

# Experimental and Numerical Analysis of Photovoltaic Solar Panel using Thermoelectric Cooling

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## Abstract

A novel technology has been developed that forwards the photovoltaic panel cooling into an innovative step ahead: solar PV/TC (photovoltaic, thermal, and cooling). In the proposed PV/TC system along with electrical energy both heat and cold energy are simultaneously generated in a useful manner based on semiconductor components. This semiconductor component is working based on Peltier effect. In this approach, thermo electric cooling (TEC) module is connected on the back side of the solar PV module firmly with aluminium heat sink. In operating mode, the PV panel generates electrical energy, simultaneously the TEC module assimilates heat from the back side of the PV panel and delivers into heat sink. The heat rejected from the sink is utilized for domestic and industrial applications. The experiments are administered on clear days during the month of August 2014. A comprehensive geometric model is developed and simulated via ANSYS workbench so as to evaluate the thermal behaviour on each layer of the PV panel. The simulated results are compared with the experimentally measured values and found to be in good agreement. The RMSE<sub>1</sub>, RMSE<sub>2</sub> and R-squared values were obtained for top panel temperature is 4.96659, 0.096469 and 0.96801 respectively. The RMSE<sub>1</sub>, RMSE<sub>2</sub> and R-squared values were obtained for rear panel temperature is 4.860556, 0.117196 and 0.92557 respectively. It is also found that the maximum electrical efficiency, panel top temperature, PV panel rear temperature and outlet air temperature of PV/TC panel is about 11.87%, 54.5°C, 43.1°C and 46.3°C respectively. The fundamental advantage of this concept is by coupling TEC with solar panel, increases electrical efficiency and life of the solar panel.

**Keywords:** PV/TC, Photovoltaic, Peltier Effect, Thermoelectric Cooling

## 1. Introduction

Photovoltaic Solar Panel converts solar radiation into electrical energy. Electrical energy is one of the outcome of solar energy conversion process. The ideal conversion efficiency of a commercial photovoltaic module lies in the range of 15%<sup>1</sup>. The remaining energy is transformed into heat and this heat will increase operational temperature of PV system that affects electrical energy production of photovoltaic modules. The temperatures of photovoltaic cell will reach around 70°C and 90°C with the solar radiation of 750 W/m<sup>2</sup> and 1200 W/m<sup>2</sup> respectively. Due to this the conversion efficiency and life of the cell is reduced<sup>2</sup>. The temperature of the photovoltaic module is increased

by the absorbed solar radiation that is not converted into electrical power, inflicting a decrease in their efficiency. For mono and polycrystalline silicon solar cells, the decrease in efficiency is about 0.45% for every degree rise in temperature. For amorphous silicon solar cells, the influence is less, with a decrease in efficiency of about 0.25% per degree rise in temperature. Therefore, so as to attain higher electrical efficiency, the photovoltaic module ought to be cooled by removing the heat<sup>3</sup>.

The photovoltaic cells are cooled by using Thermoelectric Cooling Modules (TECs). A TEC module is taken into account to be connected on the rear side of the photovoltaic cell. A comprehensive model is developed and solved by using MATLAB so as to obtain temperatures

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and heat fluxes through the PV–TEC system at each given ambient temperature and solar radiation level. It is concluded this methodology will be capable when the TEC module has a high  $Z$  value and will be more effective for higher level of solar radiation<sup>4</sup>.

Aim of this paper is to get rid of excess heat developed by photovoltaic modules to increase the efficiency of PV modules and to utilize the surplus heat fitly. Therefore, using a suitable cooling method to sustain the photovoltaic cells at a specified temperature range is essential.

To conquer this issue, an innovative cooling technique based on Peltier effect by using thermoelectric modules is proposed and examined in the present paper. The Thermoelectric Cooling (TEC) module is attached on the rear side of the solar photovoltaic module. The cooling impact of TEC module is linear with applied voltage. Intensely, there is a trade-off between the net power generated by the system and the power utilized by the TEC module. Also in this paper a comprehensive thermal model of the solar panel is simulated via ANSYS workbench in order to analyze the thermal behavior on each layer of the PV panel. The result is photovoltaic panel with maximum efficiency and extended life and the heat absorbed from the panel is utilized for domestic and industrial applications.

