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# A review of parameter estimation used in solar photovoltaic system for a single diode model

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# A review of parameter estimation used in solar photovoltaic system for a single diode model

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**Abstract**. With increased demand for theoretical solar energy, the mathematical modelling of the solar photovoltaic (PV) system has gained importance. Numerous mathematical models have been developed for different purposes. In this paper, we briefly review the progress made in the mathematical modelling of solar photovoltaic (PV) system over the last twenty years. First, a general classification of these models is made. Then, the basic characteristics of the models along with the objectives and different parameters considered in modelling are discussed. The assumptions and approximations made also parameter estimation method in solving the models are summarized. This may facilitate the mathematicians to adopt better understanding of the modelling strategies and further to develop suitable models in this direction relevant to the present scenario.

## 1. Introduction

Solar energy can be considered as a source of renewable energy that is important in the future. This is due to the climate change and pollution on the earth that are increasingly critical as lack of fossil-based resources for electricity supply. Solar energy known as the best backup energy due to high solar energy potential with daily average solar irradiation is high [2].

Solar PV systems directly convert solar energy into electricity. Various studies have been conducted to enhance solar PV system. There is a vast amount of literature on photovoltaic (PV) system and mathematical modelling of PV systems. The ultimate goals in mathematical modelling of PV system may be summarized as the study of the following: a) develop an accurate PV cell model or simulator [3]; b) investigate the performance effect PV system that influence with solar irradiance and temperature [1]; c) investigate the variation of maximum power point for various temperature and irradiance [4]; d) identify the factors that influence the efficiency of solar panel's performance [5]; e) increase the current and power ouput efficiency of the PV system [6]; f) improve the power quality of PV system [7].

## 2. Mathematical Model of Photovoltaic Cells

In PV system, there are several kind of model exist on a photocurrent source, the number of resistors, and the number of diodes. Generally, the classification of mathematical models for PV system can be grouped based on the number of diodes unknown parameters as follows:

(i) Single-diode model of 3-parameters [8]
(ii) Single-diode model of 4-parameters [9]
(iii) Single-diode model of 5-parameters [10]
(iv) Double-diode model of 5-parameters [11]

(v) Double-diode model of 6-parameters [12]
(vi) Double-diode model of 7-parameters [13]
(vii) Triple-diode model of 8-parameter [14]
(viii) Triple-diode model of 9-parameter [15]

The single-diode model of 5-parameters becomes a choice in modelling PV systems [16] and it led to more accurate current estimations [17]. In modelling PV system, the input variables are solar irradiance and temperature, which are under the category of weather data that are always changing influenced by time. On the other hand, the output variables are current, $I$ , voltage, $V$ , and power, $P$ . Subsequently, we can then obtain the characteristic of $I-V$ and $P-V$ curve. A lit bit changing in input value will affect the output. This is the reason why we need an accurate model for the PV system [1]. A general mathematical description of *I-V* output characteristics for a PV cell is not a new model, it has been studied over the last four decades with various changes to improve Has been studied over the last four decades with various changes to improve readability. According to the literature, the single diode model and the double diode model have frequently been used [7].

This research focus on single diode model of 5-parameters. This model for PV cell consists of photocurrent source, $I_{PV}$ , diode, $D$ , a shunt resistance, $R_{SH}$ and a series resistance, $R_S$ as shown in Figure 1. The diode and shunt resistance are connected in anti-parallel with the current source. The output current, $I$ is obtained by [10] as follows:

$$I = I_{PV} - I_{RC}\left[\exp\left(\frac{V+IR_S}{aV_T}\right)-1\right]-\frac{V+IR_S}{R_{SH}} \qquad (1)$$

The photocurrent generated when the cell receives the sunlight, the current called as $I_{PV}$ . The reverse saturation or leakage current of the diode ( $I_{RC}$ ), $a$ is the diode ideal constant and $V$ is the voltage imposed on the diode. $V_T = kT/q$ is the thermal voltage.

