

Determination of Unknown Parameters of Photovoltaic Module Using Genetic Algorithm

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Abstract

In this paper, the unknown parameters of the photovoltaic (PV) module are determined using Genetic Algorithm (GA) method. This algorithm based on minimizing the absolute difference between the maximum powers obtained from module datasheet and the maximum power obtained from the mathematical model of the PV module, at different operating conditions. This method does not need to initial values, so these parameters of the PV module are easily obtained with high accuracy. To validate the proposed method, the results obtained from it are compared with the experimental results obtained from the PV module datasheet for different operating conditions. The results obtained from the proposed model are found to be very close compared to the results given in the datasheet of the PV module.

Keywords: genetic algorithm, photovoltaic, unknown parameters

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1. Introduction

The basic device of a photovoltaic (PV) system is the PV cell. PV cell is a semiconductor diode whose p–n junction is effected by light [1]. Cells may be grouped in series and parallel to form a module. For large power applications, modules are grouped in series and parallel to form an array.

Manufacturer datasheets of the PV modules does not give all the required parameters to obtain the current-voltage (I-V) characteristics of the module analytically. These unknown parameters are the module intrinsic series resistance, R_s , parallel resistance, R_{sh} , the ideality factor, a , the diode reverse-bias saturation current, I_o , and the module photo current, I_{ph} . These parameters were obtained, in many previous studies by minimizing the absolute error between the PV module characteristics datasheet and the mathematical model of the PV module [2-7]. This minimizing technique was processed by different methods.

Curve fitting method was used to obtain these unknown parameters [2]. This method proposed more sophisticated model using an extra diode (double- exponential model) [3]. The parameters R_s and R_{sh} were obtained using the iterative solution to minimize the error between the experimental maximum power given in the data sheet and that obtained from the mathematical model [3-4]. The accuracy of this method depends on the proper assumption of R_s and R_{sh} . The parameters " R_s , R_{sh} and a " for the module were obtained by using Newton-Raphson method [5]. The solution obtained from this method depended on the correct assumption of the initial values of the unknown parameters to insure convergence of the solution. A trial and error algorithm was performed to obtain these unknown parameters [6]. In [7-8], the unknown parameters of the PV module were obtained using differential evolution (DE) algorithm. The values for I_o , I_{ph} and R_{sh} are analytically computed while a and R_s are computed by using DE.

In this paper, the unknown parameters, R_s , R_{sh} , a , I_o and I_{ph} are determined using GA method at standard test condition (STC) [3]. Also, I-V and power-voltage (P-V) characteristics are obtained at various cell temperature and sunlight irradiance conditions. The characteristics obtained from this proposed method are compared with those given in the module datasheet.

2. Modeling of PV Module

2.1. Modeling of PV Cell

There are several lumped equivalent circuits that describe the behavior of PV cell. These lumped circuits may be with single-diode or double-diode implementation [4]. In this paper, the equivalent circuit based on single-diode model is considered [3, 5-7, 9]. The equivalent circuit of a single-diode PV cell is shown in Figure 1 [9]. The current source, I_{ph} , represents the cell photocurrent and the cell losses are represented by R_s and R_{sh} which are series and shunt intrinsic resistances of the cell respectively.

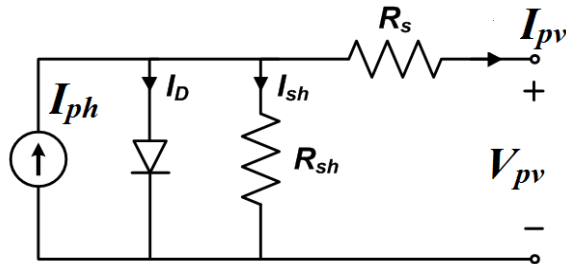


Figure 1. Equivalent Circuit of Single-Diode Solar Cell Model

The mathematical model of the PV cell is obtained by applying Kirchhoff current law on the equivalent circuit given in Figure 1 [10]. Then, the expression of the model is:

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

where, I_D is expressed as $I_o \left[\exp\left(\frac{V_{pv} + I_{pv}R_s}{aV_t}\right) - 1 \right]$, and I_{sh} is obtained as $\frac{V_{pv} + I_{pv}R_s}{R_{sh}}$

then:

$$I_{pv} = I_{ph} - I_o \left[\exp\left(\frac{V_{pv} + I_{pv}R_s}{aV_t}\right) - 1 \right] - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \quad (2)$$

where,

- V_t : the junction thermal voltage and is given by: kT/q , V
- V_{pv} : the terminal voltage of the PV cell, V
- I_{ph} : the photo- generated current by the incident light, A
- I_{pv} : the output current of the PV cell. A
- I_D : the diode current, A
- I_o : reverse saturation or leakage current of the diode, A
- I_{sh} : the shunt resistance current, A
- q : the electron charge, 1.609×10^{-19} C
- k : Boltzmann constant, 1.38×10^{-23} J/K
- T : the temperature of the PN junction, K
- a : diode quality factor (ideality factor).

2.2. Modeling of PV Module

For high values of voltage and current of the PV system, the PV cells are connected in series and parallel to construct a module. The mathematical model for number of series cells (N_s) (PV panel) is expressed as [3], [5]:

$$I_{pv} = I_{ph} - I_o \left[\exp\left(\frac{V_{pv} + I_{pv}R_s}{aN_sV_t}\right) - 1 \right] - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \quad (3)$$

The power of the module is obtained from:

$$P = V_{pv}I_{pv} = V_{pv} \left[I_{ph} - I_o \left(\exp\left(\frac{V_{pv} + I_{pv}R_s}{aN_sV_t}\right) - 1 \right) - \frac{V_{pv} + I_{pv}R_s}{R_{sh}} \right] \quad (4)$$

From equation (3), the model involves the following five unknown parameters: a , I_{ph} , R_s , R_{sh} , and I_o . Section 3 will show the procedure for obtaining these parameters by using Genetic algorithm (GA).

3. Genetic Algorithm

Genetic algorithm (GA) is an optimization technique used to solve mathematical problems for obtaining an accurate solution. GA uses the principles of selection and development to minimize a fitness function. Therefore, several solutions can be obtained to a given problem. GA is based on the genetics and development mechanisms observed in nature system and population of living beings [11-12].

The GA performs the following steps until getting the best solution:

1. A group of individual solutions created randomly where they satisfy the boundary conditions and the constraints, this step named population or initialization.
2. Calculate the fitness function with the previous populations. If any population has minimized the fitness function with satisfied accuracy, the program will be terminated and the best solution is determined. If the fitness function is still has large value, a new generation of populations are created after applying some operators. This selection scheme is known as Roulette wheel selection.
3. The next step of GA is called "crossover". Crossover combines two individual populations to form a new individual population for the next generation.
4. For the population that gives excluded value, it can make small random changes in that individual's population to enable the genetic algorithm to search a broader space. This step is named "mutation" operation.
5. The above steps (from 1 to 4) is repeated until the maximum iteration count (nc) is reached or the fitness function is minimized.

4. Determination of Unknown Parameters at STC

Usually, the only module parameters that given in the datasheet at STC are maximum power (P_{max}), voltage at maximum power (V_{mpp}), current at maximum power (I_{mpp}), open circuit voltage (V_{oc}), short circuit current (I_{sc}), temperature coefficients (k_v and k_i) of V_{oc} and I_{sc} respectively and number of series cells (N_s). The GA procedure will be used to determine the unknown parameters under STC. The effect of the cell temperature and irradiance on the PV module parameters will be studied later.

