5th International Conference on Control Engineering&Information Technology (CEIT-2017)
Proceeding of Engineering and Technology –PET
Vol.34 pp.7-12

Determination of Five Parameters of PV Module Using Iterative Method

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***Abstract*— The issue that diverse models of photovoltaic face is the number of unknown parameters which are not indicated by manufacturers datasheet. Difference methods have been used with the purpose of determination these parameters. In the present work, we are interested to outline the photovoltaic module which is typically defined by an equivalent electrical circuit and to find its parameters by adjusting the I-V Curve at three points: Open circuit, short circuit and maximum power condition to generate the performance of the module in various environmental conditions. We develop an improvement of parameters identification using an iterative method which is Newton Raphson for extraction the parameters from Manufacturers datasheet by using Matlab/Simulink Software. The simulation results indicate that this method has a better accuracy and a speed convergence of several parameters.**

***Keywords*— Single Diode model, Photovoltaic Module, Extraction Parameters, Newton Raphson Method, I-V Curve**

I. INTRODUCTION

Nowadays, the photovoltaic (PV) systems have transformed to be a portion of the electrical power worldwide as they are a part and parcel of various renewable energy resources. A solar cell is a device that transforms the energy of sunshine immediately into electricity using PV effect and it is the fundamental energy engenderment unit of the solar PV system which is distinguished by an output current and voltage [1]. At present, the cost of investment of these PV systems is relatively high, however, the lack of electricity and the evolutionary technology will render solar models more relevant.Moreover, the solar cell is mathematical models of PV cell as ideal, single and two-diode model are accessible in literature [2].

Numerous of PV cells are combined to make a PV system and several numbers of cells are regrouped together to make PV module or also named PV panel, the last one can be gathered assembly to form a solar array.

PV systems are utilized in diversity of applications as stand alone, grid connected and hybrid system. Further, for the maximum extraction power of PV array or panel, we have to model the PV device which has a non linear I-V characteristic with various parameters in need for adjusting it from experimental data [3] [4]. Further, the output power of PV device swings to a great extent depending on the changing of the temperature and the solar insolation.

The main purpose of this work is to present of PV system which is included the modeling of the solar panel equivalent circuit model, its elementary equations and simulation.

In this model, physical parameters are established by utilizing the measured data which is provided by manufacturers datasheets and to accomplish the I-V equation with the purpose of obtaining the key points for extraction these parameters and we finished with conclusion.

II. PV PANEL MODELING

A. Single Diode Model

Photovoltaic cell models have long been a source for the description of PV cell behaviour [5]. The most common model used to predict energy production in photovoltaic cell modeling is the single diode model which is non-linear but uncomplicated in structure than the two-diode model. Furthermore, it is represented by five parameters namely a photo-generated current source Ipv in parallel to a diode D through it a saturation current Io, a series resistance Rs, a parallel resistance Rp and an ideality factor a [6] [7].

The equivalent electrical circuit of a photovoltaic cell is shown in Fig 1.

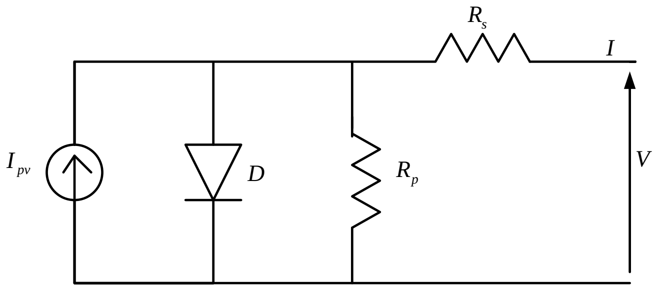

Fig. 1 Single Diode Model

This model can be expressed by the following equation, in which I and V are respectively the current and the tension of a PV cell and V_t is the thermal voltage.

$$I = I_{pv} - I_0\left(e^{\frac{V+R_sI}{aV_t}} - 1\right) - \frac{V+R_sI}{R_p} \quad (1)$$

Where:

$V_t = N_s kT / q$

ISSN 2356-5608

q: Electron charge (1.602×10−19 C)
k: Boltzmann constant (1.38×10−23 J/K)
T: Nominal Temperature (K)
*N*s: Cells connected in series
Cells connected in series supply a great output voltage and cells connected in parallel increase the current.

