2013 ISES Solar World Congress

Identification of model parameters of the photovoltaic solar cells

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Abstract

Presently, many equivalent circuit models have been developed and proposed to describe the photovoltaic (PV) cell's characteristics, and the most commonly used are single and double diode models. In a single diode model, a complete characteristic of a PV cell's can be described by five model parameters i.e.: light generated current, leakage or reverse saturation current, diode quality factor, series resistance and shunt resistance. Light generated current and reverse saturation current can be said as external influences meanwhile the others are internal influences. Accuracy of the PV system modelling is depending on the correct calculation of the internal influences. A research preliminary in order to identify internal influences have been-performed and will be presented in this paper. As a research subject, polycrystalline silicon (wafer based crystalline silicon technology) and amorphous silicon (thin film technology) modules, as components of grid-connected PV array system at Szent István University (SZIU), were used under Gödöllő climatic conditions. As an initial step, simulation results based on software packages (associated with the PV characteristics) and some calculation methods to identify internal influences are shown here. As a long term outcome of this research, internal parameters of both modules can be predicted, and furthermore PV cell's model for both modules can be developed.

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1. Introduction

Testing (referring to an experimental data) and modelling efforts are typically to quantify and then to replicate the measured phenomenon of interest. Testing and modelling of the photovoltaic (PV) system performance is very complicated and influenced by a variety of interactive factors related to the environment and solar cell physics (material technology).

The characteristics of a PV solar cell, module, panel or array can be explained with an equivalent electric circuit that is similar to the device that is to be characterized. There are a number of more or less complex models for simulating the characteristic of a PV system (the current, I – voltage, V) for specific irradiance and temperature conditions (De Blas et al., 2002).

The I–V curve is not only useful for cell arrays and system simulation, but also as an analysis tool to gain an understanding of the internal physical mechanisms of the PV solar cell (Li et al, 2013). Many equivalent circuit models have been developed and proposed to describe the PV cell's characteristic and the most commonly used are single and double diode models. In a single diode model, a complete characteristic of a PV cell's can be described by five model parameters (called as five lumped parameters) i.e.: light generated current (I_l), leakage or reverse saturation current (I_o), diode quality factor (n), series resistance (R_s) and shunt resistance (R_{sh}). I_l and I_o can be said as external influences meanwhile the others are an internal influences. The five lumped parameter model more preferable to use in simulate the characteristic of PV system due to of its simplicity.

Nomenclature

E_G	the band gap energy of the semi-conductor (eV)
G	solar irradiance (kWh/m^2)
I_l	light generated current (A)
I_o	reverse saturation current (A)
k	Boltzmann's constant (1.381 x 10^{-23} J/K)
n	diode quality factor (-)
q	electron charge (1.602 x 10^{-19} C)
R_s	the series resistance (Ω)
R_{sh}	the shunt resistance (Ω)
T_c	temperature of the photovoltaic device (K)
V_m	voltage at maximum power point (V)
V_{oc}	open circuit voltage (V)
V_t	thermal voltage (V)
μ_i	the cell's short-circuit current temperature coefficient (A/K)

In other side, accuracy of the PV system modelling (simulation) is depending on the correct calculation of the parameters such as I_l, I_o and n as well. These values are typically not provided by the PV cell producer and as consequently these parameters should be identified or calculated.

In this paper, characterizations (*I-V-P*) of two PV modules technologies i.e. polycrystalline silicon (crystalline technology: ASE-100 type) and amorphous silicon (thin film technology: DS-40 type) modules will be shown for any operating condition (any irradiance and module temperature, included STC condition) using a conventional approach, i.e. PV*SOL 3.0 software package, and is made as initial step in order to get the internal parameters (n, R_s and R_{sh}), as prerequisite to develop a PV cell's model of both PV modules.

2. Solar cell modell

2.1. General solar cell model

A PV cell's characteristic under solar irradiance (G) is given in terms of PV cell output current (I) and PV cell voltage (V). Several models have been developed to describe the *I–V* characteristic of solar cells, but only two models are used in practice i.e. single diode model and double diode model (Askarzadeh and Rezazadeh, 2013).

