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Temperature and Solar Radiation Effects on Photovoltaic Panel Power

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Abstract – Solar energy is converted to electrical energy directly by semi-conductors materials used in Photovoltaic (PV) panels. Although, there has been great advancements in semi-conductor material technology in recent years panel efficiency is very lower. There are many factors affecting the panel efficiency such as tilt angle, shading, dust, solar radiation level, temperature and wiring losses. Among these factors, solar radiation level and temperature are more prominent. The solar radiation level falling on the PV panels varies depending on the location of the panel and the time intervals in a day. Therefore, solar radiation level has a direct effect on the panel power. As a result, a decrease in solar radiation level reduces the panel power. On the other hand, there is an inverse proportion between temperature and panel power. In other words, panel power decreases as the ambient temperature increases. In this study, the equivalent circuit of the panel is simulated at PSIM and MATLAB using the catalogue data of the PV panel and the temperature and the solar radiation effects on the PV panel power are examined.

Keywords - *PV panel, temperature, solar radiation, PSIM, MATLAB.*

1. Introduction

There has been a great electrical energy demand in recent years due to the increasing population and industrialization rate. Most of the electrical energy is met by fossil fuels such as oil, natural gas and coil. However, many environmental problems arise depending on the use fossil fuels. Moreover, the fact that these energy sources will run out in the near

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future has led to the use of renewable energy sources. Solar energy- one of the renewable energy sources- affects the formation of the other renewable energy sources indirectly. Furthermore, solar energy has become more attractive since it is clean, renewable and easy to use [1, 2].

Solar cell is the smallest part of the PV systems converting the solar radiation to dc voltage directly. Solar cells form the PV module by being connected in series or parallel. A PV panel with the required current, voltage and power values is obtained by connecting the modules in series-parallel form [3, 4]. Solar energy on the PV panel is converted to electrical energy with 6%-20% efficiency depending on the semi-conductor material used in the PV panel. There have been many factors leading to low panel efficiency such as panel tilt angle, shading, dust, solar radiation level, temperature and the other losses [5, 6]. Among these factors, solar radiation level and the temperature have been more prominent.

Solar radiation level varies through the year. The annual variation of the extraterrestrial solar radiation level is shown in Figure 1.

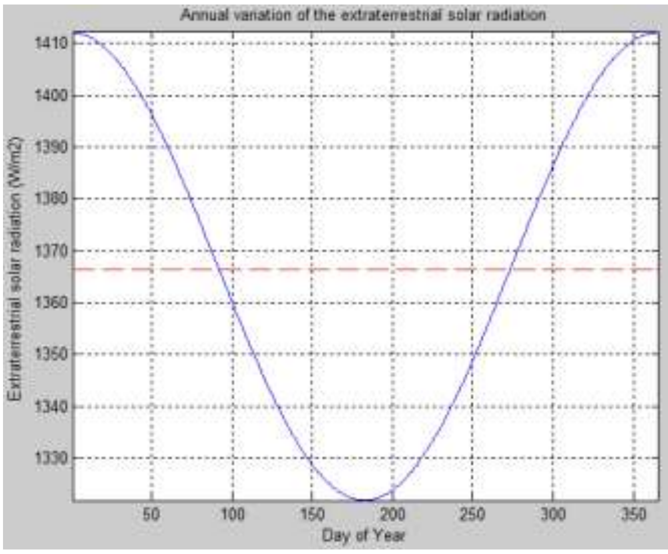


Figure 1. Annual variation of the extraterristrial solar radiation

The average annual variation of the extraterrestrial solar radiation level is 1367 W/m² and shown by dashed lines. On the other hand, the solar radiation level falling on the earth is less than the extraterrestrial solar radiation level and varies depending on the geographic position of the countries [7]. The changes in atmospheric conditions such as solar radiation level and temperature throughout the day have a great impact on the panel efficiency. Therefore, it has a great importance to know the solar radiation level and temperature effect on PV panel. However, the panel manufacturer firms give only the electrical values of the PV panel under 1000 W/m² solar radiation level, 25 ºC cell temperature and A.M. 1,5 air mass rate in the catalogues which are conducted in laboratory environment and called as Standard Test Conditions (STC). As a result, the electrical values of the PV panel different from the STC are not known. The electrical values of the PV panels under atmospheric conditions should be known. Taking these conditions into consideration especially for the design of off-grid and on-grid systems will give more accurate results [8, 9].