## 2. Theory and System Modelling

### 2.1 Solar Photovoltaic (PV) Module

Photovoltaics (PV) is a technique of transforming solar energy into a direct current electricity using semiconducting materials that exhibit the photovoltaic effect. A photovoltaic system comprises solar panels composed of multiple solar cells to supply usable electrical power. The energy conversion of solar radiation to electricity takes place with no moving components or environmental emissions throughout operation.

The energy balance mathematical equation for glass-tedlar photovoltaic module is given by<sup>5</sup>,

$$\begin{aligned} & \tau_g [\alpha_c \beta_c G + \alpha_T (1 - \beta_c) G] A_{PV} \\ & = U_t (T_{cell} - T_{amb}) A_{PV} \\ & + U_T (T_{cell} - T_{bs}) A_{PV} \\ & + \tau_g \beta_c \eta_{el} G A_{PV} \end{aligned} \quad (1)$$

Where  $T_{cell}$ ,  $T_{amb}$ ,  $T_{bs}$ ,  $G$ ,  $A_{PV}$ ,  $\alpha_c$ ,  $\alpha_T$ ,  $\beta_c$ ,  $\tau_g$ ,  $U_T$ ,  $U_t$ ,  $\eta_{el}$  are PV cell temperature, ambient temperature, back surface temperature, solar radiation intensity, the absorptivity of

solar cell, the absorptivity of tedlar, the packing factor of solar cell, the transmittivity of glass cover, conductive heat transfer coefficient from the solar cell to ambient through tedlar, overall heat transfer coefficient from the solar cell to ambient through glass cover and electrical efficiency respectively.

An energy balance mathematical equation for the back surface of tedlar is given by<sup>4</sup>,

$$\begin{aligned} U_T (T_{cell} - T_{bs}) A_{PV} & = N_{TEC} Q_c \\ + h_{amb} (T_{bs} - T_{amb}) (A_{PV} - A_{TEC}) \end{aligned} \quad (2)$$

Where  $N_{TEC}$  and  $A_{TEC}$  are number of TEC modules and surface area of TEC respectively.

The right hand side first term in equation (2) refers the heat removed by the TEC modules and the second term is the convection heat transferred between the tedlar and the streaming air from surrounding.

The electrical efficiency of a PV module is given by<sup>5</sup>,

$$\eta_{el} = \frac{V_{mp} I_{mp}}{\dot{S}} \quad (3)$$

Where,  $V_{mp}$ ,  $I_{mp}$  and  $\dot{S}$  are maximum power voltage, maximum power current and the rate of incident solar energy on the PV surface respectively.

Solar energy incident on the PV surface is given by<sup>5</sup>,

$$\dot{S} = GN_s N_m A_{PV} \quad (4)$$

Where  $N_s$  and  $N_m$  are number of modules in series per string and number of strings respectively.

The surface area of PV module ( $A_{PV}$ ) is given by,

$$A_{PV} = L_1 L_2 \quad (5)$$

Where  $L_1$  and  $L_2$  are the length and width of the PV module respectively.

### 2.2 Thermoelectric Cooler (TEC)

Thermoelectric Cooler (TEC) is a semiconductor based electronic part incorporates a number of thermoelectric components, which are connected thermally in parallel and electrically in series. The thermoelectric elements are made out of a couple of p-type and n-type semiconductors. When electric current flows across the thermoelectric components, the heat is conveyed from the cold side to the hot side caused by the Peltier effect<sup>6</sup>.

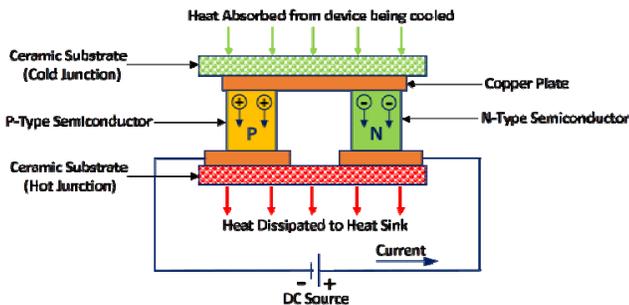
A schematic of TEC module is shown in Figure 1. A thermoelectric cooling system usually consists of a grid structured semiconductor pellets sandwiched in between two large electrodes. When a DC power is supplied in between the electrodes, the negatively charged side becomes cooler while the positively charged side becomes warmer. The negative electrode is set in contact with the medium to be cooled, while the positive electrode is coupled to a heat sink that dissipates thermal energy into the external environment.

