International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2022 Issue 51 Volume 14 Number 2 Pages 254-260

EFFECTS OF TEMPERATURE AND SOLAR IRRADIATION ON PERFORMANCE OF MONOCRYSTALLINE, POLYCRYSTALLINE AND THIN-FILM PV PANELS

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Abstract- Electrical energy is obtained by utilizing solar energy using photovoltaic (PV) panels. However, the efficiency of PV panels is low, and changes in environmental conditions (temperature, solar irradiation, dust, etc.) reduce the efficiency further. In this study, the panels were modeled in the PSIM program by using the catalog values of monocrystalline, polycrystalline and amorphous silicon thin-film PV panels with a power value of 100 W. The power performances of the modeled PV panels at temperature and solar irradiation changes were analyzed. In the study, characteristic curves were obtained by adjusting the temperature changes of the panels to be 0, 25, 50 °C and the solar irradiation changes to 250, 500, 750 and 1000 W/m^2. According to the power results obtained, it was determined that the monocrystalline PV panel was most affected by the temperature change and the polycrystalline PV panel was the least affected, while the monocrystalline PV panel was affected slightly more than the other structured PV panels in the change of solar irradiation.

Keywords: Photovoltaic Panel, Solar Irradiation, Temperature.

1. INTRODUCTION

There has been the demand for electrical energy with the increase in population, industrialization, developing technology and the increase in the welfare of societies. However, most of the electrical energy is obtained from fossil-based fuels, which causes serious environmental problems. Due to the environmental pollution caused by fossil-based fuels, limited and exhaustible reserves, the tendency towards renewable energy sources, especially solar energy and wind energy, which are environmentally friendly and inexhaustible resources, has increased [1]. Solar energy, which is one of the renewable energy sources, is inexhaustible, environmentally friendly, easy to use and reliable, making it more preferable and widespread than other renewable energy sources [2].

PV panels provide electrical energy production from solar energy. Solar cells are the smallest unit of the system that converts sunlight directly into usable electrical energy.

PV modules are obtained by connecting these solar cells in series or parallel. PV modules are combined in series-parallel to form a PV panel. The efficiency of PV panels varies between 5% and 20% depending on the semiconductor material used in its structure [3, 4]. Location, shading, inclination angle, reflection, dusting, temperature, solar irradiation and losses are among the factors affecting panel efficiency [5].

Among these parameters, solar irradiation and temperature are the two most important parameters affecting PV panels. Temperature and solar irradiation values change with the change of atmospheric conditions, and panel efficiency is significantly affected. For this reason, it is very important to know the effect of temperature and solar irradiation on panel efficiency in changing atmospheric conditions. In the catalogs of manufacturers, electrical and mechanical values of PV panels are given under the conditions of 1000 W/m² solar irradiation, 25 °C cell temperature and AM (rate of sunlight transmission of the atmosphere) 1.5, which are called Standard Test Conditions (STC). It is necessary to know the electrical values of PV panels at different values than the STC values and to design PV panels in accordance with these values [4-7].

In this study, monocrystalline, polycrystalline and amorphous silicon thin-film PV panels were modeled in PSIM program by using catalog data. The changes on the panel current, voltage and power of each PV panel at 0, 25, 50 °C temperatures and 250, 500, 750, 1000 W/m² solar irradiation were investigated. In the conclusion part, the monocrystalline, polycrystalline and amorphous silicon PV panels were compared according to their exposure to temperature and solar irradiation and the optimum temperature and solar irradiation values were evaluated.

2. MATHEMATICAL MODEL OF THE PHOTOVOLTAIC CELL

There are two mathematical models, single-diode and two-diode model of the PV cell. Figure 1 shows the circuit of a single-diode PV cell model [8].

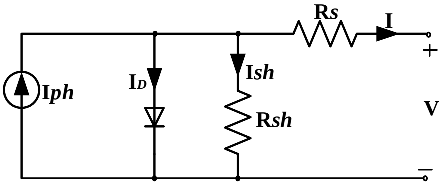


Figure 1. A single-diode PV cell model [8]

The output current (I), saturation current (I_s), reverse saturation current (I_{rs}) and photovoltaic current of the PV cell (I_{ph}) is calculated as follow [9].

