Science and Engineering Symposium
4th International Science, Social Science, Engineering and Energy Conference 2012

Comparison Study of Solar PV Cell Modeling with Applications

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Abstract

This paper presents a comparative study of solar PV cell modeling. The evolution of modeling from an easy type to a complicated one is explained in detail. Modeling parameters are changed to find out the relationship between them. PSCAD/EMTDC program is used in simulating the models. Different power levels and installation types are also discussed. Commercial solar PV cell datasheets are used to test and develop a new model in the standard form of Volt-Amp and Volt-Power curves. The results show that each solar PV cell modeling can be used, but with limitation. A simplified model is then proposed to avoid possible complications; however, for a close-to-real result in modeling, fine tuning of parameters is recommended.

Keywords: solar PV cell modeling; PSCAD/EMTDC

1. Introduction

In an era in which energy is one of the greatest concerns, different alternative electrical generators have been introduced and used widely using different sources of natural energy. Photovoltaic (PV) is one of the most popular systems because the sunlight can be found in most regions on Earth, especially in Thailand where the sun shines almost throughout the year.

The solar irradiation on the surface of a PV cell is changed naturally day by day, depending on many factors and the amount of the generated electricity actually depends on the solar radiation. Therefore, the process of energy accumulation is needed and the power electronic converter is used to boost the voltage level up to an applicable one to enable different applications to function, such as battery charging, grid connection with electrical provider [1].

The most popular method used to control the PV system is Maximum Power Point Tracking (MPPT) [2]. In order to study the controller designed by MPPT concept, it is necessary to know how to create the mathematical model of the PV system, which is useful for the study of the dynamic analysis of converters, controller design,

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and the simulation of a PV system in the power system. Moreover, there are a number of effective computer tools used in various contexts of engineering application.

1.1 Power level and installation type

A PV cell is the smallest unit in the PV system. The actual commercial PV module consists of many connected PV cells, in either series or parallel forms, where the rated power is suitable for small loads such as lighting system or a small electric pump. For a large PV power system in general, called PV panel or PV array, a set of connected modules is composed in series to generate desirable voltage. However, for a desirable current, the modules are then changed to be connected in a parallel form or a mix of both series and parallel forms to produce higher voltage and current.

In simulation (or theoretically), a basic PV cell circuit can be scaled up to represent any configurations of the PV system. However, it is rather different in practice due to the types of diode installation, a bypass diode and a blocking diode, in a PV cell for protection purpose. Generally, a bypass diode is connected in parallel with the PV cell and it allows current to pass around shaded cells and also reduces the voltage losses in these shaded cells [3]. Regarding a blocking diode, its function is to block reverse current from loads through the PV module, preventing the module to become loaded, see Fig. 1.
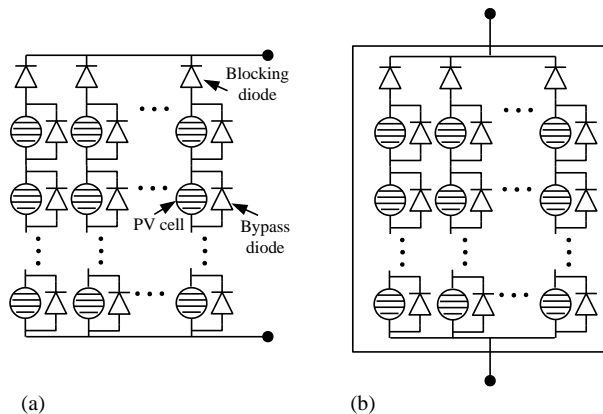

(a)   (b)

Fig. 1. the connected diodes in a practical PV module a) an inside of a PV module; b) a PV module

Nomenclature

V	PV cell terminal voltage (V)
I	PV cell terminal current (A)
q	electron charge constant $\left(1.60217646 \times 10^{-19}\right)$ C
k	Boltzmann constant $\left(1.3806503 \times 10^{-23}\right)$ J/K
T	ambient temperature (Kelvin)
T_n	nominal temperature (Kelvin)
a	diode ideality constant
N_S	Cells connected in series

2. The evolution of modeling

Regarding a datasheet provided by a manufacturer, the actual commercial information is given as shown in Table 1. Moreover, the characteristics of I-V and P-V curves of a PV module with five values: short circuit current (I_{SC}), voltage at the MPP (V_{mp}), current at the MPP (I_{mp}), power at the MPP (P_{MP}), and open circuit voltage (V_{OC}) [4-10] are shown in Fig. 2.

