

Modeling and Simulation of the Photovoltaic Cells for Different Values of Physical and Environmental Parameters

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Abstract

Both research and technological development in the area of renewable energy sources are necessary to account for the increase in energy demand and environment problems in the world. The photovoltaic (PV) cell has been described by non-linear outputs characteristics in current-voltage and power-voltage. This outputs is affected by various effects such as; series resistance (R_s), shunt resistance (R_{sh}), solar irradiance and temperature. In this paper the effect of variation of parameters has been studied such as series resistance (R_s) and shunt resistance (R_{sh}) of the diode in the photovoltaic cell and these effects could be seen in the Current-Voltage (I-V) and Power-Voltage (P-V) characteristic curves. In this paper also has been studied the effect of variation of the environmental parameters such as solar irradiance and temperature. Results show that a higher temperature at constant solar irradiance produces a decrease power. So the voltage and the photovoltaic cell output power tend to decrease at higher temperatures, but there is no noticeable effect on the photovoltaic cell current. Thus, it is important to keep the cell temperature as low as possible, because higher temperatures have negative effect on output power of photovoltaic cell. On the other hand, the effect of solar irradiance on photovoltaic cell, it reveals that higher solar irradiance gives higher current and higher power. Shunt resistance has significant effect on the operating characteristic curves of PV cells as low power output is recorded if the value of shunt resistance varies from 0.07 ohms to 1700 ohms. Finally, I have presented power-voltage characteristic curves and current voltage characteristic curves of photovoltaic cell for different solar irradiance in Shkoder, Tirana and Vlore.

Keywords:

Photovoltaic Cell;
Current-voltage Characteristic Curves;
Power-voltage Characteristic Curves;
Simulation;
MATLAB®.

Article History:

Received: 29 September 2019
Accepted: 24 November 2019
Published: 01 December 2019

1- Introduction

The photovoltaic cell is the basic unit of any photovoltaic system. The photovoltaic cells are in fact large area semiconductor. A photovoltaic cell can convert photon energy in to the form of electrical signals, this method of power generation do not harm to ecosystem hence PV power generation systems are becoming popular for generation in small scale as well as in large scale production [1]. In this context, several papers have been proposed different models, the most used is; single and double diode models. The single diode model is widely used for its simplicity and easy to implement in various software. It is called model with five parameters and characterized by photocurrent source parallel with diode and shunt resistance. The detailed single diode models has been proposed to determine the behavior of photovoltaic cell under different solar levels and temperatures [2]. The current-voltage and power-voltage are used to describe the behavior of solar cell under the variation of solar irradiance, temperature and some physical parameters such as; series resistance and shunt resistance.

Maps compiled in 2016 suggest that by 2030 the photovoltaic cells could supply around 13% of global electricity [3, 4]. The territory of Albania is located in the western part of the Balkan Peninsula, at the eastern coast of Adriatic and Ionian seas. It is situated between latitudes 39°38' - 42°38' and longitudes 19°16' - 21°04' east. Thanks to this

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DOI: <http://dx.doi.org/10.28991/esj-2019-01202>

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geographical position, Albania belongs to Mediterranean climate belt with hot dry summer, with long days of sunshine and mild winter with abundant rainfall, possessing in this way a considerable solar potential energy: most areas of Albania are exposed to more than 1500 kWh/m² per year varying from 1185 to 1690 kWh/m² per year [5]. So Albania is a very good place for installation of solar panels.

The characteristic current-voltage and is a non-linear equation with multiple parameters classified as follows: those provided by constructors, those known as constants and the ones which must be computed. Sometimes, searchers develop simplified methods where, some unknown parameters cannot be calculated. They are thus assumed constant [6].

To experiment with photovoltaic cells in the laboratory is a time consuming and costly task. So, to overcome this problem, simulation techniques are used to simulate the behavior of PV cells under different conditions [7].

This paper is presenting a mathematical model of solar array and accomplishes a simulation model in MATLAB®. Output I-V and P-V characteristic curves and performance at different series resistance, shunt resistance, temperature and solar irradiance are analyzed. Thus, this research work is helpful to understand the behavior of the PV cell.

2- Methodology

The modeling method and numerical experiment for different physical and environment parameters are helpful for power electronics designers, who need a trouble-free and simulation of photovoltaic cells. Mathematical modeling of photovoltaic cells is being continuously updated to enable researchers to have a better understanding of its working. The models differ depending on the types of software researchers used such as MATLAB® [8]. A function in MATLAB® environment has been developed to calculate the current output from data of voltage, solar irradiance and temperature in the study of Gonzaez-Longatt (2005) [9]. Here, the effect of temperature, solar irradiance, and diode quality factor and series resistance is evaluated. A difficulty of this method is to require readers programming skills so it is not easy to follow. Another method which is the combination between MATLAB® m-file and C-language programming is even more difficult to clarify [10]. This model is made only in MATLAB, based on mathematical equations that define the photovoltaic cell. From the work of Gonzaez-Longatt (2005) [9], Oi (2005) [11] and Ramos Hernanz et al. (2010) [12] a function in MATLAB® [10] has been developed which calculates the current module from data of voltage, solar irradiance and temperature. Setting the constant temperature or radiation, characteristic curves current-voltage and power-voltage will be obtained. From another script also calculates the maximum power point [13].

Equivalent electrical circuit model is one of the key models under study since the last few decades. It is configured with either single or double diode for investigation of current-voltage relationships [13]. The single diode models usually have five, four, or three unknown parameters with only one exponential term. The five unknown parameters of a single diode model are photo-current (I_{ph}), diode reverse saturation current (I_0), series resistance (R_s), shunt resistance (R_{sh}), and diode ideality factor a [14, 15]. The four parameter model infers the shunt resistance as infinite and it is ignored [16]. The three-parameter model assumes that the series resistance is zero and shunt resistance is infinite and, thus, both of these parameters are ignored, whereas, the double diode models have six unknown parameters with two exponential terms [17, 18]. In fact, both single and double diode models require the knowledge of all unknown parameters, which is usually not provided by manufacturers.