$$I = I_{ph} - I_s\left(e^{\left(\frac{V+I.R_s}{A.N_s V_T}\right)} - 1\right) - \frac{V+I.R_s}{R_{sh}} \tag{1}$$

$$I_s = I_{rs}\left(\frac{T_{op}}{T_{ref}}\right)^3 e^{\left(\frac{-q\varepsilon_G}{A.k}\left(\frac{1}{T_{op}} - \frac{1}{T_{ref}}\right)\right)} \tag{2}$$

$$I_{rs} = \frac{I_{sc}}{e^{\left(\frac{V_{oc}}{A.N_s V_T}\right)} - 1} \tag{3}$$

$$I_{ph} = (G/1000) \times (I_{sc} + \alpha_{I_{sc}} \times \Delta T) \tag{4}$$

where,
I_{ph}: Photovoltaic current of the PV cell
I_D: Parallel diode current
I_{sh}: Shunt current
I_{sc}: Short circuit current (A) at STC
R_{sh}: Shunt resistance
R_s: Series resistance
V: Output voltage
I_{rs}: Diode reverse saturation current(A)
G: Irradiance (W/m^2)
T_c: Operating cell temperature (K)
$T_{c,ref}$: Cell temperature at STC (25 + 273 = 298 K)
α_{Isc}: Coefficient temperature of I_{sc}
q: Charge of electron (1.602×10^{-19} C)
ε_G: Physical band gap energy (eV)
A: Ideality factor
k: Boltzmann constant (1.38×10^{-23} J/K)
Δt: T_c - $T_{c,ref}$ (K)

3. PSIM SIMULATION OF PV PANEL

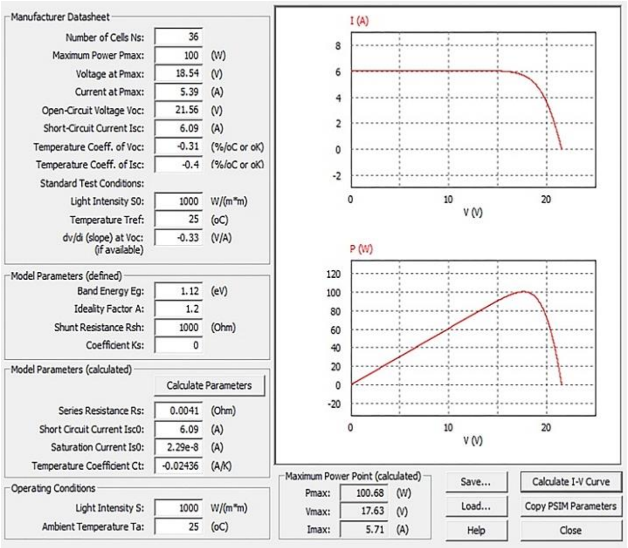
Basic parameters are required for the physical model of the PV panel. These parameters are the values in the catalogs provided by the manufacturer. Figure 2 shows the solar modulator of the PV panel modeled in the PSIM program.

For the simulation study, the circuit in Figure 3 was established and the values in the catalogs were used.

3.1. Monocrystalline PV Panel

For the monocrystalline PV panel simulation study, the catalog values of the Lexron brand SPM100 panel were used. Catalog values of the monocrystalline PV panel are given in Table 1 [10].

Monocrystalline PV panel at temperatures of 0, 25, 50 °C and the power-voltage and current-voltage characteristics at 250, 500, 750, 1000 W/m² solar irradiation were investigated.



Manufacturer Datasheet
Number of Cells Ns: 36
Maximum Power Pmax: 100 (W)
Voltage at Pmax: 18.54 (V)
Current at Pmax: 5.39 (A)
Open-Circuit Voltage Voc: 21.56 (V)
Short-Circuit Current Isc: 6.09 (A)
Temperature Coeff. of Voc: -0.31 (%/oC or oK)
Temperature Coeff. of Isc: -0.4 (%/oC or oK)
Standard Test Conditions:
Light Intensity S0: 1000 W/(m*m)
Temperature Tref: 25 (oC)
dv/di (slope) at Voc: (if available) -0.33 (V/A)

Model Parameters (defined)
Band Energy Eg: 1.12 (eV)
Ideality Factor A: 1.2
Shunt Resistance Rsh: 1000 (Ohm)
Coefficient Ks: 0

Model Parameters (calculated)
Series Resistance Rs: 0.0041 (Ohm)
Short Circuit Current Isc0: 6.09 (A)
Saturation Current Is0: 2.29e-8 (A)
Temperature Coefficient Ct: -0.02436 (A/K)

Operating Conditions
Light Intensity S: 1000 W/(m*m)
Ambient Temperature Ta: 25 (oC)