A simplified equivalent circuit model of PV cell is used since it is quite simple to implement and is compatible with the electrical behaviour of the actual cell. The equivalent electric circuit diagram single diode model of PV cell is shown in Fig. 1, which consists of a photocurrent source, a diode, a parallel resistor and a series resistor (Wenham et al., 2007).
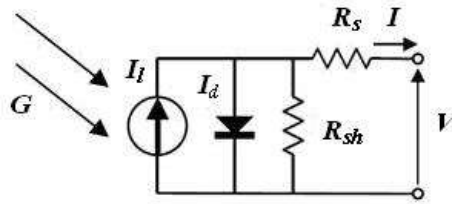

Fig. 1. General model of PV cell in a single diode model (five model parameter)

Referring to electric circuit in Fig. 1, the basic equation which describing the *I-V-P* characteristics of a PV cell model can be expressed based on the First Law of Kirchoff and written by,

$$I = I_l - I_d - I_{sh}. \tag{1}$$

and in term of single diode model (five lumped/model parameters), Eq. (1) can be written by,

$$I = I_l - I_o \left[\exp\left(\frac{V + IR_s}{\left(\frac{nkT_c}{q}\right)} \right) - 1 \right] - \frac{V + IR_s}{R_{sh}}. \tag{2}$$

In this model, the parameter identification problem reduces to find five parameters, namely, I_l, I_o, n, R_s, R_{sh}, which involves external (I_l and I_o) and internal parameters (n, R_s, R_{sh}).

The light generated current (I_l) can be expressed by,

$$I_l = \frac{G}{G_{ref}}\left[I_{l,ref} + \mu_i\left(T_c - T_{c,ref}\right)\right], \tag{3}$$

$$I_{l,ref} = I_{sc,ref}, \tag{4}$$

$$\mu_i = \frac{I_{sc} - I_{sc,ref}}{T_c - T_{c,ref}}. \tag{5}$$

meanwhile the diode (reverse) saturation current (I_o) can be expressed by,

$$I_o = I_{o,ref}\left(\frac{T_{c,ref}}{T_c}\right)^3 \exp\left[\frac{qE_G}{nk}\left(\frac{1}{T_{c,ref}} - \frac{1}{T_c}\right)\right], \tag{6}$$

$$I_{o,ref} = \frac{I_{sc,ref}}{\exp\left(\frac{V_{oc,ref}}{V_{t,ref}}\right) - 1}, \tag{7}$$

$$V_t = \frac{nkT_c}{q}. \tag{8}$$

E_G is the band gap energy of the semi-conductor (eV), μ_i is the cell's short-circuit current temperature coefficient (A/K) and subscript *ref* is showing the values at reference condition ($T_c = 25^{o}$C and $G = 1000$ W/m^2).

The resistance in parallel with the diode represents the shunt resistance that can occur in real solar cells across the surface, at pin holes in the p-n junction, or at grain boundaries (in practice, a parallel resistance expressing a leakage current). The shunt resistance value represents any parallel high-conductivity paths across the solar cell p–n junction. The series resistance accounts for all voltage drops across the transport resistances of the solar cell and its connection to a load (in practice, a series resistor describing an internal resistance to the current flow). For example, losses due to resistance introduced in cell solder bonds, emitter and base regions, cell metallisa-tion, and cell-interconnect busbars all contribute to the value of R_s (Li et al., 2013; Green, 1998).

Experiments by Van Dyk and Meyer in 2004 shows that an increase in series resistance results in a drop in voltage output while a decrease in shunt resistance will reduce current output. Their work have demonstrated that by increasing R_s from 0.36 to 1.80 ohms, both the maximum power (P_{max}) and fill factor (*FF*) were reduced by 25% making it clear that model yield is strongly influenced by loss resistance values (Ghani et al., 2013). The correlation between P_{max} and *FF* expressed by:

$$FF = \frac{P_{max}}{V_{oc}I_{sc}} = \frac{V_{mp}I_{mp}}{V_{oc}I_{sc}}. \tag{9}$$

In practice, in a simplified model, the series resistance is low (≈ 0), the shunt resistance is high ($\approx \infty$) and also diode quality factor equal 1 (although diode quality factor value is depending on the type of material), so their effects generally are neglected.

Referring to above statements and with considering $R_s = 0$ (very small) and $R_{sh} = \infty$ (very large), the Eq. (2) can be rewritten by:

$$I = I_l - I_o \left[\exp\left(\frac{V}{\frac{nkT_c}{q}} \right) - 1 \right].\tag{10}$$

The complete behavior of a single diode model PV cells (as shown in Eq. 2) is described by five model parameters (I_l, I_o, R_s, R_{sh}, n) which are representative of a physical PV cell/module. Such parameters are in fact related to two environmental parameters i.e. solar insolation (irradiation) and temperature, but due to Eqs. (2) or (11) are non-linear, a complicated analysis will be found in its determination.

