

# THE IMPACT OF SOLAR PANEL PARAMETERS ON MAXIMUM POWER POINT

## *IMPACTUL PARAMETRILOR PANOULUI SOLAR ASUPRA PUNCTULUI DE PUTERE MAXIMĂ*

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**Abstract:** *Solar photovoltaic (PV) systems play an important role in renewable energy generation by directly converting solar irradiance into usable electrical energy. To maximize the efficiency of these systems, it is essential to operate the solar panels at their maximum power point (MPP), the combination of voltage and current where the solar panel generates the highest power output. In this study we present an analysis of the impact of individual solar panel parameters on the maximum power point.*

**Keywords:** Photovoltaic panel; Simulation; Measurement; Solar panel parameters; Maximum power point (MPP);

**Rezumat:** *Sistemele solare fotovoltaice (PV) joacă un rol important în generarea de energie regenerabilă prin transformarea directă a irradianței solare în energie electrică utilizabilă. Pentru a maximiza eficiența acestor sisteme, este esențială operarea panourilor solare la punctul lor de putere maximă (MPP), combinația de tensiune și curent unde panoul solar generează cea mai mare putere. În acest studiu prezentăm o analiză a impactului individual al parametrilor panoului solar asupra punctului de putere maximă.*

**Cuvinte cheie:** Panou fotovoltaic; Simulare; Măsurare; Parametri panou solar; Punct de putere maximă;

### 1. Introduction

Solar photovoltaic technology stands at the top of sustainable energy solutions, offering a promising way to ensure the growing global demand for “green” electricity. As the world continues the transition towards renewable energy sources, understanding the interplay of various factors affecting solar panels performance is essential. Among those factors, the parameters of a solar panel, such as the irradiance, operating cell temperature, parasitic resistances, play a major role in determining the module/array efficiency and power output of photovoltaic systems.

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This article enters a comprehensive investigation of the impact of these individual solar panel parameters on photovoltaic performance. Specifically, it is a comparative analysis between real measured data and simulations generated using MATLAB, a powerful computational tool used in the field of research. The significance of this research lies in the potential to enhance the understanding of how these parameters interact and influence the efficiency of solar panels under varying environmental conditions and internal parameters. Such insights are vital for optimizing photovoltaic system designs, ensuring maximum energy generation, and ultimately advancing the adoption of solar energy as a sustainable power resource.

## **2. The photovoltaic effect**

A solar cell is an electronic device which converts sunlight directly into electricity. Light shining on the solar cell produces both a current and a voltage that generates electric power. This process requires a material in which the absorption of light raises an electron to a higher energy state and the movement of this higher energy electron from the solar cell into an external circuit. The electron then dissipates its energy in the external circuit and returns to the solar cell [1].

Solar cells can be grouped in order to form photovoltaic modules or panels. Panels can also be grouped to form photovoltaic arrays.

Measuring, modeling, and analysis of solar photovoltaic generators are important phases prior to mounting, which helps understand the behavior and characteristics in real climatic conditions.

## **3. Measuring of a solar photovoltaic generator**

Measuring a solar photovoltaic generator is an important phase which helps to understand their behavior and characteristics. The measurements were conducted at the Laboratory of Photovoltaic Systems from National Institute for Research and Development in Electrical Engineering ICPE-CA using an AFP-60-245 solar panel (properties presented in Table 1) as a reference model. Laboratory of Photovoltaic Systems is accredited by RENAR (Accreditation Association from Romania) to measure the Current-Voltage and Power-Voltage curves in the laboratory using with PASAN Highlight Solar Simulator, Flash generator, System's Generator Module, and the Flash box, which is designed to test, evaluate, and determine the operating parameters of photovoltaic modules under standard test conditions (Table 2).

The measured characteristics of AFP-60-245 solar panel are presented in Fig. 1.

Table 1. AFP-60-245W solar panel properties [2]

Electrical Properties (STC*)	
MPP Voltage ( $V_{MP}$ )	29.9 V
Open Circuit Voltage ( $V_{oc,n}$ )	37.0 V
MPP Current ( $I_{MP}$ )	8.21 A
Short Circuit Current ( $I_{SC,n}$ )	8.76 A
Maximum Power ( $P_{max}$ )	245 W
Module Efficiency (%)	15.0 ~ 15.4 %
Operating Temperature Range	-40 ~ +85 °C
Mechanical properties	
Number of cells $N_S$	60
Cell Type	Polycrystalline
Cell Dimensions	156 x 156 mm
Temperature Characteristics	
Nominal Operating Cell Temperature NOCT	45 ± 2 °C
Maximum Power/Temperature Coefficient ( $K_p$ )	-0.47 %/°C
Open-circuit Voltage/Temperature Coefficient ( $K_V$ )	-0.32 %/°C
Short-circuit Current/Temperature Coefficient ( $K_I$ )	0.04 %/°C