In literature, Salmi et al. [10] and Tsai et al. [11] developed a model at Matlab/Simulink program depending on the basic equivalent circuit of the PV cell taking into consideration the environmental factors such as solar radiation and temperature. Kishor et al. [12], Kane and Verma [13], Tobnaghi and Naderi [14], Aldwane [15] examined the environmental factors affecting the PV module performance. Sera et al. [16] conducted a study to develop a model for PV panels using the PV panel catalogue data. They tested their model examining the environmental factors.

In this study, the equivalent circuit of the PV panel is simulated at PSIM and MATLAB using the catalogue values of the panel and the effects of variations under 0, 25, 50 ºC temperatures and 200, 400, 600, 800, 1000 W/m² solar radiation levels on panel current, voltage and the power are examined. In the results section, the most appropriate temperature and solar radiation levels for the PV panels are evaluated depending on the simulation analyses.

2. The Mathematical Model of the Photovoltaic Cell

It plays a crucial role to obtain the equivalent circuit of the PV cell in order to examine the electrical energy obtained from PV panels. Solar cells are modeled by diodes since they are made by semi-conductor materials. The current-voltage characteristic of the solar cell acts like diode when it does not take solar radiation. The electric generation of the solar cell is represented by current source while the losses in PV cells are represented by series and parallel resistances. The electrical equivalent circuit of a PV cell is shown in Figure 2 [8, 17].

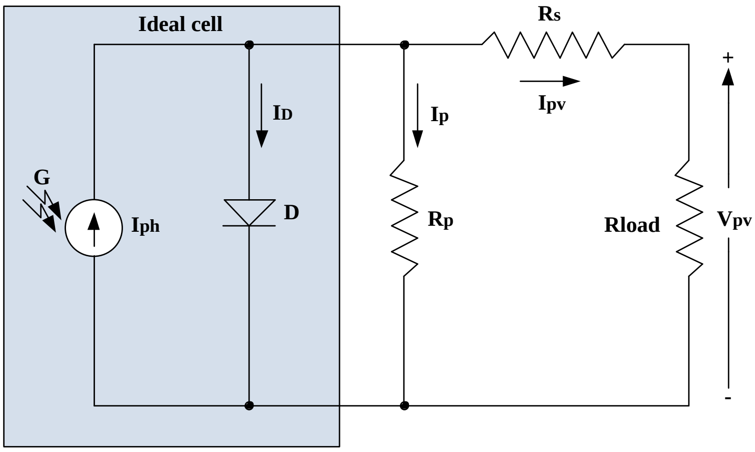


Figure 2. The equivalent circuit of PV cell

The photovoltaic current of the PV cell (I_{ph}), is proportional to the solar radiation level falling on the cell.

$$I_{ph} = \left[I_{sc} + K_i \cdot (T_c - T_r) \right] \cdot \frac{G}{G_r} \qquad (1)$$

Where;
I_{ph}: Photovoltaic current of the PV cell
I_{sc}: Short circuit current under 25 ºC and 1000 W/m²
K_i: Temperature factor of short circuit current (0.0017 A/ºC)
T_c: PV cell temperature (in Kelvin)

T_r: Reference temperature (298.15 ºK for 25 ºC)
G: Solar radiation level under W/m²
G_r: Reference solar radiation level (1000 W/m²)

Diode current (I_D), depends on the voltage and reverse leakage current (I_o).

$$I_D = I_o \cdot \left(e^{\frac{q \cdot V_d}{A \cdot k \cdot T_c}} - 1 \right) \tag{2}$$

Where;
q: Electric charge (1.602x10^{-19} C)
k: Boltzman constant (1.3806505x10^{-23} J/K)
A: Quality factor of diode

The equation of the current flowing through the parallel resistance;

$$I_p = \frac{V_D}{R_p} = \frac{V_{pv} + I_{pv} \cdot R_s}{R_p} \tag{3}$$

PV cell output current and voltage;

$$I_{pv} = I_{ph} - I_D - I_p \tag{4}$$

$$V_{pv} = V_D - I_{pv} \cdot R_s \tag{5}$$

The following mathematical model is obtained when the (2) and (3) equations are substituted in equation (4) [18, 19].