In general, thermoelectric cooler will consume more power than that of other conventional system. However, in situations on compact medium, the thermoelectric cooling strategy is more reasonable and economic than a conventional cooling system. TEC modules possess noticeable features of being lightweight, absence of moving mechanical parts, compactness, noiseless in operation, transferability, highly reliable, long working life and less maintenance requirements<sup>7-10</sup>. Thermoelectric Coolers (TECs), converting a direct current into a temperature gradient<sup>11</sup>. The cooling effect of TEC module is increasing by increasing the electrical current which in turn leads to minimize the cell temperature and higher output power. The schematic diagram of TEC module coupled with the solar panel in the proposed approach is shown in Figure 2.

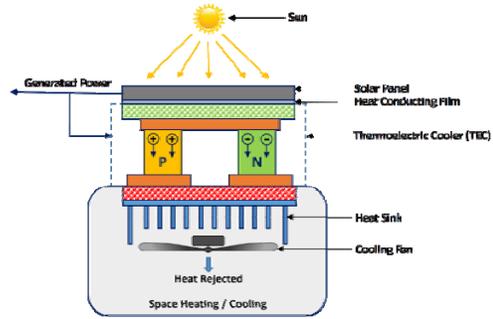
The TEC module datasheet generally consists of parameters such as  $\Delta T_{max}$ ,  $I_{max}$ ,  $V_{max}$ ,  $Q_{max}$ . By using these known parameters the module parameters,  $S_m$ ,  $R_m$  and  $K_m$  can be calculated as below<sup>12</sup>,

$$S_m = \frac{V_{max}}{T_{amb}} \tag{6}$$

$$R_m = \frac{(T_{amb} - \Delta T_{max})V_{max}}{T_{amb} \cdot I_{max}} \tag{7}$$



**Figure 1.** Schematic diagram of the Thermoelectric Cooler (TEC).



**Figure 2.** TEC module coupled with PV panel – Proposed approach.

$$K_m = \frac{0.5(T_{amb} - \Delta T_{max})V_{max} \cdot I_{max}}{T_{amb} \cdot \Delta T_{max}} \tag{8}$$

Under steady-state conditions, the theoretical equations for the TEC performance is given below,

The cooling capacity of TEC module is,

$$Q_c = S_m I_{in} T_c - 0.5 I_{in}^2 R_m - K_m \Delta T \tag{9}$$

The input voltage to the TEC module in volts is:

$$V_{in} = S_m \Delta T + I_{in} R_m \tag{10}$$

The input electrical power to the TEC module in watts is:

$$P_{in} = V_{in} \times I_{in} \tag{11}$$

The heat rejection from the hot side of the TEC module is,

$$Q_h = P_{in} + Q_c \tag{12}$$

The temperature between PV panel tedlar and the aluminium plate is given by,

$$T_{bs} = T_c + Q_h R_{jc} \tag{13}$$

The hot side temperature of the TEC module is given by,

$$T_h = T_{amb} + Q_h R_{ha} \tag{14}$$

The effectiveness of a thermocouple in TEC module is given a “figure of merit” designated as Z is given by,

$$Z = \frac{S_m^2}{R_m K_m} \tag{15}$$

The energy balance equations from (9) to (14) for PV module and thermoelectric module are solved simultaneously to obtain the temperature at different sections ( $T_{bs}$ ,  $T_{cell}$ ,  $T_c$ ,  $T_h$ ) and the values of  $Q_c$  and  $Q_h$ .

### 3. Experimental Analysis

The experiment was conducted under two different cases, one is without using thermoelectric cooling in PV panel and the second case PV panel is cooled by using TEC module. The experiment was conducted from morning 8am to evening 5pm on a sunny day. The Table 1 shows the specifications of solar panel used in this study. Table 2 shows the specifications of TEC module used in this study. The Figure 3 shows the experimental setup using thermoelectric cooling.