Nevertheless, the current-voltage equation is a transcendental expression. It has no explicit analytical solution. The analytical methods give exact solutions by means of algebraic equations. However, due to implicit nature and nonlinearity of photovoltaic cell or module characteristics, it is hard to find out the analytical solution of all unknown parameters. Analytical methods have also some limitations and could not give exact solutions when the functions are not given. Thus numerical methods preferred in this case. It is because of the fact that numerical methods give approximate solution of the nonlinear problems without searching for exact solutions [13].

Different methods has used to developed solar cell model. These methods can be categorized in indirect methods and direct. The indirect methods such as heuristic and met heuristic algorithm to predict the five, seven and eight parameters, and direct methods like Newton's method is used in several mathematical and engineering problems to find the numerical solutions of the equations. This method is iterative and iteration sequences converge to an optimal solution of the problem to be solved [19-21].

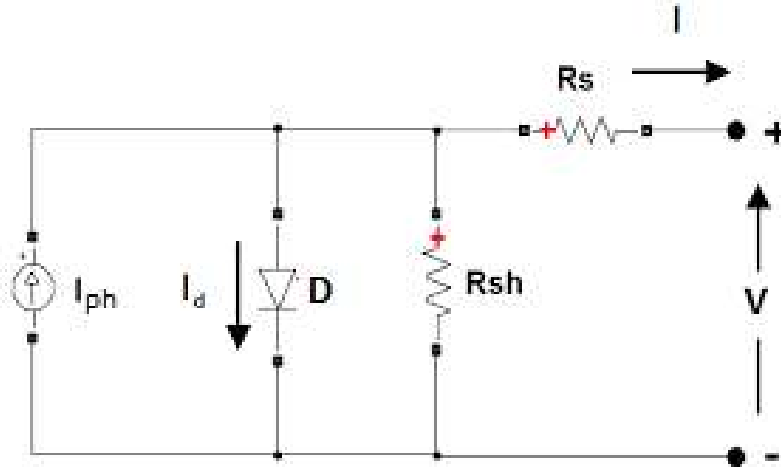


Figure 1. PV cell equivalent circuit.

The practical model of single solar cell is shown in Figure 1. This model can be expressed by the equation which mathematically describes the current-voltage and power -voltage of photovoltaic cell as follows:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{V + IR_s}{aV_T}\right) - 1 \right] - \frac{V + IR_s}{R_{sh}} \quad (1)$$

Where I_0 is the reverse saturation current of diode, a is ideality factor of the diode, V is the voltage across the diode, and $V_T = \frac{N_s k_B T}{e}$ is termed as thermal voltage due to its substantial temperature dependence, N_s is the number of photovoltaic cells modules connected in series, $k_B = 1.381 \times 10^{-23} \text{ J/K}$ is the Boltzmann's constant, $e = 1.602 \times 10^{-19} \text{ C}$ is the electron charge, T is the junction temperature (operating temperature) in Kelvin (K). The photo-current I_{ph} is generated on absorption of solar irradiance by solar cell hence photo-current value is directly related to variation in solar irradiance and temperature and that is [8, 22, 23]:

$$I_{ph} = \frac{G}{G_n} [I_{pvn} + K_i(T - T_n)] \quad (2)$$

Where I_{pvn} is rated solar current at nominal weather conditions (25°C and 1000 W/m^2) or short circuit current, K_i is short circuit temperature coefficient, G is solar irradiance in W/m^2 , G_n is nominal irradiance in normal weather conditions (25°C and 1000 W/m^2) and T_n is nominal temperature = 298.15 K . The saturation current of the diode is:

$$I_0 = I_{on} \left(\frac{T}{T_n}\right)^3 \exp\left[\frac{qE_g}{ak_B} \left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (3)$$

Where I_{on} is reverse saturation current of PV cell for nominal temperature and irradiance values and E_g is band-gap energy of silicon. The reverse saturation current of PV cell is:

$$I_{on} = \frac{I_{scn}}{\left[\exp\left(\frac{V_{ocn}}{aV_{Tn}}\right) - 1\right]} \quad (4)$$

Where I_{scn} nominal SC is current, V_{ocn} is nominal OC voltage constant. We know that series resistance is very small then for an ideal solar cell there is no series resistance (no series losses) and no leakage to ground (no shunt resistance) therefore R_s and R_{sh} are neglected by putting $R_s = 0$ and $R_{sh} = \infty$. The expression for ideal cell is simplified for current-voltage characteristic curves of photovoltaic cell and expression of ideal single cell is as follows [1]:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{V + IR_s}{aV_T}\right) - 1 \right] \quad (5)$$

In the case of short circuit mode, the voltage will be equal to zero and the photo-current is equal to short circuit current ($I_{ph} = I_0$) [24]:

$$I = I_{ph} - I_0 \left[\exp\left(\frac{V}{aV_T}\right) - 1 \right] \quad (6)$$

In case of open circuit, the current will be equal to zero, and the voltage is as follows:

$$V_{OC} = V_T \ln \left(\frac{I_{ph}}{I_0} + 1 \right) \quad (7)$$

The output power is given by:

$$P = \left\{ I_{ph} - I_0 \left[\exp \left(\frac{V + IR_s}{aV_T} \right) - 1 \right] \right\} V \quad (8)$$

According to PV cell characteristics, current will be maximum when the cell is short circuited. In this case the voltage will be zero ($V=0$). The voltage will maximum when the cell's circuit is open. In this case the current is zero ($I=0$). Between the open and short circuit the power output is greater than zero [24].