2.2. Identify model parameter

Five aspects i.e. applicability, convergence, stability, calculation speed and error should be considered in order to choice a method. The fastest estimation method for series resistance and parallel resistance is to use the reciprocals of slope of the output curve under dark conditions at 0 V and 2 V (a shunt resistance point of 2 times Voc may be used as well) to find the shunt and series resistance, respectively, as shown in Eqs. (11) and (12) (Li et al., 2013).

$$R_{sh} = \left.\frac{dV}{dI}\right|_{v=0},\tag{11}$$

$$R_s = \left.\frac{dV}{dI}\right|_{v=2V_o \ or \ 2V}.\tag{12}$$

To further extract I_o, I_l and n some complicated methods were proposed in the past years. In the literatures, many calculation methods such as genetic algorithm (GA), particle swarm optimization (PSO), simulated annealing (SA), explicit model, Lambert W-function, pattern search (PS), harmony search (HS) have been explained in order to identify a solar cell parameter, and generally built based on experimental of *I-V* characteristics through the extract parameters ((Askarzadeh and Rezazadeh, 2013; Ghani et al., 201).

The degree of complexity of the model will determine which of the methods is most suitable in extracting the parameters that are involved in the mathematical expression of the model (De Blas et al., 2002). As an illustration, since Eq. (2) is transcendental equation, it is very difficult to find the numerical solutions. In order to circumvent this problem, it is convenient to use the *Lambert W* function. By using the *Lambert W* function the current can be expressed as an explicit function of voltage as:

$$I = -\frac{V}{R_s + R_{sh}} - \frac{Lambert \ W\left(\left(\frac{R_s I_o R_{sh}}{nV_{th}(R_s + R_{sh})} \right) e^{\left(\frac{R_{sh}(R_s I_l + R_s I_o + V)}{nV_{th}(R_s + R_{sh})} \right)} \right) nV_{th}}{R_s} + \frac{R_{sh}(I_o + I_l)}{R_s + R_{sh}}.\tag{13}$$

Eq. (13) shows the *Lambert W* function method in order to obtain $I - V$ characteristic.

3. Simulation results and discussion

As described in previous section, this paper just shows *I* - *V* characteristic based on simulation results using a software packages. Further efforts still need to implement, especially in order to identify the internal influences.