$$I_{pv} = I_{ph} - \left[e^{\left(\frac{q \cdot \left(V_{pv} + I_{pv} \cdot R_s \right)}{A \cdot k \cdot T_c} \right)} - 1 \right] - \frac{V_{pv} + I_{pv} \cdot R_s}{R_p} \tag{6}$$

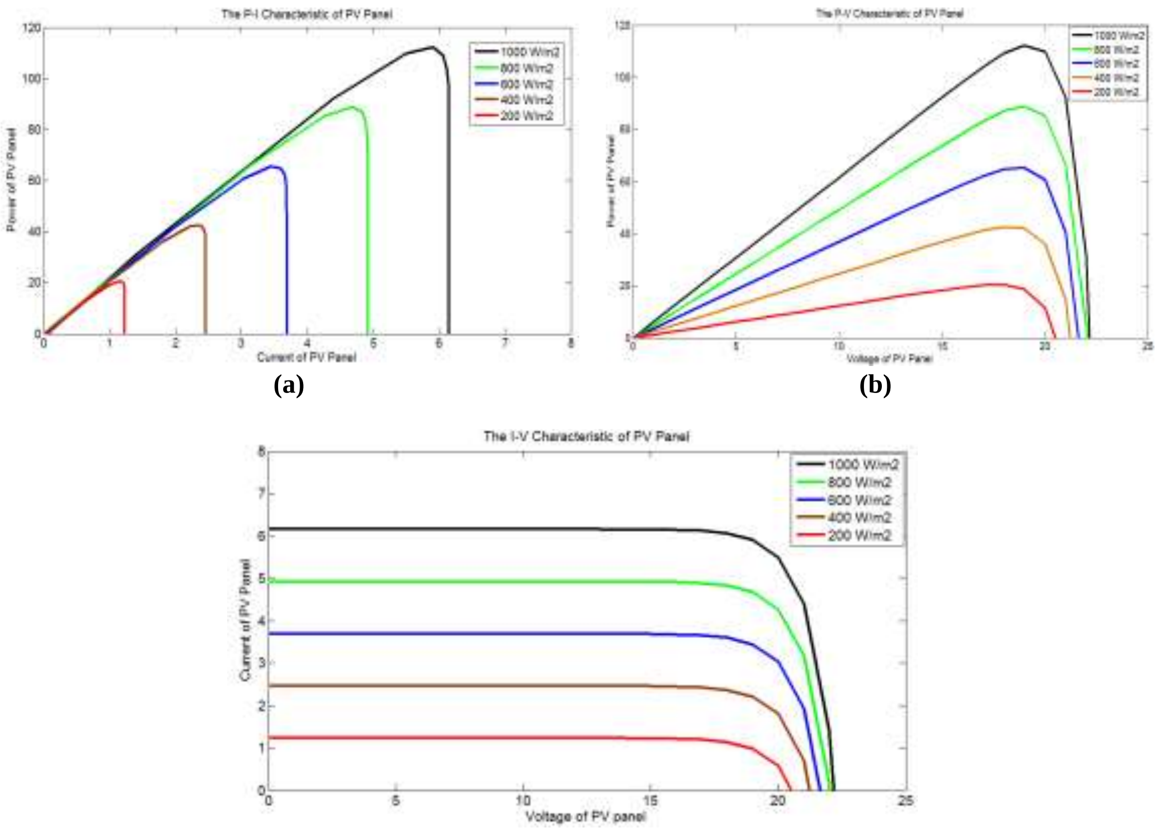
2.1. Matlab Simulation of PV Panel

PLM-100P/12 100 W Perlight polycrystalline PV panel was modeled at Matlab program using the equivalent circuit of the panel .The catalogue data of the PV panel is given in Table 1.

