Degradation of AEG PV Modules Parameters After 20 Years of Operation

Emad A. Sweelem, Electronics Research Institute, Cairo, Egypt
Abd El-Shafy A. Nafeh, Electronics Research Institute, Cairo, Egypt

The Asian Conference on Sustainability, Energy and the Environment 2015
Official Conference Proceedings

Abstract
Si-based photovoltaic (PV) modules are now a mature technology and their lifetime is in the range of 25 to 30 years in the operating field. During this period, many times, it is required to find out the health of the PV modules in the field in order to estimate the performance degradation after certain time period. In this paper, the parameters degradation of one AEG PV module (monocrystaline Si-based), operating for a period of just more than 20 years, is studied and compared to their initial reference data. The considered PV module parameters are, firstly, analytically analyzed and then estimated from the experimentally measured module characteristics. The characteristics were measured for the considered PV module twice. The first one was during the first year of purchasing and installing the PV module, while the second one was after a period of about 20 years from installation. The results showed the effect of 20 years aging on the considered PV module.

Keywords: PV Modules, PV Parameters, PV Degradation.

1. Introduction

The monitoring and performance analysis of photovoltaic (PV) modules with respect to possible causes and effects of degradation and PV ageing, over a time-dependent frame, provide a real picture of this critical issue. Degradation effects rise by weathering, initial photon degradation and module package degradation. These effects have different time evolution or dependence under exposure to weather and environmental conditions, in general [1].

PV modules are probably the most important component of any PV system. However, some modules degrade or even fail when operating outdoors for extended periods. Thus, long-term performance of photovoltaic (PV) systems is vital to their continuing success in the market place. The gradual energy output loss over long periods of time is a major concern to all renewable energy stakeholders. A wide variety of degradation rates has been reported in the literature with respect to technologies, age, manufacturers, and geographic locations. Significant variation in the data can be caused by different module types, age, construction (encapsulation, front- and back-sheet), electrical set-up, and measurement uncertainty. The literature contains an excellent review of long-term field testing based on discreet I-V measurements, but fewer reports include more comprehensive I-V parameters investigation, including voltage and current at maximum power point. [2].

The main scope of this work is to study and evaluate the effect of parameters degradation due to aging mechanism on one AEG PV module's performance characteristics after 20 years of in field operation.

2. The PV Model

The PV arrays are built up with series and/or parallel connected combinations of solar cells. A solar cell is usually represented by the equivalent circuit given in Fig. 1(a). Therefore, for an array of $n_s \times n_p$ (i.e., cells in series by panels in parallel) the current equation [3,4] is:

$$I_{PV} = n_p I_{LG} - n_p I_{os}\left[\exp\left(G\left(\frac{V_{PV} + I_{PV} R_s}{n_s}\right)\right) - 1\right] - \frac{V_{PV} + I_{PV} R_s}{R_{sh}} \tag{1}$$

Where,

$$G = \frac{q}{A_i TK} \tag{2}$$

$$I_{os} = I_{or}\left[\frac{T}{T_r}\right]^3 \exp\left(\frac{qE_{G\circ}}{BK}\left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \tag{3}$$

$$I_L = [I_{sc} + K_I(T_c - 28)] \times \frac{Rad}{1000} \tag{4}$$

$$I_{PV} = n_p I_{cell} \tag{5}$$

$$V_{PV} = n_s V_{cell} \tag{6}$$

$$R_s = R_{scell} \frac{n_s}{n_p} \tag{7}$$

$$R_{sh} = R_{shcell} \frac{n_s}{n_p} \tag{8}$$

The array temperature T_c is given, approximately, by the relation [3]

$$T_c = T_{air} + 0.3 \times Rad\% \tag{9}$$

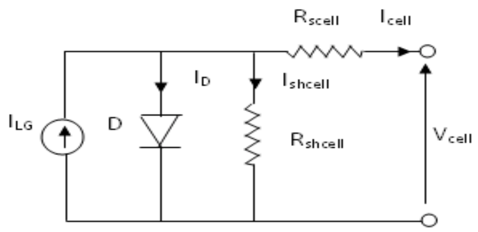
All the symbols in Eqs. (1) – (9) can be defined as