The Newton iterative method is the most popular iterative method for nonlinear function. Under the first guess and the Jacobian of the nonlinear function can converge very fast. Several papers use the Newton method, to obtain roots of implicit transcendental equations [25]. However, it uses an algorithm which search for the approximations of the roots of function $f(x) = 0$ [26]. It starts with a function $f(I)$ defined over the real numbers I , the function's derivative $f'(I)$, and an initial guess I_0 for a root of the function $f(I)$. If the function satisfies the assumptions made in the derivation of the formula and the initial guess is close, than a better approximation I_1 is [27]:

$$I_1 = I_0 - f(I_0)/f'(I_0) \quad (9)$$

Geometrically, $(I_1, 0)$ is the iteration of I -axis and the tangent of the graph of $f(I)$ at $(I_0, f(I_0))$.

$$I_1 = I_k - f(I_k)/f'(I_k) \quad (10)$$

Where, I_k present a k^{th} iteration and I_{k+1} presents the $(k + 1)^{\text{th}}$ iteration, $f'(I_k)$ is the derivative of function $f(I_k)$. Using equation (10), the output current of a solar cell can be calculated by modifying the current-voltage in equation (5) as follows [27]:

$$f(I) = I - I_{ph} + I_0 \exp \left(\frac{V + IR_s}{aV_T} \right) - I_0 \quad (11)$$

$$f'(I) = 1 + \frac{IR_s}{aV_T} + \exp \left(\frac{V + IR_s}{aV_T} \right) \quad (12)$$

By exploiting the above equations, following output current is computed iteratively [27]:

$$I_{k+1} = I_k - \frac{\left[I_k - I_{ph} + I_0 \exp \left(\frac{V + IR_s}{aV_T} \right) - I_0 \right]}{1 + \frac{IR_s}{aV_T} + \exp \left(\frac{V + IR_s}{aV_T} \right)} \quad (13)$$

3- Results and Discussions

The obtained result if current-voltage and power-voltage characteristic curves has been produced using m-file MATLAB by varying certain parameters one at a time keeping other parameters constant. The series resistance of photovoltaic cell is low, and in some cases, it can be neglected. However, to render the model suitable for any given photovoltaic cell, it is possible to vary this resistance and predict the influence of its variation on photovoltaic cell outputs.

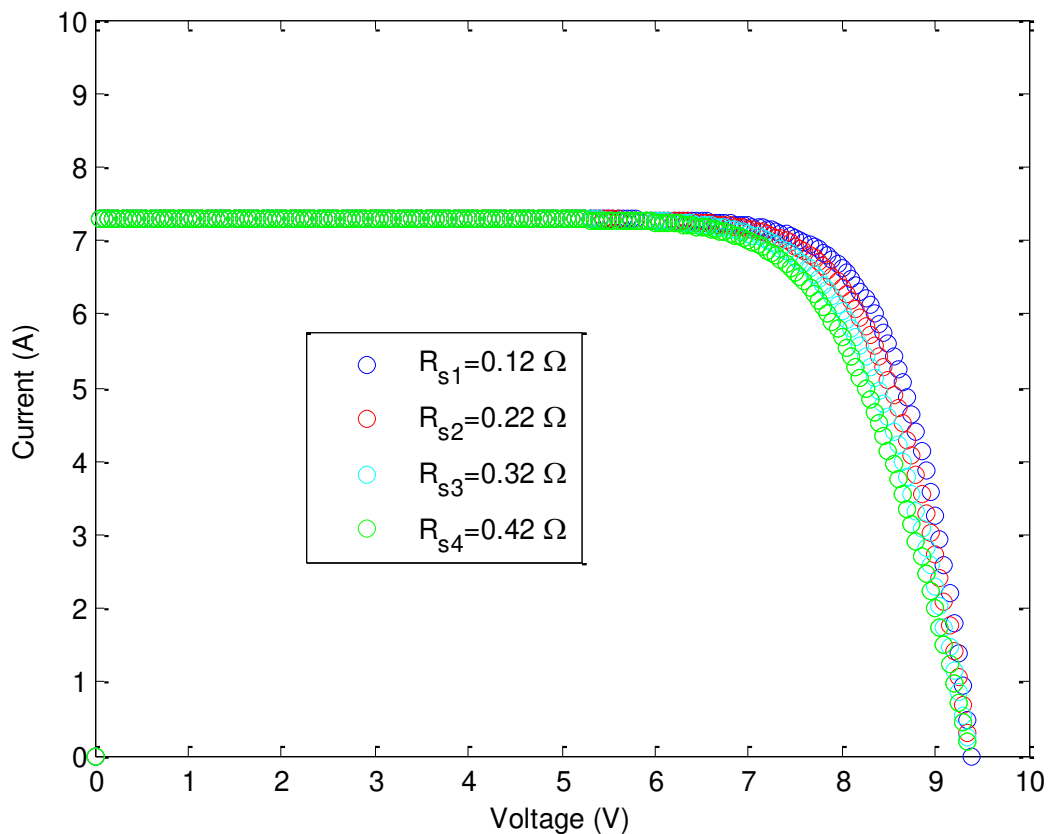
Figures 2 and 3 shows current-voltage and power-voltage characteristic curves for four different values of R_s respectively. As seen in these figures, the variation of R_s affects the slope angle of the current-voltage characteristic curves resulting in a deviation of the maximum power point. It was shown that higher values of R_s reduce the power output of photovoltaic cell. On another side the simulation was performed for the five different values of the shunt resistance, namely 0.07 ohms, 0.1 ohms, 0.15 ohms, 0.5 ohms and 1700 ohms. The shunt resistance of many photovoltaic cells should be large enough for higher output power. In fact, for a low shunt resistance, the photovoltaic cell current collapse more steeply which means higher power loss. These results can be seen in Figures 4 and 5, respectively.

Table 1 shows the distribution of the global average daily solar irradiance in Shkoder, Tirana and Vlore [28].

Table 1. The daily average of solar irradiance for some City in Albania (W/m²).