I-V-P characteristics as function of climate condition

Figs 2-3 show the relationship between output current, voltage and power of the pc-Si and a-Si PV modules, under constant T_c and at different G, and vice versa, based on PV*SOL 3.0 software packages (Rusirawan and Farkas, 2011).
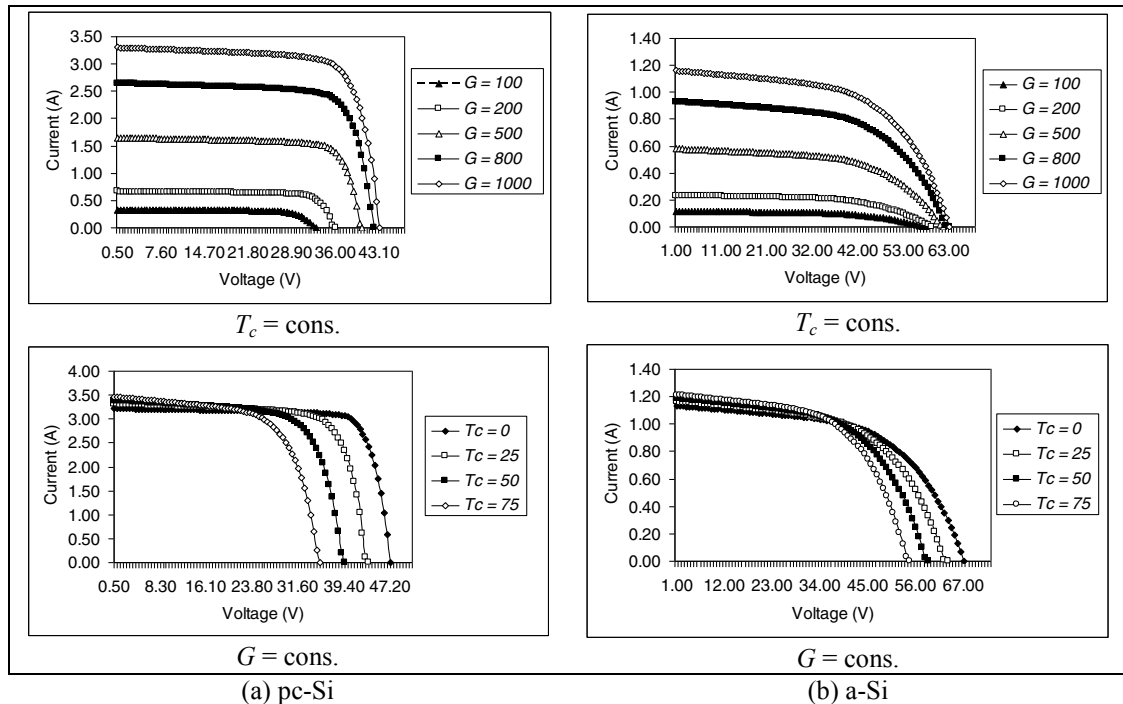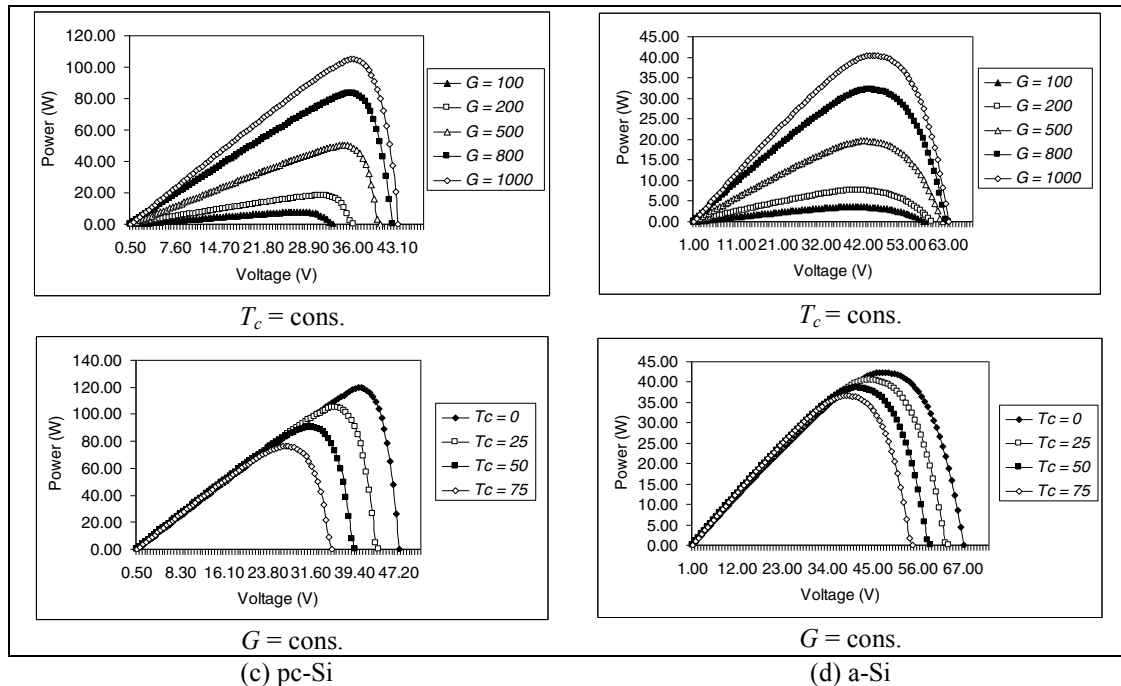

Fig. 2. The *I-V* module characteristics, based on PV*SOL 3.0

Based on characteristics in Fig. 2, it's clear that at constant module temperature, increasing of irradiation give big affect (proportional) on a short circuit current (I_{sc}) but small effect on the open circuit voltage (V_{oc}). In other side, it can be observed that increasing of module temperature at constant irradiation will increase a short circuit current (I_{sc}) slightly and decrease the open circuit voltage (V_{oc}) proportional.

Based on Fig. 3, it can be seen also that at constant module temperature, increasing of irradiation give significant affect on the output power of PV module (P). In other side, increasing of module temperature at constant irradiation will great affect on decreasing of output power (P) of PV module. This phenomena illustrated that output power (P) PV module is affected indirectly by ambient temperature, T_a.

Fig. 3. The *P-V* module characteristics, based on PV*SOL 3.0

4. Conclusion

In this paper, detail equations of one diode model of the PV cell/module have been presented. Electrical characteristics (*I-V-P*) of ASE-100 and DS-40 PV module have been determined based on software packages. From the *I-V-P* characteristics, it can be seen that the open circuit voltage (V_{OC}) is dominated by temperature, and irradiation has strong influence on short circuit current (I_{SC}). Based on this characteristic, it can be concluded that high temperature and low irradiation conditions will reduce the power conversion capability.

This paper is an initial step in order to identify internal influences of PV cell's. As a long term outcome of this research, internal parameters of both modules can be predicted, and furthermore PV cell's model for both modules can be developed.

Acknowledgements

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