Table 2. Standard Test Conditions (STC\*)

irradiance $G_{STC}$	1000 W/m <sup>2</sup>
cell temperature $t_{c,STC}$	25 °C
Air mass AM	1.5

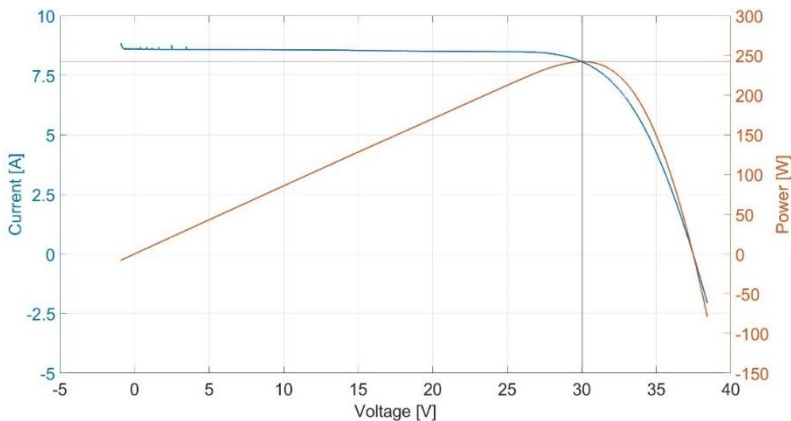


Figure 1. AFP-60-245W solar panel  
Measured Current-Voltage / Power-Voltage curves

Table 3. AFP60-245W solar panel measured properties

MPP Voltage ( $V_{MP}$ )	30.026 V
MPP Current ( $I_{MP}$ )	8.067 A
Maximum Power ( $P_{max}$ )	242.226 W
Open Circuit Voltage ( $V_{oc}$ )	37.478 V
Short Circuit Current ( $I_{sc}$ )	8.590 A
Series resistance ( $R_s$ )	0.521 $\Omega$
Shunt resistance ( $R_{SH}$ )	279.536 $\Omega$
Cell efficiency	16.59 %
Open-circuit Voltage/Temperature Coefficient ( $K_V$ )	-123.6 mV/ $^{\circ}$ C
	-0.334 %/ $^{\circ}$ C
Short-circuit Current/Temperature Coefficient ( $K_I$ )	4358.578 $\mu$ A/ $^{\circ}$ C
	0.0498 %/ $^{\circ}$ C

#### 4. Simulation and analysis of a solar photovoltaic generator

The photovoltaic characteristics of the photovoltaic device shown in Fig. 2 depend both on external influences such as irradiance and temperature as well as on the internal characteristics of the device.

A photovoltaic panel has nonlinear characteristics (Current-Voltage and Power-Voltage curves) that take a lot of time and are quite expensive to obtain under varying operating conditions.

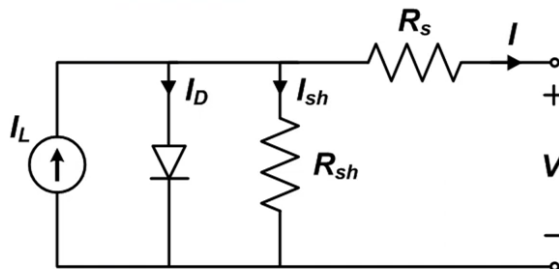


Figure 2. Simplified equivalent circuit of a photovoltaic panel [3].

Also, some of the parameters required for adjusting photovoltaic models cannot be found in the manufacturers' data sheets, such as:

- light-generated current or photovoltaic current  $I_L$
- diode reverse saturation current
- series resistance  $R_s$  / shunt resistance  $R_{SH}$
- diode ideality constant  $\alpha$

To overcome those obstacles, simple models of solar panels can be developed and integrated into engineering software. Using modeling tools or software, those characteristics can be investigated at a wide range of operating conditions and/or physical parameters. The following equations [3, 4] describe the single-diode model presented in Fig. 2:

$$I = I_L - I_D - I_{SH} \quad (1)$$

$$I_L = \left( I_{SC,n} + K_I \cdot (t_c - t_{c,ref}) \right) \cdot \frac{G}{G_{ref}} \quad (2)$$

$$I_D = I_0 \cdot \left( e^{\frac{q \cdot (V + I \cdot R_S)}{N_s \cdot k \cdot T_c \cdot \alpha}} - 1 \right) \quad (3)$$

$$I_0 = \frac{I_{SC,n} + K_I \cdot (t_c - t_{c,ref})}{e^{\frac{q \cdot (V_{oc,n} + K_V \cdot (t_c - t_{c,ref}))}{N_s \cdot k \cdot T_c \cdot \alpha}} - 1} \quad (4)$$

