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Short Circuit Current I_{SC} as a Real Non-Destructive Diagnostic Tool of a Photovoltaic Modules Performance

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Abstract - Performance, quality and reliability issues are becoming more and more important for the emerging photovoltaic markets worldwide. The purpose of this paper is to present operational performance results of a PV system. The data analyzed here is derived from analytical monitoring data, hourly values, and 5-minute-values of a selected PV system installed in Tanta, Egypt. Results obtained by subjecting mono-crystalline silicon (mono-Si) modules to the assessment procedure are presented and discussed. Results obtained indicate that visual inspection revealed that the mono- crystalline module had cracked cells. This paper accentuates the importance of characterizing all module performance parameters in order to analyze observed degradation and failure modes. The analysis of the obtained results for real Isc after nearly 4 years of using show that Isc has been decreased by 9.7%, while Pmax decreased by 4.39%.

Keywords- Performance analysis, Reliability, photovoltaic modules and non destructive testing.

1. Introduction

The operational performance, long-term reliability, sizing of photovoltaic PV systems and subsystems providing technical information to PV experts, research, PV industry, utilities, system designer & installers are the main goals of the solar energy utilization. The overall objective is to improve PV system operation and sizing by analysing and disseminating information on technical performance. Deliverables include a PV Performance Database. Activities to date include the work on investigations of building integrated PV, long-term system performance and maintenance analysis, reliability issues, monitoring techniques, normalized evaluation of PV systems and various national procedures [1-3]. This work is part of a performance analysis activity. The approach in this paper is to demonstrate the PV system performance values over time, based on in-field monitoring data, at identical climatic conditions. The goal is to state more precisely on small shifts of performance ratio that is usually superposed by larger seasonal time fluctuations. Photovoltaic (PV) modules are renowned for their reliability. However, some modules degrade or even fail when operating outdoors for extended periods. To reduce the degradation, and the number of failures, extensive research is needed on the performance of PV modules. The aim of this study was to establish a photovoltaic degradation and failure assessment procedure. This procedure should assess all parameters of PV modules to completely analyze any observed degradation or failure. In this paper some degradation modes of PV modules are discussed and a procedure used to assess these degradation modes is then presented.

This paper focuses on the analysis of results in terms of short circuit current Isc for a long-term performance and the reliability issues of selected PV module system at outdoor field conditions. Also, the study of the efficiency dependence on the Isc measurements, in spite of the overall effect of losses on the system output due to incomplete utilization of the solar irradiance, temperature effects and system component inefficiencies or failure. Upon this paper, performance shifts of PV systems over time are derived and can be used as a failure detection method.

2. Data Sets and Experimental set up

The data analyzed here is derived from analytical monitoring data, hourly values at outdoor conditions for a photovoltaic module (H500B-50W) that has been designed by Helios technology for rural electrification, data survey, telecommunications and special applications. The H500B module is used for photovoltaic systems both in the developing countries and the European market. Its performance and reliability have been recently improved by the introduction of high efficiency I-Max® single crystal cells at the typical battery operating voltage (12.5V). The I-Max® technology, developed by Helios Technology for its high-efficiency modules range, allows a remarkable increase of the current output (about 10-17%) compared to the traditional modules. This feature makes the H500B module very suitable for systems with batteries. The module under study is made with 36 high-efficiency I-Max® 102 x 102 mm single crystal silicon solar cells and it has been designed by Helios Technology to operate under the toughest environmental conditions. Helios Technology's modules have guaranteed an average lifetime more than 30 years.

The electrical characteristics of the silicon solar module under test are given in **T**able I. These values are measured at Standard Test conditions (STC). Also, the data in the table are given by the fabricated company of solar module,i.e, Helios company.

Table 1: The electrical specifications for a single crystalline silicon photovoltaic module at STC (100 mW/cm^2, 25 ^{0}C, AM 1.5) [4]

Performance parameter	Manufacturer	
Maximum power (P_R)	50	Watts
Short-circuit current (I_{sc})	3.32	A
Open-circuit voltage (V_{oc})	20.9	Volt
Voltage at a maximum power (V_R)	16.67	Volt
Current at a maximum power (I_R)	3.0	A
Nominal operating cell temperature	43	^{o}C
Voltage variation vs temperature	-90	mv/^{o}C