Table 1. The catalogue data of PV panel

Electrical and Mechanical Characteristics of PV Panel	**Numerical Values**
Maximum panel power (P_m)	100 W±%3
Maximum voltage (V_{mp})	17.7 V
Maximum current (I_{mp})	5.65 A
Open-circuit voltage (V_{oc})	22 V
Short-circuit current (I_{sc})	6.21 A
Panel efficiency (%)	15.3
Cell number	36 (4x9)
Panel sizes	1127x676x35 mm
Panel weight	9.5 kg
Operation temperature	40 ºC…+85 ºC

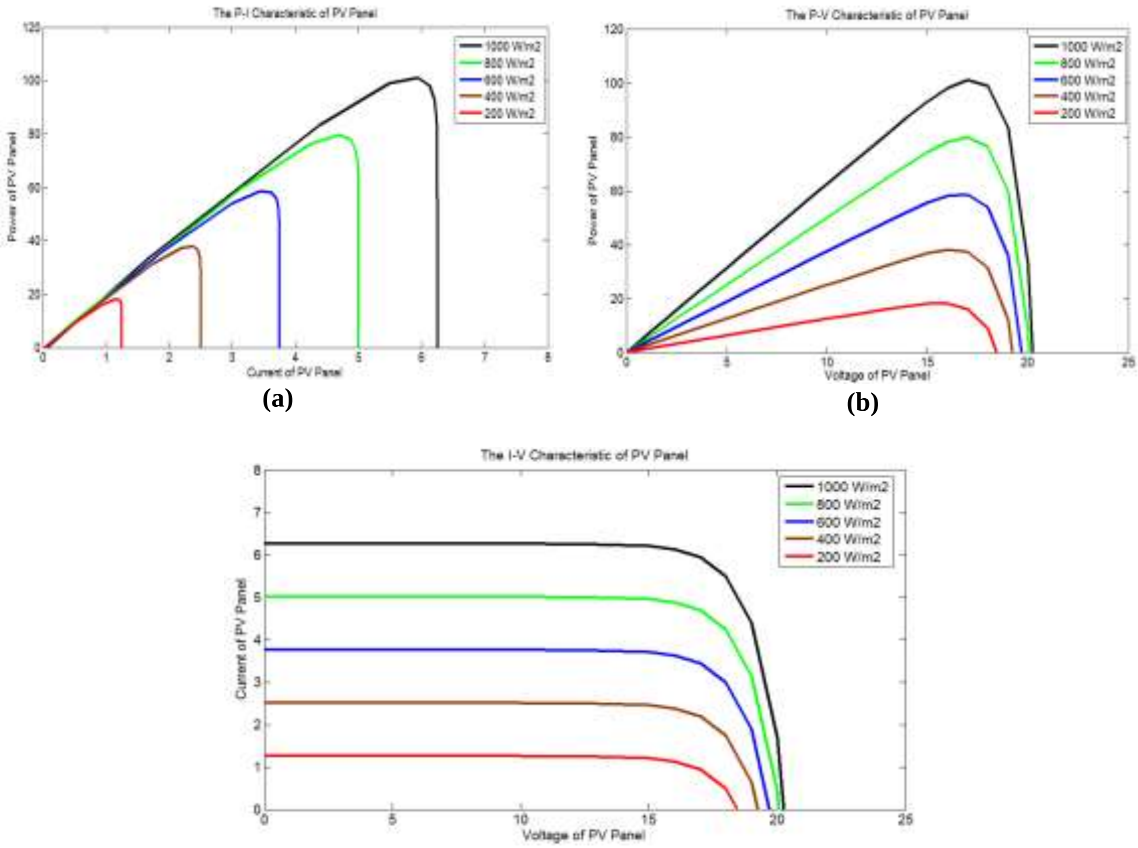
Power-current (P-I), power-voltage (P-V) and current-voltage (I-V) characteristics under 0, 25 ve 50 ºC and 200, 400, 600, 800 and 1000 W/m² changes for no-load condition of PV panel are examined.



(a) (b)