Maximum Power Point (calculated)
Pmax: 100.68 (W)
Vmax: 17.63 (V)
Imax: 5.71 (A)

Figure 2. Solar modulator in PSIM for PV panel

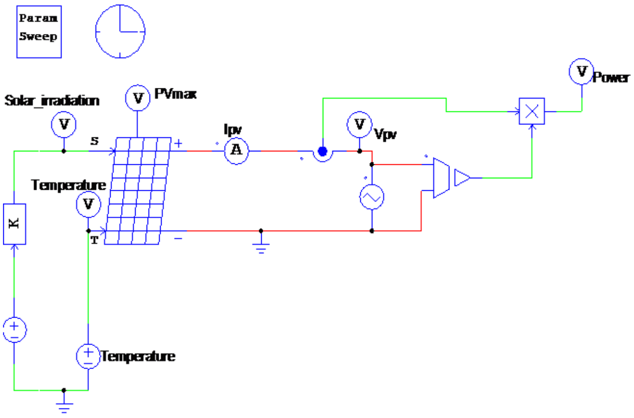


Figure 3. PSIM circuit of the PV panel

Table 1. Monocrystalline PV panel catalog values [10]

Electrical and Mechanical Properties of Monocrystalline PV Panel	Symbol	Numerical Values
Maximum panel power	P_{mpp}	100 W
Maximum power voltage	V_{mpp}	18.54 V
Maximum power current	I_{mpp}	5.39 A
Open circuit voltage	V_{oc}	21.56 V
Short circuit current	I_{sc}	6.09 A
Panel efficiency	η_m	16.27%
Number of cells		36
Operating temperature		-40 °C - +85 °C

In Table 2, the current, voltage and power values obtained in PSIM according to the changes in temperature and solar irradiation are given.

3.2. Polycrystalline PV Panel

For the polycrystalline PV panel simulation study, the catalog values of the Tera solar brand TRP-100B panel were used. Catalog values of the polycrystalline PV panel are given in Table 3 [11]. Polycrystalline PV panel at temperatures of 0, 25, 50 °C and the power-voltage and current-voltage characteristics at 250, 500, 750, 1000 W/m² solar irradiation were investigated.

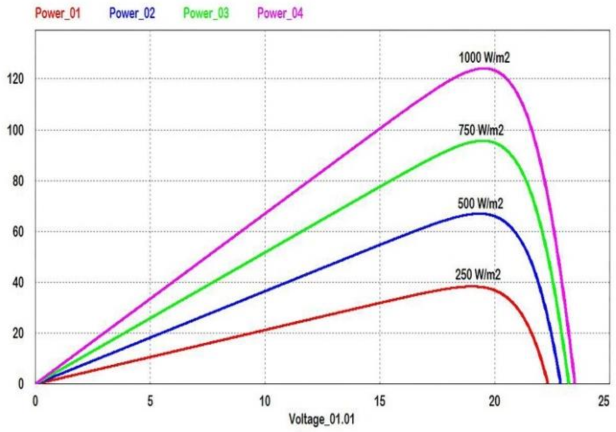


Figure 4. *P-V* curve of the monocrystalline PV panel under constant temperature (0 °C)

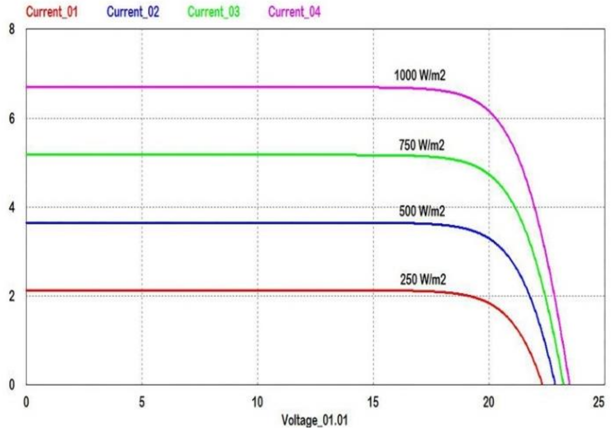


Figure 5. *I-V* curve of the monocrystalline PV panel under constant temperature (0 °C)

