# Experimental Investigation of Temperature Effect on PV Monocrystalline Module

Heba A. Mosalam*

*Electromechanics Department, Faculty of Engineering, Heliopolis University for Sustainable Development, Cairo, Egypt

(Heba.mosalam@hu.edu.eg)

‡ Heba A. Mosalam, Tel: +201005672139,

Fax: +2 0226588360 , heba.mosalam@hu.edu.eg

*Received: 09.07.2017 Accepted:21.08.2017*

**Abstract-** The importance of the module's temperature has been severally discussed in previous reviews. What is of concern to us is the percentage of the power loss with each increase in unit temperature. The experiment illustrated in this research has allowed the monitoring of the variants in the power produced during the two months of August and December. The parameters of module temperature and solar irradiation have been monitored, and the maximum output voltage and the power produced were recorded. The drop in power was usually a result of increase in temperature but on a different scale, which draws attention to other parameters that may affect the percentage of drop in power. The system was simulated using the tool of MATLAB using the module data sheet, and the difference in power produced was noted. The objective of this research is to improve the simulation tools in order to be more accurate in increasing the number of parameters that may contribute to the power produced from the cells.

**Keywords** *Mono-crystalline, PV,* $V_{OC}$, $I_{SC}$, *NOCT, MPP, MATLAB.*

## 1. Introduction

Many researches have confirmed the effect of the temperature on the current-voltages characteristics and the drop on the output power [1], [2] , [3], [4].

The I-V equations for the photovoltaic cells are solved to investigate the power effect for resistances connected in series and in parallel. Two software packages have been selected for the simulation of temperature effect and shading effect, MATLAB and PVSYST5 [5], [6]. The experiments show that by neglecting the resistance on parallel connections, the I-V curve still exactly matches the experimental data, but a significant difference has been noted in the case of series connections [7].

On studying the effect of temperature on building integrated photovoltaics (BIPV) in tropical areas, the conclusion showed that improving the indoor air quality by natural ways or passive ways of cooling could decrease the electrical load needs for cooling, especially with the type of the BIPV with no natural air circulation behind it [8]. This may increase the cell temperature, which affects the electrical power needed from the cell [9].

The electrical performance and energy yield of different PV technologies such as thin-film[10], monocrystalline and polycrystalline have been studied[11]. And have shown the non-linear behaviour of thin film modules in respect to irradiance and temperature [12]. The study has also showed the power drop according to the effect of the temperature up to -1.5% due to module design, and -4% when the temperature coefficient has been studied [13].

The simulation of the module temperature from Nominal Operating Cell Temperature (NOCT) has been used to predict the yearly performance of the cell, and the simulation has used different types and different cell technologies. The module were presented inconvenience for the BIPV for building integration when the modules were located vertically, horizontally or close to the wall. Some of them were isolated at their back because their operating conditions will be completely different than those working in the standard condition. The same problem faced the glass-glass modules [14]. Researches have improved the working condition of the cell by adapting the temperature and irradiation on the cell to be almost constant and near to the MPPT point without the need to fix the MPPT algorithm to the DC-DC converter [15].

Some other previuos work needed the cells warm-up used the cell heat caused by its caractaristc as large injuction area diaode internally with threshold voltage of about 0.6V to 0.7V. this voltage drop used to warm up the cells against the snow accumilation [16].

Most of the simulation software demonstrates that the cell performance needs the working temperature to be converted from the standard condition of 25$^0$C to the real test condition [17], but additional parameters are needed to give more accurate engineering analysis [18]. The latitude of different regions was also a parameter to predict the power of the cell, with conclusion that the cell performance as the sensitivity for the temperature should be in consideration to select the accurate type for a certain region [1].

By using condactunce MPPT algaethem in hardware and compare the output with the simulation by MATLAB, the experments showed diffrence between the hardware and the simulation by 5% [19]

Similar research has been made in Cyprus to study the temperature effect on different photovoltaic technologies. The results have shown over the test period the highest thermal loses in DC yield were 8% for monocrystalline and 9% for multi-crystalline silicon, while for thin film the average was 5%. This means that the thin film is the least affected by the temperature variance, and the results were similar to outdoor tests [20]. For a specified PV technology, monocrystalline PV, the research shows that when the temperature increases, the power and open circuit voltage decrease. On the other hand, the relation between cell temperature and short circuit current is a positive relation [21].

This research will focus on a real experiment with installed system with three types of PV: thin-film, monocrystalline and polycrystalline. The monocrystalline PV will be selected in this research because :

- It is the most widespread in Egypt.
- It has the most convenient prices among its counterparts.
- It has the greatest heat resistance according to the manufacturer reports. The reduction in power caused by increase of the temperature could be expected to be 12% to 15% which is lower than that of polycrystalline.

In this research, two months have been selected to measure the outputs, August as a summer month and December as winter month.