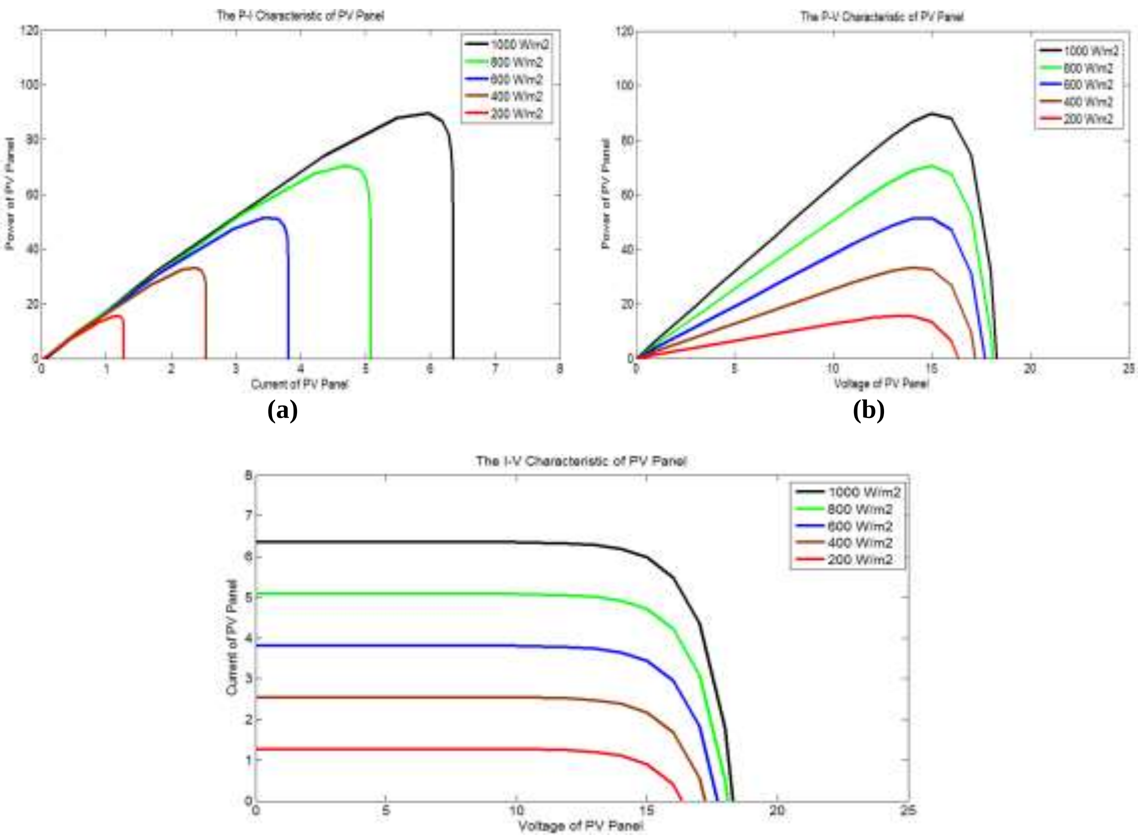
(c)

Figure 3. The (a) P-I, (b) P-V and (c) I-V characteristics of PV panel at 0 °C temperature



(c)

Figure 4. The (a) P-I, (b) P-V and (c) I-V characteristics of PV panel at 25 °C temperature



(c)

Figure 5. The (a) P-I, (b) P-V and (c) I-V characteristics of PV panel at 50 °C temperature

Short-circuit current, open-circuit voltage, maximum current, maximum voltage and maximum power values of the PV panel were obtained under 0, 25 and 50 ºC and 200, 400, 600, 800 and 1000 W/m² power using Matlab program and the results are shown in tables.

Table 2. Short-circuit current changes of PV panel

Matlab Simulation Results						
	Solar Radiation (W/m²)					
Short-Circuit Current	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Isc (A)	1.23	2.46	3.69	4.92	6.15	**0 ºC**
Isc (A)	1.25	2.5	3.75	5	6.25	**25 ºC**
Isc (A)	1.27	2.54	3.81	5.08	6.35	**50 ºC**

Table 3. Open-Circuit voltage changes of PV panel

Matlab Simulation Results						
	Solar Radiation (W/m²)					
Open-Circuit Voltage	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Voc (V)	20.54	21.24	21.66	22.03	22.18	**0 ºC**
Voc (V)	18.56	19.26	19.71	20.07	20.25	**25 ºC**
Voc (V)	16.4	17.18	17.68	18.07	18.28	**50 ºC**

Table 4. Maximum current changes of PV panel

Matlab Simulation Results						
	Solar Radiation (W/m²)					
Max Current	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Imax (A)	1.13	2.36	3.44	4.67	5.9	**0 ºC**
Imax (A)	1.12	2.37	3.44	4.69	5.94	**25 ºC**
Imax (A)	1.19	2.37	3.41	4.7	5.99	**50 ºC**

Table 5. Maximum voltage changes of PV panel

Matlab Simulation Results						
	Solar Radiation (W/m²)					
Max Voltage	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Vmax (V)	18	18	19	19	19	**0 ºC**
Vmax (V)	16	16	17	17	17	**25 ºC**
Vmax (V)	11	12	13	13	13	**50 ºC**

