



DETERMINATION OF THE SERIES RESISTANCE OF AN ILLUMINATED PHOTOVOLTAIC SOLAR CELL –THEORETICAL APPROACH

M. K. El-Adawi*

Physics Department, Faculty of Education, Ain Shams University, Roxy, Heliopolis
.P.O.Box11341, Cairo, Egypt *Corresponding Author

S. A. Shalaby

Physics Department, Faculty of Education, Ain Shams University, Roxy, Heliopolis
.P.O.Box11341, Cairo, Egypt

ABSTRACT The series resistance of a solar cell is an important parameter that affects its efficiency. The Characteristic (I-V) curves of an illuminated solar cell are considered to determine this parameter. This trial is based on the single exponential model. An analytical method starting from the maximum power point (MPP) on such curves has been developed to determine the series resistance (Rs) of the cell and other parameters. Important expressions for the open circuit voltage are obtained.

KEYWORDS : Photovoltaic Solar Cell; Maximum Power Point (MPP); Series Resistance (Rs); (I-V) Cell Characteristics.

1. INTRODUCTION

The keen desire of different authors [1-14] to extract the photovoltaic (PV) solar cell parameters is due to their vital importance in studying the cell performance and evaluating its efficiency.

Such information are necessary in designing solar cell concentrators and other solar system that depend on the solar photovoltaic cells . These parameters are usually the series resistance (R_s), the shunt resistance (R_{sh}), the reverse saturation current (I_0), the short circuit photocurrent (I_{sc}), the open circuit voltage (V_{oc}), the diode ideality factor (A) and the maximum power point (MPP).

Most of the trials are based on the single exponential model for which the steady state (IV) characteristics of a uniformly illuminated p-n silicon solar cell are generally described by an equation in the form [1-10]:

$$I = I_{sc} - I_0 \left[\exp \lambda (V + I R_s) - 1 \right] - \frac{V + I R_s}{R_{sh}} \quad (1)$$

Where :

$\lambda = q / A k T$, q , the charge of the electron = 1.6×10^{-19} C

k , Boltzmann constant = 1.38×10^{-23} J/K,

T , °K the absolute temperature, A , the diode ideality factor, kT/q , is the thermal voltage .

For most solar cells, the diode factor "A" has a value between 2.5 and 3 [11].

For a silicon solar cells the diode factor $A = 2.5$ at a moderate light intensity [2] . This value is accepted in computations in the present trial.

For $T = 300^\circ K$, $A = 2.5$ one gets $\lambda = 15.4589$.

The series resistance is an important parameter which should be kept to a minimum for efficient conversion of solar energy [2].

There are different methods to evaluate the series resistance [12], for example the two – curve method [2] considering different illumination levels.

Equation (1) is implicit and non-solvable analytically [6] .

EL-Adawi et al [5] succeeded to introduce an analytical method to solve equation (1) without neglecting of the shunt resistance R_{sh} .

The authors [5] succeeded also to determine the series resistance R_s as one root of a quadratic equation.

Moreover, they determined "Rs" considering the co-ordinates of two points (I_1, V_1) and (I_2, V_2) on one (single) (I-V) characteristic curve. R_s is given in the form [5]:

$$R_s = \frac{1}{\lambda} \frac{1}{(I_2 - I_1)} \ln \left[\frac{I_{ph} + I_2 - I_1}{I_{ph} + I_1 - I_2} \right] - \frac{V_2 - V_1}{I_2 - I_1} \quad (2)$$

The authors [7] decided that EL-Adawi method [5] to evaluate R_s is reasonably accurate among all others because it also takes care of the shunt resistance R_{sh} while deriving their expression for R_s .

The condition for maximum power output ($\frac{dP}{dV} = 0$) is considered by different authors [2,5,7] to derive some of the essential relations connecting the different parameters of the solar cell.

Nevertheless the obtained relations are either complicated or do not cover all the possible functional relations.

The aim of the present trial is to start from the same condition of maximum power output and express some vital parameters such as V_{oc} , R_s and the efficiency, in terms of the maximum power point (MPP) coordinates I_m and V_m .

2. The Basic Equations

Considering equation (1), the power $P = I V$ can be written as :

$$P = V \left[I_{sc} - I_0 \left(\exp \lambda (V + I R_s) - 1 \right) - \frac{V + I R_s}{R_{sh}} \right] \quad (3)$$

Applying the condition $\left(\frac{dP}{dV} \right)_{V=V_m} = 0$ to equation (3) one gets :

$$[I_{sc} + I_0 - I_0 \left(\exp \lambda (V_m + I_m R_s) \right) \{ 1 + \lambda V_m \} - \frac{2V_m + I_m R_s}{R_{sh}}]_{V=V_m} = 0 \quad (4)$$

Rearranging equation (4) one gets:

$$\left(\frac{I_{sc}}{I_0} + 1 \right) = e^{\lambda (V_m + I_m R_s)} \left(\lambda V_m \right) \left(1 + \frac{1}{\lambda V_m} \right) + \frac{(2V_m + I_m R_s)}{\lambda V_m I_0 R_{sh}} e^{-\lambda (V_m + I_m R_s)} \quad (5)$$

