Single Diode Circuit Model of Photovoltaic(PV) Cell: Load Current Estimator

Nor Azni Shahari*, Farah Atikah Mohamad Azraei, Nurul Nabilah Rosli, & Siti Najwa Izaham
| norazni@ns.uitm.edu.my

1. Introduction

With the increasing search for new technologies that improve the utilization of existing renewable energy sources, the use of solar energy is spreading increasingly. There are numerous ways to use solar energy to generate electricity. This generation is used here by means of photovoltaic cells. A photovoltaic (PV) cell is an energy harvesting technology, that converts solar energy into useful electricity through a process called the photovoltaic effect. This cell can be connected in series, parallel or mixed form. The electrical model with a diode is the most used, as well as two resistors' series Rs and shunt Rp respectively associated with the circuit.

Studies with photovoltaic cells in some situations can't be performed by many influences, such as rain. Therefore, it's necessary to use a model that faithfully represents a cell's features so that studies can be performed in the laboratory and a mathematical model is used to make such representation. This derived mathematical model for PV cells is implemented in MATLAB software that uses a numerical method to estimate the load current.

2. Model Formulation

To better understand the behavior of a PV panel, it is necessary to study the behavior of a single cell, as a solar panel is composed of a set of connected cells. The model is based on an electrical circuit that represents a cell. This circuit is composed by an electric current source connected in series and parallel with a diode. Pranahita, Kumar and Babu (2014) presented that the single diode PV cell model is the simplest way to represent the solar cell. In a PV cell, there is an equivalent circuit cell that consists of a diode, a series of resistor (R_s), a shunt resistor (R_{sh}) and a current source connected to a cell. This cell also need sunlight to generate current, which also called as photon current, I_{ph} The equivalent circuit of a photovoltaic cell is represented by the Figure 1 below.

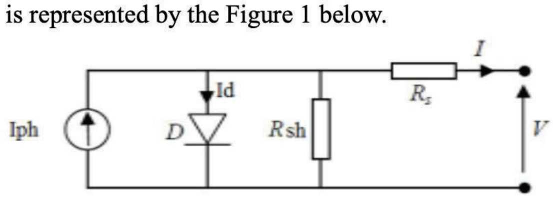

Figure 1: Electrical equivalent model of the PV cell

From the above circuit, the load current-voltage (I-V) model gives,

Ideal PV cell equation:

$$I = I_{ph} - I_D - I_{sh} \quad (1)$$

The diode equation (I_D) :

$$I_D = I_0\left(e^{\frac{V+IR_s}{nV_t}} - 1\right) \quad (2)$$

The equation of load current-voltage (I-V) for PV cell given by

$$I = I_{ph} - I_0\left(e^{\frac{V+IR_s}{nVt}} - 1\right) - \frac{V + IR_s}{R_{sh}} \tag{3}$$

$$V_t = \frac{kT}{q} = 26mV$$

Where:

I : The supplied current by the cell when it operates as a generator / Load current (Amp, A)

I_{ph} : The cell photon current dependent on the illumination and the temperature (Amp, A)

I_0 : The diode saturation current (Amp, A)

V : The voltage at the same cell terminals (Volt, V)

R_s : The series resistance represents the various contacts and connections resistances (Ohm, Ω)

R_{sh} : The shunt resistance characterizing the current leakage currents (Ohm, Ω)

n : Diode ideality factor $(1 < n < 2)$

V_t : Thermal voltage (Volt, V)

k : Boltzmann constant $(1.38x10^{-23}$ Joule, J/Kelvin, K)

T_c : Operating temperature (303.33 Kelvin, K)

q : Electric charge of electron $(1.602x10^{-19}$ Coulomb, C)

The equation (3) is a nonlinear and implicit equation that represents two ends of the total amount of current provided by the solar cell, therefore, it is difficult to derive an analytical solution for a set of model parameters at a specific temperature and irradiance. The equations only can be solved by iterative methods, thus, various numerical methods have been applied in solving a PV cell model. The equation is solved by applying three numerical analysis methods which are the Secant method, exponential method and three points Secant method.

Then, an equation (3) can be rewritten as follows:

$$F(I) = I_{ph} - I_0\left(e^{\frac{V+IR_s}{nVt}} - 1\right) - \frac{V + IR_s}{R_{sh}} \tag{4}$$

$$Y = I - F(I) \tag{5}$$

which results in:

$$Y = I - \left(I_{ph} - I_0\left(e^{\frac{V+IR_s}{nV_t}} - 1\right) - \frac{V + IR_s}{R_{sh}}\right) \tag{6}$$

Table 1 below illustrates the PV cell parameters by some research papers which will be implemented by the numerical methods.