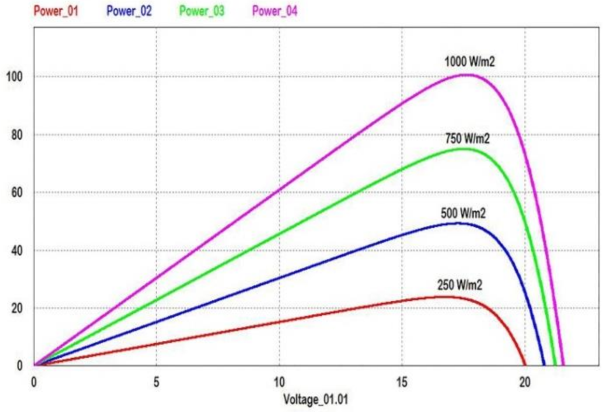


Figure 6. *P-V* curve of the monocrystalline PV panel under constant temperature (25 °C)

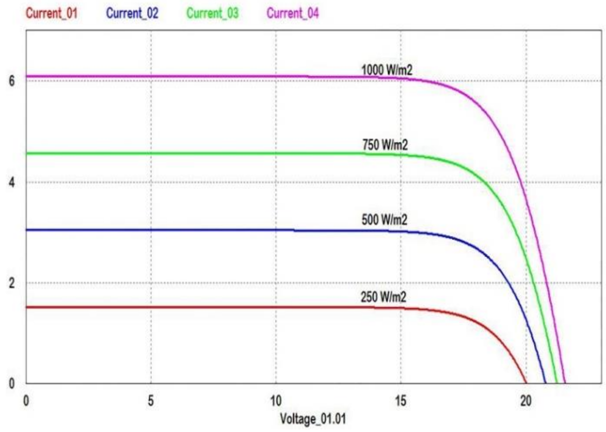


Figure 7. *I-V* curve of the monocrystalline PV panel under constant temperature (25 °C)

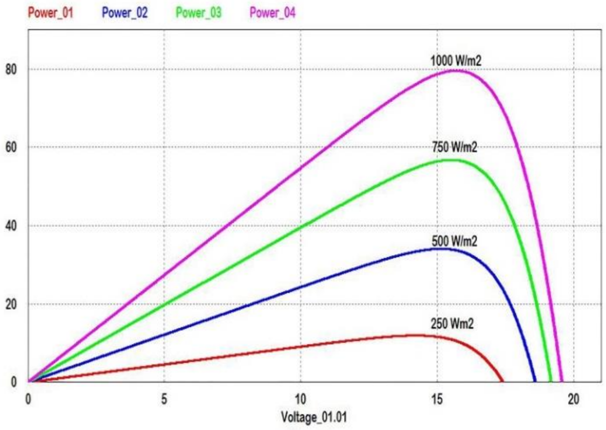


Figure 8. *P-V* curve of the monocrystalline PV panel under constant temperature (50 °C)

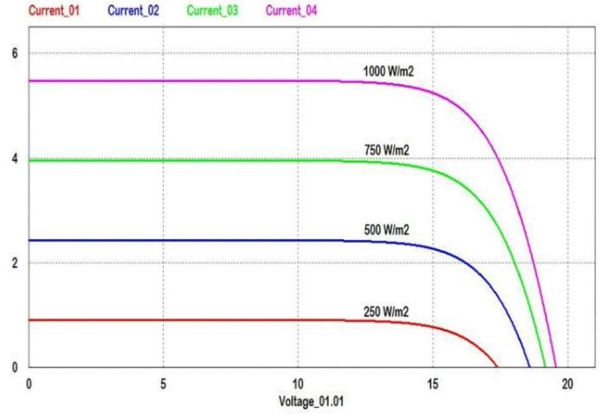


Figure 9. *I-V* curve of the monocrystalline PV panel under constant temperature (50 °C)

Table 2. PSIM result of monocrystalline PV panel

Temperature		Solar Irradiation (W/m²)			
		250	500	750	1000
0 °C	I_{mpp}	1.95 A	3.38 A	4.79 A	6.22 A
	V_{mpp}	19.51 V	19.70 V	19.87 V	19.89 V
	P_{mpp}	38.04 W	66.58 W	95.17 W	123.71 W
25 °C	I_{mpp}	1.39 A	2.81 A	4.26 A	5.61 A
	V_{mpp}	17.10 V	17.51 V	17.59 V	17.91 V
	P_{mpp}	23.76 W	49.20 W	74.93 W	100.47 W
50 °C	I_{mpp}	0.83 A	2.15 A	3.55 A	4.92 A
	V_{mpp}	14.24 V	15.69 V	15.91 V	16.08 V
	P_{mpp}	11.81 W	33.73 W	56.48 W	79.11 W

