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ELECTRICAL PERFORMANCE DEGRADATION ANALYSIS OF FIELD EXPOSED SILICON-BASED PV MODULES

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Abstract

Degradation of on-field PV modules is inevitable but a normal process; however, it is a challenging task to explore the causes behind it. Manufacturers and researchers, to know the causes of degradation, employ both destructive and non-destructive procedures. In this study, nine different PV modules from three different manufacturers have been taken and their electrical output data, over several days, has been collected. The electrical parameters of PV modules are compared with the nameplate data to analyze the average yearly degradation in the electrical performance. Moreover, using visual inspection different degradation modes are identified. Finally, it is concluded that environment is not the only factor but the material used and the processing techniques employed by manufacturers are equally responsible for degradation in the output efficiency of PV modules.

Keywords: Electrical Performance, Degradation modes, PV Reliability, Visual Inspection, PV modules.

I. Introduction

The world is facing a real threat to fulfill energy demand as conventional energy sources are depleting at a very fast pace. This greatly necessitates a shift from conventional to non-conventional sources of energy [XIII]. One of the most important sources of energy is the sun and various methods are employed to harvest the energy from the sun. One such method is the use of PV modules which directly convert the sunlight into electricity [XIV]. Because of the exponential increase in the efficiency of solar PV modules, its entrance to the commercial market is further improving [VI] The main reason that solar PV modules were hailed by the market is a constant reduction in its cost [X].

It is quite obvious that PV modules will degrade with time, however, to ensure efficient performance, PV modules need to be timely examined. PV modules can be damaged during transportation as well as the installation [XII]. Moreover, they also tend to degrade in the field due to various environmental conditions such as high temperature & humidity, UV radiations, dust, wind etc. Degradation hurts the electrical performance parameters of PV modules [VI]. The PV module is considered to be valuable if it can withstand in the field for 25 years with certain degradation limits. These limits have been established by the International Electro-technical Commission (IEC). Moreover, IEC has also developed certain standards to ensure the reliability of PV modules.

There are various methods to study the reliability of the PV modules such as Visual Inspection, Electroluminescence (EL) Imaging, Ultraviolet (UV) Imaging, and Infrared (IR) imaging, etc. [X]. At times, PV modules appear faultless during Visual Inspection but they do not come up with the desired output which means some defects cannot be detected by the Visual Inspection alone [III]. They need other tests such as EL, UV and IR imaging to detect hidden defects [II].

This paper is focused on analyzing the electrical performance of PV modules exposed in the field for more than 10 years, by comparing their real-time open-circuit voltage (V_{oc}) and short circuit current (I_{sc}) data with nameplate data. Moreover, a visual inspection technique is utilized to detect the possible degradation modes. Finally, the extent of degradation in PV module performance over a certain period is determined.

II. Methodology:

9 PV modules manufactured by 3 different companies installed in the field were randomly selected for this study. The modules along with their type, age and rated performance parameters are listed in table 1 below. The modules were named “Type 1”, “Type 2” and “Type 3” for identification. The ‘Type 1’ modules were 10 years old, the ‘Type 2’ were 30 years old, while the ‘Type 3’ modules were 35 years old.

These modules were first inspected visually, using the National Renewable Energy Laboratory (NREL) Visual Inspection checklist was used [IX]. The electrical parameters of the modules were then examined by performing the outdoor as well as the indoor IV curve testing of the modules. For outdoor testing, the modules were temporarily dismantled from the field [I], and their Voc and Isc were recorded in the daylight and the indoor testing was performed on the solar flash tester. The results obtained were then compared with the nameplate data of the modules and analyzed for degradation.

Table 1: Sample PV modules specification used in this study

Type	No of modules	Time spent on filed (years)	Rated power (W)
Type 1 (Poly-Si)	3	10	100
Type 2 (Poly-Si)	3	30	57
Type 3 (Poly-Si)	3	35	36

III. Results & Discussion:

a. Visual Inspection

The goal of the suggested visual inspection method was to identify various degradation modes that one can see easily in the field-aged modules. This proposed method allowed us to find the correlation between I-V characteristics and the degradation of performance parameters like encapsulant browning, backsheet delamination, backsheet bubbles, wire defects, junction box damage etc.