### 4. Thermal Simulation

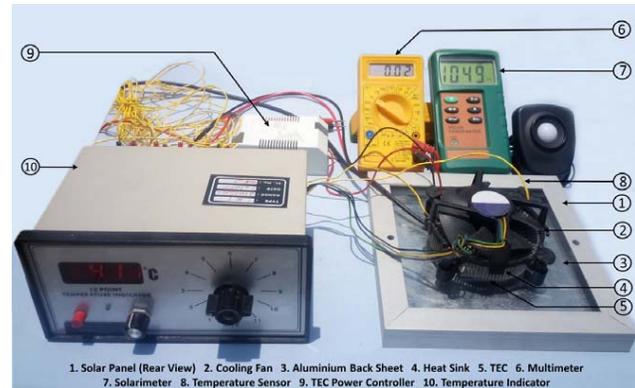
Thermal simulation is a method of solving mathematical equations, governing various physics including heat flow and many other phenomena. In this study the thermal simulation of solar panel is studied by using ANSYS workbench. The sequential stages performed in thermal simulation of solar PV/TC panel are geometrical model, meshing, setup boundary conditions, solution and results.

**Table 1.** Solar Panel Specifications

Description	Characteristics value
Maximum Power	3.00 W
Maximum Power Voltage	8.80 V
Maximum Power Current	0.34 A
Short Circuit Current	0.38 A
Open Circuit Voltage	10.0 V
Dimensions, (mm)	155 x 155 x 5

**Table 2.** TEC Module Specification

Description	Characteristics value
Operational Voltage	12 V (DC)
Current Max	6 A
Voltage Max	15.2 V (DC)
Power Max	92.4 Watts
Power Nominal	60 Watts
Couples	127
Dimensions, (mm)	40 x 40 x 3.5



**Figure 3.** Experimental setup of TEC module coupled with PV panel.

#### 4.1 Geometric Domain

The 3-D domain of the solar PV/TC system was modelled using ANSYS design modular. Table 3 shows the geometrical dimensions of the solar PV/TC system. The 3D geometric model of the solar PV/TC system is shown in Figure 4.

#### 4.2 Mesh Generation

The mesh generation of PV/TC geometric domain is done by using ANSYS workbench. The hexahedral elements of fine size and patch conforming method are employed to create a good quality mesh. After meshing, the number of elements and nodes are found to be 74676 and 263382 respectively. The settings used in the present thermal analysis is shown in the Table 4. The mesh output of the present thermal analysis is shown in the Figure 5.

#### 4.3 Boundary Condition and Setup

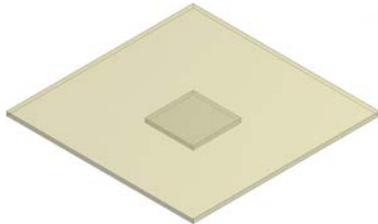
According to the physics of the problem, appropriate boundary conditions are impressed on the computational domain. The side surfaces of the photovoltaic system and thermoelectric cooling module are defined as wall with adiabatic conditions to effect insulated conditions. The various material properties are employed to perform the solution and calculation tasks. The different material properties used in thermal analysis is shown in Table 5.

#### 4.4 Results

After the solution is converged, the output results are visualized by using post processing tool. ANSYS workbench post-processor is an adaptable, best in class

**Table 3.** Geometrical dimensions of PV/TC system

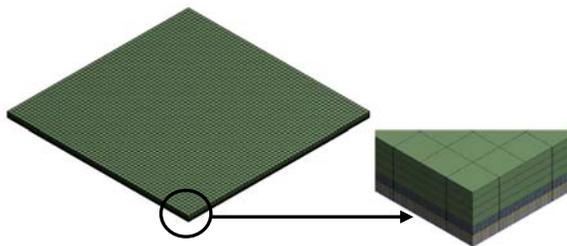
Parameter	Dimensions (m)
Top Glass Layer	0.155 x 0.155 x 0.003
EVA Layer	0.155 x 0.155 x 0.0005
PV Cell Layer	0.155 x 0.155 x 0.0003
Tedlar Layer	0.155 x 0.155 x 0.0005
TEC Module	0.040 x 0.040 x 0.003



**Figure 4.** 3D Geometric model of solar PV/TC system.

**Table 4.** Mesh settings

Name	Option / Value
Element	Hexahedral
Method	Patch Conforming
Relevance Centre	Fine
No. of Elements	74676
No. of Nodes	263382
Element	Hexahedral



**Figure 5.** 3D Mesh of solar PV/TC system.

post-processor. It is designed to empower simple perception and quantitative examination of the consequences of thermal simulations.