In the Egyptian market, there are mainly three types of photovoltaic: thin film, monocrystalline and polycrystalline. The polycrystalline is the most common type and has the highest price.

The composition of the silicon substrate used to make solar cells may be monocrystalline, which refers to single crystals, or polycrystalline, which refers to multi crystals.

**Nomenclatures:**

| | |
|---|---|
| Related maximum power [W] | $p_{max}$ |
| Short Circuit Current [A] | $I_{SC}$ |
| Related Current [A] | $I_{mpp}$ |
| Temperature coefficient of short-circuit current | $TCI_{Sc}$ |
| Temperature coefficient of open-circuit voltages | $TCU_{OC}$ |
| Temperature coefficient at maximum power point | $TCP_{mpp}$ |
| Maximum PV module voltage [V] | $V_{DCmaxMOD}$ |
| Open-Circuit voltage of PV module [V] | $V_{oc}$ |
| Temperature coefficient at minimum expected temperature | $T_{min}$ |
| Temperature variance between STC and minimum expected temperature | $\Delta T_{min}$ |
| Minimum PV module voltage [V] | $V_{DCminMOD}$ |
| Voltage of PV module at maximum power [V] | $V_{mpp}$ |
| Temperature coefficient at maximum expected temperature | $T_{max}$ |
| Temperature variance between STC and maximum expected temperature | $\Delta T_{max}$ |
| Diode current (A) | $I_d$ |
| Diode voltage (V) | $V_d$ |
| Diode saturation current (A) | $I_0$ |
| Diode ideality factor, a number close to 1.0 | $nI$ |
| Boltzmann constant = 1.3806e$^{-23}$ J.K$^{-1}$ | $k$ |
| Electron charge = 1.6022e$^{-19}$ C | $q$ |
| Cell temperature (K) | $T$ |
| Number of cells connected in series in a module | $Ncell$ |

## 2. System specifications

Experimental PV systems were installed in the aforementioned region in Belbes-Cairo Desert Road N30.153, E31.433 Egypt with a total power capacity of 4.5 kW

.

### *2.1 System description*

The system consists of three different types of PV. Thin film (produced by First Solar), polycrystalline (produced by Canadian Solar) and monocrystalline (produced by Solar World). Each photovoltaic PV module generates a peak power of 1400W; the short circuit current of the module is 4.7A and open circuit voltage is 18V. Every module consists of a number of cells and is connected in series to feed Sunny Island converter. Systems were placed in the following coordinates: 30.153°N/31.431°E, and at an elevation of 120m above sea-level. A detailed description of the modules is provided.

The efficiency of the monocrystalline PV has been found to be better than the efficiency of the polycrystalline PV in hot countries [22].

Table 1 and table 2, illustrates the electrical characteristics of the monocrystalline cell with 175W.

**Table 1:** Electrical characteristics of 175W monocrystalline solar panel

| | | |
|---|---|---|
| Related max. power [W] | $p_{max}$ | 175 +/-3% |
| Open Circuit Voltage [V] | $V_{OC}$ | 44.4 |
| Related voltage at maximum power [V] | $V_{mpp}$ | 35.8 |
| Short Circuit Current [A] | $I_{SC}$ | 5.3 |
| Related Current at maximum power [A] | $I_{mpp}$ | 4.9 |

**Table 2:** Thermal characteristics of 175W monocrystalline solar panel

| Thermal characteristics | |
|---|---|
| NOCT | 47 °C |
| $TCI_{Sc}$ | 0.034 %/K |
| $TCU_{OC}$ | -0.34 %/K |
| $TCP_{mpp}$ | -0.48 %/K |

NOCT is the acronym for Normal Operating Cell Temperature, and is one of the mostly used testing conditions alternative to STC.

### *2.2 The mathematical equations for the temperature effect*

The theoretical equations determine the effect of the temperature on the maximum open circuit voltage. They show that the open circuit voltages are expected to have the highest value at the lowest temperature. The temperature coefficient and the open circuit voltage are the parameters in the equations. Also, the lowest temperature in the site should be kept into consideration and should be known before the project installation [23] as shown in equations (1), it explain the expected DC voltage from the module at maximum expected temperature:

$$V_{DCmaxMOD} = V_{DCocMOD(-10^{\circ}C)} = V_{ocM} \times \left(1 + \frac{T_{min} \times \Delta T}{100\%}\right) \quad (1)$$

To determine the minimum MPP voltage, we need the highest temperature that can be expected at the location. As it was mentioned in the literature [15] , the open circuit voltage has the lowest value at the highest temperature as shown in equation (2), it explain the expected DC voltage from the module at minimum expected temperature:

$$V_{DCminMOD} = V_{DCmppMOD(70^{\circ}C)} = V_{mpp} \times \left(1 + \frac{T_{max} \times \Delta T}{100\%}\right) \quad (2)$$

Also, the temperature has a significant effect on determining the maximum PV module current. As opposed to what happens with the voltage, the PV module current is highest at high temperature. When the modules are connected in series, the PV module current is the same as the string current as shown in equation (3). It explains the expected maximum DC current at the Maximum temperature for the module at 70$^{0}$C. It is relation between the short circuit current with the maximum temperature of the module and the Temperature variance between STC and maximum expected temperature

$$I_{DCmaxSTR} = I_{DCscMOD(70^{\circ}C)} = I_{Sc} \times \left(1 + \frac{T_{max} \times \Delta T}{100\%}\right) \quad (3)$$

The three aforementioned equations illustrate the important role of the temperature on the voltage and current of the module for both summer and winter.