Table 3. Polycrystalline PV panel values [11]

Electrical and Mechanical Properties of Polycrystalline PV Panel	Symbol	Numerical Values
Maximum panel power	P_{mpp}	100 W
Maximum power voltage	V_{mpp}	18.35 V
Maximum power current	I_{mpp}	5.45 A
Open circuit voltage	V_{oc}	22.52 V
Short circuit current	I_{sc}	5.78 A
Panel efficiency	η_m	17.5%
Number of cells		36
Operating temperature		-40 °C - +85 °C

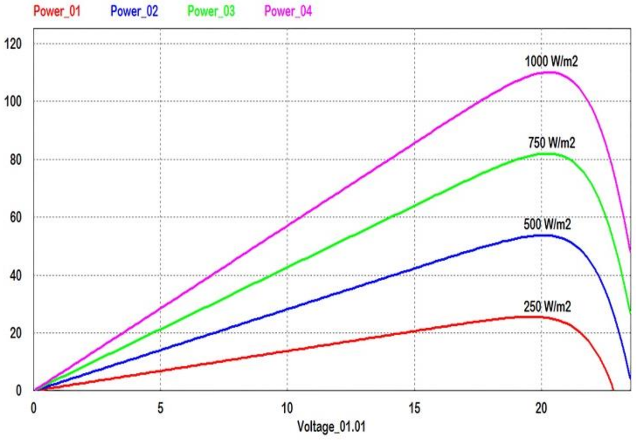


Figure 10. *P-V* curve of the polycrystalline PV panel under constant temperature (0 °C)

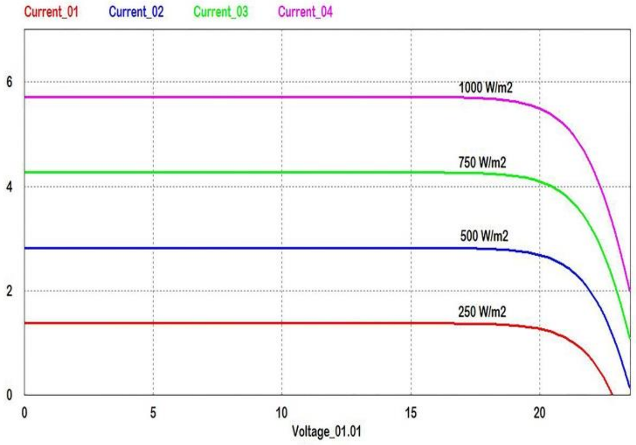


Figure 11. *I-V* curve of the polycrystalline PV panel under constant temperature (0 °C)

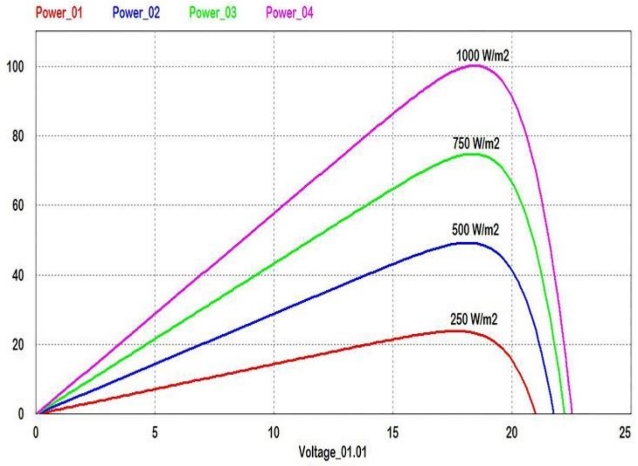


Figure 12. *P-V* curve of the polycrystalline PV panel under constant temperature (25 °C)

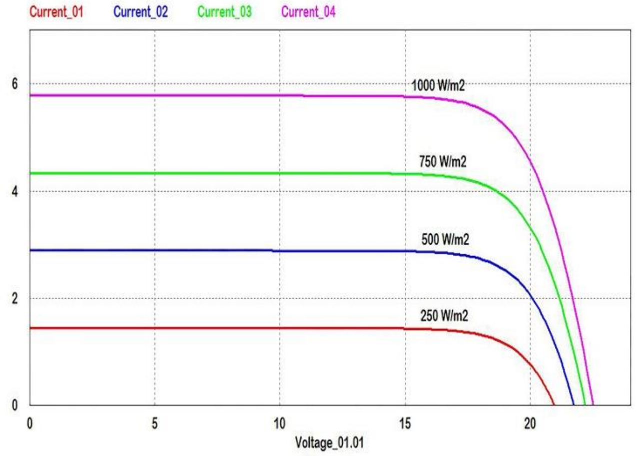


Figure 13. *I-V* curve of the polycrystalline PV panel under constant temperature (25 °C)