To measure Isc for the solar PV module/system, a schematic diagram is used as shown in Fig. 1. The field measurements by using this tool are nearly 4 years done, to record the fluctuations on Isc parameter through this long time of measurements. The solar radiation data are measured by using the Eppley-Precision Spectral Pyranometer (E-PSP). The (E-PSP) is connected to an instantaneous solar radiation meter (model No.455). This meter is usually scaled to the sensitivity of a particular radiometer to read out directly in the standard international units of watt per square meter. In addition, there is a change in the open circuit voltage V_{oc} of the solar PV module /system, but these fluctuations is due to the effect of temperature increasing of the solar module /system. The data of module temperature are recorded by NiCr-Ni thermocouples connected to a digital voltmeter,

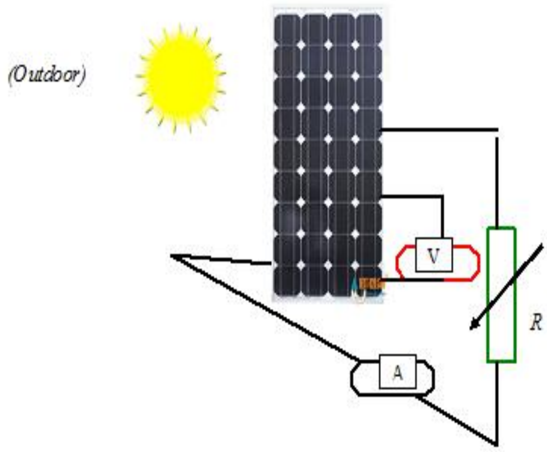

Fig. 1. Schematic diagram for outdoor and indoor measurement system set up, where A, V are digital multimeters for current and voltage measurements and R load resistance.

3. Theoretical background

3.1. Illuminated Current and Short Circuit Current (I_L or I_{sc})

I_L is the light generated current inside the solar cell and is the correct term to use in the solar cell equation. At short circuit conditions the externally measured current is I_{sc}. Since I_{sc} is usually equal to I_L, the two are used interchangeably and for simplicity and the solar cell equation is written with I_{sc} in place of I_L. In the case of very high series resistance (> 10 Ωcm^2) I_{sc} is less than I_L and writing the solar cell equation with I_{sc} is incorrect. Another assumption is that the illumination current I_L is solely dependent on the incoming light and is independent of voltage across the cell. However, I_L varies with voltage in the case of drift-field solar cells and where carrier lifetime is a function of injection level such as defected multicrystalline materials.

Generally, the short-circuit current is the current through the solar cell when the voltage across the solar cell is zero (i.e., when the solar cell is short circuited). The short-circuit current is due to the generation and collection of light-generated carriers. For an ideal solar cell at most moderate resistive loss mechanisms, the short-circuit current and the light-generated current are identical. Therefore, the short-circuit current is the largest current which may be drawn from the solar cell. The electrical circuit model of PV cell, which is corresponding to the mathematics model, is given in the Fig.2

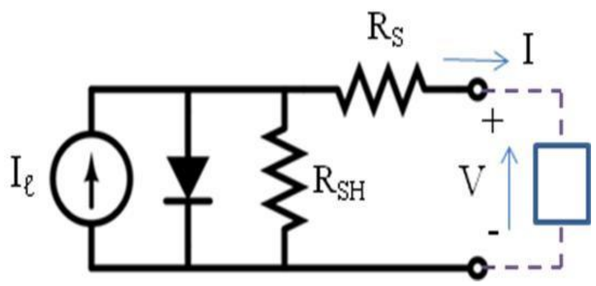

Fig. 2. Simplified Equivalent Circuit Model for a Photovoltaic Cell/module

Short-circuit current depends on a number of factors which are described below:

i. The area of the solar cell. To remove the dependence of the solar cell area, it is more common to list the short-circuit current density (Jsc in mA/cm^2) rather than the short-circuit current;
ii. The number of photons (i.e., the power of the incident light source). Isc from a solar cell is directly dependant on the light intensity ;
iii. The spectrum of the incident light. For most solar cell measurement, the spectrum is standardized to the AM1.5 spectrum;
iv. The optical properties (absorption and reflection) of the solar cell ; and
v. The collection probability of the solar cell, which depends chiefly on the surface passivity and the minority carrier lifetime in the base.

When comparing solar cells of the same material type, the most critical material parameter is the diffusion length and surface passivity. In a cell with perfectly passivated surface and uniform generation, the equation for the short-circuit current can be approximated as:

$$J_{SC} = qG\left(L_n + L_p\right) \quad (1)$$

where G is the generation rate, and Ln and Lp are the electron and hole diffusion length respectively. Although this equation makes several assumptions which are not true for the conditions encountered in most solar cells, the above equation indicates that the short-circuit current depends strongly on the generation rate and the diffusion length.