### *2.3 Experimental results*

The experiment set on a real system for the monocrystalline PV produces 1400 Watts, and combined with the other two types produces a total of 4500 Watts for a system on/off grid integrated with deep cycle batteries (2V, 300A). In total, there were 24 batteries connected in series to feed the Sunny Island inverter which had initial parameters of 48$V_{DC}$ and 120A.

The experiment was set for two months, August and December. August was selected as the summer month as it is generally considered the hottest month of the year in the test region, Egypt, and December was selected as the winter month as it considered the coldest month of the year in Egypt.

The measurement was recorded by a data logger for the system on the SMA portal website. The data of the inputs were: solar irradiation, ambient temperature and module temperature. The outputs of power, DC voltage and current were recorded by the system over the complete year of 2015. Fig. 1 illustrates the total energy yield for 2015 for each month and the three different module types i.e. thin film, monocrystalline and polycrystalline. The system monitoring shows that during the year, the performance of the three types of PV module change according to the meteorological change. The polycrystalline PV gives the highest power value during January, February, March and April, while during June, July, August and September, the thin-film PV gave better performance and highest values of power production. For monocrystalline PV, the curve shows that in the hot months from April to September, the total yield was the lowest with the monocrystalline module. It could be a slight difference but for the big scale installation it should have a significant effect on the power produced.

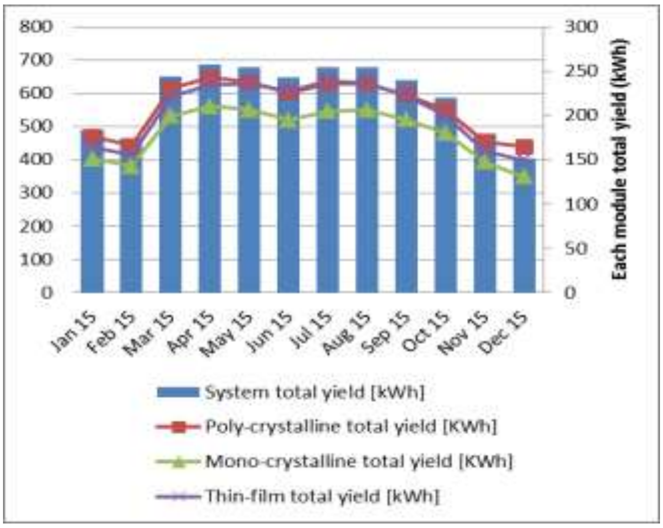


**Fig. 1.** The energy yield produced for a complete year

Table 3 illustrates the values of the maximum output power ($P_{max}$) during the whole month of August calculated from the module temperature ($^0C$), daily solar irradiation ($W/m^2$) and the output voltages created from the panel photons.

**Table 3:** Solar PV power versus the module temperature, the solar irradiation and the output voltage for August

| Day | Module temperature [$^0C$] | Solar irradiation [$W/m^2$] | Output voltage [V] | Maximum power [W] |
|---|---|---|---|---|
| 1 | 56 | 303.160 | 287.833 | 0.931673 |
| 2 | 55 | 289.205 | 287.020 | 0.919000 |
| 3 | 56 | 295.584 | 290.408 | 0.896688 |
| 4 | 56 | 286.548 | 285.408 | 0.873729 |
| 5 | 56 | 290.579 | 278.592 | 0.966306 |
| 6 | 57 | 296.639 | 289.694 | 0.942104 |
| 7 | 55 | 292.202 | 284.286 | 0.942020 |
| 8 | 58 | 290.814 | 283.816 | 0.928184 |
| 9 | 58 | 298.872 | 284.854 | 0.931286 |
| 10 | 58 | 291.332 | 280.542 | 0.961449 |
| 11 | 57 | 282.171 | 281.043 | 0.927146 |
| 12 | 55 | 296.736 | 282.694 | 0.977388 |
| 13 | 55 | 298.132 | 285.229 | 0.988367 |
| 14 | 55 | 302.689 | 288.816 | 0.992080 |
| 15 | 58 | 299.324 | 286.521 | 0.975041 |
| 16 | 59 | 259.647 | 281.306 | 0.877083 |
| 17 | 55 | 275.669 | 279.796 | 0.926816 |
| 18 | 55 | 280.919 | 288.729 | 0.963633 |
| 19 | 55 | 281.527 | 289.633 | 0.961898 |
| 20 | 55 | 290.085 | 286.755 | 0.954208 |
| 21 | 54 | 285.786 | 290.959 | 0.987714 |
| 22 | 54 | 278.103 | 289.184 | 0.975837 |
| 23 | 54 | 272.246 | 290.313 | 0.957184 |
| 24 | 53 | 261.826 | 288.188 | 0.979149 |
| 25 | 53 | 254.049 | 289.043 | 0.986960 |
| 26 | 54 | 255.755 | 288.857 | 0.950708 |
| 27 | 55 | 269.693 | 287.163 | 0.937531 |
| 28 | 55 | 282.337 | 280.938 | 0.965271 |
| 29 | 53 | 273.006 | 287.750 | 1.048776 |
| 30 | 53 | 265.198 | 290.813 | 1.016979 |
| 31 | 54 | 274.548 | 289.854 | 1.017102 |