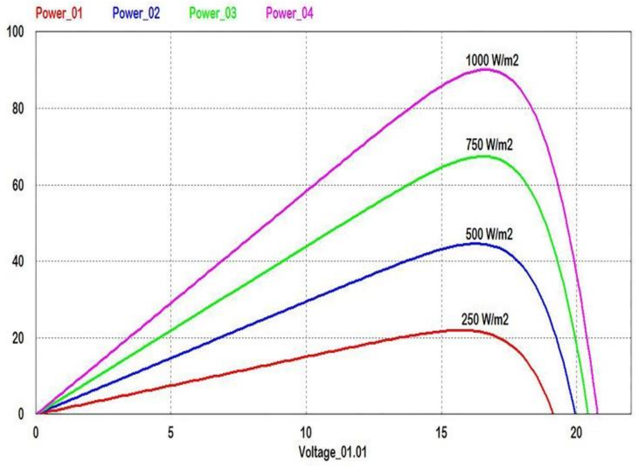


Figure 14. *P-V* curve of the polycrystalline PV panel under constant temperature (50 °C)

In Table 4, the current, voltage and power values obtained in PSIM according to the changes in temperature and solar irradiation are given.

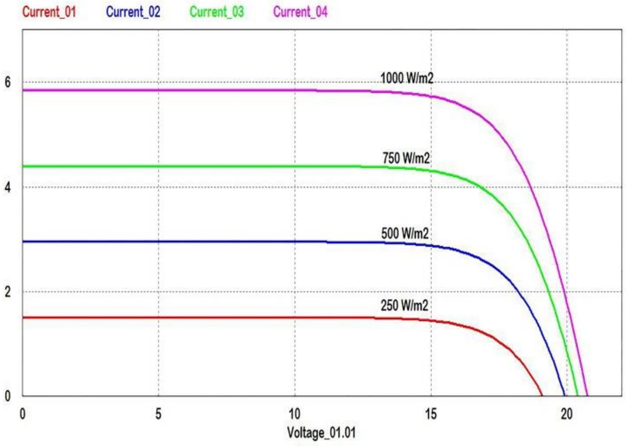


Figure 15. *I-V* curve of the polycrystalline PV panel under constant temperature (50 °C)

Table 4. PSIM result of polycrystalline PV panel

Temperature		Solar Irradiation (W/m²)			
		250	500	750	1000
0 °C	I_{mpp}	1.29 A	2.69 A	4.06 A	5.36 A
	V_{mpp}	19.76 V	19.90 V	20.15 V	20.46 V
	P_{mpp}	25.49 W	53.53 W	81.80 W	109.66 W
25 °C	I_{mpp}	1.36 A	2.74 A	4.06 A	5.41 A
	V_{mpp}	17.61 V	17.97 V	18.41 V	18.51 V
	P_{mpp}	23.94 W	49.23 W	74.74 W	100.13 W
50 °C	I_{mpp}	1.40 A	2.73 A	4.09 A	5.43 A
	V_{mpp}	15.68 V	16.31 V	16.46 V	16.60 V
	P_{mpp}	21.95 W	44.52 W	67.32 W	90.13 W

3.3. Amorphous Silicon Thin-Film PV Panel

For the amorphous silicon thin-film PV panel simulation study, the catalog values of the Schott brand Schott ASI 100 panel were used. Catalog values of the amorphous silicon thin-film PV panel are given in Table 5 [12].

Table 5. Amorphous silicon thin-film PV panel catalog values [12]

Electrical and Mechanical Properties of Amorphous Silicon PV Panel	Symbol	Numerical Values
Maximum panel power	P_{mpp}	100 W
Maximum power voltage	V_{mpp}	30.7 V
Maximum power current	I_{mpp}	3.25 A
Open circuit voltage	V_{oc}	40.9 V
Short circuit current	I_{sc}	3.85 A
Panel efficiency	η_m	6.9%
Number of cells		72
Operating temperature		-40 °C…+85 °C

Amorphous silicon thin-film PV panel at temperatures of 0, 25, 50 °C and the power-voltage and current-voltage characteristics at 250, 500, 750, 1000 W/m² solar irradiation were investigated.

