

Step By Step Analyzing, Modeling and Simulation of Single and Double Array PV system in Different Environmental Variability

M.S. Mahmodian¹⁺, R. Rahmani², E.Taslimi¹, S. Mekhilef¹

¹ Department of Electrical Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

² Centre for Artificial Intelligence and Robotics, Universiti Teknologi Malaysia international campus, 54100 Kuala Lumpur, Malaysia

Abstract. This research analyses the mathematical model of the PV array with all the parameters involved, in the sequential steps. Then it is going to simulate the I-V and P-V characteristics of PV array in different climatology conditions, by using both MATLAB M-file and Simulink. Finally the capability of this method is demonstrated in simulated results, which are performed for both Single and Double Array PV system.

Keywords: photovoltaic Module, MATLAB Simulink, PV characteristics, Array configuration.

1. Introduction

Intensive positive slope of technology development causes massive demand of energy for enhancing its growth. On the other hand, statistic results show the conventional fossil energies are following another story which warns that these sources are being decreased, rapidly. In recent decades, diverse procedure of supply and demand, in addition to the high level of environmental pollution resulted by fossil energy, have made renewable energy as a hot topic for researchers [1-5]. Among all renewable energy strategies, photovoltaic systems own several fundamental advantages compare to others. By using semiconductor devices, solar energy has been identified as a static, movement-free and quiet alternative energy which can result to a long-term and low maintenance-cost renewable system. Furthermore, due to its infinite and clean source of energy, there is not any controversial issue in term of sustainability [6, 7]. Therefore working on each part of the photovoltaic system is a valuable effort, which motivates us to do this research related to mentioned technology. When it comes to connection strategies, there are two configurations of solar systems applied in any application. The first is Stand-Alone system, which is widely used in remote areas, and the second is Grid-Connected system, which is shown in the following figure [8-10].

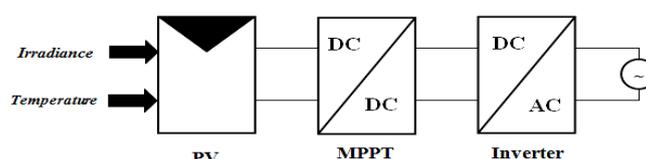


Fig. 1: the Grid connected PV system

2. Modelling

In general the output of photovoltaic system directly depends on the solar irradiance and cell temperature, so finding maximum power point must be based on updated temperature and irradiance values. Recently this procedure has been taken into account, as one of the most interesting topic in the field of solar energy, called Maximum Power Point Tracking or MPPT. The first and most influential step to track the Maximum power

⁺ Corresponding author. Tel.: +60322761931; fax: +60326970815.
E-mail address: msmahmodian@gmail.com

point is to model the PV array properly, because all subsequent operations in all aspects of the PV system are affected by circumstances of this model. Despite the fact that, a precise algorithm is needed to be applied for these operations, but only an inaccurate PV model is enough to end up with an unreliable enough [11].

2.1. PV cell model

The mathematical model of PV directly depends on short circuit current (I_{sc}) and open circuit voltage (V_{oc}), which can be found from the PV cell manufacturer data sheet (Table 1). According to the following circuit, the output current, is obtained by applying KCL on circuit shown in figure 2(a).

Table 1: PV Module Specification

Electrical Characteristic	BP SX 150s
Open circuit voltage	43.5 V
Short circuit current	4.75 A
Maximum power voltage	34.5 V
Maximum power current	4.35 A
Maximum power	150 W

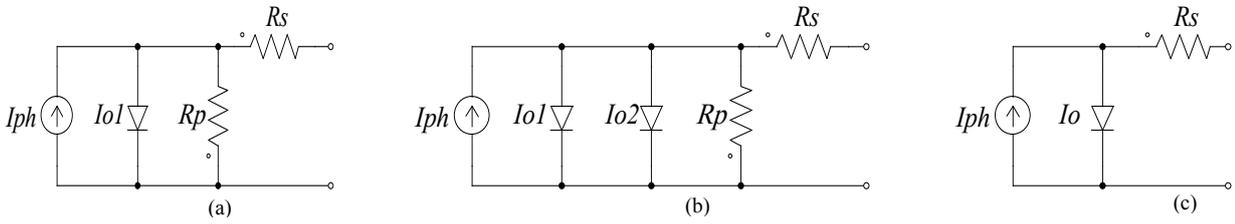


Fig. 2: (a) General module. (b) Double exponential model. (c) Appropriate model

$$I_{pv} = I_{ph} - I_o \quad (1)$$

In which, I_{pv} is the output current, I_{ph} is the solar generated current which is affected by solar irradiance and temperature [1], that can be calculated by:

$$I_{ph} = (I_{scr} + K_i T_{dif}) \frac{G}{G_r} \quad (2)$$

Wherein, I_{scr} is the solar generated current at the nominal condition (25 °C and 1000W/m), K_i is known as the cell short-circuit temperature/current coefficient which considered as 0.065% in this Module. G is illumination in which the PV is currently operating and G_r is the PV cell's nominal irradiance which is normally considered as 1000 W/m². The parameter T_{dif} , is defined as the difference between current temperature and reference temperature ($T_k - T_{ref}$) in which T_k is the current PV cell temperature based on Kelvin degree and T_{ref} is the reference temperature which is normally considered as 298⁰K (or 25⁰C+273). As mentioned earlier, open circuit voltage can be obtained from the PV cell data sheet, measured from the output voltage while the output current is assumed zero. So the diode saturation current at the certain reference temperature will be calculated by:

$$I_{rs} = \frac{I_{scr}}{\exp\left(\frac{qE_{oc}}{N_s K A T_K} - 1\right)} \quad (3)$$

Wherein, A is the diode ideality factor; q is the constant known as the electron charge and it value can be considered 1.602* 10⁻¹⁹ C ; K is the Boltzmann constant, and finally N_s and N_p are the number of cells in each PV module which are connected in series and parallel form, respectively. According to the aforementioned equations, the diode saturation current (I_o) is directly influenced by environmental changes and it can be determined by following mathematical statements:

$$I_o = I_{rs} \left(\frac{T_k}{T_{ref}} \right)^3 \exp \left[\frac{qE_{go}}{AK} \left(\frac{T_{dif}}{T_{ref}T_k} \right) \right] \quad (4)$$

In the above equation, the E_{go} parameter is the band gap energy for the silicon semiconductor, which is between 1.1 and 1.2 eV. Finally according to the KCL which described before, the output current of PV array is equal to:

$$I_{pv} = I_{ph} - I_o \left[\exp \left(\frac{q(V_{pv} + I_{pv}R_s)}{AKT_k} \right) - 1 \right] - \frac{(V_{pv} + I_{pv}R_s)}{R_p} \quad (5)$$

2.2. PV Module and Array model

Practically speaking, the output power of single solar cell is not strong enough to apply for almost any application. So in order to increase the capability of overall PV systems, the cells should be configured in series and parallel features. If we consider N_p as the number of cells connected in parallel and N_s as the number of cells connected in series, the Equation (5) can be express as bellow:

$$I_{pv} = N_p I_{ph} - N_p I_o \left[\exp \left(\frac{q(V_{pv} + I_{pv}R_s)}{N_s AKT_k} \right) - 1 \right] - \frac{(N_p V_{pv} + I_{pv}R_s N_s)}{R_p N_s} \quad (6)$$

It should be considered that, when N_p represents the total parallel cells and N_s also represents the overall series cells, the output will be related to the whole PV array. On the other hand, when the N_p is unit, and N_s represents the overall series cells, this is just related to PV module. And when both N_p and N_s , are unit, the output current will be correlated to the PV array. A more precise equivalent circuit of solar cell is known as double exponential or double diode model and it is referred to the physical manner of solar cell which is constructed by polycrystalline silicon. This kind of model is consisting of two parallel diodes, which are connected to the parallel and series resistance as shown in figure 2(b). However, according to the nonlinear nature of the PV cell model, there is a challenging argument about the limitations of this model to be used as an expression of I-V curve, thus, this model is not widely used in the previous and present researches [14]. From the other point of view, the R_p can be assumed infinity in the applicable PV module, due to its slight impression. But, because of the sensitivity of output power over series resistance (R_s), the value and variation of this resistance cannot be neglected in the consequent model as depicted in figure 2(c). Therefore, the output current of the PV module as discussed earlier should be revised considering the parallel resistance elimination:

$$I_{pv} = N_p I_{ph} - N_p I_o \left[\exp \left(\frac{q(V_{pv} + I_{pv}R_s)}{N_s AKT_k} \right) - 1 \right] \quad (7)$$

2.3. The Nonlinear Characteristic of Photovoltaic System

According to the nonlinearity manner of the output current, the proper nonlinear methods such as Simple fixed point method, Newton-Raphson method and Secant method should be applied in this case. In this research Newton Raphson method is chosen and it can be described as;