1) Parameters of Single Diode Model at STC

The model is mathematically expressed by the Equation (1) in which the current, voltage and the power can be resolved thanks to Newton Raphson method or analytically with approaches [8]. As in the case of equation (1), there are five unknown parameters, Ipv, Io, a, Rs and Rp to determine. The characteristics behavior of a PV panel relies on its manufacturing technology, materials and operating conditions. The widely essential points utilized for outlining the cell electrical performance are: the open circuit, the short circuit point and the maximum power point [9]. Hence, the equation (1) can be written as:

- Short Circuit Equation ($I = I_{sc}, V = 0$)

$$I_{sc} = I_{pv} - I_0 \left[e^{\frac{I_{sc} R_s}{a V_t}} - 1 \right] - \frac{I_{sc} R_s}{R_p} \quad (2)$$

From equation (2), the photo-generated current can be expressed by the following expression:

$$I_{pv} = \frac{R_p + R_s}{R_p} I_{sc} \quad (3)$$

Moreover, the photo-generated current of the PV cell varies with the solar irradiation and the temperature according to the following equation [10]:

$$I_{pv} = \frac{G}{G_{STC}} \left[I_{pv-STC} + K_i (T - T_{STC}) \right] \quad (4)$$

Where:

I_{pv-STC}: Photo-generated current at Standard Test Condition.

G: Solar irradiance (W/m²).

G_{STC}: Solar irradiance at Standard Test Condition (1000W/m²).

T_{STC}: Temperature at Standard Test Condition (25°C).

- Open Circuit Equation ($I = 0, V = V_{oc}$)

$$0 = I_{pv} - I_0 \left[\exp\left(\frac{V_{oc}}{a V_t} \right) - 1 \right] - \frac{V_{oc}}{Rp} \quad (5)$$

From equation (5), the saturation current can be expressed by the following expression:

$$I_0 = \frac{\left(R_p + R_s \right) I_{sc} - V_{oc}}{R_p e^{\left(\frac{V_{oc}}{a V_t} \right)}} \quad (6)$$

- Maximum Power Point Equation ($I = I_{mp}, V = V_{mp}$)

$$I_{mp} = I_{pv} - I_0 \exp\left[\left(\frac{V_{mp} + I_{mp} R_s}{a V_t} \right) - 1 \right] - \frac{V_{mp} + I_{mp} R_s}{R_p} \quad (7)$$

2) Adjustment of the model:

For including the maximum power experimental from the datasheet equal to the maximum calculated power of the model ($P_{mp,e} = P_{mp,m} = I_{mp} V_{mp}$) at the point (V_{mp} , I_{mp}) of the I-V curve, it is necessary that both of Rs and Rp are an only pair [11].
According to the equation (7), (13) and for $P_{mp,e} = P_{mp,m}$, the maximum calculated power of the model can be written as:

$$P_{mp,m} = V_{mp} \left\{ \begin{array}{l} I_{pv} - I_0 \left[\exp\left(\frac{V_{mp} + I_{mp} R_s}{a V_t} \right) - 1 \right] \\ - \frac{V_{mp} + I_{mp} R_s}{R_p} \end{array} \right\} = P_{mp,e} \quad (8)$$

$$R_p = V_{mp} (V_{mp} + I_{mp} R_s) / \left\{ \begin{array}{l} V_{mp} I_{pv} - V_{mp} I_0 \exp\left[\frac{V_{mp} + I_{mp} R_s}{a V_t} - 1 \right] \\ - P_{mp,e} \end{array} \right\} \quad (9)$$

The equation (9) proves that for any value of series resistance there will be a value of parallel resistance that gets the mathematical I-V curve traverses the experimental (V_{mp} , I_{mp}) point as in Fig. 4 is shown.

3) Estimating Series and Parallel Resistance at STC Using Newton Raphson:

In this paper, we use Newton Raphson Method which is used to solve nonlinear equations systems to solve Equation (1) and to determine its parameters. Moreover, this method is popular in iterative computational applications because of its simplicity and fast convergence, it is given by the expression [12]:

$$I_{mp+1} = I_{mpi} - \frac{f(I_{mpi})}{f'(I_{mpi})} \tag{10}$$

The equation (10) interprets Newton Raphson method to determine Imp iteratively. The subscript i designates the i^{th} iteration, f and f' are consecutively indicated in (11) and its derivative in (12). At the time I_{mpi} is defined, V_{mp} and P_{mp} (13) can be determined, as follows:

$$f(I_{mpi}) = I_{pv} - I_0 \exp\left[\left(\frac{V_{mp} + I_{mp} R_s}{aV_t} \right) - 1 \right] - \frac{V_{mp} + I_{mp} R_s}{R_p} - I_{mp} \tag{11}$$