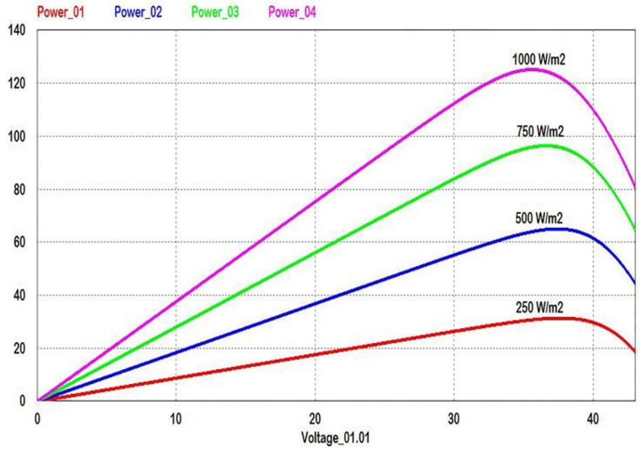


Figure 16. *P-V* curve of the amorphous silicon thin-film PV panel under constant temperature (0 °C)

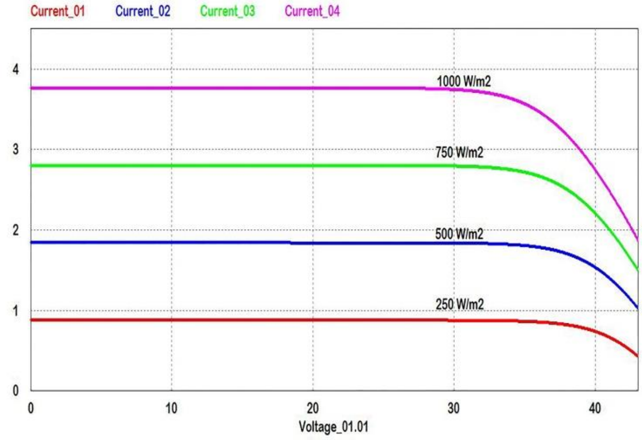


Figure 17. *I-V* curve of the amorphous silicon thin-film PV panel under constant temperature (0 °C)

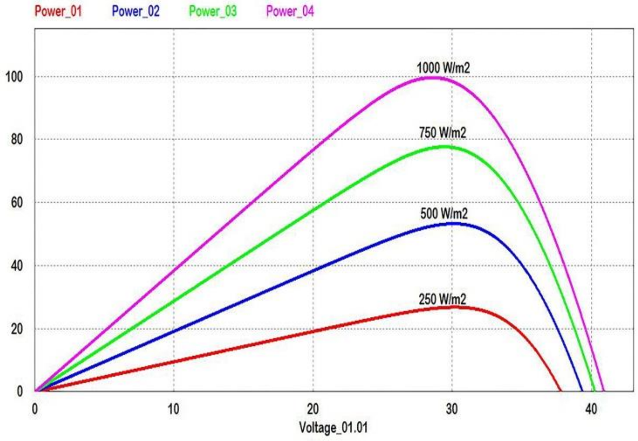


Figure 18. *P-V* curve of the amorphous silicon thin-film PV panel under constant temperature (25 °C)

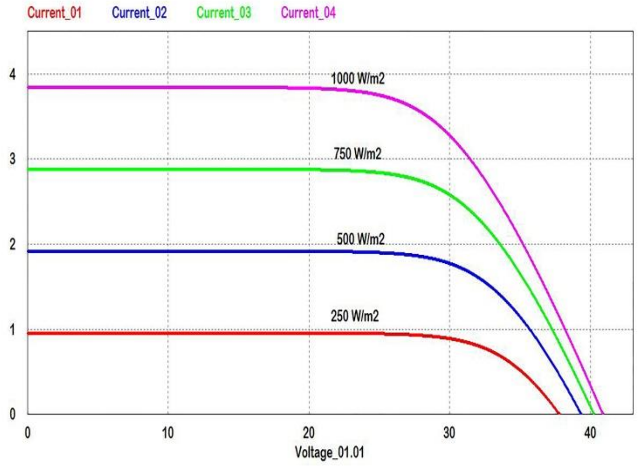


Figure 19. *I-V* curve of the amorphous silicon thin-film PV panel under constant temperature (25 °C)