I_{PV}	PV array output current, A
V_{PV}	PV array output voltage, V
n_s	number of cells connected in series
n_p	number of panels connected in parallel
I_{LG}	light-generated current, A
I_{or}	reverse saturation current at T_r, A
$A_i = B_i$	ideality factors
K	Boltzmann's constant (1.380×10^{-23})
G	radiation, W/m^2
q	electronic charge (1.6×10^{-19} coulombs)
T_r	reference temperature ^{o}C
I_{os}	cell reverse saturation current, A
T_c	cell temperature, ^{o}C
T	cell temperature, ^{o}K
K_{Isc}	short-circuit current temperature coefficient, A/^{o}C
Rad	cell illumination, W/m^2 (1000 W/m^2 $\equiv$ 100 % illumination)
I_{sc}	cell short-circuit current, A
$E_{G\circ}$	band gap for silicon, eV
T_{air}	ambient temperature,^{o}C
R_s	PV array series resistance, Ω
R_{sh}	PV array shunt resistance, Ω
I_{cell}	cell output current, A
V_{cell}	cell output voltage, V
R_{scell}	cell series resistance, Ω
R_{shcell}	cell shunt resistance, Ω

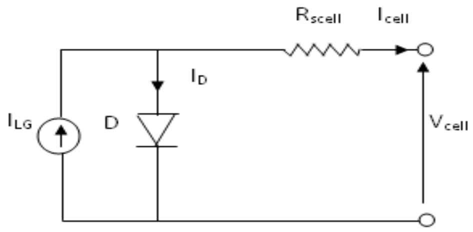
Since the value of the shunt resistance R_{sh} is very large, the last term in Eq. (1) becomes very small with respect to the other terms. Therefore, the last term will be neglected, in this work, as it will not cause a large error in the PV array model; hence, Eq. (1) can now be modified to the form

$$I_{PV} = n_p I_{LG} - n_p I_{os}\left[\exp\left(G\left(\frac{V_{PV} + I_{PV} R_s}{n_s}\right)\right) - 1\right] \tag{10}$$

Equation (10) can be represented (for one cell) by the simplified equivalent circuit shown in Fig. 1(b).



(a) Actual cell model



(b) Simplified cell model

Fig. 1 Equivalent circuit models of a PV cell.

3. PV Parameters

There are some important parameters that can characterize the PV performance. One of these parameters is the short–circuit current I_{SC} which is simply the generated current I_{LG}. A second parameter is the open-circuit voltage V_{OC} which is obtained by setting I = 0 in Eq. (10)

$$V_{OC} = \frac{n_S}{G}.\ln\left((1 + \frac{I_{LG}}{I_{OS}})\right) \tag{11}$$

No power is generated under short or open circuit. The maximum power P_{max} produced by the device is reached at a point on the characteristics where the product I by V is maximum value. This is shown graphically in Fig. 2, where the position of the MPP represents the largest area of the rectangle. While, the third characterized parameter is the fill-factor FF that is defined as

$$FF = \frac{V_{mp} I_{mp}}{V_{OC} I_{SC}} \tag{12}$$

Where, V_{mp} and I_{mp} are the voltage and current at maximum power point.

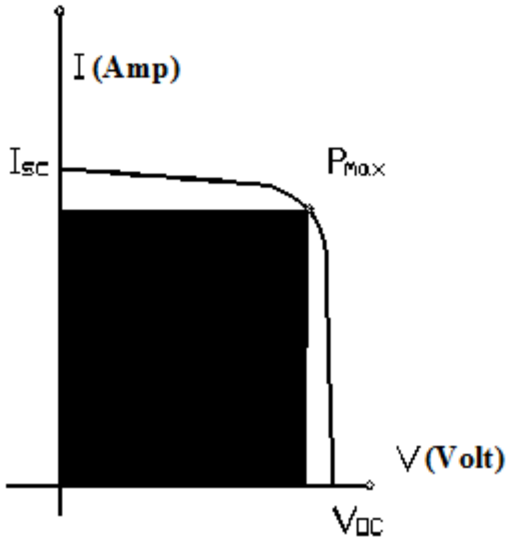


Fig. 2 The I-V characteristics of a solar cell with the maximum power point.

Also, the PV module efficiency η is calculated as shown in the following equation

$$\eta = \frac{P_{\max}}{A_m Rad} \tag{13}$$

Where, A_m is the area of module in m^2.

4. Determination Of Series Resistance

The data of the PV modules are based on actual manufacturers' information. Some of the manufacturers did not supply series resistance specification for the PV modules. However, it can be easily calculated using the method of Wolf and Rauschenbach [4,5] as follows:

1- Trace the I-V characteristics of the module at room temperature and at two different irradiances (magnitudes need not be known). During the two measurements, the cell temperature must not vary by more than 2 ^{o}C.

2- Choose a point P on the higher curve at a voltage slightly higher than the voltage for maximum power (Fig. 3). Measure δI, the difference between the current at this point and I_{sc1}.

