THE PERFORMANCE OF PHOTOVOLTAIC CELLS FOR DIFFERENT VALUES OF PHYSICAL PARAMETERS

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Abstract

In this paper presented the effects of the variation of the physical parameters such as series resistance, shunt resistance, saturation current and the variation of the ideality factor current-voltage and power-voltage characteristic curves of the photovoltaic (PV) cells. The operating characteristics of photovoltaic cell are also investigated at a wide range of operating conditions and physical parameters. The PV cell has nonlinear characteristics which make quite expensive and time consuming to study experimentally the operation curves of a PV cell under varying parameters. Therefore a simulation code is built for this purpose by using MATLAB®. Results show that the increase of the ideality factor of the diode lead to an increase in the output power of a PV cell, while on the other hand the increase of the diode saturation current leads to a decrease of the power. Shunt resistance has a significant effect on the operation characteristic curves of PV cells as low power output is recorded if the value of shunt resistance varies from 0.05 Ω to 1500 Ω. In this study the environment parameters (i.e. solar radiation and temperature) are taken constant.

Key words: Series resistance, shunt resistance, diode characteristic curves, ideality factor.

Introduction

The research in renewable energy has become an increasingly important topic in the 21st century with the problem of energy crisis becoming more and more aggravated, resulting in increased exploitation and search for new energy resources such as wind, water, geothermal and solar energy around the world. Solar energy is green energy, which is inexhaustible and environment friendly. It is becoming one of the most promising alternatives for conventional energy sources. Due to this, photovoltaic solar energy has been increasingly used to generate electric power from sunshine. 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. The characteristic I-V 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.

To experiment with PV 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. In this paper, output I-V and P-V characteristic curves and performance at different series resistance, shunt resistance, saturation current of the diode and the ideality factor of the diode are analyzed. Thus, this research work is helpful to understand the behaviour of the PV cells.

Methods

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. 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. The four parameter model infers the shunt resistance as infinite and it is ignored. 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. 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.

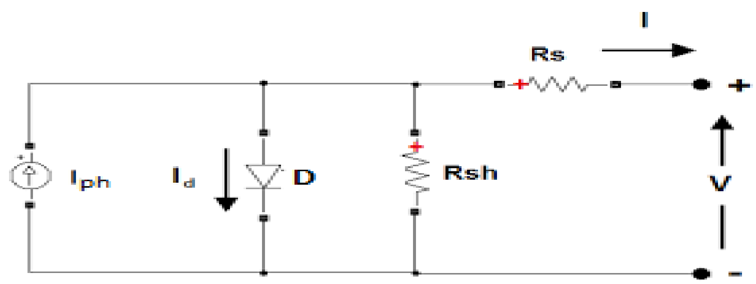

Figure 1. PV cell equivalent circuit.

The practical model of single solar cell is shown in Figure 1. It incorporates a current source, a diode, a series arrangement resistance and a shunt resistance, these two resistances added because there is no ideal solar cell in practice. With the identical circuit Figure 1 and utilizing Kirchhoff's law, we get the accompanying condition for the load current:

$$I = I_{ph} - I_0\left[exp\left(\frac{V+IR_s}{a\left(\frac{N_s k_B T}{e}\right)}\right) - 1\right] - \frac{V+IR_s}{R_{sh}} \qquad (1)$$

Where I_0 is the reverse saturation current of diode, a is ideality factor of the diode, V is the voltage across the diode, N_s is the number of photovoltaic cells modules connected in series, k_B=1.381×10^{-23} J/K is the Boltzmann's constant, e = 1.602×10^{-19} C is the electron charge, T is the junction temperature (operating temperature) in Kelvin. The photo-current I_{ph} is generated on absorption of solar radiation by solar cell hence photo-current value is directly related to variation in solar irradiance and temperature and that is:

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

where I_{pvn} is rated solar current at nominal weather conditions ($25^o C$ 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^{o}C and 1000 W/m^2) and T_n is nominal temperature (298.15 K). The saturation current of the diode is

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

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

$$I_{on} = \frac{I_{scn}}{\left[exp\left(\frac{eV_{ocn}}{aN_s k_B T}\right) - 1\right]} \qquad (4)$$

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} = ∞. The expression for ideal cell is simplified for current-voltage characteristic curves of photovoltaic cell and expression of ideal single cell is as follows:

$$I = I_{ph} - I_0\left[exp\left(\frac{e(V+IR_s)}{aN_s k_B T}\right) - 1\right] \qquad (5)$$

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

$$I = I_{ph} - I_0\left[exp\left(\frac{eV}{aN_s k_B T}\right) - 1\right] \quad (6)$$

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 power output can be expressed:

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

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.