The following three graphs illustrate separately the effect of each parameter on the power produced. Fig. 2 shows the effect of the module temperature on the output voltages. It is clear on the 16th August, when the module temperature reached 59$^0$C, the produced voltage dropped significantly.

Also the output voltages has dropped on 5th although the temperature was not much high compared to what was on 16th and that means some other parameters like dust or clouds has influence on the output voltages.

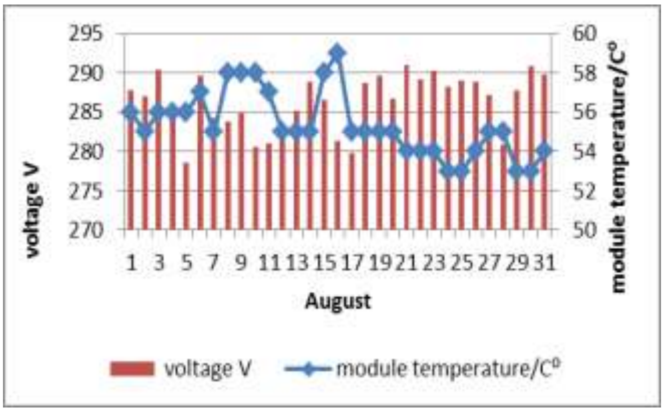


**Fig. 2.** The effect of the module temperature ($^0$C) on the produced voltage (V) during August

Accordingly, the following graph in Fig. 3 shows a drop in energy production on the same day due to the high temperature of the module.

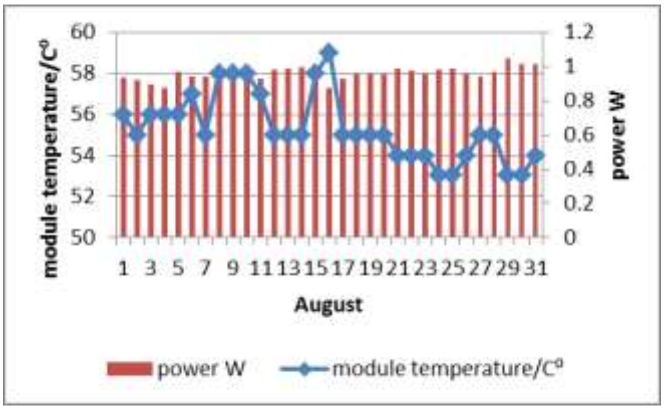


**Fig.3.** The effect of the module temperature ($^0$C) on the produced power (W) during August

Whilst for the 16$^{th}$ the and 25$^{th}$ of August, the solar irradiation has dropped as shown in Fig. 4 the produced power on the 16$^{th}$ has shown a drop in production and on the 25$^{th}$ had no effect. This means that the solar irradiation is not the main parameter leading to a drop in the produced power.

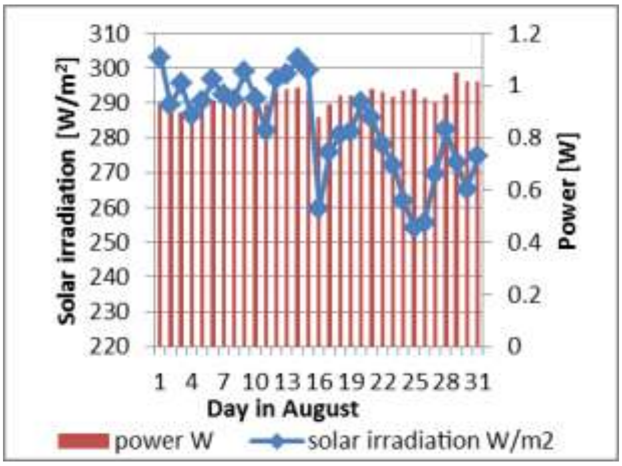


**Fig. 4.** The effect of the solar irradiation (W/m$^2$) on the produced power (W) during August

Table 4 illustrates the value of the maximum output power ($P_{max}$) during the whole month of December calculated from the module temperature ($^0$C), daily solar irradiation (W/m$^2$) and the output voltages (V) created by the module. The reason for described December in 24 days only that there were a malfunction in the Governmental grid in Egypt which made the Sunny Island device can't be operated for the days from 25$^{th}$ till end of December and had no recorded data at this period.