## 5. Validation

Numerical analysis is based on some assumptions. Due to these presumptions, numerical investigation in some cases

**Table 5.** Material properties used in thermal analysis

Material	Layer	Thermal Conductivity (W/m.K)	Specific Heat Capacity (J/kg.K)	Density (kg/m <sup>3</sup> )
Tempered Glass	Top Cover	2	500	2450
EVA	Encapsulant	0.311	2090	950
Silicon	PV Cell	130	677	2330
Tedlar	Bottom Cover	0.15	1250	1200
Aluminium Oxide	TEC Outer Cover	30	880	3890

yields more prominent difference. Therefore, a proper error analysis of the numerical results is needed with the experimental measures before applying the numerical simulation for further analysis. In this work the simulated results are validated with the experimental results and the Root Mean Square (RMS) errors and R-Squared value is calculated using following equations<sup>13</sup>.

$$RMSE_1 = \sqrt{\frac{1}{m} \sum_{i=1}^m d_i^2} \tag{16}$$

$$RMSE_2 = \sqrt{\frac{1}{m} \sum_{i=1}^m \left(\frac{d_i}{Y_i}\right)^2} \tag{17}$$

$$R\text{-Squared} = \left[ \frac{m \left( \sum_{i=1}^m X_i Y_i \right) - \left( \sum_{i=1}^m X_i \right) \left( \sum_{i=1}^m Y_i \right)}{\left[ m \sum_{i=1}^m X_i^2 - \left( \sum_{i=1}^m X_i \right)^2 \right] \left[ m \sum_{i=1}^m Y_i^2 - \left( \sum_{i=1}^m Y_i \right)^2 \right]} \right]^2 \tag{18}$$

Where,  $d_i$  is the deviation between the  $i^{th}$  measured and the predicted values,  $X_i$  is the  $i^{th}$  predicted value,  $Y_i$  is the  $i^{th}$  measured value and  $m$  is the number of data points.

The  $RMSE_1$ ,  $RMSE_2$  and R-squared values were obtained for top panel temperature is 4.96659, 0.096469 and 0.96801 respectively. The  $RMSE_1$ ,  $RMSE_2$  and R-squared values were obtained for bottom panel temperature is 4.860556, 0.117196 and 0.92557 respectively. Though some discrepancies arise due to some simulation assumptions, even though from the RMS errors and R-square values it is clearly visible there is good agreement of the simulated data with the experimental values. Therefore, the calibrated accuracy of the simulated values can be considered to be acceptable for the analysis.

## 6. Results and Discussion

The outcomes obtained from the experimental and thermal analysis simulation of PV/TC solar panel are exhibited in this section. The experiment is conducted from 8 am to 5 pm and the measurements are noted for every 1-hour interval and also the individual thermal analysis simulation at each hour is simulated for the corresponding inputs at that time. The line graph is plotted to show and estimate the experimental and simulated temperatures versus time for with and without cooling PV/TC panel.

Figure 6 shows the hourly variation of top panel glass surface temperature of PV/TC panel from 8 am to 5 pm. The experimental top panel surface temperature with TEC varies from a least value of 40.1°C at 8 am to an extreme value of 54.5°C at 1 pm whereas for without TEC it varies from a least value of 42.7°C at 8 am to an extreme value of 68.2°C at 1 pm. Also the simulated top panel surface temperature with TEC varies from a least value of 40.5°C at 8 am to an extreme value of 63.6°C at 1 pm. It is clear from the graph that top glass surface temperature is higher in without TEC solar panel than in with TEC solar panel. The  $RMSE_1$ ,  $RMSE_2$  and R-squared value for top panel temperatures are calculated by using Eqs. (16), (17) and (18), respectively. It is found that there is a good agreement between the experimental and the simulated results of top panel temperatures with a value of  $RMSE_1 = 4.96659$ ,  $RMSE_2 = 0.096469$  and the R-squared value = 0.96801.