City	Shkoder	Tirana	Vlore
January	1734	1830	1931
February	2362	2468	2618
March	3343	3346	3535
April	4431	4465	4757
May	5442	5602	5829
June	6317	6477	6753
July	6571	6781	6984
August	5744	5990	6117
September	4444	4631	4808
October	2997	3190	3293
November	1840	1981	2095
December	1521	1546	1680

Figure 6 show the P-V curves for different solar irradiances and constant temperature $T = 25^{\circ}\text{C}$ in Tirana. The effect of increasing solar irradiance while temperature was fixed is increasing the output and short circuit current, the output voltage almost not affected very much. Figure 7 show current-voltage characteristic curves for various solar irradiances and constant temperature $T = 25^{\circ}\text{C}$ in Tirana. Figure 8 show the power-voltage curves for different solar irradiances and constant temperature $T = 25^{\circ}\text{C}$ in Shkoder. Figure 9 show the power-voltage curves for different solar irradiances and constant temperature $T = 25^{\circ}\text{C}$ in Vlore. The figures (Figures 6, 7, 8 and 9) show that with the increase in irradiance values, the values of the cell current and the maximum power also increase proportionately, but cell voltage increases very less. This is because the open circuit voltage is logarithmically dependent on the solar irradiance, yet the short circuit current is directly proportional to solar irradiance.

**Figure 2. I-V characteristic curves for parametric variation of series resistance.**

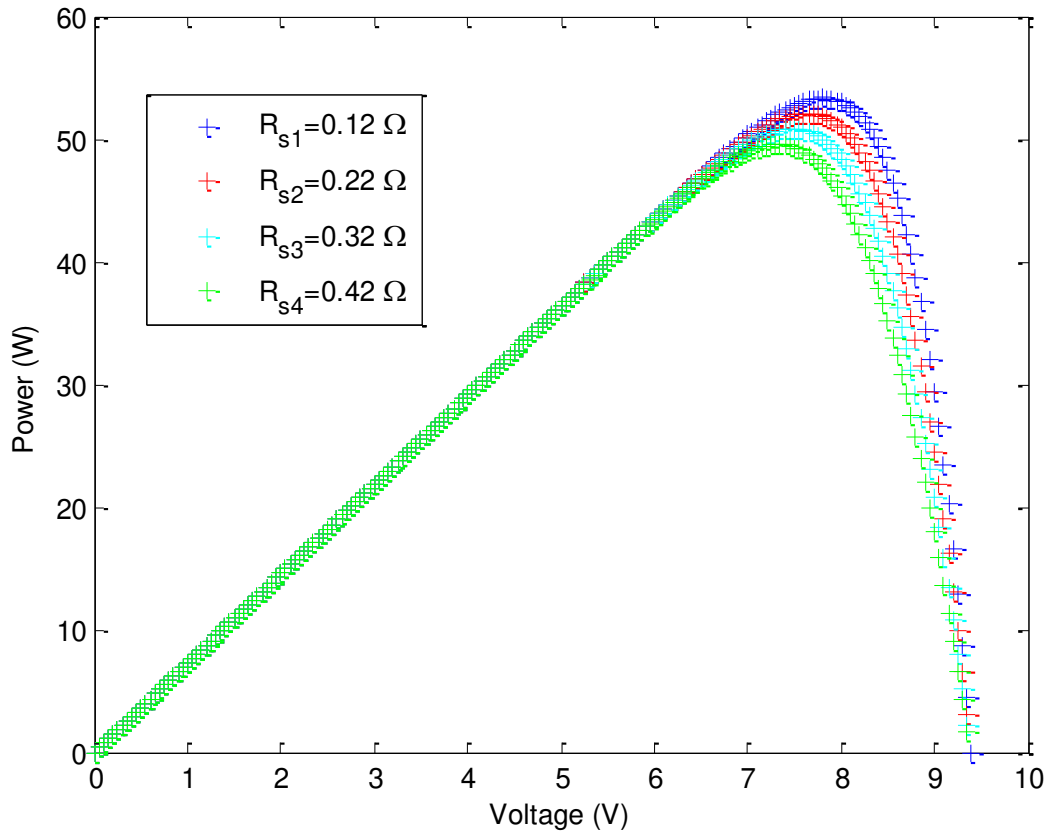


Figure 3. P-V characteristic curves for parametric variation of series resistance.