**Table 4:** Solar PV power versus the module temperature, the solar irradiation and the output voltage for December

| Day | Module tempera [$^0$C] | Solar irradiation [W/m$^2$] | Output voltage [V] | Maximum power [W] |
|---|---|---|---|---|
| 1 | 42 | 184.01 | 304.53 | 0.99768 |
| 2 | 42 | 197.44 | 302.78 | 0.95705 |
| 3 | 43 | 157.88 | 303.31 | 0.66000 |
| 4 | 41 | 184.13 | 300.95 | 0.97705 |
| 5 | 39 | 134.00 | 302.08 | 0.90487 |
| 6 | 39 | 220.46 | 308.10 | 0.99213 |
| 7 | 40 | 190.27 | 295.11 | 0.89752 |
| 8 | 41 | 191.31 | 297.69 | 0.90477 |
| 9 | 41 | 170.77 | 298.85 | 0.88840 |
| 10 | 42 | 151.90 | 304.90 | 0.81573 |

| | | | | |
|---|---|---|---|---|
| 11 | 42 | 149.96 | 291.04 | 0.76202 |
| 12 | 41 | 147.57 | 303.58 | 0.83695 |
| 13 | 39 | 103.31 | 298.22 | 0.95429 |
| 14 | 41 | 132.22 | 304.35 | 0.76346 |
| 15 | 41 | 131.48 | 305.25 | 0.84700 |
| 16 | 40 | 122.20 | 313.10 | 0.69466 |
| 17 | 41 | 160.88 | 309.54 | 0.82341 |
| 18 | 40 | 150.89 | 171.98 | 0.88610 |
| 19 | 40 | 128.03 | 174.37 | 0.73892 |
| 20 | 37 | 128.11 | 167.53 | 0.78871 |
| 21 | 40 | 201.77 | 303.05 | 0.55000 |
| 22 | 40 | 171.65 | 313.78 | 0.66264 |
| 23 | 41 | 155.56 | 210.22 | 0.73482 |
| 24 | 40 | 133.15 | 217.02 | 0.65602 |

For Wiinter, December has been selected to be the model month in order to study the effect of the module temperature and the solar irradiation on the output voltage. The following three graphs illustrate separately the effect of each parameter on the power produced. Figure 5 shows the effect of the module temperature on the output voltages. When the module temperature dropped on the 20th of December, the output voltage dropped as well. But when the module temperature dropped on the 5th, 6th and 13th, the output voltage showed high values. This means that the module temperature behind the NOCT value, which is 47°C for the tested module, has no significant effect on the output voltage. For 20th the voltage dropped which was unexpected and that was because of the dust accumulated on the panels after a rainy day on 19th .

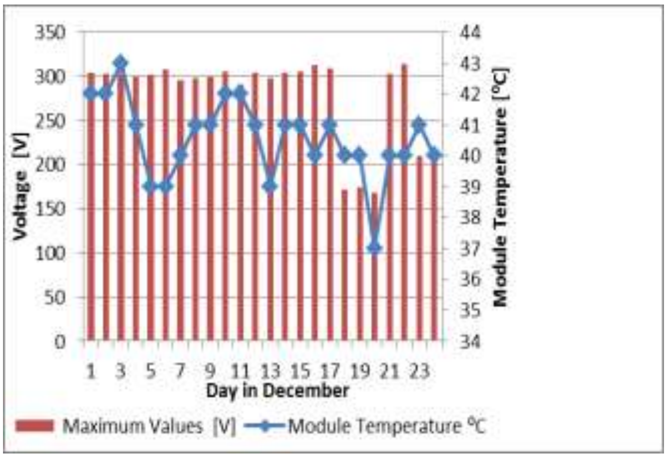


**Fig. 5.** The effect of the module temperature (°C) on the produced voltage (V) during December

The following graph in Fig. 6 shows a drop in energy production on the 20st of December according to the drop that happened in the module temperature, whilst on the 5th and the 7th the module temperature dropped but the power produced was in its high values for the month.