$$I_{SH} = \frac{V + I \cdot R_S}{R_{SH}} \quad (5)$$

$$I = \left( I_{SC,n} + K_I \cdot (t_c - t_{c,ref}) \right) \cdot \frac{G}{G_{ref}} - \frac{I_{SC,n} + K_I \cdot (t_c - t_{c,ref})}{e^{\frac{q \cdot (V_{oc,n} + K_V \cdot (t_c - t_{c,ref}))}{N_s \cdot k \cdot T_c \cdot \alpha}} - 1} \cdot \left( e^{\frac{q \cdot (V + I \cdot R_S)}{N_s \cdot k \cdot T_c \cdot \alpha}} - 1 \right) - \frac{V + I \cdot R_S}{R_{SH}} \quad (6)$$

$$P = V \cdot I \quad (7)$$

To simulate the photovoltaic characteristics the Eq. (6) for Current-Voltage curve and Eq. (7) for Power-Voltage curve are used. The resulting characteristics of the simulation are presented and compared to the measurement results in Fig. 3.

The difference between the simulated and measured Current-Voltage / Power-Voltage curves as the error  $\varepsilon$  is presented in the Fig. 4.

Utilizing MATLAB [5] for simulations offered several advantages, including robust computational capabilities that enabled the modeling and analysis of photovoltaic systems with high efficiency. It also allowed the utilization of diverse algorithms and numerical approaches. Additionally, MATLAB's user-friendly interface and adept visualization tools facilitated the

accurate portrayal of outcomes, enhancing the precision and comprehensibility of the results.

Table 4. Simulation results for AFP60-245W solar panel

Irradiance ( $G = G_{STC}$ )	1000 W/m <sup>2</sup>
Cell temperature ( $t_c = t_{c,STC}$ )	25 °C
Short Circuit Current ( $I_{SC} = I_{SC,n}$ )	8.76 A
Open Circuit Voltage ( $V_{oc} = V_{oc,n}$ )	37.0 V
Open-circuit Voltage/Temperature Coefficient ( $K_V$ )	-0.32 %/°C
Short-circuit Current/Temperature Coefficient ( $K_I$ )	0.04 %/°C
Series resistance ( $R_S$ )	0.2374 Ω
Shunt resistance ( $R_{SH}$ )	995.49 Ω
Diode ideality constant ( $\alpha$ )	1.1818
MPP Voltage ( $V_{MP}$ )	29.9 V
MPP Current ( $I_{MP}$ )	8.21 A
Maximum Power ( $P_{max}$ )	245.479 W

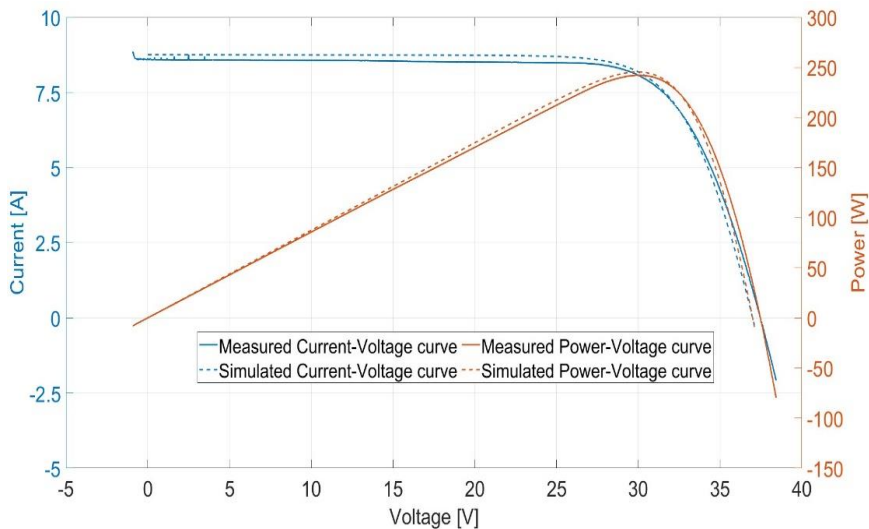
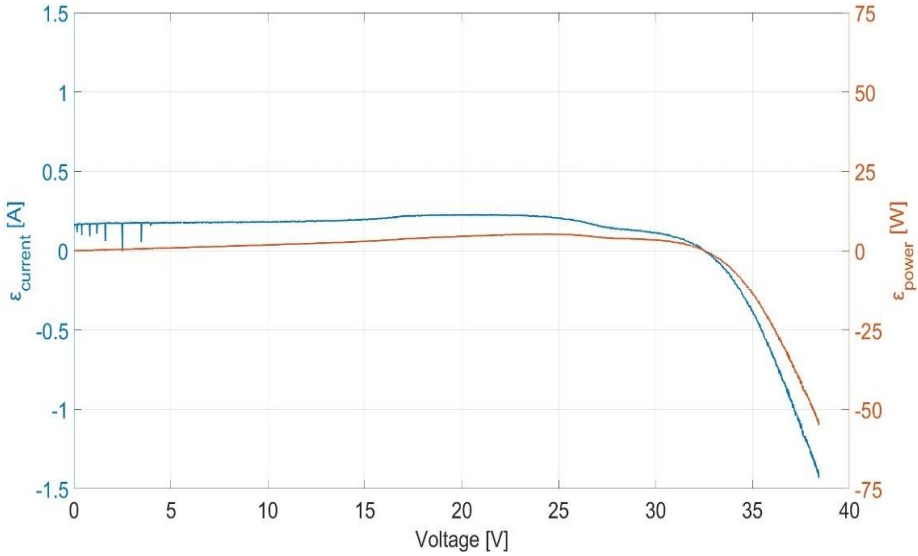