The analysis of the order of magnitudes of different terms in equation (5) reveals that the term :

$$\frac{(2V_m + I_m R_s)}{\lambda V_m I_0 R_{sh}} e^{-\lambda (V_m + I_m R_s)} \ll \left(1 + \frac{1}{\lambda V_m} \right) \quad (6)$$

This term can be neglected. Equation (5) can thus be rewritten in the form:

$$\left(\frac{I_{sc}}{I_0} + 1 \right) = e^{\lambda (V_m + I_m R_s)} \left(\lambda V_m \right) \left(1 + \frac{1}{\lambda V_m} \right) \quad (7)$$

Taking the Logarithm of both sides of equation (7) one gets:

$$\ln \left(\frac{I_{sc}}{I_0} + 1 \right) = \lambda (V_m + I_m R_s) + \ln (\lambda V_m) + \ln \left(1 + \frac{1}{\lambda V_m} \right) \quad (8)$$

Taking into consideration that [13]: $V_{oc} = \frac{1}{\lambda} \ln \left(\frac{I_{sc} + I_0}{I_0} \right)$ (9)

Substituting for V_{oc} in equation (8) one gets :

$$V_{oc} = V_m + I_m R_s + \frac{1}{\lambda} \ln (\lambda V_m) + \frac{1}{\lambda} \ln \left(1 + \frac{1}{\lambda V_m} \right) \quad (10)$$

It is worth to note that, $\frac{1}{\lambda V_m} \ll 1$ thus one can make use of the expansion: [15]

$$\ln (1+x) = x - \frac{1}{2} x^2 + \frac{1}{3} x^3 - \dots \dots \dots , \quad -1 < x \leq 1 \quad (11)$$

This makes it possible to rewrite equation (10) in the form:

$$V_{oc} = V_m + I_m R_s + \frac{1}{\lambda} \ln (\lambda V_m) + \frac{1}{\lambda} \left\{ \frac{1}{\lambda V_m} - \frac{1}{2} \left(\frac{1}{\lambda V_m} \right)^2 \right\} \quad (12)$$

From equation (12) one can express the series resistance R_s in the form:

$$R_s = \frac{V_{oc}}{I_m} - \frac{V_m}{I_m} - \frac{1}{\lambda I_m} \ln (\lambda V_m) - \frac{1}{\lambda^2 I_m V_m} + \frac{1}{2 \lambda^3 I_m V_m^2} \quad (13)$$

Equation (13) introduces a simple method to determine the value of the series resistance from a single (I-V) characteristic curve through the coordinates I_m, V_m of the maximum power point (MPP) .

Substituting for V_{oc} from equation (9) into equation (12) one gets:

$$\frac{1}{\lambda} \left\{ \ln \left(\frac{I_{sc} + 1}{\lambda I_m V_m} \right) \right\} = V_m + I_m R_s + \frac{1}{\lambda} \left\{ \left(\frac{1}{\lambda V_m} - \frac{1}{2 \lambda^2 V_m^2} \right) \right\} \quad (14)$$

Since $\frac{I_{sc}}{I_0} \gg 1$ one can simplify and rearrange equation (14) to get:

$$V_m = \frac{1}{\lambda} \left\{ \ln \left(\frac{I_{sc}}{\lambda I_m V_m} \right) \right\} - I_m R_s - \frac{1}{\lambda^2 V_m} + \frac{1}{2 \lambda^2 V_m^2} \quad (15)$$

In the light of equation (15) one can express R_s in the following form:

$$R_s = \frac{1}{\lambda I_m} \left[\ln \left(\frac{I_{sc}}{\lambda I_m V_m} \right) \right] - \frac{1}{\lambda^2 I_m V_m} + \frac{1}{2 \lambda^2 I_m V_m^2} - \frac{V_m}{I_m} \quad (16)$$

3. Determination of the Efficiency “ η ” of the Cell:

The accepted definition for “ η ” is:

$$\eta = \frac{I_m V_m}{P_m} \quad (17)$$

Where P_m is the solar power received and absorbed by the irradiated surface of the solar cell.

From equation (15) and (17) one can express the efficiency through the following relation:

$$\eta = \frac{I_m}{P_m} \left[\frac{1}{\lambda} \left\{ \ln \left(\frac{I_{sc}}{\lambda I_m V_m} \right) \right\} - I_m R_s - \frac{1}{\lambda^2 V_m} + \frac{1}{2 \lambda^2 V_m^2} \right] \quad (18)$$

Since the Logarithmic function is a slowly varying function, one can conclude from equation (18) that the predominating factors affecting the efficiency are: I_m , V_m , R_s , T and the ideality factor (A) in the expression of λ .

Moreover equation (18) reveals that R_s should be kept to a minimum for efficient conversion of solar energy [2].

The ideality factor, governing the value of (λ) has to be controlled to attain an optimum value to realize maximum efficiency. This requires further studies concerning this factor.