Table 6. Maximum power changes of PV panel

Matlab Simulation Results						
	Solar Radiation (W/m²)					
Max Power	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Pmax (W)	20.49	42.64	65.46	88.84	112.2	**0 ºC**
Pmax (W)	18.02	38.03	58.57	79.83	101.1	**25 ºC**
Pmax (W)	15.59	33.29	51.54	70.6	89.66	**50 ºC**

Simulation results show that when the panel temperature is 0 ºC, short circuit current and maximum current of the panel increase as proportional to solar radiation level. On the other hand, there is a little increase in open-circuit voltage and maximum voltage of the panel. Therefore when the solar radiation level is increased from 200 W/m² to 1000 W/m², panel power increases 5.5 times. Similarly, when the solar radiation level is increased gradually under 25 and 50 ºC panel temperature, the short circuit and maximum current of the panel increase proportionally. However, little increase in open-circuit voltage and maximum voltage is observed. When the panel temperature under 0 ºC and 25 ºC are compared it is observed that as the panel temperature increases there is a little increase in short circuit current and the maximum current values are nearly the same. On the contrary, open-circuit and maximum voltage values decrease in proportion to the increase in panel temperature. Therefore, panel power decreases. The similar results are obtained for 50 ºC panel temperature.

2.2. PSIM Simulation of PV Panel

As shown in Figure 6, the physical model of the PV panel is placed at renewable energy module of PSIM program. The basic parameters are required for the physical model of the PV panel. These parameters are the panel catalogue data given by PV panel manufacturers. I-V and P-V characteristic curves of the panel are obtained after these parameters are used. In this study, Perlight PLM-100P/12 panel parameters are used and the physical model of the panel is formed.

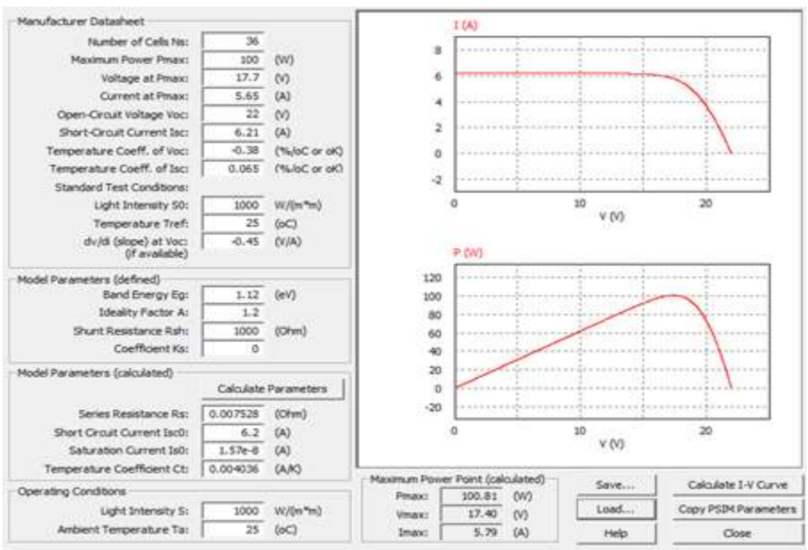


Figure 6. Solar module simulator at PSIM

The circuit where the temperature and solar radiation level will change gradually after the physical model of the PV panel is formed as shown in Figure 7.

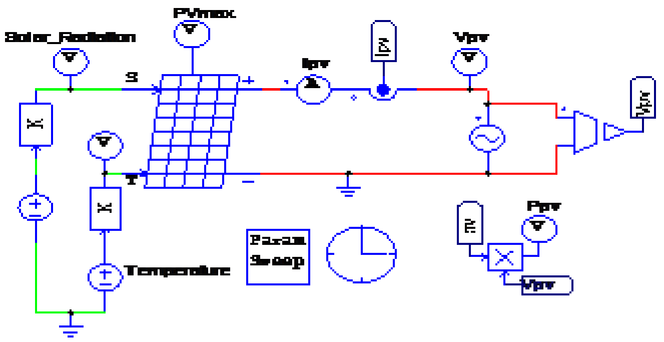


Figure 7. Examining the temperature and solar radiation changes effects on PV panel at PSIM

Figure 7 presents the power changes depending on time under 0, 25 and 50 ºC and 200, 400, 600, 800 and 1000 W/m² solar radiation level for the modeled circuit and variable load PV panel.