$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)} \quad (9)$$

In which $f(x_n)$ is the actual amount of the function, $f'(x_n)$ is the derivation of function, X_n is the present amount and the X_{n+1} is the next amount. Thus now, if $F(I_{pv})$ considered as $f(x_n)$, we will have;

$$F(I_{pv}) = N_p I_{ph} - I_{pv} - N_p I_o \left[\exp\left(\frac{q(V_{pv} + I_{pv} R_s)}{N_s A K T_k}\right) - 1 \right] \quad (10)$$

Then, referring to the Newton-Raphson Principle the equation (7) can be expressed as following mathematical statement;

$$I_{pv(n+1)} = N_p I_{pv(n)} - \frac{N_p I_{ph} - I_{pv(n)} - N_p I_o \left[\exp\left(\frac{q(V_{pv} + I_{pv(n)} R_s)}{N_s A K T_k}\right) - 1 \right]}{-1 - N_p I_o q R_s \left[\exp\left(\frac{q(V_{pv} + I_{pv(n)} R_s)}{N_s A K T_k}\right) \right]} \left/ (N_s A K T_k) \right. \quad (11)$$

This method needs one iteration loop which continues its operation, until the stopping point condition is met. Depends on the situation, the stopping condition can be offered by two different ways:

- A. Once the pre-specified numbers of iteration is done
- B. Once the present error which can be obtained by equation (12) is less than the pre-specified error.

Both of the method can be used depend on problem and proposed accuracy.

$$Error = \frac{|I_{pv(n+1)} - I_{pv(n)}|}{|I_{pv(n+1)}|} \times 100 \quad (12)$$

3. Simulation and Results

In this research, the PV module simulated using both MATLAB M-File and MATLAB Simulink. Higher flexibility and higher user friendly aspect of MATLAB M-file shows itself in several steps of PV module simulation especially, when the MPPT method is the purpose of the work. But, to display and inspect different part of the simulation, we can apply MATLAB Simulink by using the Sink tools and User Defined Functions, at the final section of the simulation. In this research the simulation will cover both Single and Double Array PV system.

3.1. Single Array PV system

In the simulated PV, by using value of I_o , I_{ph} and I_{pv} from the earlier equations, and the constant parameters obtained from manufacturer's data sheet (Table1), the output characteristic in the normal condition can be depicted in figure (4). The temperature variation from highest toward lowest is elucidated in figure (4.a), in which both output current and power are being reduced respective to this variation, and it shows the negative effect of temperature on overall PV yield. From the other side of view, in the Figure (4.b), the output current and power are plotted for different solar irradiance intensities. In contrary with the effect of temperature, by increasing the value of irradiance, both of output power and current are being increased, which shows the positive impression of solar irradiance on the overall system efficiency.

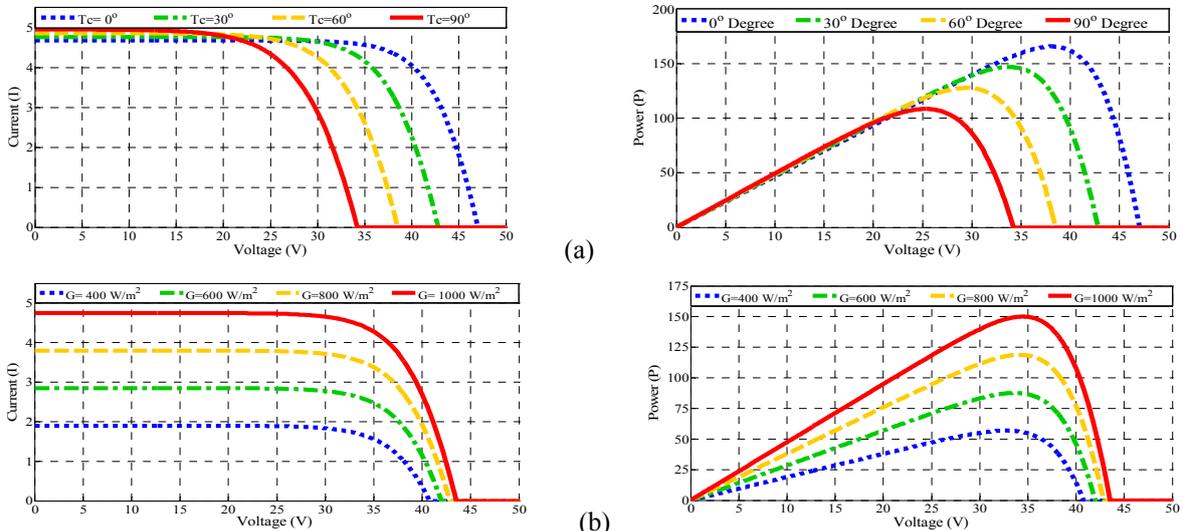


Fig. 4: (a) Output I-V and P-I curves for different temperature of 0° , 30° , 60° , and 90° , (b) Output V-I and P-I curves for different Irradiance intensity.