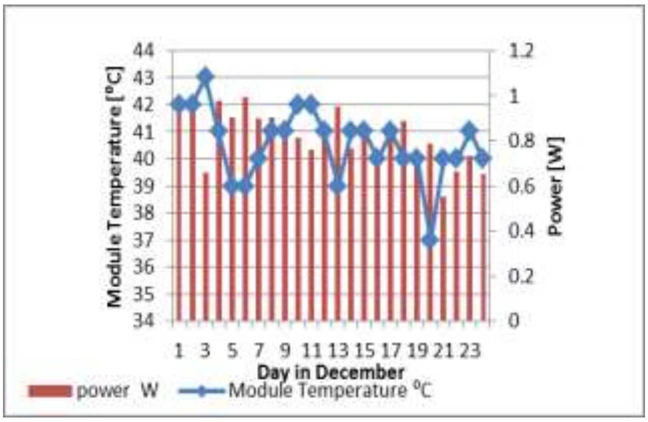


**Fig.6.** The effect of the modüle temperature (ºC) on the produced power (W) during december

Figure 7 shows that on the 5th and the 6th of December, the power has been affected by the solar irradiation. When the solar irradiation dropped, the produced power dropped. On the 20th the produced power dropped whilst the solar irradiation was high.

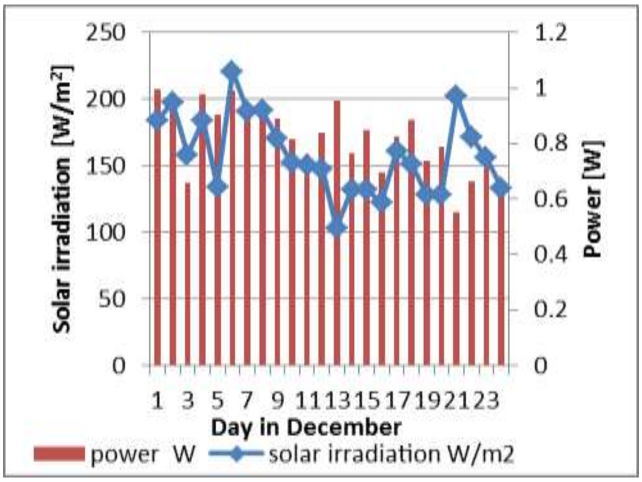


**Fig. 7.** The effect of the solar irradiation (W/m$^2$) on the produced power (W) during December

From the previous six Figures demonstrating the relationships between produced power and module temperature, output voltage and solar irradiation, we can make some conclusions. The thermal characteristic value of the module plays an important role to obtain the maximum power from the panel. In the monocrystalline case, the relation between the temperature and the power is a direct relation until the module reaches the NOCT value then the relation is revered to be an inverse relation. Fig. 8 is the confirmation of the inverse relation between the module temperature and the output voltage when the module temperature reaches above the NOCT value.

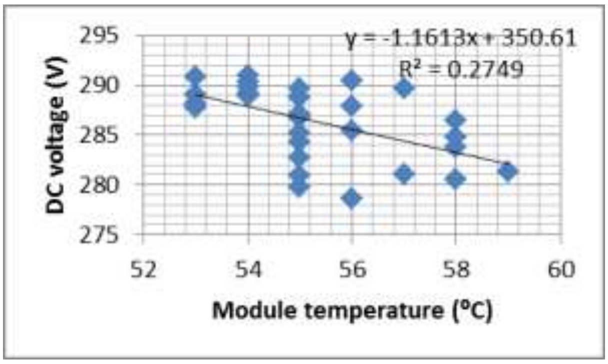


**Fig. 8.** The inverse relationship between module temperature ($^0$C) and output voltage (V) at during August

## 3. Validation Experiment with MATLAB Simulation:

MATLAB simulation tool was used to set the module type, the expected I-V curve and the output power for two months, August as a summer month and December as a winter month. The validation of the experimental results was applied by Matlab/Simulink simulation. The simulation validated the results using the data sheet for the three PV modules, thin-film, polycrystalline and monocrystalline shown respectively from top to bottom in Fig. 9.

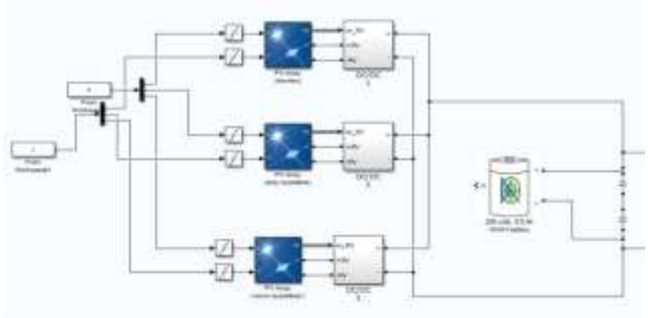

**Fig. 9.** The MATLAB simulation block for the three PV modules

The following equations (4) and (5) are the simulation equations that illustrate the I-V characteristics curve for the single module:

$$I_d = I_0 \left(\exp\left[\frac{V_d}{V_T}\right] - 1\right) \quad (4)$$

$$V_T = \frac{K_T}{q} \times nI \times N_{cell} \quad (5)$$

Where:

| | |
|---|---|
| $I_d$ | Diode current (A) |
| $V_d$ | Diode voltage (V) |
| $I_0$ | Diode saturation current (A) |
| *nI* | Diode ideality factor, a number close to 1.0 |
| *K* | Boltzmann constant = 1.3806e$^{-23}$ J.K$^{-1}$ |
| *q* | Electron charge = 1.6022e$^{-19}$ C |
| *T* | Cell temperature (K) |
| *Ncell* | Number of cells connected in series |

The simulation system runs for two models, 56$^0$C representing summer and 40$^0$C representing winter. The solar irradiation for both models was 1000 W/m$^2$. The actual measurements illustrate the variation of solar irradiation, whilst the simulation represents fixed solar irradiation at 1000$^0$C.