The fitness function (FF) of the GA is dependent on minimizing the absolute error between the maximum power obtained from the manufacturer datasheet with the maximum power that obtained from the PV mathematical model, Equation (4). Then the fitness function is:

$$FF = \left| P_{max} - V_{mpp} \left[I_{ph,n} - I_{o,n} \left(\exp\left(\frac{V_{mpp} + I_{mpp}R_s}{aN_sV_t}\right) - 1 \right) - \frac{V_{mpp} + I_{mpp}R_s}{R_{sh}} \right] \right| \quad (5)$$

where $I_{ph,n}$ and $I_{o,n}$ are the values of I_{ph} and I_o at STC that can be calculated from [5] as follows:

$$I_{o,n} = \left(I_{sc} - \frac{V_{oc} - I_{sc}R_s}{R_{sh}} \right) \exp\left(-\frac{V_{oc}}{aN_sV_t}\right) \quad (6)$$

$$I_{ph,n} = I_{o,n} \exp\left(-\frac{V_{oc}}{aN_s V_t}\right) + \frac{V_{oc}}{R_{sh}} \quad (7)$$

The values of the R_s , R_{sh} , and a will be randomly generated by the GA to calculate the values of $I_{ph,n}$, $I_{o,n}$ and then the fitness function is minimized. The generation of the population will take into considerations these constraints. The boundaries of the parameters: R_s , R_{sh} and a are as follows:

R_s is assumed to be between 0 and 2.5 Ω , R_{sh} is assumed to be between $R_{sh,min}$ and 10k Ω [2] and a is assumed to be between 1 and 2. Where $R_{sh,min}$ is expressed as [3]:

$$R_{sh,min} = \frac{V_{mpp}}{I_{sc} - I_{mpp}} - \frac{V_{oc} - V_{mpp}}{I_{mpp}} \quad (8)$$

The proposed GA technique including initialization, selection, crossover and mutation must be probably selected to obtain the best solution. The GA procedure is shown in the following flowchart, Figure 2.

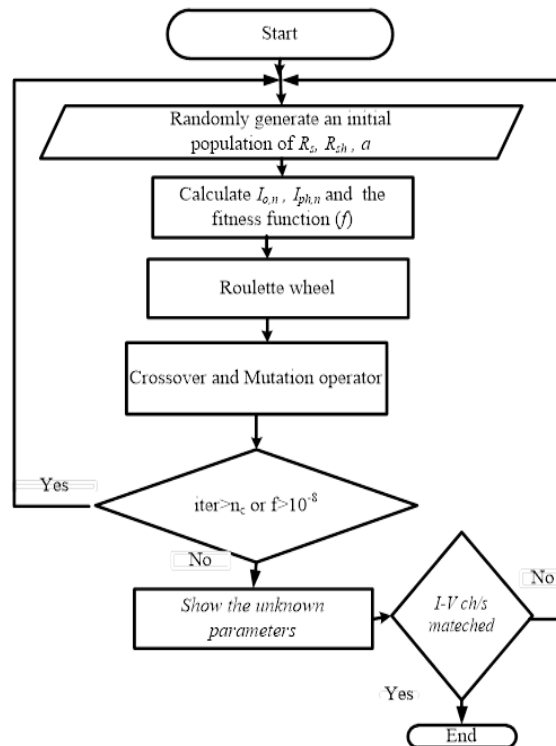


Figure 2. Flowchart of GA Technique

5. Effect of Irradiance and Cell Temperature on the PV Module Parameters

Obviously, all parameters of the PV module effected by the change in the cell temperature (T) or the irradiance level (G). Therefore, the module parameters obtained at STC must be modified at any value of G and T .

The short circuit current (I_{sc}) should be corrected as follows [5]:

$$I_{sc}(T) = I_{sc} + k_i(T - T_{STC}) \quad (9)$$

The open circuit voltage (V_{oc}) should be corrected as follows [13]:

$$V_{oc}(T, G) = V_{oc} + k_v(T - T_{STC}) + N_s a(T) V_t \ln\left(\frac{G}{G_{STC}}\right) \quad (10)$$

where T_{STC} and G_{STC} are the temperature and irradiance at STC respectively. k_i (A/°C) and K_v (V/°C) are the temperature coefficient of short circuit current and open circuit voltage respectively.