Figure 3. AFP-60-245W solar panel Measured/Simulated Current-Voltage / Power-Voltage curves.



**Figure 4.** AFP-60-245W solar panel  
Error between Simulated and Measured Current-Voltage / Power-Voltage curves.

The previous errors (Fig. 4) are the combined result of the compensation of irradiance and cell temperature for the measured characteristics, as well as different values of parasitic resistances.

*Table 5. Measured/Simulation parameters for AFP-60-245W solar panel*

Parameter	Measured value	Simulated value
irradiance $G$	1000 W/m <sup>2</sup> (compensated)	1000 W/m <sup>2</sup>
cell temperature $t_c$	25 °C (compensated)	25 °C
series resistance $R_S$	0.521 Ω	0.2374 Ω
shunt resistance $R_{SH}$	279.536 Ω	995.49 Ω
ideality factor $\alpha$	undefined	1.1818

Since:

- $t_{c,ref}$ ,  $G_{ref}$ ,  $q$ , and  $k$  are constants.
- $I_{SC,n}$ ,  $K_I$ ,  $V_{oc,n}$ ,  $K_V$ ,  $N_S$  are solar panel properties (see Table 2),

the five parameters of the solar panel that can impact Eq. (6) are  $G$ ,  $t_c$ ,  $R_S$ ,  $R_{SH}$ ,  $\alpha$ :

$$I = I(V, G, t_c, R_S, R_{SH}, \alpha)$$

The individual impact of each parameter in Eq. (6) can be ignored by assigning an ideal value:

- The ideal value for solar irradiance  $G$  can be considered the value in standard testing conditions.
- The ideal operating temperature  $t_c$  can be considered the standard testing temperature for solar cells
- Ideally, the series resistance ( $R_S$ ) should be as close to zero as possible to minimize power losses in the solar cell.
- An ideal shunt resistance ( $R_{SH}$ ) would be extremely high, approaching infinity. This would minimize the leakage current and prevent any significant diversion of current through the shunt resistance path.
- When  $\alpha$  is close to 1, it implies that the solar cell behaves like an ideal diode, and the recombination and other non-ideal effects are minimal. This is the case for high-quality, well-designed solar cells.

*Table 6. Ideal values for solar panel parameters*

Parameter	Ideal value
irradiance $G^* = G_{ref}$	1000 W/m <sup>2</sup>
cell temperature $t_c^* = t_{c,ref}$	25 °C
$T_c^* = T_{c,ref}$	298.15 K
series resistance $R_S^*$	0 $\Omega$
shunt resistance $R_{SH}^*$	$\infty \Omega$
ideality factor $\alpha^*$	1

Since it's impossible to measure a photovoltaic panel to understand the impact of each parameter on the maximum power point, we will use MATLAB simulations. The following subchapters explore the individual effects of each parameter in 5 cases.

#### ***4.1. Case 1: Individual impact of irradiance***

The irradiance is the first and the most important parameter that affects the characteristics of a photovoltaic panel. It has a major impact on the performance of a photovoltaic panel, referring to the amount of solar energy that falls on a given surface area.

The individual impact of irradiance can be determined by considering  $G$  the only variable and assigning the ideal values (Tab. 6) for the other

parameters ( $t_c, R_S, R_{SH}, \alpha$ ), thus ignoring their effects. By modifying Eq. (6) according to the previous assumptions Eq. (6.1) for Current-Voltage curve becomes solely dependent on irradiance:

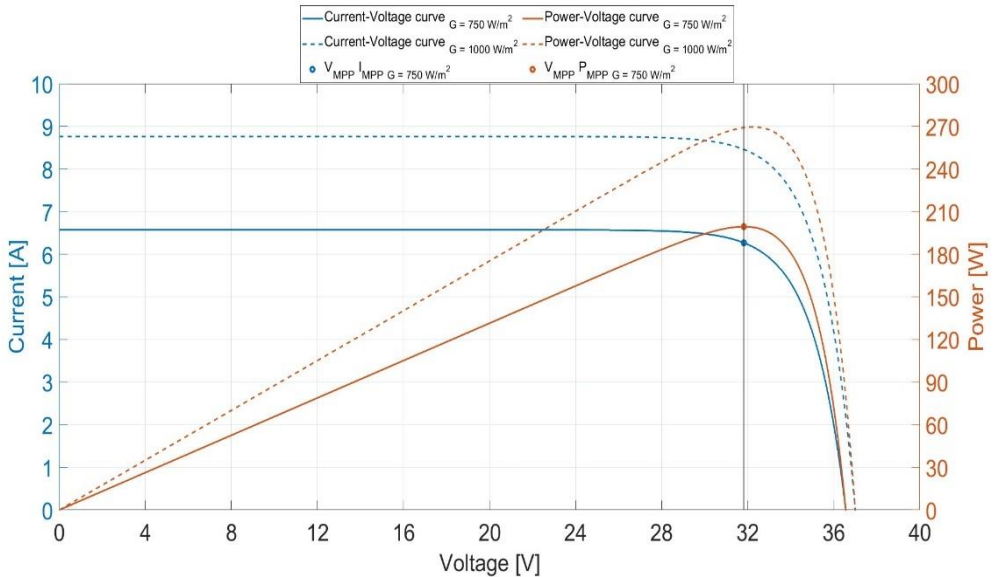
$$I = I(V, G, t_c^*, R_S^*, R_{SH}^*, \alpha^*) \quad (6.1)$$

The values for the maximum power point of the simulated PV characteristics determined using both Eq. (6.1) and Eq. (7) for different values of irradiance are presented in Tab. 7.

**Table 7. Simulation results for AFP-60-245W solar panel  
Maximum Power Point for different irradiance values**

G [W/m <sup>2</sup> ]	1000 ( $G_{ref}$ )	750	500	250
$P_{max}$ [W]	269.543	199.378	130.308	62.926
$V_{MP}$ [V]	32.24	31.82	31.22	30.20
$I_{MP}$ [A]	8.361	6.266	4.174	2.084

The simulated PV characteristics of the AFP-60-245W solar panel using Eq. (6.1) for Current-Voltage curve and Eq. (7) for Power-Voltage curve are presented in Fig.5.



**Figure 5.** AFP-60-245W solar panel  
Simulated Current-Voltage / Power-Voltage curves for different irradiance values

According to the simulation results higher irradiance levels lead to increased current/power output, while lower irradiance levels lead to a reduced current/power. However, the voltage at maximum power remains relatively constant under varying irradiance levels. A variation of the irradiance changes the short-circuit current, the open-circuit voltage, the panel efficiency, and obviously the maximum power point.

#### 4.2. Case 2: Individual impact of cell temperature

Irradiance is closely linked to the operating temperature of a photovoltaic cell/panel, the second parameter, because higher irradiance can lead to heat buildup, which in turn affects the panel's efficiency. Like all other semiconductor devices, solar cells are sensitive to temperature [6]. Temperature increases reduce the bandgap of a semiconductor, thereby affecting most of the semiconductor material parameters.

The individual impact of cell temperature can be determined by considering  $t_c$  the only variable and assigning the ideal values (Tab. 6) for the other parameters ( $G, R_S, R_{SH}, \alpha$ ), thus ignoring their effects. By modifying Eq. (6) according to the previous assumptions Eq. (6.2) for Current-Voltage curve becomes solely dependent on cell temperature.

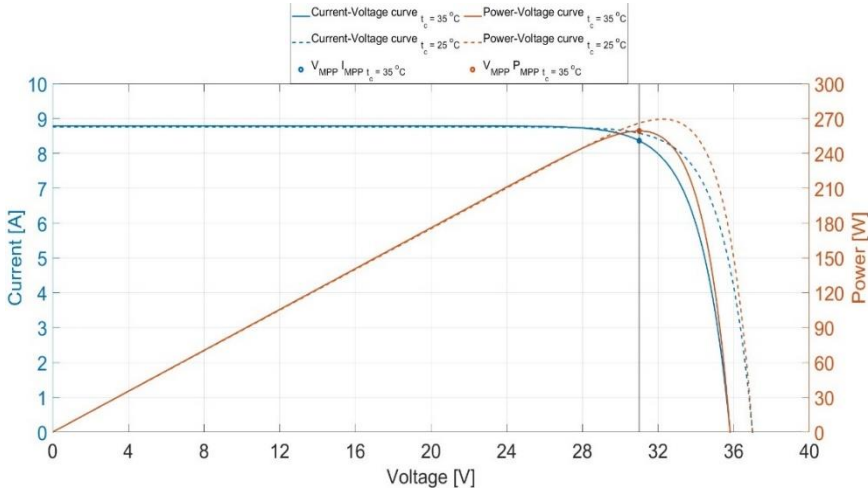
$$I = I(V, G^*, t_c, R_S^*, R_{SH}^*, \alpha^*) \quad (6.2)$$

The values for the maximum power point of the simulated PV characteristics determined using both Eq. (6.2) and Eq. (7) for different values of cell temperature are presented in Tab. 8.