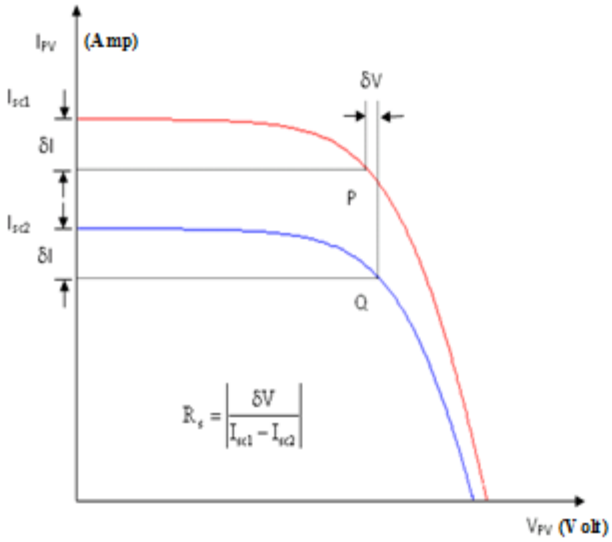


Fig. 3 Determination of R_s.

3- Determine the point Q on the lower curve at which the current is equal to $I_{sc2} - \delta I$.
4- Measure the voltage displacement δV between points P and Q.
5- Calculate R_{s1} from

$$R_{s1} = \frac{\delta V}{I_{sc1} - I_{sc2}} \tag{14}$$

Where, I_{sc1} and I_{sc2} are the two short-circuit currents.

6- Repeat steps (3) to (5), using a characteristic taken at a third irradiance and the same temperature, in combination with each of the first two curves, to determine two more values, R_{s2} and R_{s3}.
7- Take the mean of R_{s1}, R_{s2}, and R_{s3} as the definitive value of R_s.

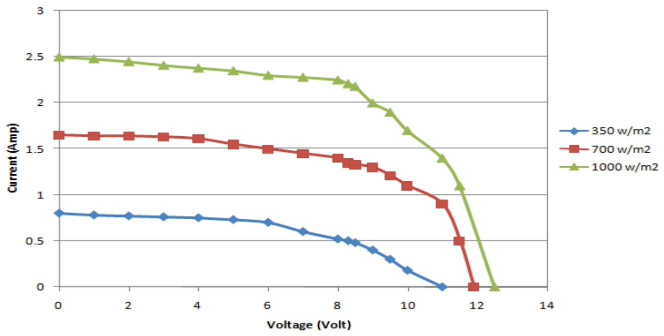
5. Experimental Measuring Circuit

The PV parameters were measured by building up the experimental circuit shown in Fig. 4. In this circuit, the considered PV module, which is connected in series with a variable resistance load, is an AEG module that can give 23.2 W_P at standard test conditions (i.e., 1000 W/m^2 and 25 ^{o}C). This module contains 20 monocrystalline silicon solar cells of 10 × 10 cm^2, connected in series. The variable resistance load is used to vary the PV operating point on a certain I-V curve. Also, two avometers are used to measure the PV voltage and current. In addition, a pyranometer is used to measure the level of the incident solar insolation on the considered PV module. Moreover, a thermocouple, connected to a digital temperature meter, is used to measure the module surface temperature. Thus, the considered experimental circuit becomes able to measure the I-V characteristics of the considered PV module at different atmospheric conditions.

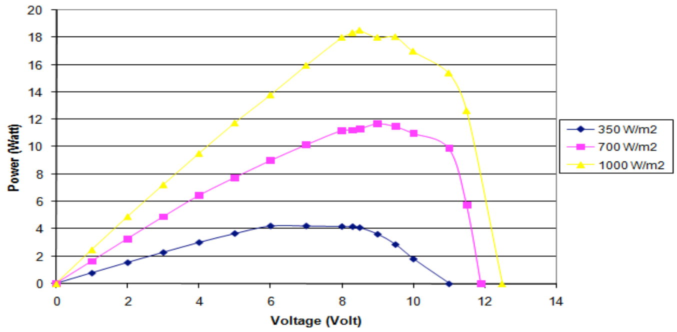
Fig. 4 Experimental PV measuring circuit.

6. Results And Discussion

In this work, the I-V characteristics of the considered PV module were measured, using the experimental circuit, twice. The first one represents the initial-module I-V characteristics during the first year of purchasing and installing the PV module on the roof of the PV Cells Dept., Electronics Research Institute, Cairo, Egypt (i.e., from about 20 years ago). While, the second characteristics represent the currant I-V characteristics of the considered module. Both characteristics are shown, together with their corresponding P-V characteristics, in Figs. 5 & 6. Noting that both characteristics were measured at three different insolation levels (i.e., 350, 700 and 1000 W/m^2) and at nearly 46 ^oC. Noting, also, that the module temperature was kept nearly constant at 46 ^oC, for both cases, by cooling the PV module throughout the measuring periods. Thus, these two Figurers indicate that the output current, voltage and power of the considered PV module are decreased, at all insolation levels, after 20 years of in field operation. Therefore, the effect of aging mechanism on the considered PV module leads to a corresponding degradation in its performance.