Figure 7 shows the hourly variation of bottom surface temperature of PV/TC panel from 8 am to 5 pm. The bottom panel surface temperature with TEC varies from a least value of 33.3°C at 8 am to an extreme value of 43.1°C at 1 pm whereas for without TEC it varies from a least value of 41.4°C at 8 am to an extreme value of 68.1°C at 1 pm. Also the simulated bottom panel surface temperature

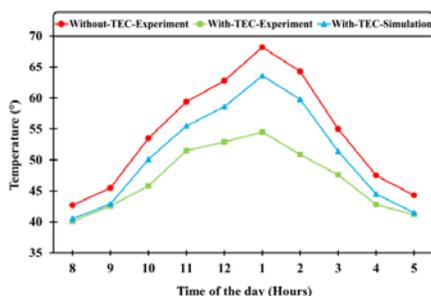


Figure 6. Top Glass Temperature.

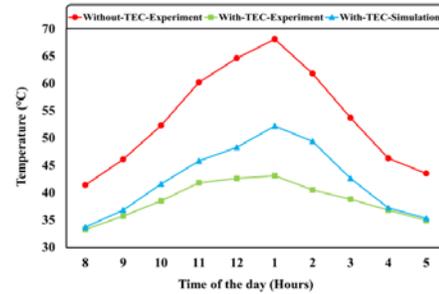


Figure 7. Bottom Surface Temperature.

with TEC varies from a least value of 33.7°C at 8 am to an extreme value of 52.2°C at 1 pm. From the line graph it is clear that the bottom panel surface temperature is higher in without TEC solar panel than in with TEC solar panel. It is found that there is a closer agreement between the experimental and the simulated results of bottom panel temperatures with a value of  $RMSE_1 = 4.860556$ ,  $RMSE_2 = 0.117196$  and the R-squared value = 0.92557.

Also from Figure 6 & 7, it is perceived, the top glass and bottom surface temperature is initially low due to poor solar radiation, when the solar radiation increases due to this the top glass and bottom panel surface temperature is also increased. The top glass and bottom panel surface temperature will attain a peak value at 1 pm.

Figure 8 shows the hourly variation of ambient temperature and heat sink outlet temperature of PV/TC panel from 8 am to 5 pm. The ambient temperature varies from a least value of 33.4°C at 8 am to an extreme value of 41.2°C at 1 pm. The heat sink air outlet temperature varies from a least value of 36.2°C at 8 am to an extreme value of 46.3°C at 1 pm. From the graphs it is observed, the heat sink outlet air temperature is initially low due to less bottom panel temperature. The rise in solar radiation increases the photovoltaic panel temperature. In order to minimize the panel temperature, the more heat released by the TEC hot side is required to maintain the temperature on TEC cold side. Hence the heat sink outlet air temperature is increased. Also heat sink air outlet temperature is always greater than that of ambient temperature and hence it is suitable for industrial and residential drying process.

Figure 9 shows the hourly variation of electrical efficiency and solar intensity of PV/TC panel from 8 am to 5 pm. The electrical efficiency of solar panel with TEC ranges between 11.52 - 11.87 % from 8 am to 5 pm whereas for without TEC it ranges between 10.18 - 11.37

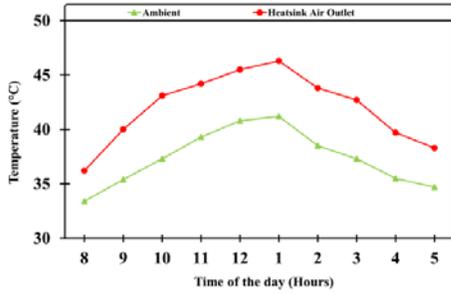


Figure 8. Ambient vs Heat Sink Air Outlet Temperature.