The Visual Inspection of the PV modules used in this study showed several defects. However, the analysis revealed that not all the visual defects have effects on the performance of PV modules. Three flaws were noted in every field exposed PV module. These were: EVA browning, Chalking of back sheet and soiling. While some defects were observed in some of the modules which include delamination, burn marks, damage of junction box and bubbles shown in Figure 1.

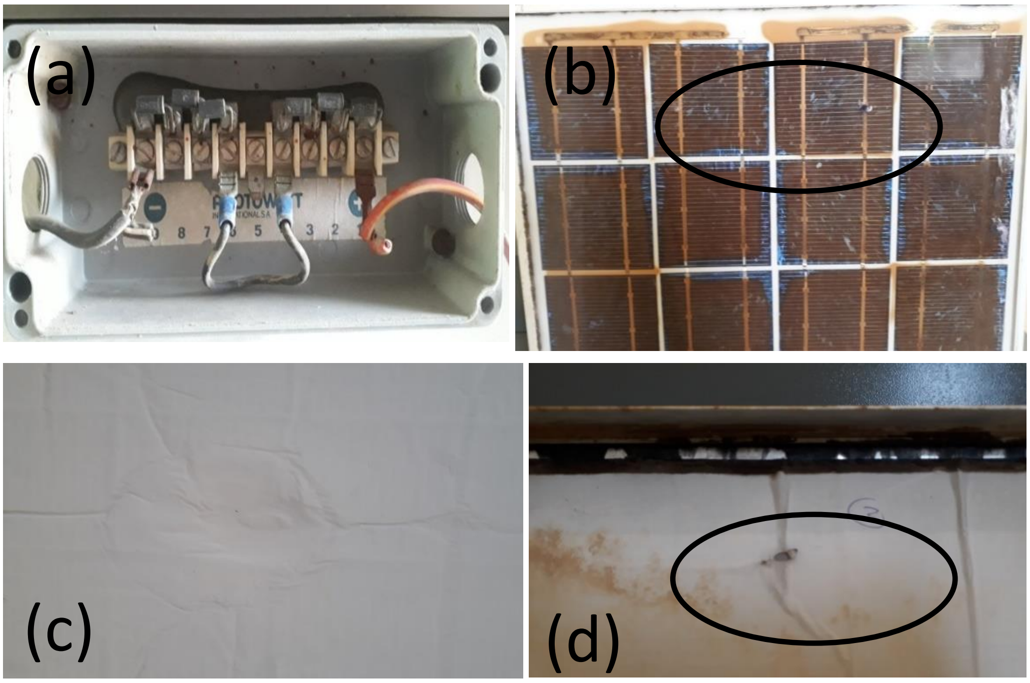

Figure 1. Visual defects found in field aged PV modules (a) Junction box cover lost, (b) encapsulant browning and corrosion of the bus bars, (c) delamination and chalking of the back sheet bubble, (d) damaged back sheet and corrosion of the frame

b. I-V characteristics

I-V curve of a PV string (or module) depicts its energy changing capability at the present conditions of irradiance (light measurement) and temperature. I-V characterization is one of the significant methods to find degradation in performance parameters like Voc, Isc, Pmax, FF and efficiency. To find the electrical performance, the I-V curves at the present conditions were compared with the nameplate data of the respective modules. The data obtained through the outdoor IV testing of Type 1, Type 2 and Type 3 modules are given in Tables 2, 3, and 4 respectively.

Table 2: Data obtained via outdoor IV testing of Type 1 PV modules

S. No.	Light Intensity (W/m^2)	Voc (V)	Isc (A)	Humidity (%)	Temperature (ºC)	Light Intensity (Lux)	Weather
1	260	17.32	0.892	56.6	35.6	2204	Cloudy
2	300	18.2	3.54	51.3	39.3	6200	Clear
3	750	17.33	3.475	36.4	44.7	6360	Clear
4	750	17.38	3.205	37.1	4.6	6257	Clear
5	670	16.82	3.4	50.5	26.6	5180	clear

Table 3: Data obtained via outdoor IV testing of Type 2 PV modules

S. No.	Light Intensity (W/m^2)	Voc (V)	Isc (A)	Humidity (%)	Temperature (ºC)	Light Intensity (Lux)	Weather
1	950	20.89	1.69	39.3	35.9	5510	Clear
2	950	19.63	1.759	39.2	37.8	7110	Clear
3	950	19.58	1.74	47.1	36.2	5210	Clear
4	910	19.73	1.672	43.7	34.1	4680	Clear
5	890	19.78	1.608	49.9	36.2	6120	clear