Results

The series resistance of PV cell is low, and in some cases, it can be neglected. However, to render the model suitable for any given PV cell, it is possible to vary this resistance and predict the influence of its variation on PV cell outputs.

Figure 2 and 3 shows I-V and P-V characteristic curves for five different values of R_s respectively. As seen in these Figures, the variation of R_s affects the slope angle of the I-V 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 PV cell. On another side the simulation was performed for the four different values of the shunt resistance, namely 0.05 ohms, 0.1 ohms, 0.5 ohms and 1500 ohms. The shunt resistance of many PV cell should be large enough for higher output power. In fact, for a low shunt resistance, the PV cell current collapse more steeply which means higher power loss. These results can be seen in Figures 4 and 5.

I-V and P-V characteristics under varying saturation current of the diode are shown in Figure 6 and 7. In this case, I_0 changes with five values of 1, 2, 3, 4, 5 nA, respectively. Figure 6 shows that higher diode saturation current produces a smaller voltage and PV cell output power, however the current remains constant, according to Equation (1).

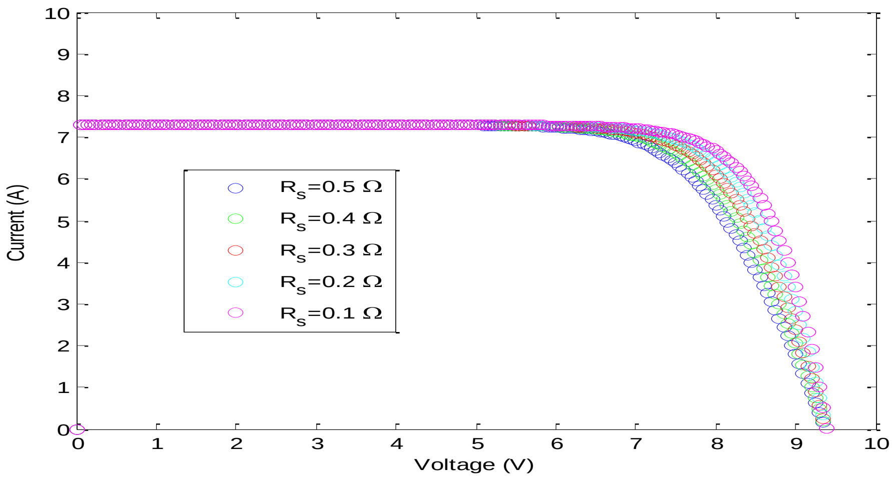

Figure 2. I-V characteristic curves for parametric variation of series resistance.

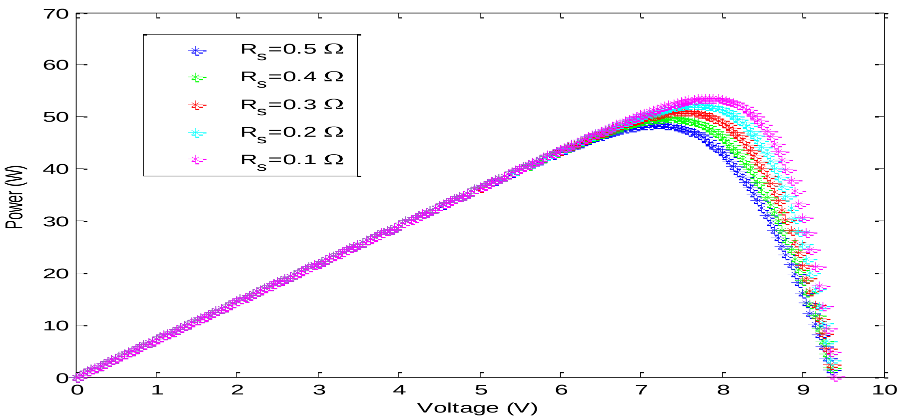

Figure 3. P-V characteristic curves for parametric variation of series resistance.

