

Discoloration of Photovoltaic Module and Correlation with Electrical Parameters Degradation

Najib Hamisu Umar, Pallavi Gupta, Birinchi Bora, Chandan Banerjee



Abstract: In this paper, the effect of module discoloration on electrical parameters degradation was analyzed. The discoloration was initially identified through visual inspection method. The visual image shows that the module has changed color to brown, and there is no discoloration on the module metallization. Furthermore, the module discoloration was correlated with the electrical parameters degradation. The analysis shows that I_{sc} and P_{max} have degraded high. This indicates that discoloration defect has correlated well with I_{sc} and P_{max} degradation. The annual power degradation rate of module 1 and 2 are found to be 2.25/year and 1.56/year respectively.

Keywords: photovoltaic system, module degradation, discoloration, correlation, module performance.

I. INTRODUCTION

The power output of photovoltaic (PV) modules decreases with time due to the degradation of materials and components. The lifetime of a PV module is expected to be over 25 years under the climatic conditions where it's installed. However, the issues of reliability have been the main threat facing both the PV industry and investors. Degradation analysis of the PV module is very essential for assessing the long-term performance reliability of the PV system [1], [2]. Module degradation may be defined as a gradual depreciation of its thermal and electrical characteristics; that may affect it's to the ability to perform within the prescribed manner [3]. Discoloration of the PV module is a type of degradation generally described as a change of color of the ethylene-vinyl acetate (EVA) encapsulant that turns to brown or yellow. EVA discoloration significantly reduces the module power output due to the reduction of sunlight reaching the module of solar cells [4], [5]. According to [6], [7], high ultraviolet (UV) rays and high temperature (usually above 40 °C) are the main courses for EVA discoloration. The main purpose of this work is to correlate degradation due to EVA discoloration with performance parameters such as short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum current (I_m), maximum voltage (V_m), output power (P_{max}) and fill factor (FF) to determine the most affected parameters(s).

II. MATERIAL AND METHODS

The 5.4 kW solar power plant installed at the National Institute of Solar Energy Gurgaon, India in the year 1998 was used for this experiment. The region is located in the northern part of India at 28.43° N and 77.15° E latitude and longitude respectively. This location has a composite climate which is known for its high temperature and less rainfall. The monthly average minimum and maximum temperatures are 12°C and 34°C respectively, with the annual average relative humidity of 51.5%. The region has average solar radiation of 5.13kWh/m²/day and average annual wind speed of 2.30 m/sec. The modules are made up of monocrystalline silicon technology having rated power and rated efficiency of 75W and 12.1%. The specifications of the module are given in table I.

A. Visual Inspection

The modules underwent visual inspection to record visible degradation. Photographs of the modules with the module discoloration were taking using a high-resolution camera. In this work, two modules were used for the analysis.

Table I: The specifications of the module

Module 1		Module 2	
I_{sc} (A)	4.75	I_{sc} (A)	4.75
V_{oc} (V)	21.4	V_{oc} (V)	21.4
I_m (A)	4.45	I_m (A)	4.45
V_m (V)	17.0	V_m (V)	17.0
P_{max} (W)	75.0	P_{max} (W)	75.0
FF	0.738	FF	0.738

B. Illuminated Current-Voltage (I-V) Measurement

I-V data were taken using the PVPM I-V tracer to ascertain the performance of the module. The measurement was conducted at solar radiation above 800 W/m² between 11:30 – 1:30pm to avoid any impact due to the incident angle. Meanwhile, more than 10 sets of I-V data were taken for each module during the experiment. These I-V data were then extrapolated to standard test condition (STC) i.e. 1000W/m², 25°C and 1.5AM using IEC 60891[8].

C. Standard Test Condition (STC) Measurement

The STC measurement is the standard procedure for module performance assessment. The modules are tested in the laboratory at solar radiation 1000W/m², module temperature 25°C and Air Mass 1.5. In this study, the I-V data were taken for each module. Furthermore, the measured STC data were compared with the measured extrapolated data to examine the translation accuracy.