3.2. Double Array PV system

In some circumstances, the solar system is consisting of more than one PV Array parallelized with each other. This is a common case, especially when these modules are going to be controlled by one central controller, instead of several individual ones. Thus, it leads PV system to be more cost-effective system [15]. In this kind of systems also, the PV modelling is considered as one of the most fundamental steps and it is slightly more complicated compare to one with several individual controllers. Both I-V and P-V characteristic of a Double-Array PV system for three different temperature and irradiance values are plotted in figure 5(a) and 5(b), which demonstrate the same story as discussed for Single-Array PV system, earlier.

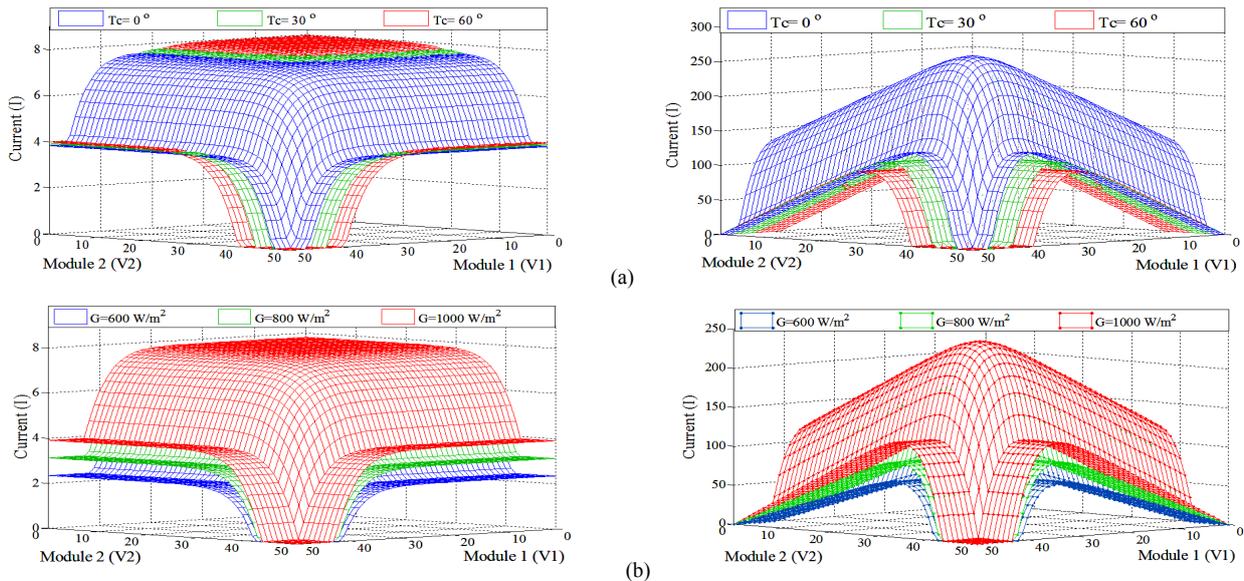


Fig.5: Output I-V and P-I curves for tow PV array by central controller (a) In different temperature of 0° , 30° , 60° , and 90° , (b) In different Irradiance intensity of 600 W/m^2 , 800 W/m^2 and 1000 W/m^2 .

4. Conclusion

As we have concerned, most of the researches in surrounding area of the PV modeling have been performed exclusively based on the MATLAB Simulink, but modeling procedure offered in this research is slightly different from most of studies in this area, and as it mentioned earlier, it is sequentially based on both MATLAB Simulink and M-file coding, which might be more effective in some of the MPPT methods. The simulation method has been done in different environmental values, and the final results, demonstrate the capability of this method for other configuration of photovoltaic systems, such as Single and Double Array systems. In the future work we are eager to use this sequential PV model, in different Mismatching conditions.

5. References

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