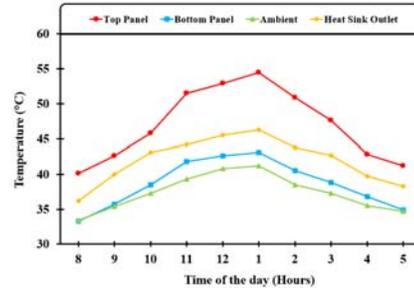


Figure 10. Experimental Temperatures.

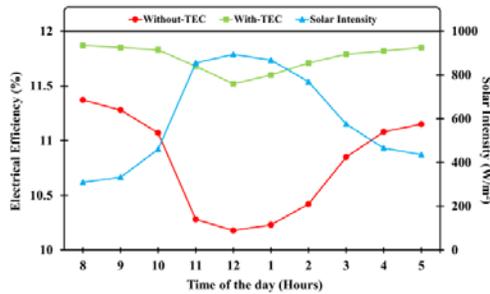


Figure 9. Electrical Efficiency.

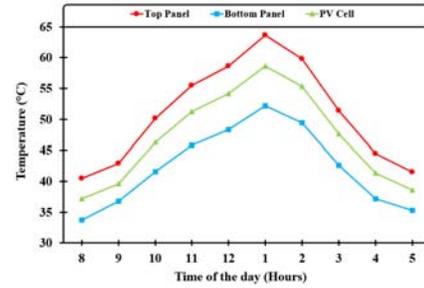


Figure 11. Simulated Temperatures.

%. The solar intensity varies from 309.6 – 893.9 W/m<sup>2</sup> from 8 am to 5 pm.

From Figure 9, it is observed clearly, cooling the PV panel using TEC the electrical efficiency is considerable increased when compared with without cooling PV panel. Also in with TEC cooling PV panel the drop in electrical efficiency from morning to evening is very less when compared to that of without cooling PV panel. The drop in electrical efficiency of PV panel without cooling is found to be an extreme value of 1.4 % at 1 pm and a least value of 0.5 % is obtained.

Figure 10 and 11 shows the experimental and simulation temperatures of PV/TC panel from 8 am to 5 pm. From figure 10 it is observed the bottom panel surface temperature is lower than that of top glass temperature and also bottom panel surface temperature will close to that of ambient temperature due to TEC coupled on rear side of the PV panel. The temperature difference between the bottom panel and ambient ranges between 0.1 – 2.5°C and it indicates the bottom panel temperature is closer to that of ambient temperature. From fig. 11 it is observed that the simulated cell temperature varies from a minimum value of 37.2°C at 8 am to a maximum value

of 58.6°C at 1 pm. The temperature difference between the bottom panel and PV cell ranges between 2.8 – 6.4°C and the temperature difference between the top glass and PV cell ranges between 2.9 – 5.0°C. It is also found that there is a closer agreement between the experimental and the simulated results of bottom panel and top glass temperatures. Hence the simulated cell temperature values can be considered to be acceptable for the analysis.

Figure 12 and 13 show the temperature contours of top glass and PV cell layer respectively. The top glass temperature varies from a least value of 54.47°C at mid of the panel to an extreme value of 62.79°C at outer area of the top panel layer. The cell temperature varies from a least value of 45.48°C at mid of the panel to an extreme value of 62.79°C at outer area of the cell layer. From figure 12 and 13 it is clearly observed, the maximum reduction in temperature of top glass and cell layer will takes place in the mid portion and the temperature reduction is gradually reduced away from the mid portion of the layers. Also in commercial PV panel measuring the experimental temperature of PV cell layer is difficult since the PV cell layer is permanently covered by EVA, tempered glass and tedlar. So simulation studies are used to predict and visualize these types of complicated temperature distribution.

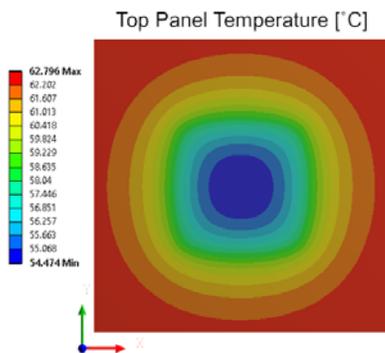


Figure 12. Top Panel Temperature Contour.