The basic components of a typical photovoltaic (PV) system are the photovoltaic panel, which is the active power generator, and the load that dissipates the electrical energy. The PV panel is constituted by several solar cells connected in series and/ or in parallel depending on the specific design. Each illumination intensity, there is a maximum power point (MPP) in the output curve, corresponding to the point of the panel characteristic where the current–voltage product is maximum (point black as in Fig. 3). The power which is actually supplied by a PV panel to a load depends on the working point of the system, given by the intersection between panel and load characteristics. In the case of resistive loads, as schematically depicted in Fig. 3, the power delivered to the load equals the maximum available power (Pmax.) for just one illumination intensity.

The I-V curve data of a module using the following five parameters: V_{oc}, I_{sc}, R_s, R_p, and ekT is given by the five-parameter model (Eq. 2) as follows:

$$I = I_{sc} - \left[\frac{I_{sc} - \frac{V_{oc}}{R_p}}{\exp(ekT.V_{oc}) - 1}\right]\{\exp[ekT(V + R_s I)\} - \frac{V + R_s I}{R_p} \quad (2)$$

where I = Module output current (A), V = Module voltage (V), I_{sc} = Short circuit module current (A), V_{oc} = Open circuit module voltage (V), R_s = Module series resistance (Ohms) and R_p = Module parallel resistance (Ohms) and:

$$ekT = \frac{q}{nkT}(V^{-1})$$

q Is the electronic charge (Coulomb), n = Ideality factor per cell (unit less), k = Boltzmann's constant (Joule/K) and T = Temperature (K)

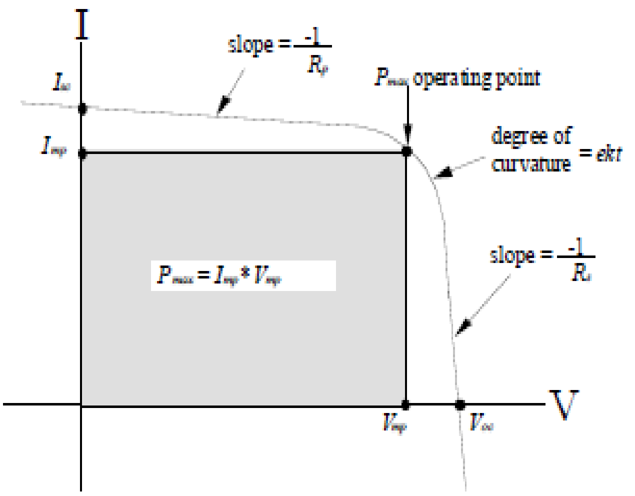

Fig. 3. I-V characteristic curve for a monocrystalline silicon solar module at test conditions of solar irradiance of 1000 W/m^2, spectrum AM 1.5 Global irradiance and a module temperature of 25 ^{0}C.

The IV-curve parameters contain information of the electrical characteristic of the modules. The most important parameters are I_{SC}, V_{OC}, VMPP and IMPP. These parameters are used directly in characterizing the performance of the modules and degradation of module performance is also shown through them. The actual measurement of IV-curves requires the module to be connected to an electronic circuit in which the load changes at a certain rate with the help of microcontroller control.

4- Results and Discussions

In this section from the paper, the results over 4 years are measured and discussed. Fig.4 shows the outdoor field measurements of solar radiation of an average value of solar radiation of 942 W/m^2 from 11:00 am to 12:00 pm at an ambient temperature of 33 ^{0}C. Fig.5. illustrates the corresponding I-V for the single crystal silicon solar module Helios 500B-50W. Where to measure a short circuit current for a module without damage in it connects an ammeter between the two output leads, and reading the ammeter. And the ammeter has a very low resistance and acts as a short. The I_{sc} (the photo generated current) was 2.79 A, and the corresponding V_{oc} was 19.9 V. From Fig.5 it is obvious that V_{oc} decreases by a range 3.9% to 4.2% because of module temperature increases up to 45 ^{0}C where Voc is decreasing by 2.3 mV/ ^{0}C [5].On the other hand, I_{sc} decreases by 9.7%. The corresponding values of the conversion efficiency and fill factor are 10.08% (data sheet value 14.9%) and 65% (data sheet value 72%) respectively.