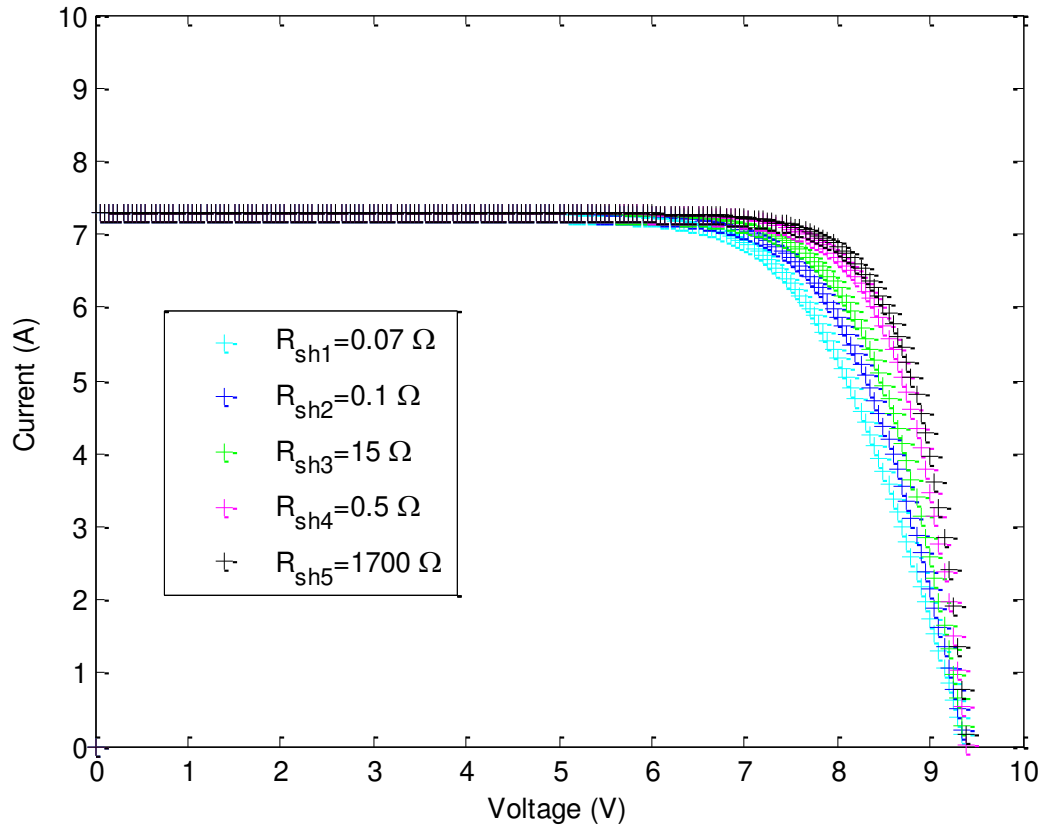


Figure 4. I-V characteristic curves for parametric variation of shunt resistance.

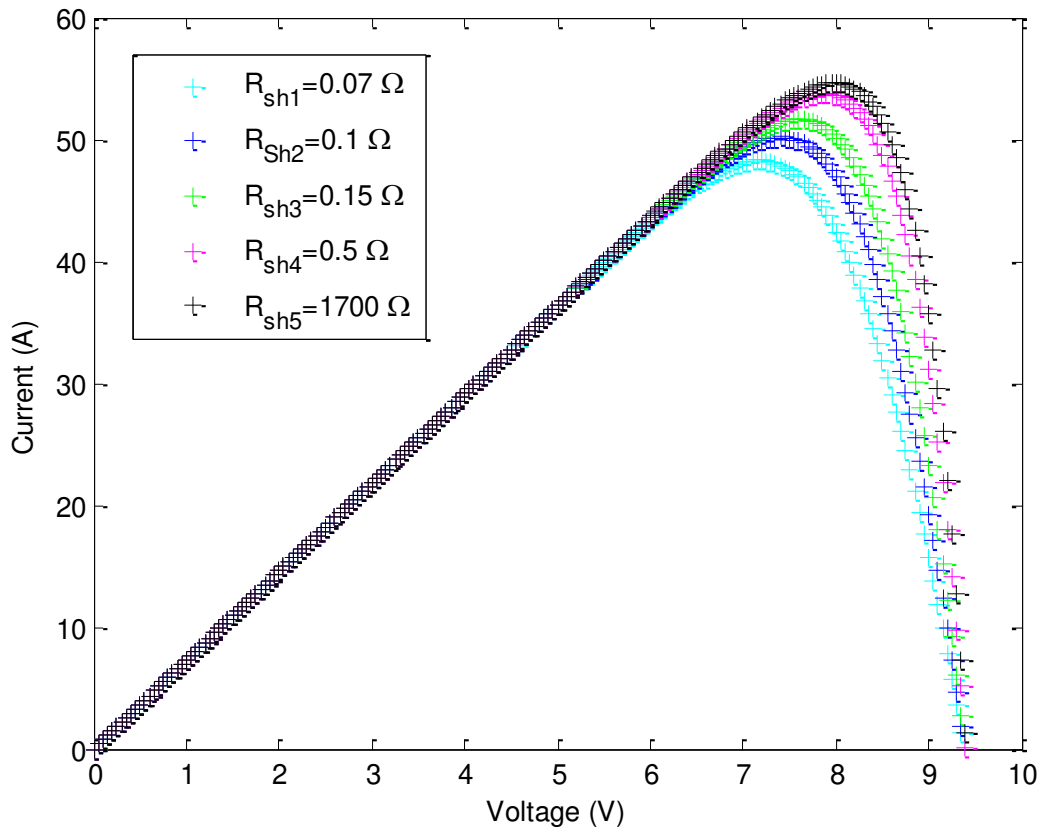


Figure 5. P-V characteristic curves for parametric variation of shunt resistance.