$$f'(I_{mpi}) = -\frac{I_0 R_s}{aV_t} \exp\left(\frac{V_{mp} + I_{mp} R_s}{aV_t} \right) - \frac{R_s}{Rp} - 1 \tag{12}$$

$$P_{mp} = I_{mp} V_{mp} \tag{13}$$

4) *Algorithm of the Newton Raphson Method :*

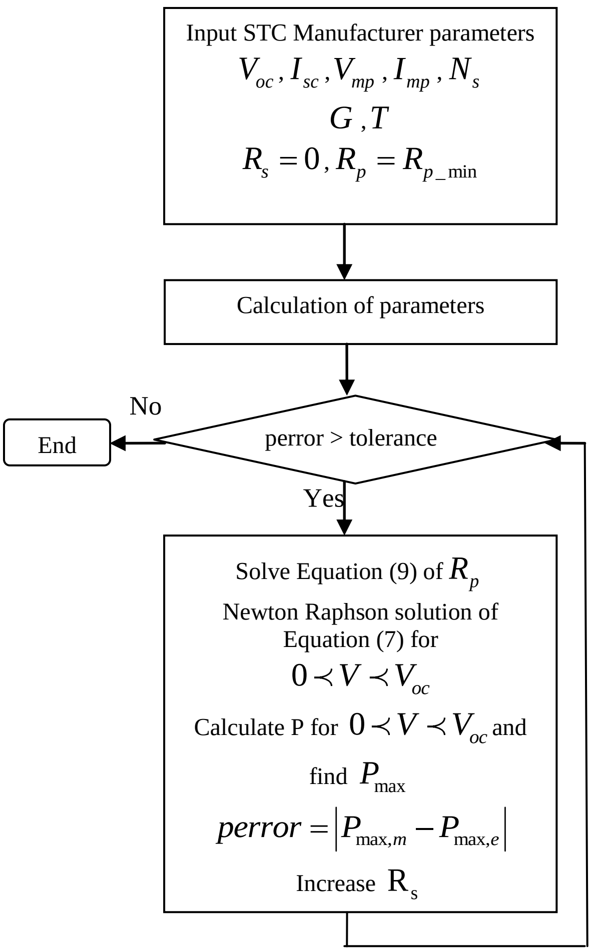

Fig. 2 Algorithm of Newton Raphson method

Started with an initial guess value of Rs=0 Ω, it must be gradually increased, the initial value of Rp is given by equation (14):

$$R_{po} = \left(\frac{V_{mp}}{I_{sc} - I_{mp}} \right) - \left(\frac{V_{oc} - V_{mp}}{I_{mp}} \right) \tag{14}$$

The purpose for the repetitive method is to find the value of R_p and R_s which it makes the peak of I-V curve occurs at the same time with the experimental peak power point at (V_{mp},I_{mp}) and that needs several iterations till $P_{max,m}$ equal to $P_{max,e}$. Moreover, for plotting the I-V curve, necessary to solve the equation (1) for the current appertains from 0 to I_{sc} and for the voltage appertains from 0 to V_{oc} at Standard Test Condition by a numerical method.

B. *Results Analysis*

The SM65 solar panel was selected for modeling owing to its suitable fitted to PV applications system.

The technical characteristics of the module used are shown in TABLE I and the program caculated the parameters of the PV module in accordance with the solar irradiance and the temperature.

Firstly, the I-V characteristics under varying series resistance equal to 0 and 0.36Ω with constant temperature and irradiance, neither Voc nor Isc are influenced by the changing of Rs as in Fig 7. Despite of this, when series resistance decreases, the shape changes to the rectangular form. The same for P-V curves, the P-V curves shifts to the left and the maximum summet power heads for the experimental MPP (Vmp,Imp) as long as Rs is high.

Moreover, the I-V curves are shown in Fig 8 under varying of Irradiance from 600W/m² to 1000W/m² with respect to Temperature 25°C, the short circuit current decreases with the diminution of Irradiance which is evident as they own a linear relation.