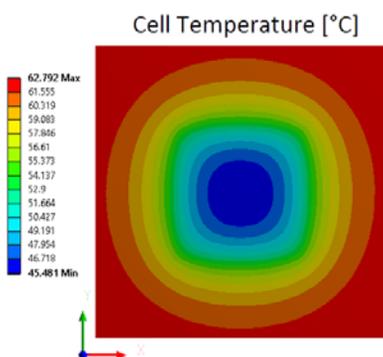


Figure 13. PV Cell Layer Temperature Contour.

## 7. Conclusion

This paper proposes a utilization of thermoelectric cooling system for PV module for the improvement of efficiency and longer life. The heat absorbed from the panel can be used for drying applications. At the point when the mean and maximum temperature of the solar cell is lessened, the efficiency of the cell and its life impressively increases. From Figure 9 it is perceived that the electrical efficiency is increased by the use of thermoelectric cooling. Also in this approach a detailed geometric model is developed and simulated in ANSYS workbench in order to determine the various temperatures in the different layer of PV/TC system. In case of smaller PV panel sometimes the generated power is not sufficient to power the TEC. Hence additional power is required to compensate this lack of power. However, in situations on compact medium, the thermoelectric cooling strategy is more reasonable and economic than a conventional cooling system. Other benefits of thermoelectric cooling include absence of moving parts, more compact, less weight, ability to cool below

ambient condition, precise temperature control, high reliability and low maintenance requirements. This cooling methodology will be more effective when the TEC module has a high figure of merit value ( $Z$ ) and also switch off the power input to the TEC automatically when the panel temperature will go down to the safe critical level. The developments in thermoelectric materials and the electronic components for controlling the power input to the TEC can leads to more capable and economic use of the proposed method.

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## Nomenclature

G	solar radiation intensity ( $W/m^2$ ).	$h_{amb}$	convective heat transfer coefficient from hot side of TEC to ambient ( $W/m^2K$ ).
PV	photovoltaic.	S	the rate of solar energy incident on the PV surface (W).
PV/TC	photovoltaic/thermal cooling.	$V_{mp}$	maximum power point voltage.
Z	thermoelectric figure of merit ( $K^{-1}$ ).	$I_{mp}$	maximum power point current.
TEC	thermoelectric cooler.	$\Delta T_{max}$	TEC hot side and cold side maximum temperature difference (K).
$N_{TEC}$	number of TEC.	$I_{max}$	TEC maximum current (A).
$A_{TEC}$	surface area of TEC ( $m^2$ ).	$V_{max}$	TEC maximum voltage (V).
$A_{PV}$	surface area of PV module ( $m^2$ ).	$Q_{max}$	maximum heat absorbed at the cold side of TEC.
$U_t$	overall heat transfer coefficient from solar cell to ambient through glass cover ( $W/m^2K$ ).	$K_m$	TEC module thermal conductance (W/K).
$U_T$	conductive heat transfer coefficient from solar cell to flowing air through tedlar ( $W/m^2K$ ).	$Q_h$	heat rejected from the hot side of the TEC module (W).
$N_m$	number of modules in series per string.	$P_{in}$	electrical input power to the TEC module (W).
$N_s$	number of string.	$V_{in}$	TEC input voltage (V).
$L_1$	length of the PV module.	$I_{in}$	TEC input current (A).
$L_2$	width of the PV module.	$T_c$	TEC module cold side temperature (K).
$T_{amb}$	ambient temperature (K).	$T_h$	TEC module hot side temperature (K).
$T_{bs}$	tedlar back surface temperature (K).	$S_m$	TEC module Seebeck coefficient (V/K).
$Q_c$	rate of cooling capacity of TEC module on cold side (W).	$R_m$	TEC electrical resistance ( $\Omega$ ).
		$\Delta T$	TEC hot side to cold side temperature difference (K).
		$R_{jc}$	Thermal resistance from junction to TEC (K/W).
		$R_{ha}$	Resistance from TEC hot side to ambient (K/W).
		$\alpha_T$	absorptivity of tedlar.
		$\eta_{el}$	electrical efficiency (%).
		$\tau_g$	transmittivity.
		$\alpha_c$	absorptivity of solar cell.
		$\beta_c$	packing factor of solar cell.