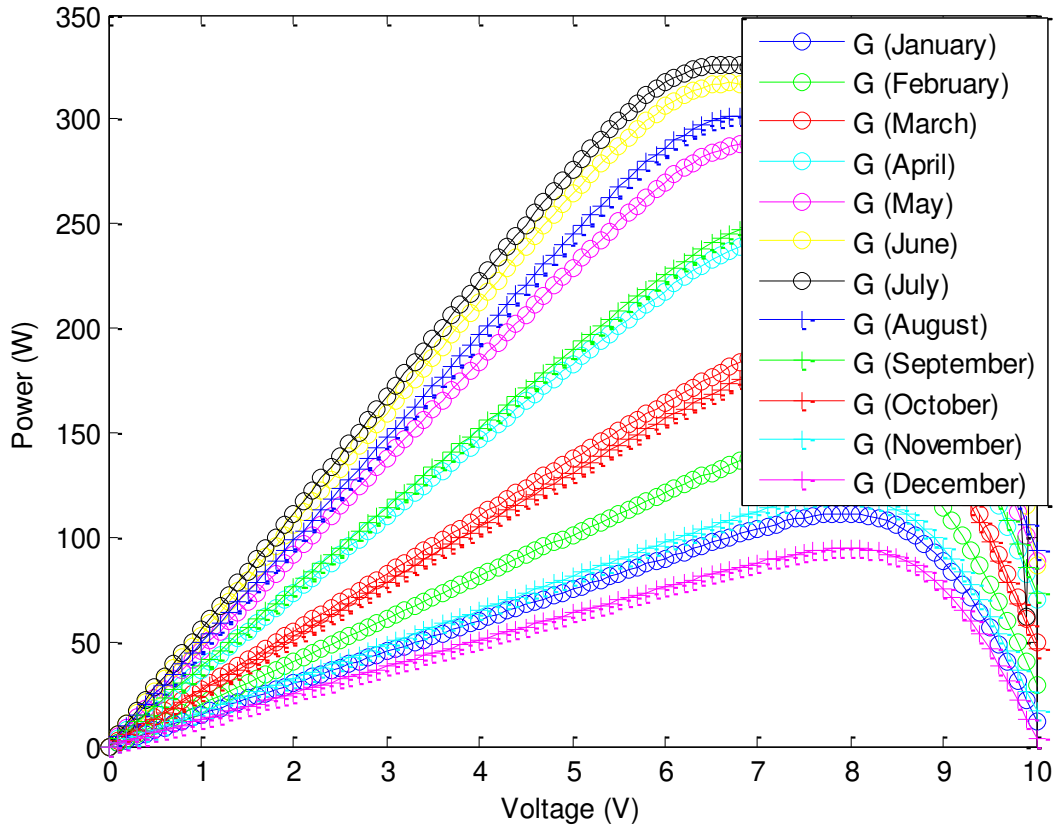


Figure 6. Power-voltage characteristic curves of photovoltaic cells for various irradiation and constant temperature in Tirana, Albania.

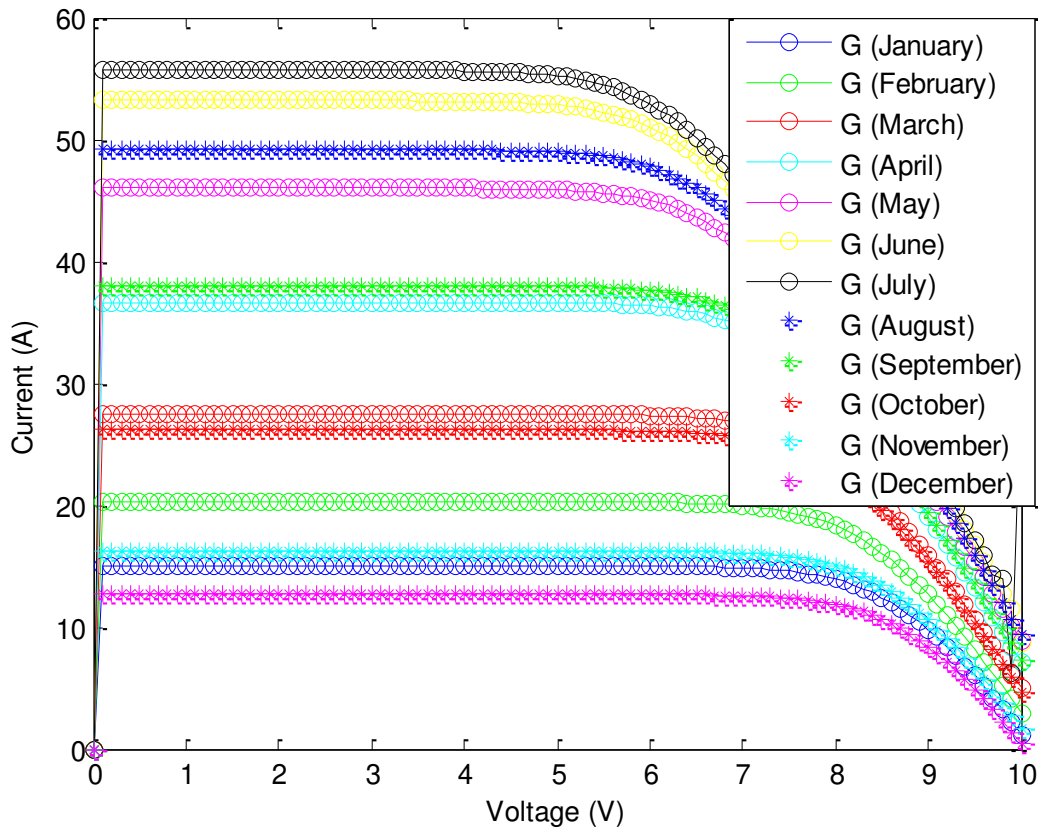


Figure 7. Current-voltage characteristic curves of photovoltaic cell for various irradiation and constant temperature in Tirana, Albania.