Table 1. an example of basic information of a PV module on datasheet

Parameter of PV array at 25 °C, A.M 1.5, 1000 W/m² [7]	
Open circuit voltage (V_{OC})	32.9 V
Short circuit current (I_{SC})	8.21 A
The voltage at the MPP (V_{mp})	26.3 V
The current at the MPP (I_{mp})	7.61 A
The open circuit voltage / temperature coefficient (K_v)	-0.1230 V/K
The short circuit current / temperature coefficient (K_I)	0.0032 A/K
The maximum experimental peak output power (P_{MAX})	200.143 W

Most given datasheets generally provide the information on characteristics and performance of a PV module with respect to the so-called standard test condition (STC), which means an irradiation of 1000 W/m² with an AM1.5 spectrum at 25 °C [7]. The PV characteristics therefore vary on external influences such as irradiation level and temperature.
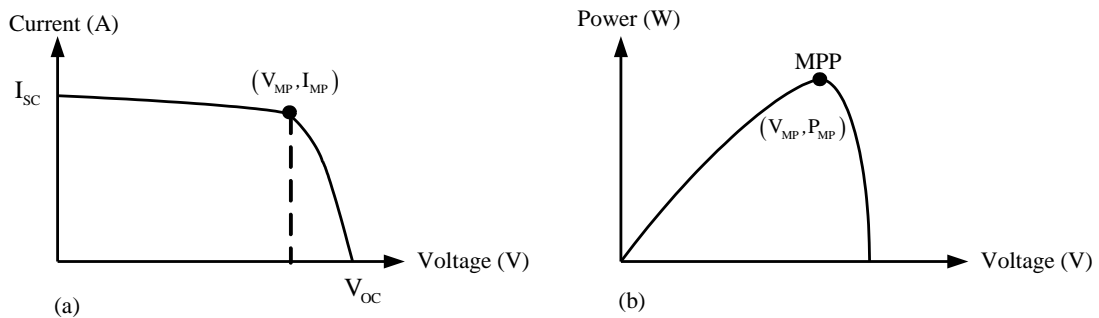

Fig. 2. characteristics of I-V and P-V curves of a PV module

2.1 Ideal PV cell

The equivalent circuit of the ideal PV cell and its I-V characteristic curve in correspondence with the mathematical expression in equation (1) [1-10] are shown in Fig. 3.

$$I = I_{PV} - I_O \left[exp\left(\frac{qV}{akT}\right) - 1 \right] \tag{1}$$

when the light-generated current (I_{PV}) is directly proportional to the solar irradiation and temperature as shown in equation (2),

$$I_{PV} = \left(I_{PV,n} + K_I \Delta_T \right) \frac{G}{G_n} \tag{2}$$

where $I_{PV,n}$ is the light-generated current at STC, Δ_T equals $T - T_n$, T_n is the nominal temperature, G is the irradiation (watts per square meters) and G_n is the nominal irradiation.
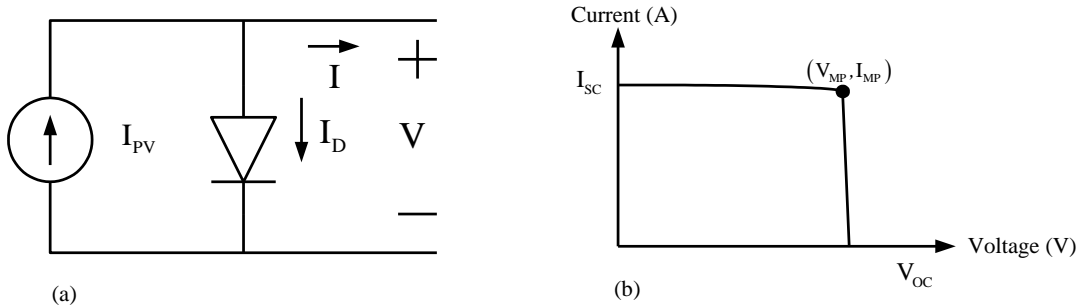

