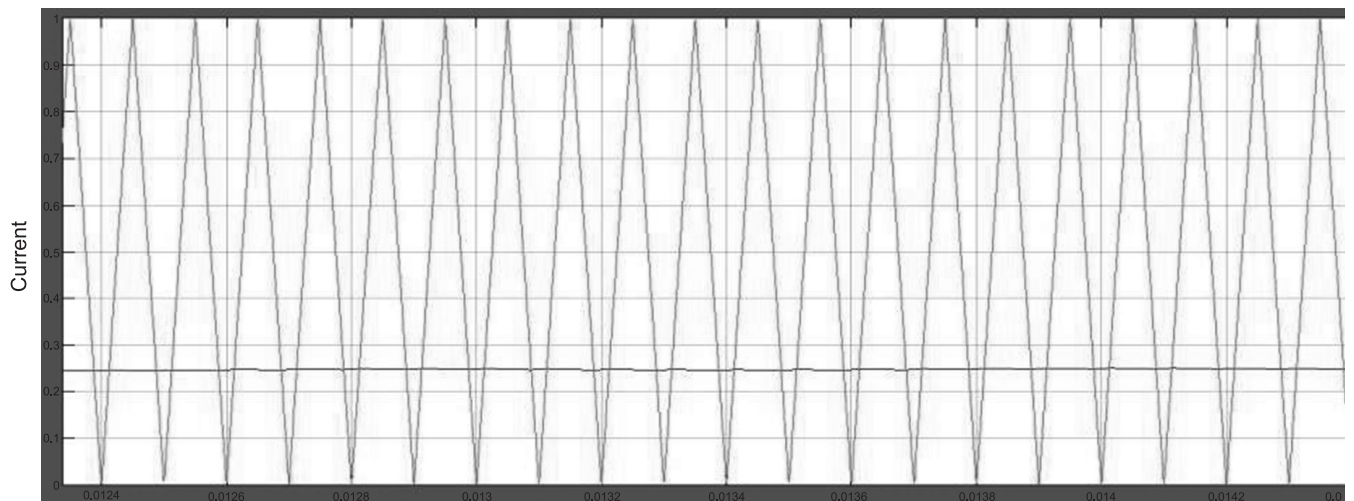


Figure 15: Waveform of duty ratio

6. CONCLUSION AND FUTURE SCOPE

Novel modified parabolic Trough Collector integrated with grid has been modeled. From the above discussion it can be concluded that the efficiency of PTC can be enhanced with the incorporation of a novel algorithm. The algorithm manipulates the duty ratio and other controlling parameters of the boost converter

according to the temperature of PTC .The series and parallel combination of the TEG cells are done by the controller with the input of temperature, voltage and current of TEG. Efficiency of the system can be improved with the suitable connection of TEG. Further the efficiency can be done by integration of convex lens by which temperature of the surface can be increased.

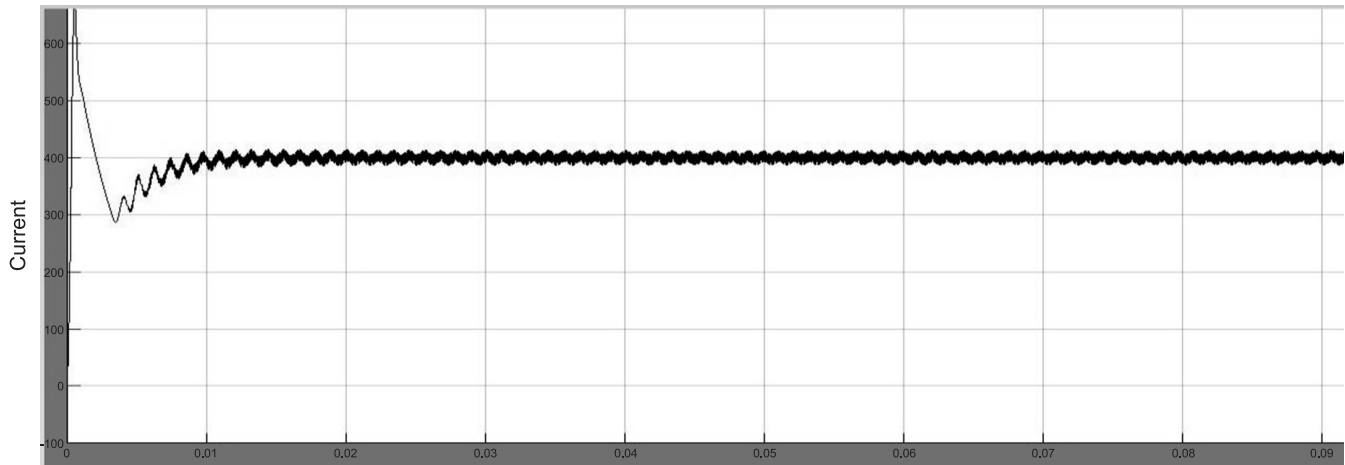


Figure 16: Waveform of PI controlled voltage

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