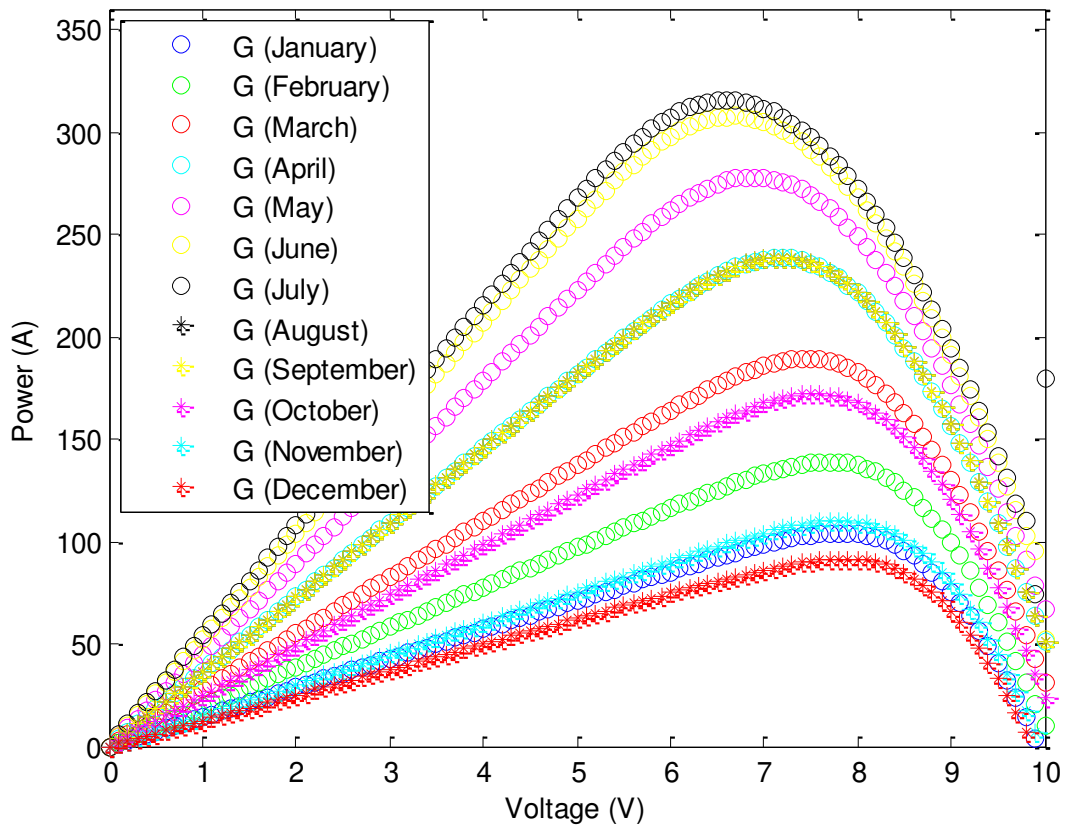


Figure 8. Power-voltage characteristic curves of photovoltaic cells for various irradiation and constant temperature in Shkoder, Albania.

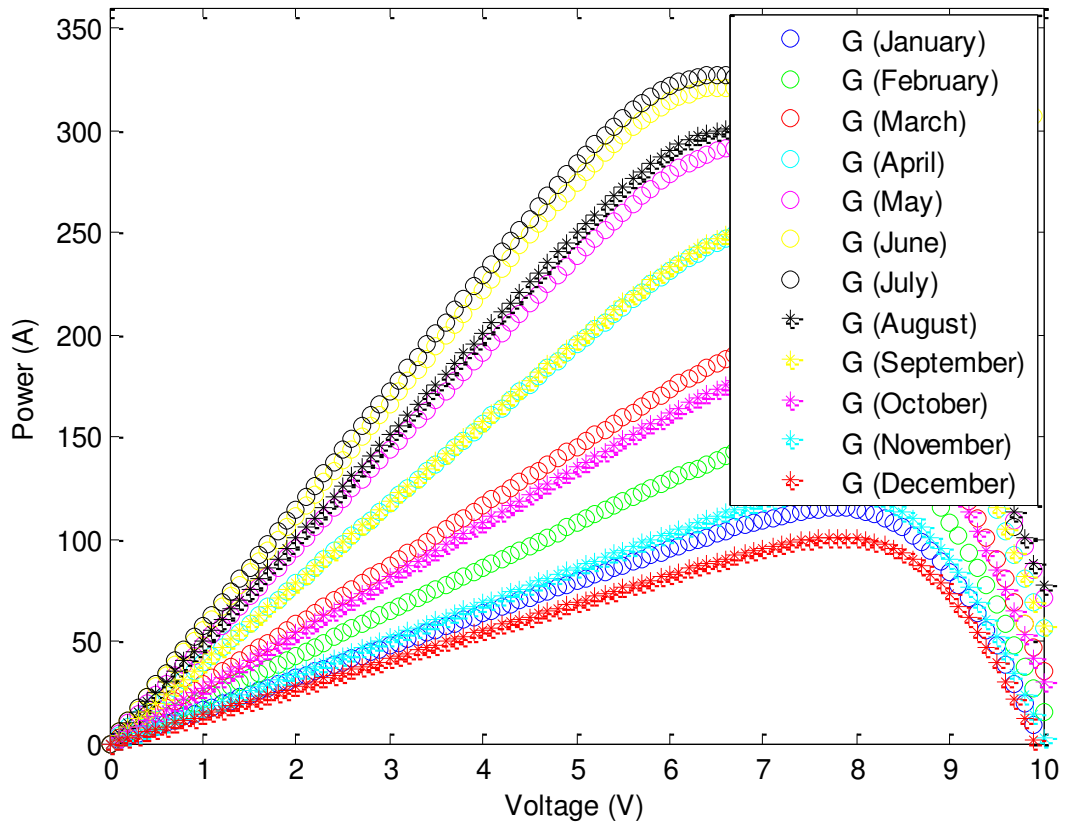


Figure 9. Power-voltage characteristic curves of photovoltaic cells for various irradiation and constant temperature in Vlore, Albania.