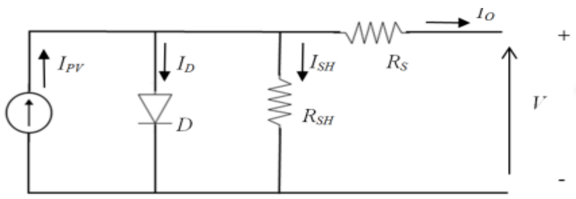

Figure 1 : PV circuit model with a single-diode.

Notice that the current, $I$ in Equation. (1) depends on the voltage, $V$ . By referring to Equation (1). the current, $I$ appears on both sides of the equations. It expressed a nonlinear implicit character and forcing its solution through iterative methods or approximate solutions, for example Newton Raphson iterative method [6]&[18]. Despite this, the implicit expression of output current can be transformed into explicit by using Lambert W-function [19]. Many explicit expressions of I-V characteristics have been proposed for single-diode model.

The main requirement in model development are estimate of the unknown parameters and use of these parameters in the simulation. The result showed the behavior of PV modules were influenced environmental change [7]. Matlab becomes the choice of researchers as a medium to present the modelling of PV system. [7]. The output from the developed model are I-V and P-V characteristics curve. The simulation result will be compared with the curves provided by the datasheets.

## 3. Parameter estimation

The accuracy of PV mathematical model depends on technique in estimating the parameters. In other words, parameter estimation is a crucial step in developing a mathematical model. Most of the parameter estimation was conducted using the information that given by the manufacturer's datasheet at Standard Test Conditions (STC) [7]. Three remarkable points of the *I-V* characteristics at STC are short circuit (0, $I_{SC}$), maximum power point ($V_{MAX}$ , $I_{MAX}$) and open-circuit ($V_{OC}$ , 0). $I_{SC}$ is short circuit current – the current occurs when the cells is short-circuited and would be the maximum current. $V_{OC}$ is open circuit current – it obtained when there is no load connected across the circuit and would be the maximum voltage. $V_{MAX}$ (maximum power voltage) and $I_{MAX}$ (maximum power current) are being produced by the cell.

Also, the values of parameters depend on the assumptions adopted by the searchers. Accurate determination of these parameters those influenced by environmental conditions (which are solar irradiance and temperature) is a challenge for researchers. The characteristics parameters of PV modules, usually provided in manufacturer datasheet and totally different with real condition of operation [18]. In real conditions of work, these parameters have to evaluate continuously in modelling a good and accurate PV systems [18].

There are several methods in determination the values of parameters, which can be grouped into three categories, named as; 1) analytic methods; 2) iterative methods; and 3) evolutionary methods [7]. These three methods give different levels of accuracy. Analytical methods solve only explicit mathematical equations. It is very simple method and reduce the time for calculations. An examples of analytical methods was used to estimate the parameters of the PV module i Lambert W function. Iterative method is also known as numerical methods. When a system is unable to solve analytically, the numerical methods will be the best choice. The well-known iterative method is Newton Raphson but it is not suitable because the accuracy and convergence are affected the initial conditions [7].

Some researchers aimed to determine the best method for looking the close value of accuracy, efficiency and convergence in comparing the parameter estimation for PV cell modelling. Some researcher concluded that analytical methods required less computational time and some of them were still unable to find all the parameters by using iterative methods suffered from convergence problem. The selection factors depend on the selection model of PV cell/array/module. Although the researcher might suffer from premature convergence in the case of improper selection of control parameters and initial conditions [7].For single-diode model of 5-parameters, the five unknown parameters $R_S$ , $R_{SH}$ , $I_{RC}$ , $I_{PV}$ , will be calculated.

### *3.1 Determination of photocurrent, $I_{PV}$*

Photocurrent $I_{PV}$ is determined differently and depends on either solar irradiance, temperature or resistance. The different studies determine the different factors.