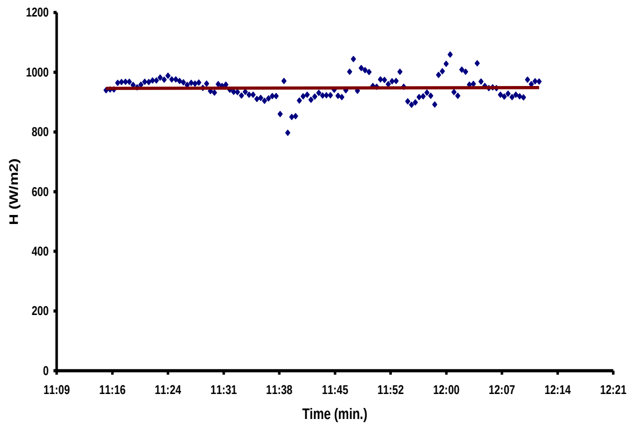

Fig. 4. Variation of solar radiation H with time during a day of May at Tanta (latitude 30^0 41'), Egypt.

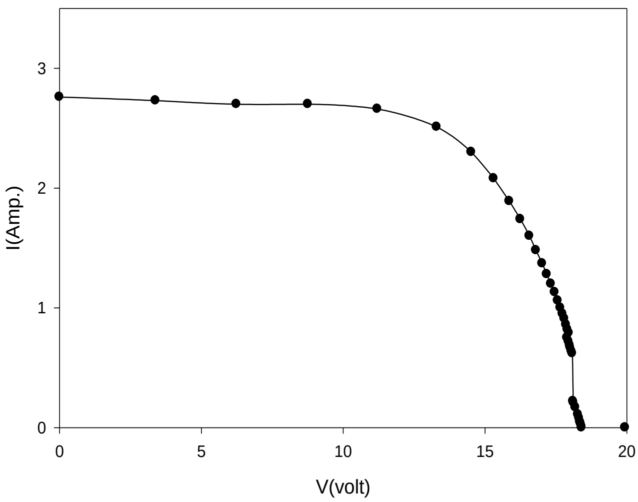

Fig. 5. The outdoor measurements (I-V) for a single crystal

silicon solar module (50W) on a typical day of May at Tanta (latitude = 30^0 41'), Egypt.

I_{sc} as a reliability tool and its correlation with the other PV module electrical parameters as a function of field exposure are shown in Fig. 5 the figure illustrates that I_{sc} decreases with exposure time.

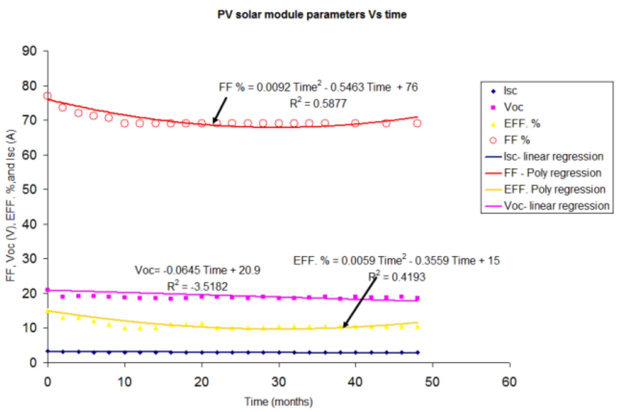

Fig.6. I_{sc}, V_{oc}, Fill Factor FF and Efficiency EFF. as a function of field exposure time for the solar photovoltaic module (50W) single crystalline silicon.

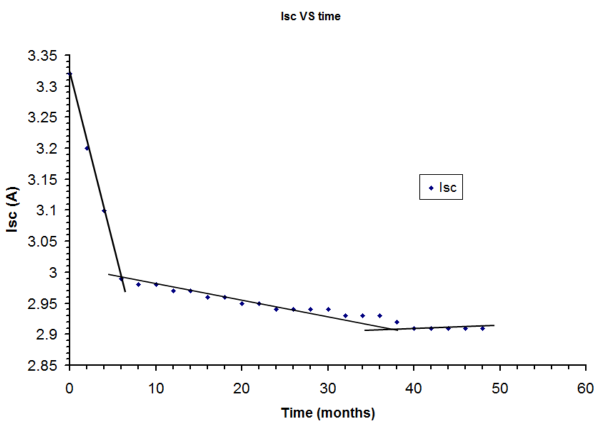

Fig. 7. Short circuit current Isc with time for photovoltaic solar module 50W.