The effect of cell temperature and irradiance on the saturation current is given as [5]:

$$I_o(T, G) = \left(I_{sc}(T) - \frac{V_{oc}(T, G) - I_{sc}(T) * R_s(T)}{R_{sh}(T)} \right) \exp\left(-\frac{V_{oc}(T, G)}{N_s a(T) V_t}\right) \quad (11)$$

The corrected values of I_{ph} and a are given as [5, 14]:

$$I_{ph}(T, G) = \left(I_o(T, G) \exp\left(\frac{V_{oc}(T, G)}{a(T) N_s V_t}\right) + \frac{V_{oc}(T, G)}{R_{sh}(T)} \right) \frac{G}{G_{STC}} \quad (12)$$

$$a(T) = a \frac{T_{STC}}{T} \quad (13)$$

The corrected values of R_s and R_{sh} , when the cell temperature is changed, are obtained as [10]:

$$R_s(T) = R_s \left[1 + 3.37 * 10^{-3} (T - T_{STC}) + 9.71 * 10^{-5} (T - T_{STC})^2 \right] \quad (14)$$

and

$$R_{sh}(T) = \frac{R_{sh}}{1 + 5.8 * 10^{-3} (T - T_{STC}) + 1.61 * 10^{-4} (T - T_{STC})^2} \quad (15)$$

6. Simulation Results and Validation

The proposed GA is used to obtain the unknown parameters of the PV module using MATLAB/SIMULINK software package. The I - V and P - V characteristics are obtained from this proposed algorithm and compared with those given in the KC200GT PV module datasheet at STC. Also, these characteristics are obtained when the cell temperature and irradiance are changed. Table 1 shows the electrical specifications of the module at STC. Number of series cells is 54. Table 2 shows the experimental values of the I - V data extracted from the module datasheet at STC [15].

Table 1. Electrical Specification of the KC200GT PV Module at STC

■ Electrical Performance under Standard Test Conditions (*STC)	
Maximum Power (Pmax)	200W (+10%/−5%)
Maximum Power Voltage (Vmpp)	26.3V
Maximum Power Current (Impp)	7.61A
Open Circuit Voltage (Voc)	32.9V
Short Circuit Current (Isc)	8.21A
Max System Voltage	600V
Temperature Coefficient of Voc	−1.23×10 ^{−1} V/°C
Temperature Coefficient of Isc	3.18×10 ^{−3} A/°C

*STC : Irradiance 1000W/m², AM1.5 spectrum, module temperature 25°C

Table 2. Experimental *I-V* values from Datasheet at STC

V_{pv}	I_{pv}
0	8.21
2.29946	8.19104
5.66022	8.15312
8.6672	8.13416
13.1777	8.1152
25.7363	7.83079
28.1242	7.01547
17.4228	8.07727
19.8992	8.03935
28.9202	6.37081
29.8046	5.51758
30.6005	4.53162
31.3081	3.37501
31.8387	2.14256
32.3694	1.27037
32.6347	0.606744
32.9	0

6.1. Algorithm Validation

The parameters of the module at STC obtained from the proposed GA method are tabulated in Table 3.

Figure 3 shows the simulink block diagram which is used to obtain the *I-V* characteristics of the PV module depending on the proposed method.

Figure 4 shows the *I-V* characteristics obtained from the proposed algorithm and that obtained from the KC200GT PV manufacturer datasheet.