**Table 8. Simulation results for AFP-60-245W solar panel  
Maximum Power Point for different cell temperature values**

$t_c$ [°C]	25 ( $t_{c,ref}$ )	35	45	55
$P_{max}$ [W]	269.543	259.377	249.191	238.989
$V_{MP}$ [V]	32.24	31.01	29.78	28.56
$I_{MP}$ [A]	8.361	8.364	8.368	8.368

The simulated PV characteristics of the AFP-60-245W solar panel using Eq. (6.2) for Current-Voltage curve and Eq. (7) for Power-Voltage curve are presented in Fig.6.



**Figure 6.** AFP-60-245W solar panel

Simulated Current-Voltage / Power-Voltage curves for different cell temperature values.

For a solar panel, the open-circuit voltage is the most affected by an increase in temperature, resulting in decrease. Although the short-circuit current increases slightly with temperature photovoltaic panels experience a decrease in power output as the temperature rises.

### 4.3. Case 3: Individual impact of series resistance

Series resistance in a solar cell has three causes [7]: the movement of current through the emitter and base of the solar cell, the contact resistance between the metal contact and the silicon and the resistance of the top and rear metal contacts. Series resistance causes a voltage drop across the panel leading to power loss, reducing the amount of usable power generated.

The individual impact of series resistance can be determined by considering  $R_S$  the only variable and assigning the ideal values (Tab. 6) for the other parameters ( $G$ ,  $t_c$ ,  $R_{SH}$ ,  $\alpha$ ), thus ignoring their effects. By modifying Eq. (6) according to those assumptions Eq. (6.3) for Current-Voltage curve becomes solely dependent on series resistance:

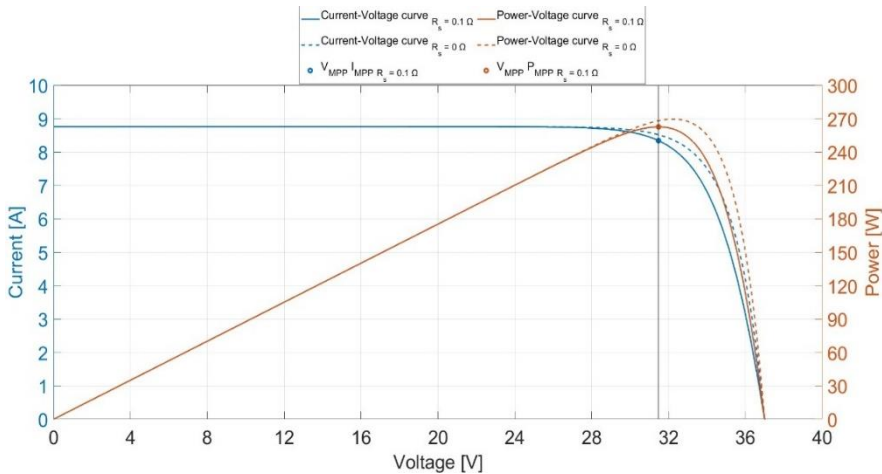
$$I = I(V, G^*, t_c^*, R_S, R_{SH}^*, \alpha^*) \quad (6.3)$$

The values for the maximum power point of the simulated PV characteristics determined using both Eq. (6.3) and Eq. (7) for different values of series resistance are presented in Table 9.

**Table 9. Simulation results for AFP-60-245W solar panel  
Maximum Power Point for different series resistance values**

$R_S$ [ $\Omega$ ]	0 (ideal)	0.1	0.25	0.5
$P_{max}$ [W]	269.543	262.57	252.176	235.058
$V_{MP}$ [V]	32.24	31.48	30.36	28.53
$I_{MP}$ [A]	8.361	8.341	8.306	8.239

The simulated PV characteristics of the AFP-60-245W solar panel using Eq. (6.3) for Current-Voltage curve and Eq. (7) for Power-Voltage curve are presented in Fig.7.



**Figure 7.** AFP-60-245W solar panel  
Simulated Current-Voltage / Power-Voltage curves for different series resistance values.

Near the maximum power point, the characteristics are strongly affected due to the combination of high current and high voltage. The series resistance does not affect the solar panel at open-circuit voltage since the current flow through the solar panel, therefore through the series resistance is zero. The higher the value of the series resistance, the higher the voltage drop/power loss and excessively high values can even reduce the short-circuit current.

#### 4.4. Case 4: Individual impact of shunt resistance

Power losses caused a shunt resistance,  $R_{SH}$ , are typically due to manufacturing defects, rather than poor solar cell design. Low shunt

resistance causes power losses in solar cells by providing an alternate current path for the light-generated current [8].