Isc losses may be as a result of recombination in the bulk semiconductor and its surfaces. The changes observed in the performance parameters are shown as the efficiency varies from 10.0% to 11%. Whereas efficiency is the ratio of the electrical power output P_{out}, compared to the solar power input, P_{in}, into the PV cell. P_{out} can be taken to be $P_{max.}$, since the solar cell can be operated up to its maximum power output to get the maximum efficiency as follows:

$$\eta = \frac{P_{out}}{P_{in}} \Rightarrow \eta_{\max.} = \frac{P_{\max.}}{P_{in}} \qquad (3)$$

Also, the efficiency is:

$$\eta = \frac{J_{sc} V_{oc} FF}{P_{in}} \qquad (4)$$

The four quantities Jsc, Voc, FF (fill factor) and η are frequently used to characterize the performance of a solar cell and Pin is taken as the product of the irradiance of the incident light, measured in W/m^2 or in suns (1000 W/m^2), with the surface area of the solar cell [m^2]. The maximum efficiency ($\eta_{max.}$) found from a light test is not only an indication of the performance of the device under test, but, like all of the I-V parameters, can also be affected by ambient conditions such as temperature and the intensity and spectrum of the incident light. For this reason, it is recommended to test and compare PV cells using similar lighting and temperature conditions.

Also Isc and Voc decrease by 9.7% and 3.6% respectively. Data in (Fig.6) illustrate the range reported for PV modules that have been in the field for four years. As it clair from Fig.6 that the fluctuation- ,.e, decreasing rate- of Voc is clear it can not be used as reliability and diagnostic tool to analyze the solar cell/module performances. Generlly, the V_{oc} fluctuations are due to the increasing in module/cell temperature as it exposed to solar radiation at outdoor conditions (about 25-30 ^{0}C more above ambient). This leads to a decreasing in the open circuit voltage of the cell/module. So the fluctuations in V_{oc} can not be considered as a reliability tool (diagnostic tool) of the cell/module performance. Figure 7 shows the decreasing rate of the Isc of the PV solar module 50W with time at tilt angle of 30^0 from horizontal sun tracking orientation. The data obtained in the figure can be divided into 3 sections. In section I, the rate of decreasing is high, while that for sections II & III the rate is low and nearly constant. In addition, the obtained results of Isc denotes that, a stablity procss for Isc at nearly 2.92 to 2.98 A at outdoor conditions of 10^3 W/m^2, 300 tilt angle, and suntracking orientation has been remarked. K.Machida et al. have [6]investigated the degradation of individual single crystalline PV modules and reported a percent decline in Pmax of

4.8%, in Isc of 9.3% and a minimal change in Voc after five years of field exposure. The results of the PV modules under test explain that after 4 years period there is no more decrease in the electrical parameters. Throughout the year in their coastal environment, modules have been reported to degrade faster than subjected to higher ambient and operating temperatures [7-12].

5. Conclusions

Comprehensive studies of field-aged modules must be conducted to better understand degradation mechanisms and, more importantly, to define degradation rates. Most studies of degradation have been conducted on failed modules and results have been compared to limited baseline and field-aged module information. Minimal studies have been conducted on healthy field-aged modules to establish the factors surrounding their satisfactory performance. The electrical parameters analysis has been performed for single crystal silicon solar module (50W) operating under local climatic conditions for Tanta (30^0 41'), Egypt over a period of five years. The PV module performance is decreased than the data sheet values given by the manufacturing company. Even though there is a little change in the average value of the Voc of the solar module. While, the Isc has an average decrease of 9.38% leading to an average decrease of 4.39% in its maximum power Pmax. The results obtained, the analysis and observations made in this paper indicate that one can expect a stable on the PV system performance over a period of many years.

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AM1.5	Air Mass 1.5 solar spectrum
ekT	Thermal voltage
FF	Fill factor
G	Generation rate
I	Output current
I_l	Photo generation current
I_{sc}	Short-circuit current
I_{MPP}	Maximum power point current
J_{sc}	Short – circuit current density
L_n	Electron diffusion length
L_p	Hole diffusion length

n	Ideality factor
PV	Photovoltaics
P_{in}	Input power
P_{out}	Output power
$P_{max.}$	Maximum output power
q	The electronic charge
R_s	Series resistance
R_{sh}	Shunt resistance
STC	Standard Test conditions
V_{MPP}	Maximum power point voltage
V	Output voltage
V_{oc}	Open-circuit voltage
T	Temperature
η	Efficiency
$\eta_{max.}$	Maximum efficiency