Table 3. Module Parameters Obtained from the Proposed GA Algorithm

$R_s (\Omega)$	$R_{sh} (\Omega)$	a
0.177	1824.26	1.51

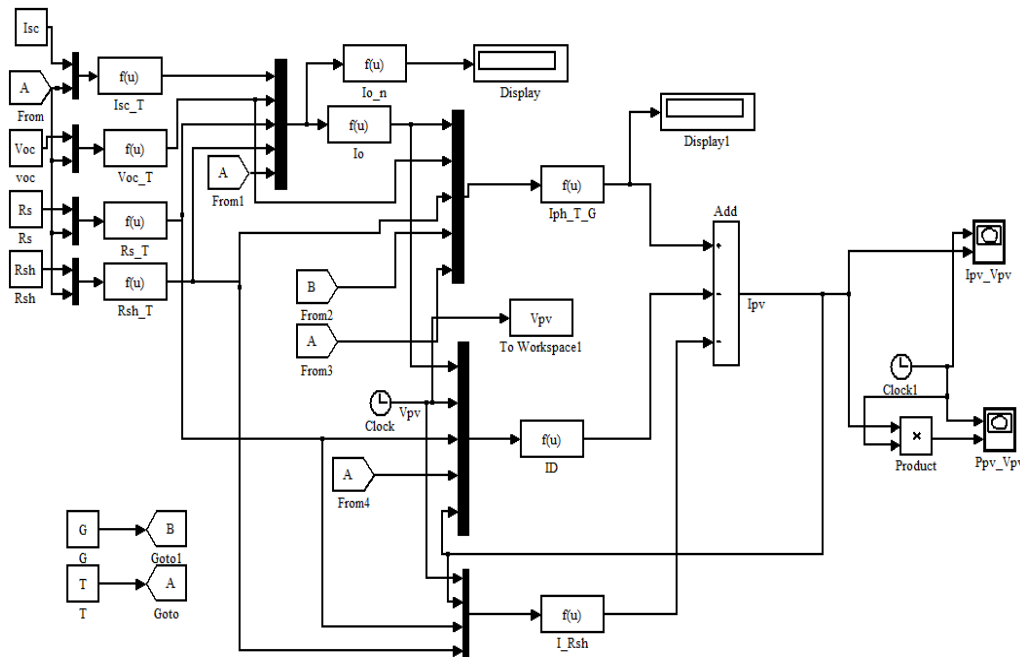


Figure 3. Simulink Block Diagram for Obtaining the PV Module Characteristics

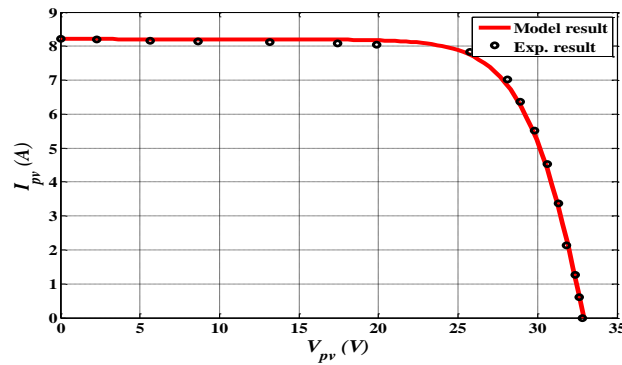


Figure 4. *I-V* Characteristic Curve and Experimental Data of the KC200GT Solar Module at STC

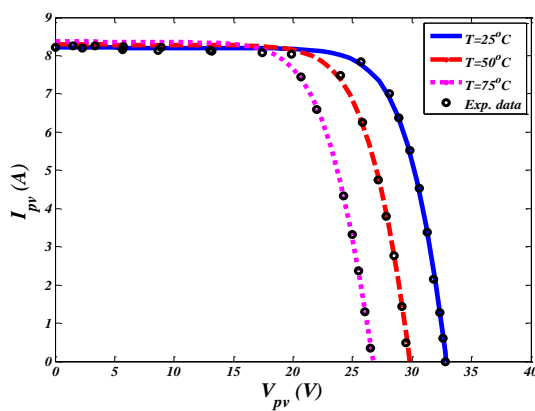


Figure 5. *I-V* Characteristics of a PV Module at Standard Irradiance and Varying Cell Temperature