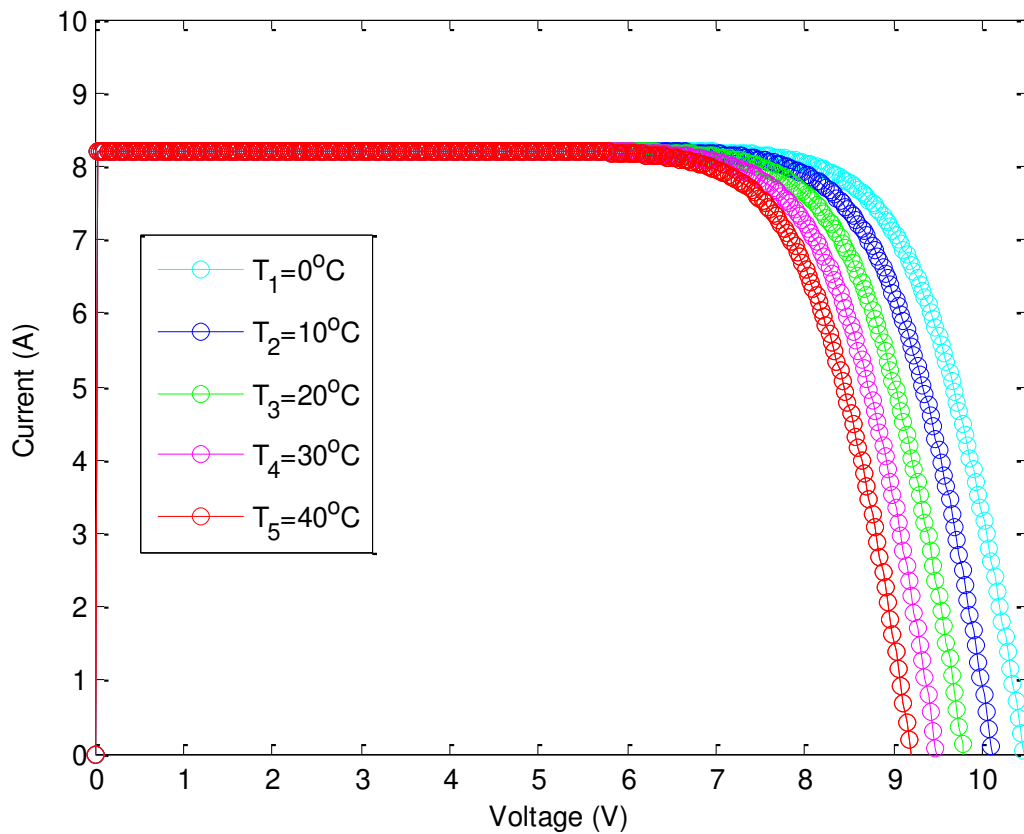


Figure 10. Current-voltage characteristic curves of photovoltaic cell for various temperature and constant irradiation.

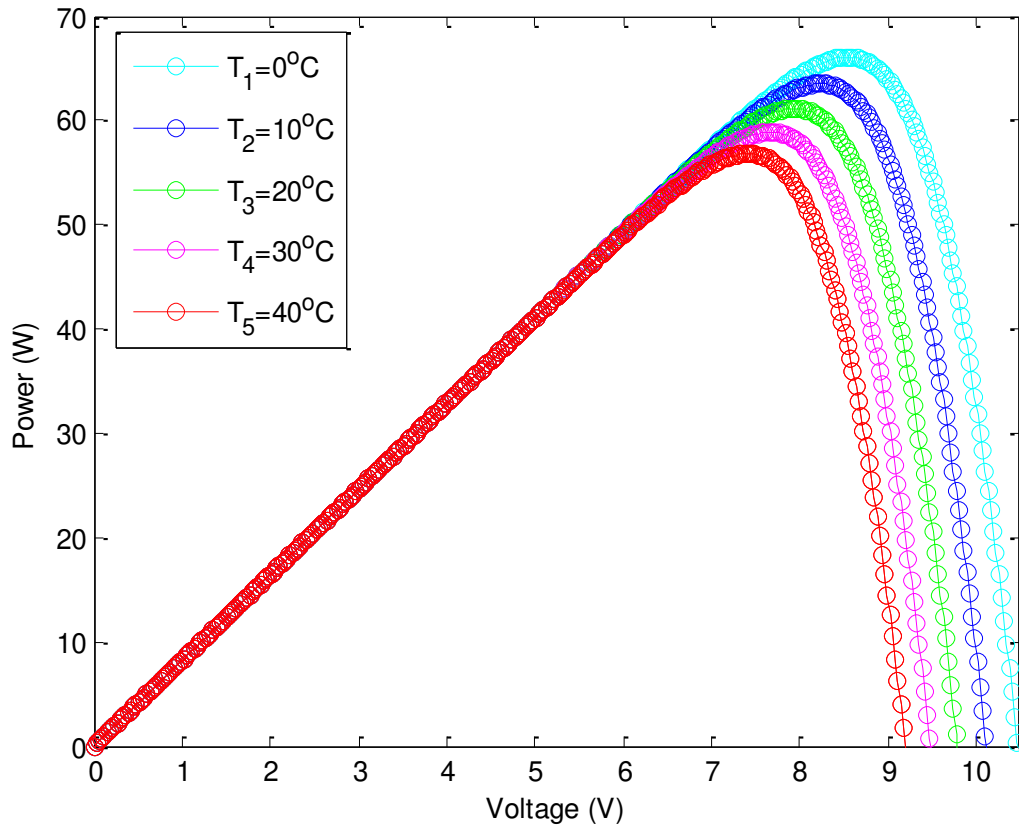


Figure 11. Power-voltage characteristic curves of photovoltaic cells for various temperature and constant irradiation.

Figures 10 and 11 show current-voltage and power-voltage characteristics curves for various temperature (0, 10, 20, 30, 40°C) respectively with constant irradiation $G=1000 \text{ W/m}^2$. The photovoltaic cell's performance was noted to be best at 0°C. From Figures 10 and 11, it is observed that as temperature increases cell current also increases slightly and cell voltage shows a significant decrease in its value. The increase in the short-circuit current is much less than the decrease in the open-circuit voltage, whereas the maximum power output decreases.

4- Conclusion

This paper presents the simulation of photovoltaic cells using the software MATLAB®. The main objective was to find the nonlinear current-versus-voltage and power-versus voltage characteristics curves for photovoltaic cells. The simulation results showed us that photovoltaic cell output current, voltage and power vary with the changes irradiation, temperature and some physical parameters such as series resistance and shunt resistance. As a result of the study, higher values of series resistance R_s reduce the power output of photovoltaic cell.

When shunt/parallel resistance varies between 0.07 ohm and 1700 ohm, the current output and voltage output decreases slightly and this results in slight net reduction in power output. However, a significant decrease in current, voltage and power output is recorded when the value of shunt/parallel resistance is 0.07 ohm.

As the increase in irradiation the photovoltaic cell output voltage will increase in slightly manner, also, higher magnitude of power will be produced. The change in temperature will affect the behavior of the solar cell, the output current will increase but in negligible value, while the output voltage will decrease, and this will affect the photovoltaic cell efficiency.

5- Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancies have been completely observed by the authors.

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