(a)

(b)

Fig. 3. the ideal PV cell a) the equivalent circuit; b) the I-V characteristic curve

The diode saturation current I_0 is changed according to the temperature, shown in equation (3),

$$I_0 = I_{0,n}\left(\frac{T_n}{T}\right)^3 exp\left(\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right) \tag{3}$$

where E_g is the bandgap energy of the semiconductor and $I_{0,n}$ is the nominal saturation current.

2.2 Practical PV array

In practice, a PV array is composed of several connected PV cells. Therefore, additional parameters to the ideal PV cell equation can be extended as in equation (4). The equivalent circuit of a PV array represented by four elements: a light-induced current source, a diode, a series resistor and a shunt resistor, and its I-V characteristic curve [1-10] are shown in Fig. 4.

$$I = I_{PV} - I_0\left[exp\left(\frac{V + IR_s}{V_t a}\right) - 1\right] - \frac{V + IR_s}{R_P} \tag{4}$$

In some cases, more than one single-diode may be added to represent the effects of the recombination in the semiconductor's depletion region. But in other cases where only one single-diode is connected, the value of R_s is very low and the value of R_P is generally high, and sometimes this parameter is neglected [7].
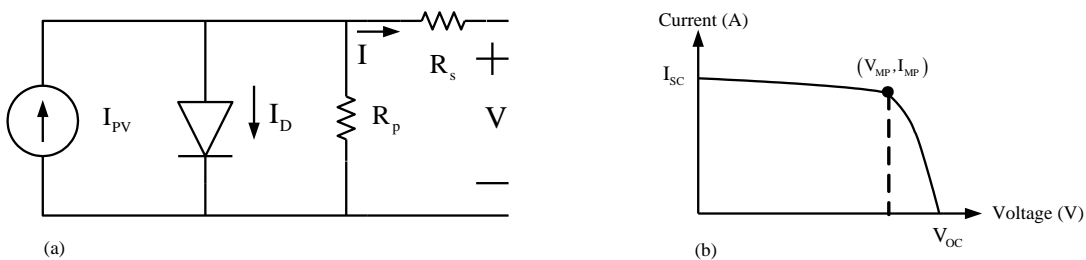

(a)

(b)

Fig. 4. the practical PV array a) the equivalent circuit; b) the I-V characteristic curve