Table 1: PV cell parameters used in simulation models based on some research.

Parameters	Traiki, Ouajji, Bifadene & Bouattane, (2018)	Bonkoungou, Koalaga & Njomo, (2013) Solarex MX60 module for G =1000W/m^2 and T=25°C	El-Sayed, Nafeh, Fahmy & Yousef, (2015) LORENTZ LC80-12M PV module at STC.
I_{ph} (A)	0.5610	3.8119	5.0
I_O (A)	$5.514x10^{-3}$	$1.859x10^{-7}$	$3.838x10^{-8}$
R_s (Ω)	$77.69x10^{-3}$	0.180	0.216
R_{sh} (Ω)	25.9	360.002	66.8
n	1.7225	1.36	1.25

3. Graphical User Interface (GUI)

The Model is performed using MATLAB solver as shown in figure 2 below. The model attempts to determine the LOAD CURRENT. Fill up the entry boxes or text area for the Diode saturation current, cell photon current, voltage, series resistance and shunt resistance, Diode ideality factor on the left-hand side of the system. State the initial point for the system to be used for the method that is in the middle of the system. Then, select one of the listed methods from the right-hand side of the system, that is, execute code and give the answer in terms of load current that has been estimated. This product allows us to quickly see the effects of changes in various parameters on the output of the product.

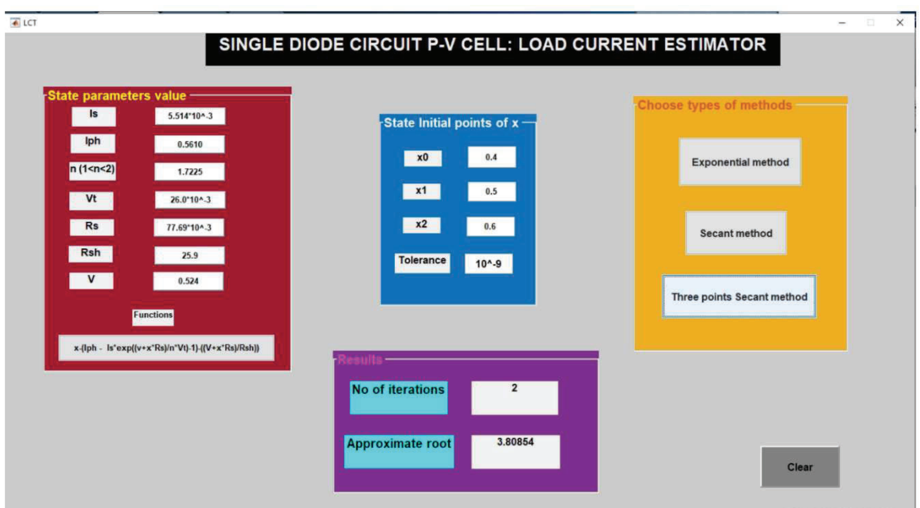

Figure 2: Simulation GUI MATLAB for PV cell equation

4. Result and Discussion

An application of a single diode PV was used or also known as solar cell model and made comparison between the Secant, exponential and three-point Secant method. Comparison of the results of these three numerical methods indicated that three-point Secant method and Secant method need almost similar number of iterations when converge to the root (Load current) for every type of parameters and both methods are less influenced by the selected initial approximations. These results contradict the exponential method since the number of iterations for this method will be increased if the initial points are far from exact value. Not only that, the exponential method also will diverge if the negative initial approximations are used since the exponential formula is unable to compute the number of iterations needed. Thus, this study has provided a deeper insight into the existing knowledge of Secant method by providing more effective and better method in computing load current of PV cells.

References

Bonkoungou, D., Koalaga, Z., & Njomo, D. (2013). Modelling and simulation of photovoltaic modules considering single-diode equivalent circuit models in matlab. *International Journal of Emerging Technology and Advanced Engineering*, *3*(3), 493-502.

Traiki, G., Ouajji, H., Bifadene, A. K., & Bouattane, O. (2018). Single solar cell ideality factor determination using a fixed-point method. *Periodicals of Engineering and Natural Sciences (PEN)*, 6(2), 331-337.

El-Sayed, T. M., Nafeh, A. E. S. A., Fahmy, F. H., & Yousef, H. K. (2015). PV parameters estimation using a developed iterative method. *International Journal of Scientific Research & Engineering Trends*, *1*(1), 13-17.

Pranahita, B. S., Kumar, A. S., & Babu, A. P. (2014). A study on modelling and simulation of photovoltaic cells. *International Journal of Research in Engineering and Technology*, *3*(11), 101-108.