Figure 10 presents the I-V characteristics of the module at 56$^0$C which refer to the average temperature during the month of August as well as the power versus voltage characteristics.

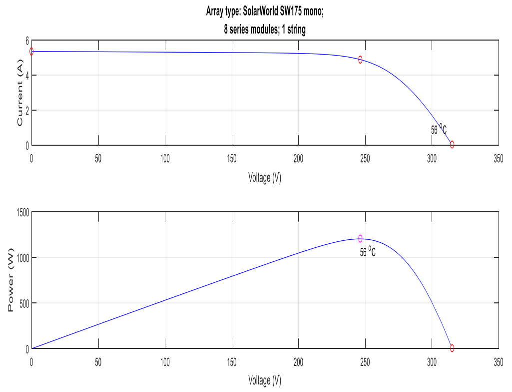


**Fig. 10.** The I-V and power curves for monocrystalline PV at $56^0$C

Figure 11 presents the I-V characteristics curve for the average module temperature of $40^0$C, representing the average temperature of December. Also, the power curve versus the output voltage at the same temperature is shown.

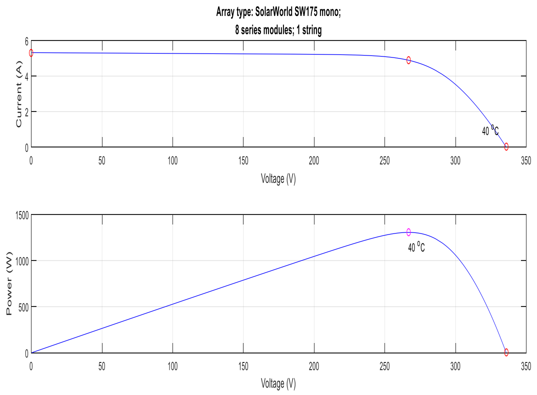


**Fig. 11.** The I-V and power curves for monocrystalline PV at $40^0$C

## Conclusion

The comparison between the results of the real experiment and the simulation were in agreement with an approximate error of ±8% where the positive sign goes for the simulation in August. This agrees with the literature. On the other hand, the positive sign goes for the real experiment in December. The results met with the previous work that the temperature has an effect on the power produced, and this effect is significant when the temperature exceeds the NOCT value. Also, the paper confirmed that there is a clear difference between the module simulation and the real experiment and this is because there are other parameters than the module's description that have an effect on the DC model, other than the solid state theory. The simulations programs should contain additional parameters in order to increase the accuracy for further analysis of the power produced. When the temperature exceeds the NOCT, the results agree with the previous researches that the output power decreases only by 0.4% when the temperature increase is equal to 1K more than the NOCT value [24]. The new technologies for PV nowadays trying to increase the NOCT values to be more adapted to the hot countries.

The location also has an effect on the power produced, and in areas like the desert of El-Sharqia, Egypt, there is both direct and diffused radiation. This means that in some days when the temperature is high, the DC current produced is not as high as expected since the solar irradiation is almost 50% direct and 50% diffused, hence the power produced will be less than that expected. In other areas like the Sahara of West Egypt, the percentages of direct solar irradiation and diffused irradiation are 80% and 20% respectively. Further research should contribute to specify the effect of solar irradiation and the temperature rise for the huge plants planned to be installed in the Sahara of Egypt because each single drop in power reflects to more $CO_2$ emission from traditional power plants. The type of module should be selected carefully by selecting the type of high NOCT adequate to a hot climate like Egypt.

Future research will illustrate the power produced for three different types of PV in hot climates like the Sahara of Egypt.

## Acknowledgements

The author is very grateful for the support of the team and the Energy Department of Heliopolis University for Sustainable Development, as well as the SMA inverter manufacturer in Egypt and Dubai for their support in adjusting the data logger for the system monitoring. Also, many thanks to Mr. Maximilian Abouleish for allowing the author to access the data logger system to analyze the data recorded.

**References**

[1] S. Dubey and B. S. , Jatin Narotam Sarvaiya, “Temperature Dependent Photovoltaic (PV) Efficiency and Its Effect on PV Production in the World A Review,” *Energy Procedia*, vol. 33, pp. 311–321, 2013.

[2] E. Radziemska, “The effect of temperature on the power drop in crystalline silicon solar cells,” *Renew. Energy ELSEVIER*, vol. 28, no. 1, pp. 1–12, 2003.