2.3 Modeling parameter relationship

The series resistance, R_s, is the sum of several structural resistances of the device, which depends on the contact resistance of the metal base with the p and n semiconductor layer, the resistances of the p and n bodies, and the resistance of the grid [7]. The R_P resistance exists mainly due to the leakage current of the p-n junction and depends on the fabrication method. The I-V characteristics of the PV array depend on different factors; for examples, the internal resistance (R_s, R_P), external influences such as irradiation level and temperature, and the PV characteristics of the PV array as shown in Fig. 5., Fig. 6., and Fig. 7. respectively.
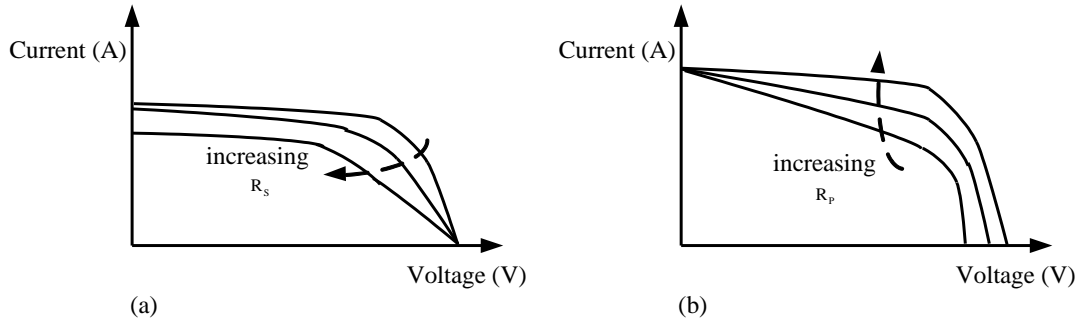
Fig. 5. the I-V characteristic curve of a practical PV array a) at different series resistance; b) at different parallel resistance
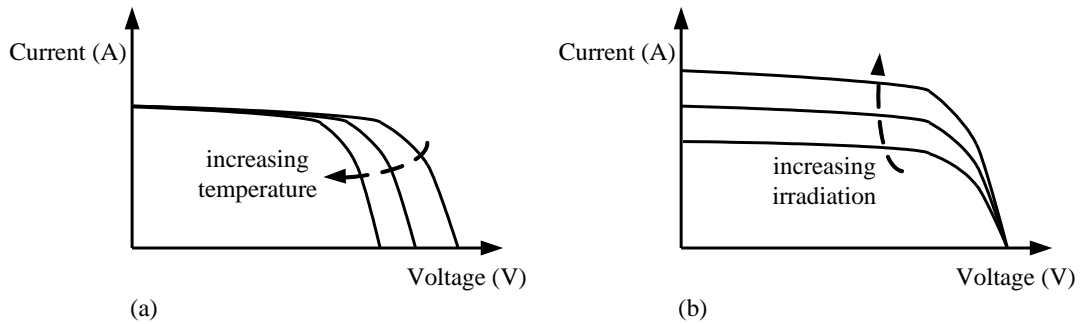
Fig. 6. the I-V characteristic curve of a practical PV array a) at different temperature; b) at different irradiation
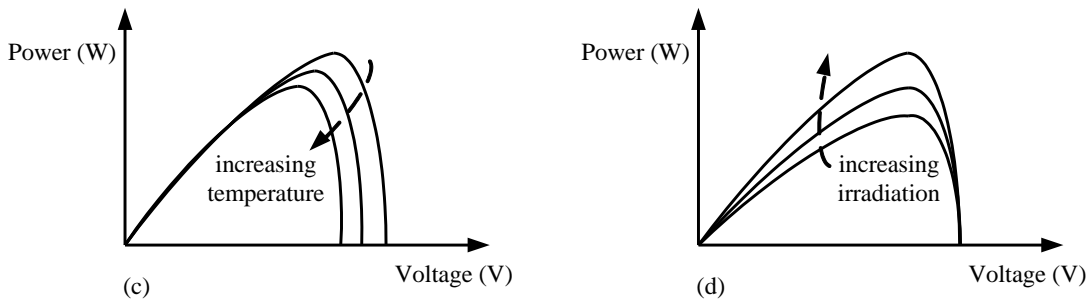
Fig. 7. the P-V characteristic curve of a practical PV array a) at different temperature; b) at different irradiation