[20], [22], [23] and [1] determined $I_{PV}$ by taking into account the factors of solar irradiance and temperature simultaneously. For example, [20] formulate $I_{PV}$ *as:*

$$I_{PV} = (I_{PVn} + K_I \Delta T)\frac{G}{G_n} \tag{2}$$

where $I_{PVn}$ is the current that generated from sunlight at the STC condition (usually $25°C$ and $1000 W/m^2$) and defined as $I_{PVn} = I_{SCn}\left((R_{SH} + R_S)/R_{SH}\right)$, $\Delta T = T - T_n$ (being $T$ and $T_n$ the actual and nominal temperatures); $G$ is the irradiation on the device surface; $G_n$ is the nominal solar irradiation and $K_I$ is the current coefficients was provided by manufacturer. [22] discussed that $I_{PV}$ is given by;

$$I_{PV} = I_{PVn} + \left(\frac{G}{G_n}\right)\left(1+\alpha'_T\left(T-T_n\right)\right) \tag{3}$$

where $\alpha'_T = \alpha_T / I_{PVn}$ , $\alpha_T$ is absolute temperature coefficient of the short circuit current and provided by manufacturers. [23] made slightly different with Equation (3) still considering solar irradiance and cell temperature but the constant in this equation represented the rate of the short-circuit current changing due to temperature (%). The equation given as below;

$$I_{PV} = I_{PVn}\left(1+\alpha_{ISC}\left(T-T_n\right)\right)\left(\frac{G}{G_n}\right) \tag{4}$$

where $\alpha_{I_{SC}}$ is the relative temperature coefficient of the short-circuit current $(\%/K)$. In [1], $I_{PV}$ was formulated by including the coefficient temperature of short circuit current, $\mu_{SC}$ (A/K), provided by the manufacturer. The equation given as below;

$$I_{PV} = \left(\frac{G}{G_n}\right)\left(I_{PVn} + \mu_{SC}\left(T-T_n\right)\right) \tag{5}$$

On the other hand, [21] describes the $I_{PV}$ changes with temperature as the equation below;

$$I_{PV} = I_{PVn} + \mu_{I_{SC}}\left(T-T_n\right) \tag{6}$$

where $\mu_{I_{SC}}$ is thermal coefficient of the short circuit current $(A/°C)$. [24] defined the different equation where is series and shunt resistance are influencing of $I_{PV}$ as follows;

$$I_{PV} = I_{SC}\left(1+\frac{R_S}{R_{SH}}\right)+\left[\left(I_{SC}-\frac{V_{OC}}{R_{SH}}\right)e^{\frac{-V_{OC}}{AV_T}}\right]\left[e^{\left(\frac{I_{SC}R_S}{AV_T}\right)}-1\right] \tag{7}$$

Hence, environmental working factors (such as solar irradiance & temperature) and physical factors (such as series and shunt resistance) should be included in formulating $I_{PV}$ .

*3.2 Determination of saturation current* $I_{RC}$

Saturation current $I_{RC}$ is determined differently depends on parameter estimation. [20] and [21] decided that $I_{RC}$ depends on temperature. [20] aimed to suite the open-circuit voltages of the PV model with the experimental data for each range of temperatures. $I_{RC}$ was formulated by including the current and voltage coefficients $K_I$ and $K_V$ as follows;

$$I_{RC} = \frac{I_{SCn}+K_I\Delta T}{e^{\left(\left(V_{OCn}+K_V\Delta T\right)/aV_T\right)-1}} \tag{8}$$

[21] discussed the same factor and $I_{RC}$ is given as;

$$I_{RC} = I_{RCn} - \mu_{I_{SC}}\left(T-T_n\right) \tag{9}$$

[22] and [1] studied band gap and temperature were influencing $I_{RC}$ . $I_{RC}$ was formulated by [22] shown as;

$$I_{RC} = I_{RCn}\left(\frac{T}{T_n}\right)^3 \exp\left[\frac{E_{g_n}}{kT_n}-\frac{E_g}{kT}\right] \tag{10}$$