[3] E. V. Vivar M, Clarke M, Pye J, “A review of standards for hybrid CPV-thermal systems,” *Renew. Sustaiable Energy Rev.*, vol. 16, pp. 443–448, 2012.

[4] E. R. E. Klugmann, “Thermally affected parameters of the current–voltage characteristics of silicon photocell,” *Energy Convers. Manag.*, vol. 43, no. 14, pp. 1889–1900, 2002.

[5] A. Al-khazzar, “Behavior of Four Solar PV Modules with Temperature Variation,” 2016.

[6] T. C. F. G. and J. R. M. R. Rashel, A. Albino, M. Tlemcani, “MATLAB Simulink modeling of photovoltaic cells for understanding shadow effect,” in *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Birmingham*, 2016, pp. 747–750.

[7] H. A. R. and M. Y. H. M. Almaktar, “Effect of losses resistances, module temperature variation, and partial shading on PV output power,” in *EEE International Conference on Power and Energy (PECon), Kota Kinabalu*, 2012, pp. 360–365.

[8] G. Patrono, S. Vergura, and A. Massi Pavan, “LCOE for Zero-Energy Greenhouse,” in *2015 International Conference on Renewable Energy Research and Applications, ICRERA 2015*, 2015.

[9] R. Pillai, G. Aaditya, M. Mani, and P. Ramamurthy, “Cell (module) temperature regulated performance of a building integrated photovoltaic system in tropical conditions,” *Renew. Energy*, 2014.

[10] A. A. E.-A. Ibrahim, A., “Temperature Effect on the Performance of N-type c -Si Film Grown by Linear Facing Target Sputtering for Thin Film Silicon Photovoltaic Devices,” *Int. J. Renew. ENERGY Res.*, vol. 2, no. NO.1, 2012.

[11] V. V. Ramana, D. Jena, and D. N. Gaonkar, “An accurate modeling of different types of photovoltaic modules using experimental data,” *Int. J. Renew. Energy Res.*, vol. 6, no. 3, 2016.

[12] P. Mohanty, T. Muneer, E. J. Gago, and Y. Kotak, “Solar radiation fundamentals and PV system components,” in *Green Energy and Technology*, vol. 196, Springer International Publishing Switzerland, 2016, pp. 7–47.

[13] A. Sayyah, M. N. Horenstein, and M. K. Mazumder, “Energy yield loss caused by dust deposition on photovoltaic panels,” *Sol. Energy*, vol. 107, 2014.

[14] M. C. Alonso Garca and J. L. Balenzategui, “Estimation of photovoltaic module yearly temperature and performance based on Nominal Operation Cell Temperature calculations,” *Renew. Energy*, 2004.

[15] D. C. M. and J. C. P. N. M. Martins da Rocha, “MPPT method based on temperature control of the photovoltaic cells,” in *2016 12th IEEE International Conference on Industry Applications (INDUSCON), Curitiba*, 2016, pp. 1–8.

[16] A. Weiss; H. Weiss, “Photovoltaic cell electrical heating system for removing snow on panel including verification,” in *IEEE International Conference on Renewable Energy Research and Applications (ICRERA)*, 2016, pp. 995–1000.

[17] E. B. and A. K. D. O. Esen, “An experimental investigation of thermoelectric cooling with solar panel,” in *International Conference on Renewable Energy Research and Applications (ICRERA)*, 2012, pp. 1–6.

[18] E. Skoplaki and J. A. Palyvos, “Operating temperature of photovoltaic modules: A survey of pertinent correlations,” *Renew. Energy*, 2009.

[19] D. P. G. and R. D. Gautam, D. B. Raut, P. Neupane, “Maximum power point tracker with solar prioritizer in photovoltaic application,” in *2016 IEEE International Conference on Renewable Energy Research and Applications (ICRERA), Birmingham*, 2016, pp. 1051–1054.

[20] G. Makrides, B. Zinsser, A. Phinikarides, M. Schubert, and G. E. Georghiou, “Temperature and thermal annealing effects on different photovoltaic technologies,” *Renew. Energy*, 2012.

[21] M. A. M. R. and N. A. N. H. Zaini, M. Z. A. Kadir, M. Izadi, N. I. Ahmad, “he effect of temperature on a mono-crystalline solar PV panel,” in *2015 IEEE Conference on Energy Conversion (CENCON), Johor Bahru*, 2015, pp. 249–253.

[22] and D. B. S.W. Gulnz, R. Preu, “Crystalline silicon solar cells- state of the art and future development,” in *Comprehensive renewable energy. vol 1*, 2012, p. Chapter 1.16.

[23] S. Guideline, “SMA Solar technology AG,” *WWW.SMA.DE*, 2014. [Online]. Available: WWW.SMA.ED.

[24] H. H. T.Rogass, “Latent heat storage on photovoltaic,” in *Sixteenth European Photovoltaic Solar Energy Conference, Glasgow, uk*, 2000, pp. 2265–2267.