Table 4: Data obtained via outdoor IV testing of Type 3 PV modules

S. No.	Light Intensity (W/m^2)	Voc (V)	Isc (A)	Humidity (%)	Temperature (ºC)	Light Intensity (Lux)	Weather
1	260	21.76	0.54	56.6	35.6	2204	Cloudy
2	700	21.7	1.59	47.3	41.3	5780	Clear
3	730	21	1.65	52.7	28.7	6060	Clear
4	640	20.21	0.712	53.2	23.3	4680	Slightly cloud
5	540	21.16	1.038	46.3	28.2	5110	clear

This data was recorded at various times of the day under different temperatures and different intensity levels ranging from 750 W/m^2 to 900 W/m^2. Some other variables which might affect the performance of the PV modules were also recorded; such as weather conditions, light flux through the Digital Lux meter and temperature of the environment through the FLUKE Temperature Humidity Meter. The same PV modules were then tested under standard testing conditions (STC) to compare the outdoor testing data with the STC data. There is a slight difference between the two recorded data through different methods which is because the outdoor conditions are harsh with high temperature, humidity, airflow and often have a cloud cover that results in lowering the intensity levels and consequently the power output of the modules. The indoor testing results obtained using the solar flash tester are given in Table 5 below.

Table 5: Data obtained via indoor IV testing at STC of the PV module under observation

S. No.	Parameter (Unit)		Type 1	Type 2	Type 3
1	Short Circuit Current	Isc (A)	5.192	2.259	2.117
2	Open Circuit Voltage	Voc (V)	19.573	24.826	23.44
3	Peak Power	Pmax (W)	77.786	40.794	26.471
4	Current at Peak Power	Imax (A)	4.736	2.085	1.654
5	Voltage at Peak Power	Vmax (V)	16.429	19.574	16.006
6	Efficiency	Eff (%)	14.11	7.43	5.68
7	Fill Factor	FF (%)	76.74	72.74	53.34
8	Temperature	(ºC)	27.9	29.9	29.3
9	Light Intensity	(mW/cm2)	100.734	97.922	100.792
10	Series Resistance	Rs (mOhm)	363.432	1338.454	2802.363
11	Parallel Resistance	Rsh (Ohm)	94.69	677.056	158.369

This study is mainly focused on Isc and Voc [V] and the modules under observation showed variation in the results. Even the modules from the same manufacturer returned different results, which means that varying nature and magnitude of degradation had occurred in each PV module. Visual inspection showed various defects in the modules such as browning, scratches on the glass and back sheet, and cracks in the front glass. VOC and Isc were also noted subsequently at different times of the day. To calculate the degradation of various PV modules, the IV data obtained from the outdoor testing was compared with the nameplate data. Comparision of the IV characteristics is presented in Figures 2 & 3.