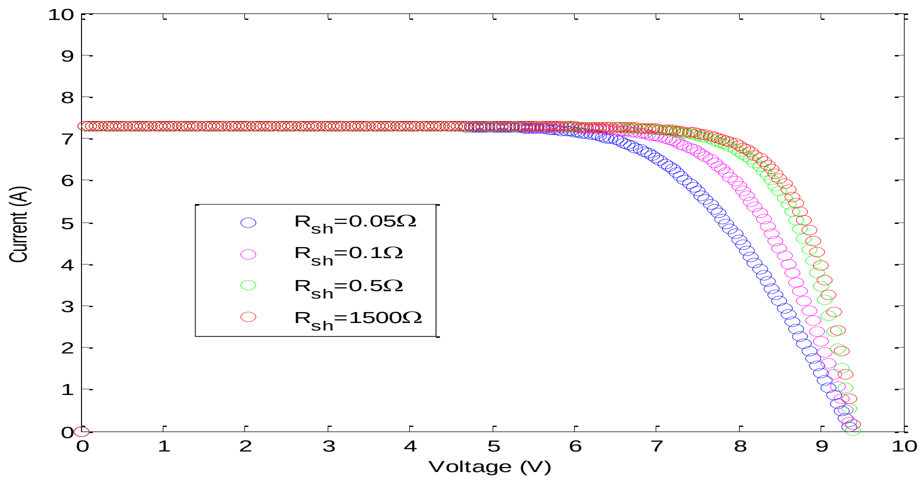

Figure 4. I-V characteristic curves for parametric variation of shunt resistance.

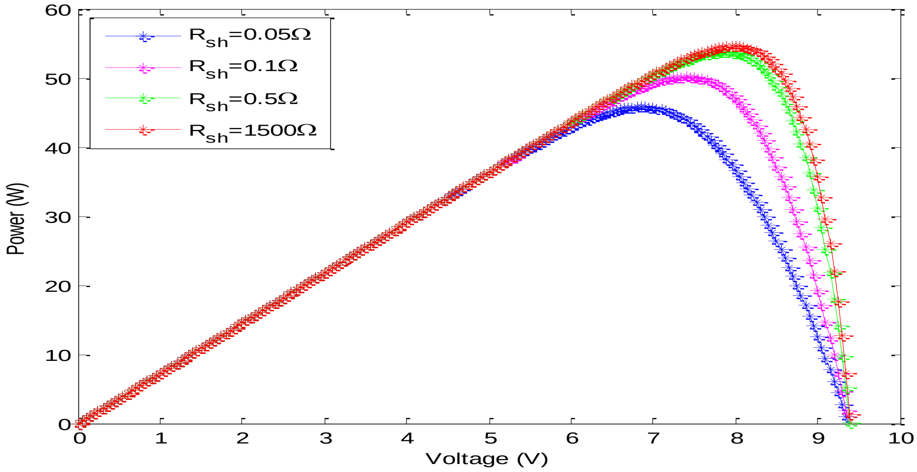

Figure 5 .P-V characteristic curves for parametric variation of shunt resistance.

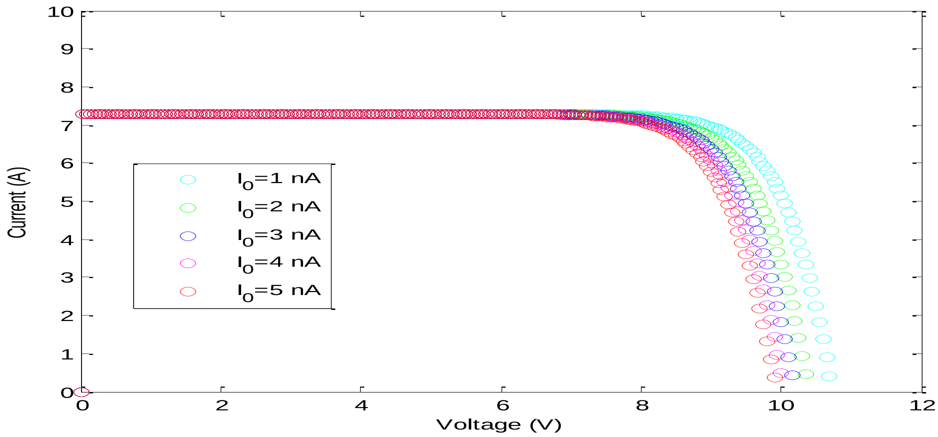

Figure 6 .I-V characteristic curves for variation in saturation current of the diode.

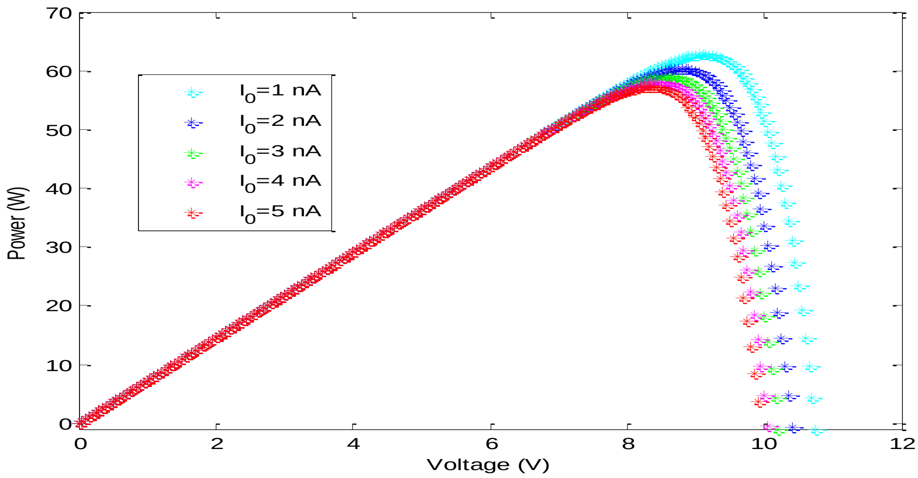

Figure 7. P-V characteristic curves for variation in saturation current of the diode.