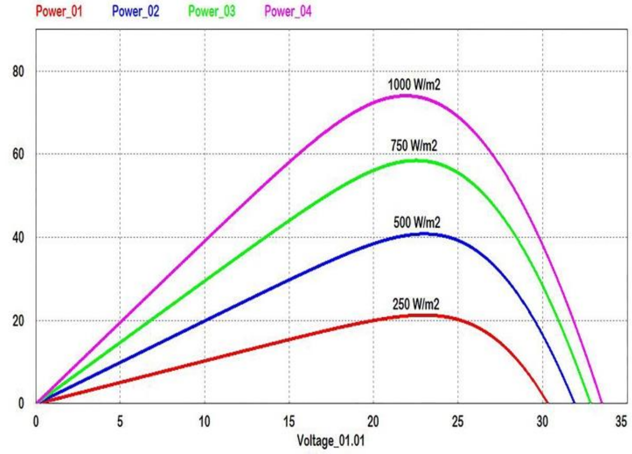


Figure 20. *P-V* curve of the amorphous silicon thin-film PV panel under constant temperature (50 °C)

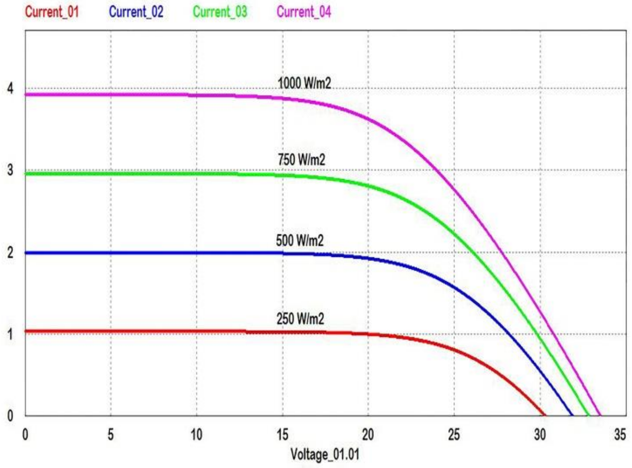


Figure 21. *I-V* curve of the amorphous silicon thin-film PV panel under constant temperature (50 °C)

In Table 6, the current, voltage and power values obtained in PSIM according to the changes in temperature and solar irradiation are given.

Table 6. PSIM result of amorphous silicon thin-film PV panel

Temperature		Solar Irradiation (W/m²)			
		250	500	750	1000
0 °C	I_{mpp}	0.82 A	1.73 A	2.62 A	3.51 A
	V_{mpp}	38.28 V	37.64 V	36.85 V	35.70 V
	P_{mpp}	31.38 W	65.11 W	96.54 W	125.30 W
25 °C	I_{mpp}	0.86 A	1.77 A	2.63 A	3.45 A
	V_{mpp}	31.06 V	30.04 V	29.56 V	28.83 V
	P_{mpp}	26.71 W	53.17 W	77.74 W	99.46 W
50 °C	I_{mpp}	0.92 A	1.77 A	2.61 A	3.34 A
	V_{mpp}	23.31 V	23.05 V	22.44 V	22.19 V
	P_{mpp}	21.44 W	40.79 W	58.56 W	74.11 W

4. CONCLUSIONS

According to the results obtained by the simulation test conducted using the PSIM program, it was found that panel currents in monocrystalline and polycrystalline PV panels increased depending on the increase in solar irradiation. On the other hand, panel voltages less increased depending on the increase in solar irradiation. In the amorphous silicon thin-film PV panel, the increase in solar irradiation increased the panel current proportionally, and the panel voltage slightly decreased. Due to the increase in temperature, the voltage and the current decreased in the monocrystalline PV panel.

Therefore, the power of the monocrystalline PV panel also decreased. As the temperature increased in the polycrystalline PV panel, the panel current increased and the voltage decreased. Since the decrease in voltage was higher, the power of the polycrystalline PV panel also decreased. In the amorphous silicon thin-film PV panel, the panel current increased or decreased and the voltage decreased as the temperature increased. Since the decrease in voltage was higher, the power of the amorphous silicon PV panel also decreased.

When examined in terms of the obtained power, the temperature change affected the monocrystalline PV panel more, while it less affected the polycrystalline PV panel. When examined in terms of the obtained power, the change in solar irradiation affected the monocrystalline PV panel more, and the amorphous silicon thin-film PV panel was less affected. According to these results, it has been concluded that low temperature and high solar irradiation are the most suitable situations for obtaining maximum power from PV panels.

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BIOGRAPHIES

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