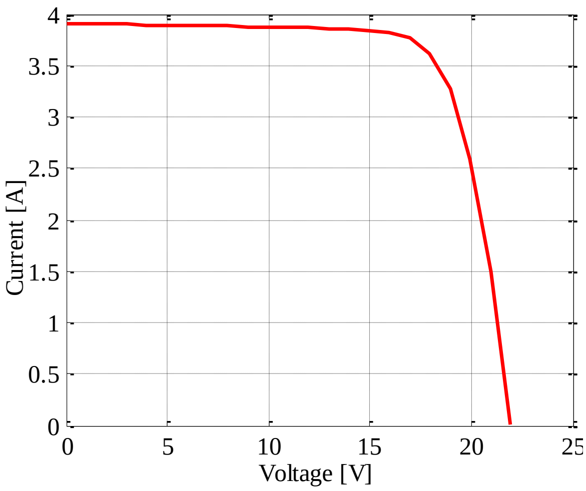

Fig. 3 I-V curve under Standard Test Condition (1000W/m²,T=25°C).

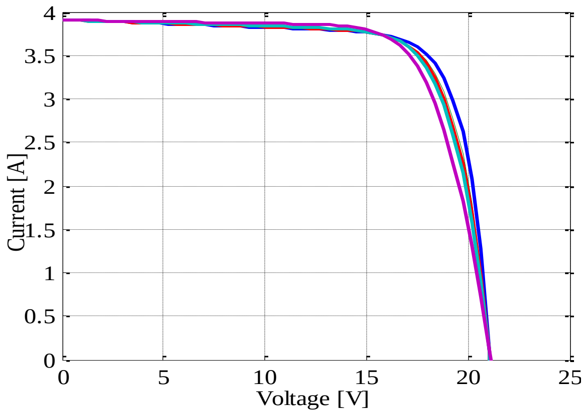

Fig. 4 I-V Characteristics for different values of Rp and Rs.

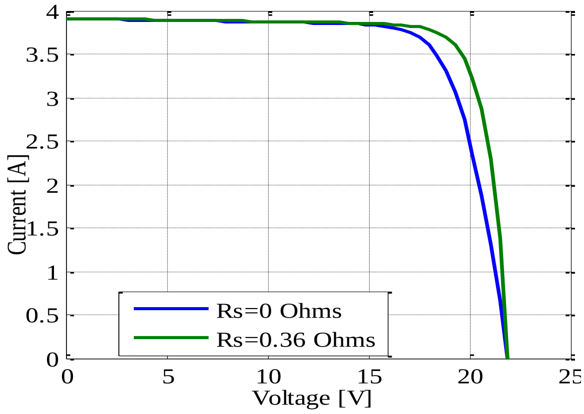

Fig. 7 I-V Characteristics for different values of Rs

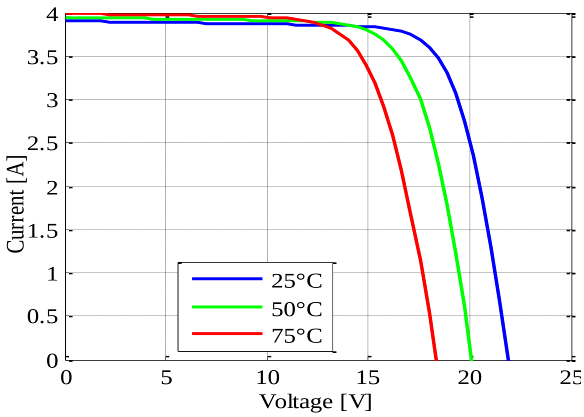

Fig. 5 I-V Curve at different variations of Temperature,1000W/m².

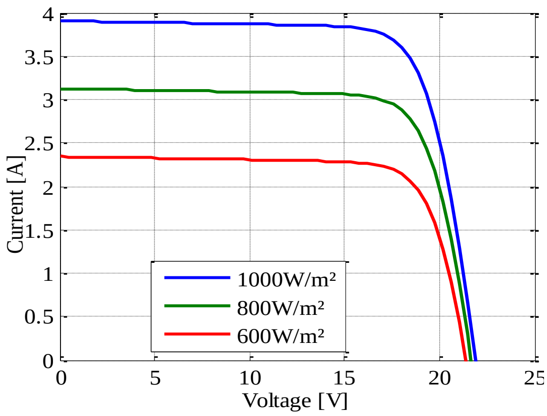

Fig. 8 I-V Curves at different variations of Irradiance,25°C.