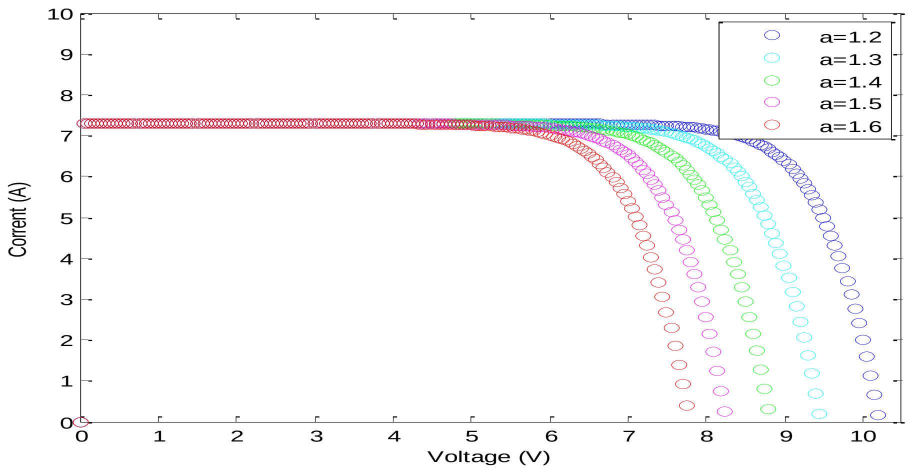

Figure 8. I-V characteristic curves for parametric variation of ideality factor of the diode

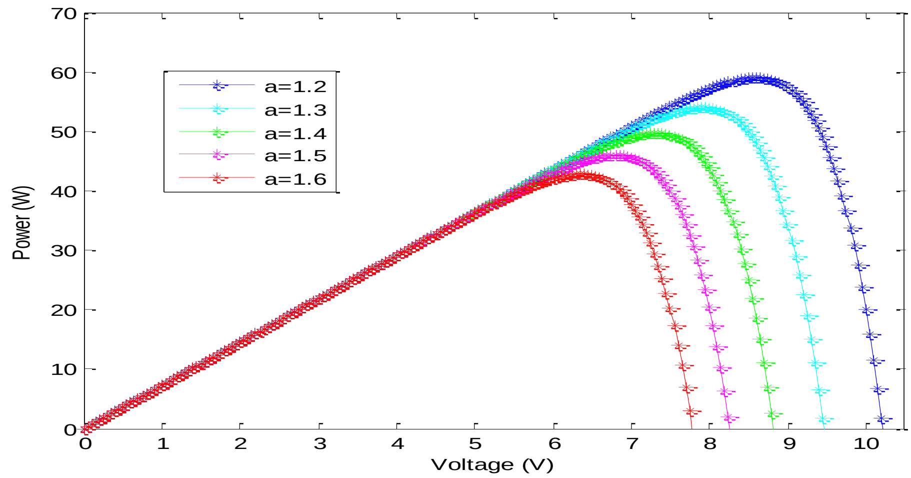

Figure 9. P-V characteristic curves for parametric variation of ideality factor of the diode

Figure 8 and 9 shows I-V and P-V characteristic curves for five different values of parametric variation of the ideality factor of the diode, respectively. Ideality factor of the diode was varied as 1.2, 1.3, 1.4, 1.5 and 1.6. The ideality factor of the diode is generally between 1 and 2. It can be observed from simulation results in Figure 8 and Figure 9, which more the value of ideality factor was towards 2, more was the power obtained from the PV cell. But the simulation results with *a*=1.5, do not reflect realistic results, as obtaining such high value of Voc (open-circuit voltage, i.e., voltage when current is 0) is practically not possible with the type of PV cell with high ideality factor also show high reverse saturation current which would normally result in low open-circuit voltage.

Conclusions

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. 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 0.05 ohm and 1500 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 0.05 ohm. The influence of an increase in saturation current of the diode is evidently seen as decreasing the open-circuit voltage. The voltage and photovoltaic cell output power have higher values at a higher ideality factor of the diode; however the current is not affected by the ideality factor of the diode.

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