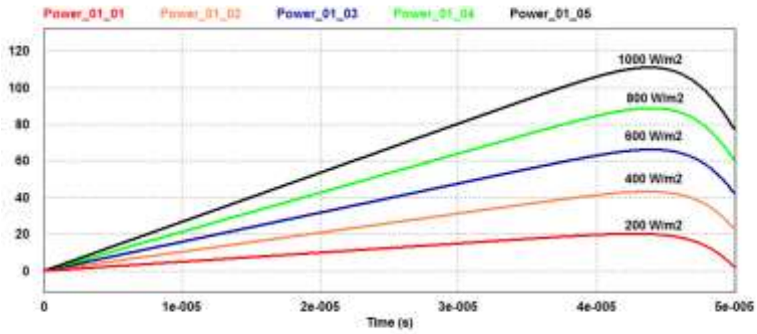


Figure 8. The power changes of PV panel at 0 ºC temperature

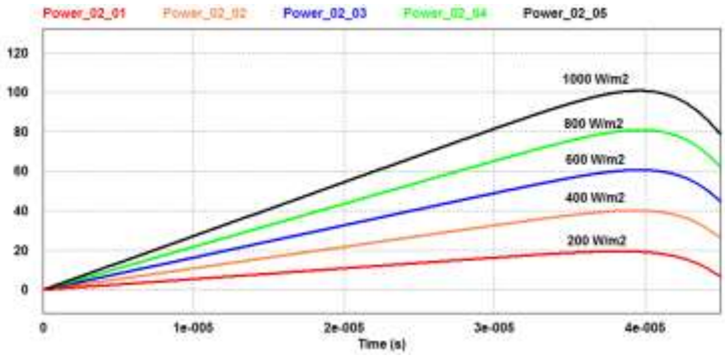


Figure 9. The power changes of PV panel at 25 ºC temperature

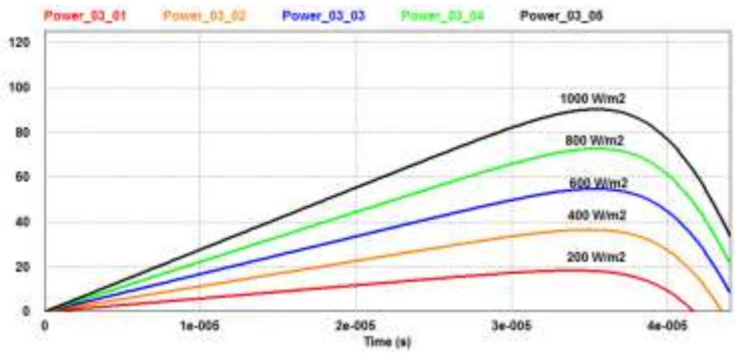


Figure 10. The power changes of PV panel at 50 ºC temperature

The obtained short circuit current and maximum power values are shown in the table.

Table 7. Short-circuit current changes of PV panel at PSIM

PSIM Simulation Results						
	Solar Radiation (W/m²)					
Short-Circuit Current	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Isc (A)	1.14	2.38	3.62	4.86	6.1	**0 ºC**
Isc (A)	1.24	2.48	3.72	4.96	6.2	**25 ºC**
Isc (A)	1.34	2.58	3.82	5.06	6.3	**50 ºC**

Table 8. Maximum power changes of PV panel at PSIM

PSIM Simulation Results						
	Solar Radiation (W/m²)					
Max Power	**200**	**400**	**600**	**800**	**1000**	**Temperature**
Pmax (W)	20.26	43.3	66.26	88.88	111.06	**0 ºC**
Pmax (W)	19.54	40.14	60.69	80.95	100.8	**25 ºC**
Pmax (W)	18.44	36.64	54.82	72.74	90.3	**50 ºC**

3. Results

The simulation results show that while panel current increases in proportion to solar radiation level, there is a little increase in panel voltage. Similarly, panel power increases in proportion to solar radiation level. On the other hand, panel temperature leads to a little increase in panel current while it decreases the panel voltage proportionally. Panel power decreases since the voltage decrease rate is more than the increase in current rate. The results indicate that low temperature and high solar radiation level conditions are more appropriate for the obtained power values.

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