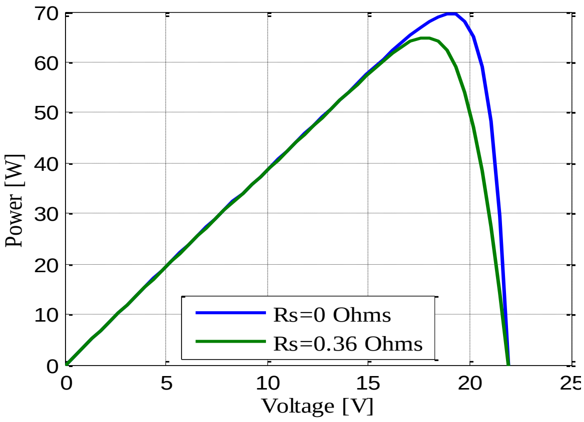

Fig. 6 P-V Curves for different values of Rs.

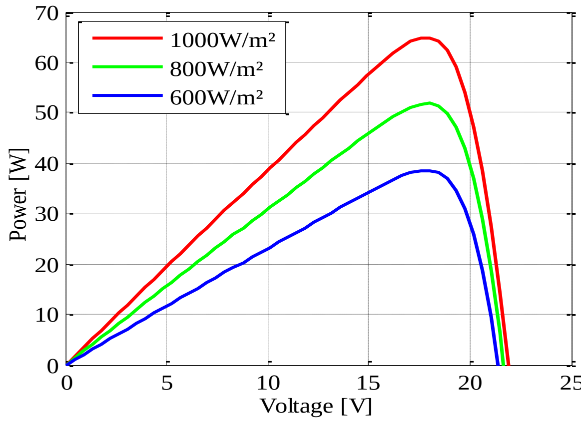

Fig. 9 P-V Curves at different variations of Irradiance,25°C.

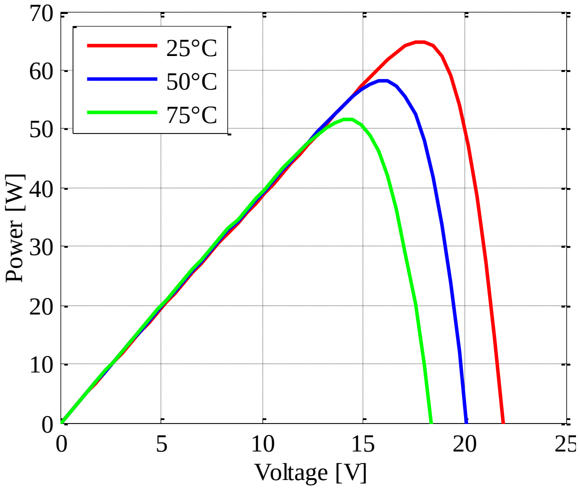

Fig. 10 P-V Curves at different variations of Temperature,1000W/m².

I-V curves are represented in Fig 5 with varying of Temperature from 25°C to 75°C and constant Irradiance equal to 1000W/m², the open circuit voltage decreases with the increment of Temperature.
Further, all I-V characteristics traverse the experimental maximum power point at (Vmp,Imp) as shown in Fig 4, for different values of Rs from 0 to 0.36Ω and Rp from 246.16 Ω to 274.51Ω, there is a unique point equivalent to a single value of Rp and Rs that approves the supposed condition Pmp,e=Pmp,m=Imp*Vmp.

III. Conclusions

In this work, the five unknown parameters of the photovoltaic panel are determined by extraction it from the datasheet information in TABLE I by using the iterative method which is Newton Raphson. Moreover, the I-V mathematical equation is adjusted at the three key points which are the open circuit, short circuit and the maximum power condition.

The algorithm in Fig 2 is programmed in MATLAB software to determine the PV panel parameters using the single diode model and the parameters are presented in TABLE II.

The simulation results indicated that the iterative method has a better accuracy and a speed convergence of several parameters which it can be applied in real-time applications.

TABLE I
TYPICAL ELECTRICAL CHARACTERISTICS OF PV MODULE AT 25°C, 1000W/M² BY THE MANUFACTURER

Designations	*Value*
Maximum Power (Pmax)	65W
Voltage at Maximum Power (Vmp)	17.75V
Current at Maximum Power (Imp)	3.66A
Open Circuit Voltage (Voc)	21.92V
Short Circuit Voltage(Isc)	3.91A
Number of Cells (Ns)	36

TABLE III
OBTAINED PARAMETERS BY ITERATIVE METHOD AT NOMINAL OPERATING CONDITIONS

Designations	*Value*
Ipv	3.915 A
Io	3.106×10^{-10} A
Rs	0.36 Ω
Rp	274.51 Ω
a	1.02

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