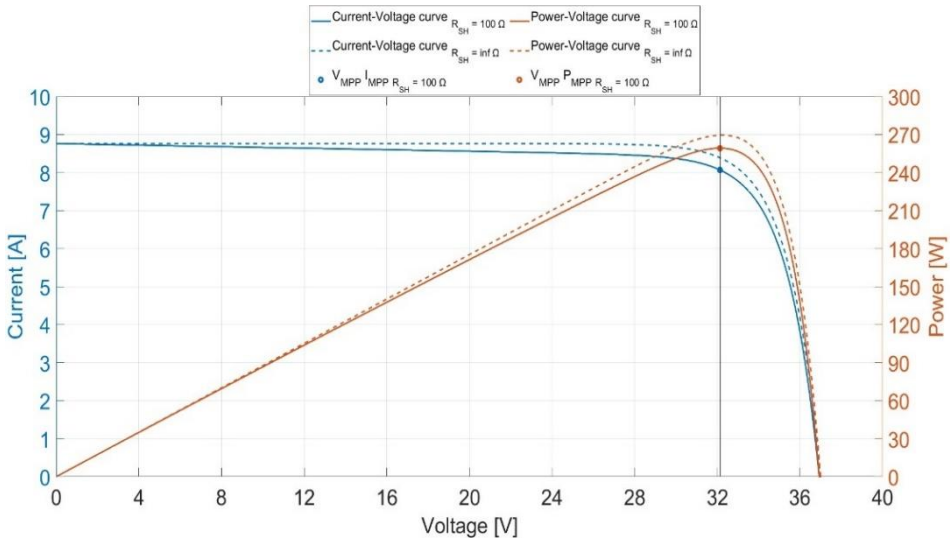
The individual impact of shunt resistance can be determined by considering  $R_{SH}$  the only variable and assigning the ideal values (Tab. 6) for the other parameters ( $G, t_c, R_S, \alpha$ ), thus ignoring their effects. By modifying Eq. (6) according to those assumptions Eq. (6.4) for Current-Voltage curve becomes solely dependent on shunt resistance:

$$I = I(V, G^*, t_c^*, R_S^*, R_{SH}, \alpha^*) \tag{6.4}$$

The values for the maximum power point of the simulated PV characteristics determined using both Eq. (6.4) and Eq. (7) for different values of shunt resistance are presented in Tab. 10.

**Table 10. Simulation results for AFP-60-245W solar panel  
Maximum Power Point for different shunt resistance values**

$R_{SH}$ [ $\Omega$ ]	Infinity (ideal)	$10^6$	$10^4$	$10^2$
$P_{max}$ [W]	269.543	269.543	269.439	259.184
$V_{MP}$ [V]	32.24	32.24	32.24	32.13
$I_{MP}$ [A]	8.361	8.361	8.357	8.067



**Figure 8.** AFP-60-245W solar panel  
Simulated Current-Voltage / Power-Voltage curves for different shunt resistance values.

The simulated PV characteristics of the AFP-60-245W solar panel using Eq. (6.4) for Current-Voltage curve and Eq. (7) for Power-Voltage curve are presented in Fig.8.

A lower shunt resistance value leads to a higher leakage current, resulting in a loss of current that should be utilized for power generation. Unlike the series resistance, the effects of shunt resistance are severe at open-circuit due to high voltage.

#### 4.5. Case 5: Individual impact of ideality factor

The ideality factor of a diode is a measure of how closely the diode follows the ideal diode equation. The derivation of the simple diode equation uses certain assumptions about the cell. In practice, there are second-order effects so that the diode does not follow the simple diode equation and the ideality factor provides a way of describing them [9].

The individual impact of ideality factor can be determined by considering  $\alpha$  the only variable and assigning the ideal values (Tab. 6) for the other parameters ( $G$ ,  $t_c$ ,  $R_S$ ,  $R_{SH}$ ), thus ignoring their effects. By modifying Equations (6) according to those assumptions Equation (6.5) for Current-Voltage curve becomes solely dependent on ideality factor:

$$I = I(V, G^*, t_c^*, R_S^*, R_{SH}^*, \alpha) \quad (6.5)$$

The values for the maximum power point of the simulated PV characteristics determined using both Eq. (6.5) and Eq. (7) for different values of ideality factor are presented in Tab. 11.