4. Computations

In the present trail, some of the cell parameters are computed and compared with the corresponding published data. Let us introduce the following example:

Two (I-V) characteristic curves are published by Thongron et al [12] under two different illumination conditions.

The First Curve

with parameters: irradiance 1100 W/m², $V_{oc} = 9.25$ V, $I_{sc} = 0.597$ A, $MP = 3.48$ W, $V_m = 6.60$ v and $I_m = 0.528$ A.

The authors [12] applied EL-Adawi method [5] and extracted the following results: $R_s = 4.59$ Ohm, $R_{SH} = 149.60$ Ohm. The published parameters [12] are introduced in equation (13) of the present present trial to compute the value of the series resistance.

The obtained computed value is $R_s = 4.45$ Ohm. The relative unfitting is 3%.

The Second Curve [12]:

With parameters: The irradiance 900 W/m², $V_{oc} = 9.10$ V, $I_{sc} = 0.460$ A, $MP = 2.83$ W, $V_m = 6.75$ V, and $I_m = 0.419$ A, $R_s = 4.29$ ohm, $R_{SH} = 110.50$ ohm.

According to equation (13) in the present trail, one gets: $R_s = 4.889$ ohm.

The relative unfitting is 14 %.

It is worth to note that computations revealed that the fourth and the fifth terms in the R.H.S. of equation (12) to calculate V_{oc} are negligible.

V_{oc} can thus be expressed as:

$$V_{oc} = V_m + I_m R_s + \frac{1}{\lambda} \ln(\lambda V_m) \quad (19)$$

6. CONCLUSIONS

1. The present trial to compute some of the solar cell parameters from one (I-V) curve through the maximum power point coordinates is promising.

The relative shift between the computed and the published data may be attributed to the uncertainty in the value of the ideality factor.

2. The expression for the efficiency equation (18) reveals that the

series resistance R_s should be kept to a minimum for efficient conversion of solar energy.

- The absolute temperature of the cell T_K0 should be kept to a minimum to realize better efficiency. Thus cooling conditions have to be adjusted in order to improve the performance of a solar cell.
- Simple expressions for V_{oc} , R_s , and the efficiency in terms of the (MPP) coordinates V_m, I_m are given.

REFERENCES

- Rauschenbach H.S., Solar Cell Array Design Handbook, Van Nostrand Reinhold Company New York, 1980, p. 56.
- Singh VN, Singh R.P.A method for measurement of solar cell series resistance J. of Physics D:Appl.Phys. 1983;10:1823-5.
- Chakrabarty k., Singh S.V. Solid State Electronics, 1996, vol.39(4): pp.577-581
- Oman D.M., Dugan K.M.Killiw J.L., Ceekala V., Ferekides C.S., Morel D.L. Solar Energy Matter & Solar Cells; 1999,58,pp.361-73.
- El-Adawi, Al-Nuaim I.A.A Method To Determine The Solar Cell Series Resistance From A Single I-V Characteristic Curve Considering Its Shunt Resistance-New Approach, Vacuum, 2002, Vol.64, pp.33-36, UK.
- Chegaar M., Ouennoughi Z., Guechi F., Extracting dc parameters of solar cells under illumination, Vacuum 2004,75, pp.367-372.
- Suresh P.V. and Solonki C.S., series resistance measurement of PV modules, Advances in Energy Research, 2006, pp.262-267.
- Khan F., Singh S.N. and Hussain M., determination of diode parameters of a silicon solar cell from variation of slopes of the I-V curve at open circuits and short circuits condition with the intensity of illumination, Semiconductor Sci.Technol.2010,25, (8pp) IOP Publishing.
- El-Adawi M.K., El-Nahass M.M., Farid A.S., Shalaby S. A., Hegab N.A., The Intensity Dependency of the series resistance and other parameters of a photovoltaic silicon solar cell in relation to its performance, Indian Journal of Applied Research, (2019), Vol.9, Issue 4, pp.63-66.
- Khan F., Baek S., Park Y., Kim J., Extraction of diode parameters of silicon solar cells under high illumination conditions, Energy conversion and management 2013),76,421-429.
- Wolf M., Rauchenbach H.S., " Series Resistance, Effects On Solar Cell Measurements "Advances Energy Conversion; 1963, 3 : 455 Pergamon Press, New York.
- Thongpron J., Kirtikara K., Jivacate C., A method for the determination of dynamic resistance of photovoltaic modules under illumination, Iut1 PVSEC-14, Bangkok, Thailand, 2004, 196, pp.905-906.
- Green M.A., solar cells operating principles technology and system applications Englewood Cliffs, NJ : Prentice-Hall, 1982 (chapter 5) p.971.
- Wang J., Shieh J., Su Y., Kuok., Chang Y., Liang Y., Chou J., Lio K., Jang J., A novel method for the determination of dynamic resistance for photovoltaic modules, Energy 2011,36,5968-5974.
- Granville W.A., Smith P.F. and Longley W.L., Elements of differential and integral calculus, Blaisdel Int. Text book Series, 1962, ch.xx, p.360.