3. Simulation results

This computer software simulation is done by using PSCAD/EMTDC version 4.2.1 evaluation. The PV array model can be implemented by using different techniques. Instead of using a single diode, [5] proposes a model constructed by using standard library components. Here, three series diodes and two low valued bypass resistors are used to fit the non-linear curve of the I-V characteristic. In a different way, [8] has shown a model which was implemented as a custom component. Here, the equation (4) is used to calculate voltage and the previous calculated voltage is then used to determine the next current injections. This paper, however, proposes a less complicated black box concept by changing the complicated equation (4) to a simpler one as I equals V function for a good fit to the Fig. 4's non-linear curve, using the same parameters provided in Table 1. In this concept, the proposed mathematical function can be implemented by using the standard component called piece-wise linear look-up table, in which the XY coordinate points can be specified. The piece-wise linear look-up table can be used in specifying PV array characteristics shown in Fig. 8., using 10 XY coordinate points of the data of the Fig. 4's non-linear curve. Moreover, a simple example of the new concept application in a testing circuit, where the terminal voltage generated by triangle input voltage source and measurement of the current output flow in resistor load, is shown in Fig. 9. The simulation result shows that the current changes according to the voltage change in good agreement with I-V characteristic curve generated shown in Fig. 8.
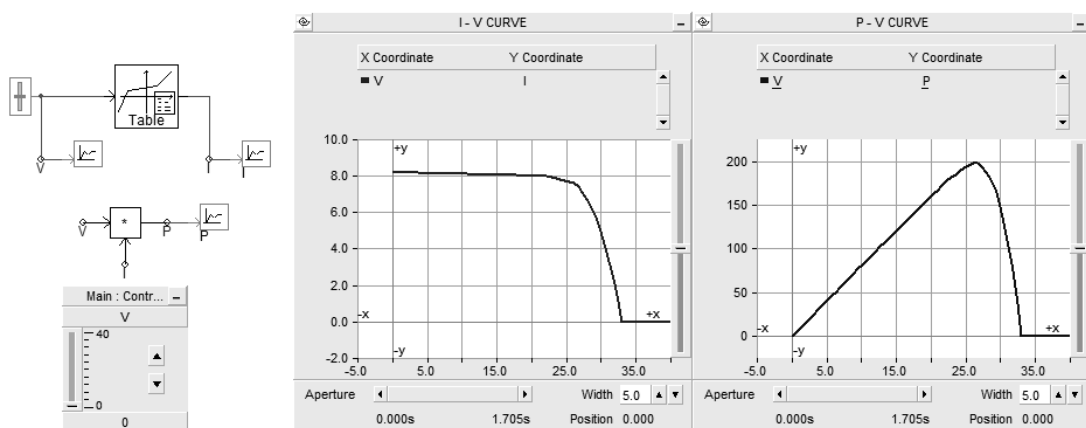

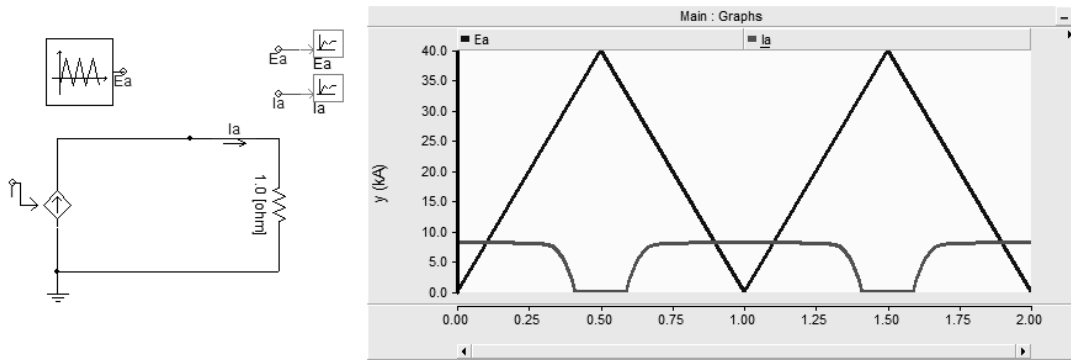Fig. 8. the I-V and P-V characteristic curve of practical PV array

Fig. 9. testing circuit

4. Conclusion

This paper has analyzed the evolution of the mathematical modeling of the PV array and has also presented in detail the equations that form PV array characteristics both in I-V and P-V styles. A PV device model was implemented in an electromagnetic transient-like simulation program. The difficulty in making a model is due to not only the complication of the non-linear PV characteristic equation itself, but certain needed parameters are not even provided by the manufacturer. Therefore, this paper proposes a simplified model using piece-wise linear look-up table to avoid unnecessary complications in concerning with less time-consuming rather than highly exact model. In practice, however, fine tuning of the PV parameters is recommended for the result close to the real PV system.

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