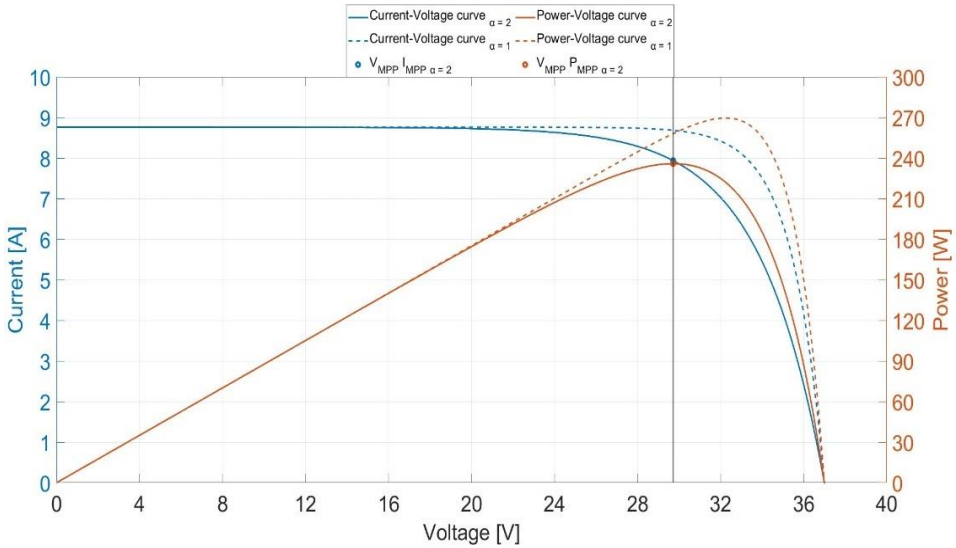
**Table 11. Simulation results for AFP-60-245W solar panel Maximum Power Point for different ideality factor values**

$\alpha$	1 (ideal)	1.25	1.5	2
$P_{max}$ [W]	269.543	260.046	251.336	235.798
$V_{MP}$ [V]	32.24	31.5	30.84	29.71
$I_{MP}$ [A]	8.361	8.255	8.15	7.937

The simulated PV characteristics of the AFP-60-245W solar panel using Eq. (6.5) for Current-Voltage curve and Eq. (7) for Power-Voltage curve are presented in Fig.9.

The ideality factor is related to the recombination processes occurring within the photovoltaic panels. A lower ideality factor indicates fewer

recombination losses, resulting in higher overall efficiency. Photovoltaic panels with lower ideality factors convert a larger portion of incident sunlight into electrical energy. As it can be seen in the last figure, the ideality factor has no effect on the short-circuit current or the open-circuit voltage.



**Figure 9.** AFP-60-245W solar panel

Simulated Current-Voltage / Power-Voltage curves for different ideality factor values.

## 5. Conclusions

➤ Irradiance and cell temperature, which represent environmental factors, were found to significantly impact the agreement between measured and simulated data. Additionally, the contributions of series resistance, shunt resistance, and diode coefficient to simulation accuracy are analyzed, providing valuable insights into the model's predictive capabilities.

➤ Understanding how these parameters affect the reliability of MATLAB simulations is vital for optimizing the design and performance prediction of photovoltaic systems.

➤ This research contributes to the ongoing efforts to enhance the precision of photovoltaic systems modeling, facilitating more informed decision-making in the deployment and management of solar energy technologies. Furthermore, it underscores the importance of considering real-world conditions when evaluating the performance of photovoltaic systems,

ultimately advancing the adoption of sustainable and efficient solar energy solutions.

### Short Biography of the authors



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### Appendix

$q$	electron charge	$1.60 \cdot 10^{-19} \text{ C}$
$k$	Boltzmann constant	$1.38 \cdot 10^{-23} \text{ J/K}$
$t_{c,ref}$	nominal cell temperature	25 °C
$t_{c,STC}$	cell temperature Standard Test Conditions (STC*)	
$T_{c,ref}$	nominal cell temperature (absolute)	298.15 K
$G_{ref}$	nominal irradiance	1000 W/m <sup>2</sup>
$G_{STC}$	irradiance Standard Test Conditions (STC*)	
$I_{SC,n}$	nominal short-circuit current [A]	
$V_{oc,n}$	nominal open-circuit voltage [V]	
$K_I$	short-circuit current/temperature coefficient [%/°C]	
$K_V$	open-circuit voltage/temperature coefficient [%/°C]	
$N_S$	number of cells connected in series	
$G$	solar irradiance on the panel surface [W/m <sup>2</sup> ]	
$t_c$	cell temperature [°C]	
$R_S$	equivalent series resistance of the panel [ $\Omega$ ]	
$R_{SH}$	equivalent parallel resistance of the panel [ $\Omega$ ]	
$\alpha$	diode ideality constant	
$I_L$	current generated by the incident light [A]	
$I_D$	diode current [A]	
$I_0$	saturation current [A]	
$I_{SH}$	shunt resistance current [A]	
$V$	output voltage [V]	
$I$	output current [A]	
$P$	output power [W]	
$P_{MP}$	maximum power [W]	
$V_{MP}$	voltage at maximum power [V]	
$I_{MP}$	current at maximum power [A]	