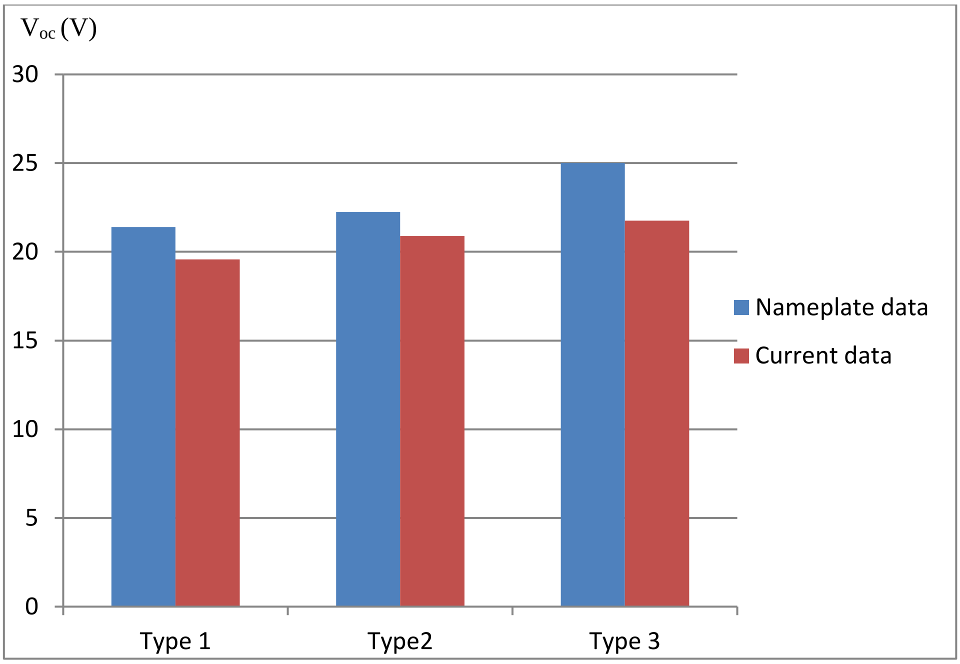

Figure 2. Comparison of VOC of the three different types of PV modules with their nameplate data that were installed in the field

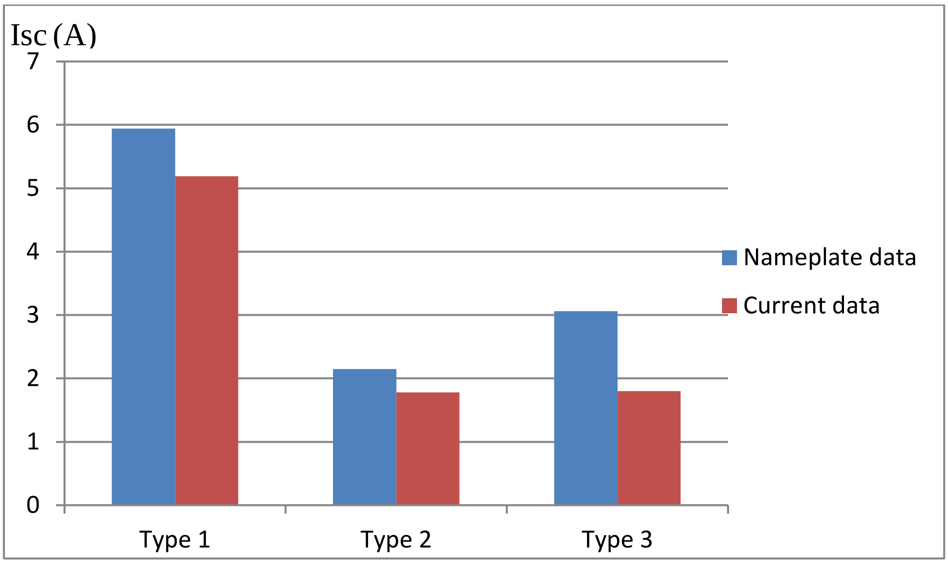

Figure 3. Comparison of Isc of the three different types of PV modules with their nameplate data that were installed in the field

The average degradation shown by these modules in the different performance parameters was: 12.6% in Isc and 8.54% in Voc by Type 1, which had been in the field for only 10 years, 17.21% in Isc and 6.11% in Voc by Type 2, and 26.2% in Isc and 12.96% in Voc by Type 3. Type 2 & III had been installed in the field for 30 years. All of the three types of PV modules had been installed and operating in the same place under the same environmental conditions. Type 1 modules, however, showed more degradation despite being in the field for only 10 years, a relatively smaller period as compared to type 2 and 3 modules which withstood the same environment for more than 30 years. This means that degradation is not caused solely by the environment, but it can also depend on the quality of the material used in the manufacturing of the PV modules.

IV. Conclusion:

Three different types of PV modules installed at the same geographical location from 10 to 30 years and studied under current research showed different degradation rates which means that degradation is not only due to the environmental factors but also because of the type of material used for the modules' manufacturing. The type 2 & 3 modules, which were installed for 30 years came up with better results as compared to type 1 that stayed on the field only for 10 years but exhibited worse performance; although no major defects had been observed in them through Visual Inspection. Along with other various degradation modes, the major causes of performance degradation that were observed in these PV modules were Encapsulant Browning and Solder Bond Breakage due to which Short Circuit Current decreases and Series Resistance increases.

Conflict of Interest:

There is no conflict of interest regarding this article

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