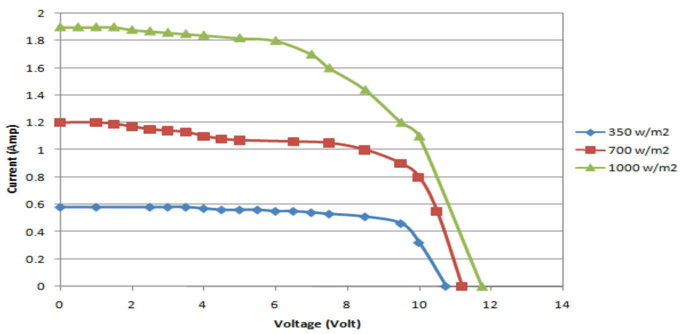


(a) I-V characteristics

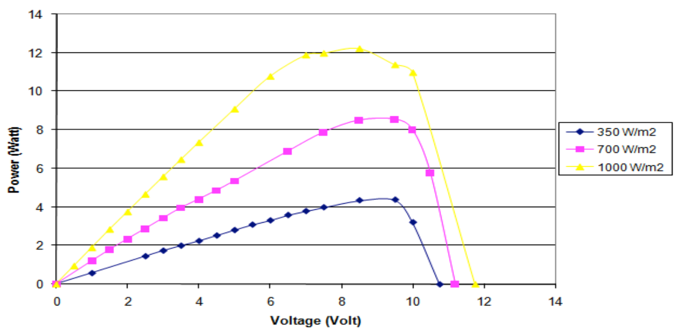


(b) P-V characteristics

Fig. 5 Initial characteristics of the PV module (i.e., from 20 years ago).



(a) I-V characteristics



(b) P-V characteristics

Fig. 6 Current I-V, P-V characteristics of the PV module.

Table 1 shows a comparison between the initial- and the current-module's parameters. Thus, this table indicates that all the current-module's parameters are decreased compared to its initial parameters except for the case of the series resistance.

Table 1 Initial- and current- PV parameters of the PV module.

Par.	V_{oc} (V)		I_{sc} (A)		I_{mp} (A)		V_{mp} (V)		P_{max} (W)		η (%)		FF		R_s (Ω)	
Rad (W/m²)	Initial value	Current value	Initial value	Current value	Initial value	Current value	Initial value	Current value	Initial value	Current value	Initial value	Current value	Initial value	Current value	Initial value	Current value
350	11	10.7	0.8	0.58	0.55	0.5	9.5	8.74	5.24	4.37	5.8	4.85	0.61	0.6	0.46	0.52
700	11.9	11.2	1.65	1.2	1.35	0.9	9.5	9.5	12.83	8.55	7.12	4.74	0.66	0.63		
1000	12.5	12	2.5	1.84	2.18	1.42	9.5	8.5	19.86	12.2	7.7	4.74	0.64	0.55		

7. Conclusion

The effect of parameters degradation due to aging mechanism on one AEG 23.2 W_P PV module is studied and evaluated for a period of 20 years of in field operation. The considered module parameters are analytically analyzed, at first, and then estimated from the experimental measured module characteristics. The characteristics of the considered PV module are determined by building up an experimental PV measuring circuit, which can measure the I-V characteristics of the PV module at different insolation levels. Experimental results indicate that all the parameters of the considered PV module are degraded due to aging mechanism. Thus, the entire current-module's parameters are decreased compared to that of the initial-module's parameters except for the case of the series resistance.

References

S. Kaplanis and E. Kaplani, “Energy Performance and Degradation Over 20 Years Performance of BP c-Si PV modules”, Simulation Modeling Practice and Theory, Vol. 19, pp. 1211-1217, 2011.

R. M. Smith, D. C. Jordan, and S. R. Kurtz, “Outdoor PV Module Degradation of Current-Voltage Parameters”, Web Site: http://www.nrel.gov/docs/fy12osti/53713.pdf, 2013.

A. A. Nafeh, F. H. Fahmy, and E. M. Abou El-Zahab, “Maximum-Power Operation of a Stand-Alone PV System Using Fuzzy Logic Control”, International Journal of Numerical Modelling: Electronic Networks, Devices and Fields, Vol. 15, pp. 385-398, 2002.

A. A. Nafeh, “Fuzzy Logic Controller for Maximum Power Point Tracking in a Stand-Alone Photovoltaic System”, Ph.D. Thesis, Faculty of Engineering, Cairo University, pp 26-32, 2000.

F. Lasnier, and T.G. Ang, Photovoltaic Engineering Handbook, IOP Publishing Ltd, pp. 207-208, 1990.