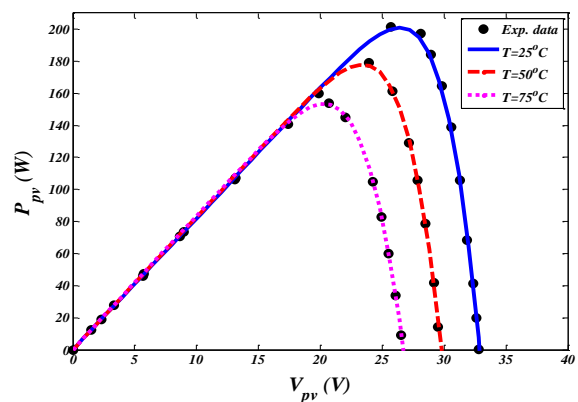


Figure 6. *P-V* characteristics of a PV module at standard irradiance and varying temperature

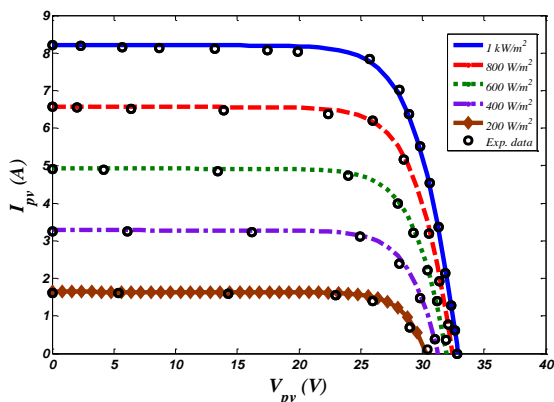


Figure 7. *I-V* Characteristics of a PV Module at Standard Temperature and Varying Irradiance

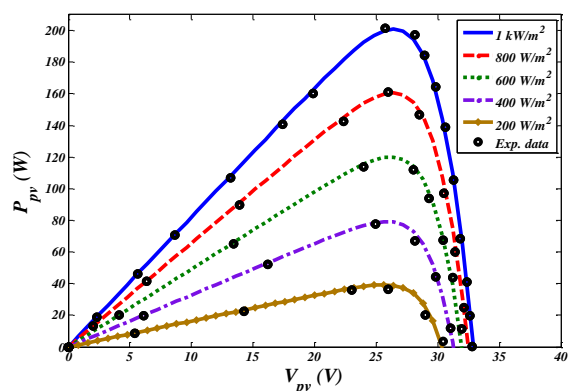


Figure 8. *P-V* Characteristics of PV Module at Standard Temperature and Varying Irradiance

Figure 5 and 6 shows the effect of the cell temperature changing on the *I-V* and *P-V* characteristics of the module. Figure 5 shows that as the temperature increases V_{oc} decreases and I_{sc} increases. Figure 6 shows that as the temperature increases the module power is decreased.

The effect of changing the irradiance on the I - V and P - V characteristics of the module are shown in Figures 7 and 8. The figures show that as the irradiance increases, the short circuit current, the open circuit voltage, and the PV module power are increased. Figures (4-8) show that the results obtained from the proposed method are very close to those obtained from the manufacturer datasheet of the PV module.

7. Conclusions

Genetic algorithm has been proposed to determine the missing parameters of a PV module. Without these parameters the I - V characteristics of the module and tracking of the maximum power are so difficult to be realized. The proposed technique is an accurate algorithm with one fitness function. Also, the proposed technique doesn't need to assume initial values compared with other methods. The results obtained from the proposed algorithm are compared with those obtained from the experimental datasheet of Kyocera KC200GT module at STC. The comparison shows that the characteristics obtained using the GA method are very close to the characteristics given in the PV module datasheet. It is evident to say that the best solution was obtained when the parameters of the GA are adjusted to population size equal 50, number of generations=100, crossover rate=0.8, and mutation function is adaptive.

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