$I_{RC}$ was derived by [1] as follows;

$$I_{RC} = I_{RCn}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \tag{11}$$

[23] used the same influencing factors as mentioned [20], [21], [22] and [1] added another factor which is module area ( $A$ ) as represent the real working condition. Thus the relationship is expressed as;

$$I_{RC} = AT^3 e^{-Eg/nkT} \tag{12}$$

[25] discussed $I_{RC}$ was influenced with the short-circuit current and open-circuit voltage. The relation shows as follows;

$$I_{RC} = \frac{I_{SCn}}{e^{V_{OCn}/nV_T} - 1} \tag{13}$$

The previous study agreed that $I_{RC}$ as represent the characteristics of a component that caused the accuracy of $I$ . Thus the estimation of $I_{RC}$ must be considered with environmental (band gap), working condition (temperature) and physical (module area) of the PV cell/module/array for having more accurate solution.

*3.3 Determination of series resistance, $R_S$ and shunt resistance $R_{SH}$*

Several different methods had created and used in determining the series and shunt resistance. The series and shunt resistance have a significant effect on the slope of the *I-V* curve [6] and [25] assumed that $R_{SH}$ very large ( $R_{SH} \to \infty$ ). Some researchers stated $R_S$ and $R_{SH}$ are independent variables and it based on the properties of the cell in the specific research [25]. [11], [24] approximated $R_{SH}$ and $R_S$ by using the function of the slope of the *I-V* curve. In simplified model, $R_{SH}$ is neglected [11].

[22] assumed the parallel leakage resistance or shunt resistance $R_{SH}$ and series resistance $R_S$ are independent parameters and not influence by temperature and solar irradiation at any operating conditions. As approximations are;

$$R_{SH} = 10V_{OC}/I_{SC} \; ; R_S < 0.1V_{OC}/I_{SC} \tag{14}$$

[21] analysed both the series and shunt resistance almost inverse linear mode with solar irradiation as follows;

$$R_{SH_G} = \frac{R_{SH}}{\alpha_G} \; ; R_{S_G} = \frac{R_S}{\alpha_G} \tag{15}$$

where the values of the resistances $R_{SH}$ and $R_S$ are evaluated in STC. [20] and [3] compute the values of $R_{SH}$ and $R_S$ by using an iterative method, the process shown a unique pair of values for $R_S$ and $R_S$ and it matched with $P_{MAX}$ provided by the manufacturer. Calculating the value of $R_{SH}$ and $R_{SH}$ using the relationship as below;

$$R_{SH} = \frac{V_{MAX}}{I_{SCn} - I_{MAX}} - \frac{V_{OCn} - V_{MAX}}{I_{MAX}} \; ; R_S = R_{SH}\left(\frac{I_{PVn}}{I_{SCn}} - 1\right) \tag{16}$$

$R_S$ and $R_{SH}$ are initially unknown but as the solution of the algorithm is refined along successive iterations. The formula which derived by [21] and [20] proved that the resistances are changes influence of solar irradiance. Thus, to determine the value of resistances have to consider the solar irradiance besides the physically condition (such as $V_{OC}$, $I_{SC}$, $V_{MAX}$ and $I_{MAX}$).

## 4. Conclusion

In this paper, a review of the different parameter estimation used in PV system has been presented. The main parameter estimation identified in the literature are short-circuit current, open-circuit voltage and band gap. However, according to literature, solar irradiance and temperature are the predominant parameter estimation used in PV system. Both parameters are influencing in calculating the five parameters $I_{PV}$, $I_{RC}$, $R_S$ , $R_{SH}$ and $a$ in single diode model. The work presented in this paper has underlined the parameters estimation to consider in modelling are short-circuit current, open-circuit voltage and band gap. This review can be used as a reference in PV system modelling purpose. The development of mathematical model for this PV system is very interesting field to explore due to the variety of factors or parameters that can be included to improve accuracy and efficiency.

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