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D. Electroluminescence (EL) imaging

EL imaging is the method used to identify the inactive area or cracks in the module solar cells. In this paper, Greateyes EL device was used. The current is applied through the module terminals and the module invisible radiation is detected by a camera installed in the EL device.

E. Analysis of discoloration defects

The module discoloration was initially identified through visual inspection. The module I-V characteristics under illumination were taken. These I-V data were translated into STC. Moreover, the modules are dismantled from the plant and taken to the indoor laboratory to measure the I-V characteristics at STC. In order to examine the accuracy of the data, the translated I-V data and STC I-V data was compared. However, the degree of discoloration of each module was quantified through discoloration index (DI) and is presented in Table II. The D.I can be calculated using the following relations:

$$D.I = \frac{PYI_{present} - PYI_{initial}}{PYI_{range}} \quad (1)$$

Table II: Severity of discoloration

Discoloration Index (D.I)	Category of Discoloration
0–0.05	Nil
0.05–0.25	Low
0.25–0.5	Medium
0.5–0.75	High
0.75–1	Very High

F. Degradation Analysis

The percentage degradation of the electrical parameters such as I_{sc} , V_{oc} , I_m , V_m , P_{max} , and FF was calculated. Module nameplate data was used as reference data in this analysis. The module year of exposure is 19 years. Percentage degradation (D) and annual degradation rate (D_R) can be calculated using the following equations:

$$D = \frac{\text{reference value} - \text{measured value}}{\text{reference value}} \times 100$$

$$D_R = \frac{\text{degradation}}{\text{year of exposure}} \quad (2)$$

$$D_R = \frac{\text{degradation}}{\text{year of exposure}} \quad (3)$$

III. RESULTS AND DISCUSSION

The effect of module discoloration on electrical parameters degradation was analyzed. The discoloration was initially identified through visual inspection. The visual image and EL images of module 1 and 2 are shown in figure I. It was observed that in the visual images, the module color was has changed to brown. The visual images also show that there is no discoloration on module metallization. However, in the EL images, the dark area implies the inactive area. Furthermore, the degree of discoloration was quantified. The result shows that module 1 has high discoloration ($DI = 0.55$) while module 2 has medium discoloration ($DI = 0.47$). The comparison between translated I-V data and STC I-V data indicated that there is slight variation in the values. This is due to the correction procedure or measurement uncertainties. The electrical parameters degradation and annual degradation rate were presented in table III. It can be noticed that I_{sc} and P_{max} have degraded high. This shows that the module discoloration defect has correlated well with I_{sc} and P_{max} degradation. The annual power degradation rate of module 1 and 2 are found to be 2.25/year and 1.56/year respectively.

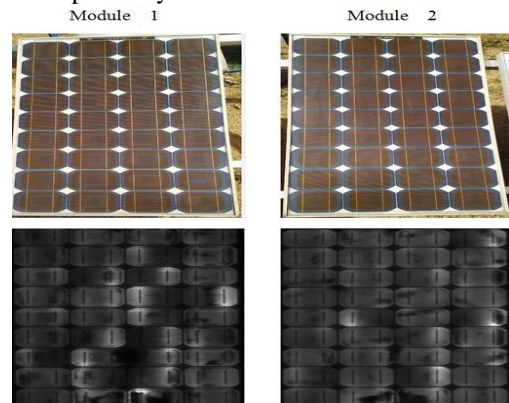


Fig. 1: Visual and EL image of module 1 and 2

Table III: performance parameters degradation of module 1 and 2

Module 1			Module 2		
Electrical Parameter	Degradation (%)	Annual Degradation (%/year)	Electrical Parameter	Degradation (%)	Annual Degradation (%/year)
I_{sc} (A)	32.21	1.79	I_{sc} (A)	19.79	1.10
V_{oc} (V)	7.85	0.44	V_{oc} (V)	4.72	0.26
I_m (A)	28.04	1.56	I_m (A)	19.03	1.06
V_m (V)	14.11	0.78	V_m (V)	8.05	0.45
P_{max} (W)	37.66	2.15	P_{max} (W)	24.91	1.46
FF	0.23	0.01	FF	1.77	0.10

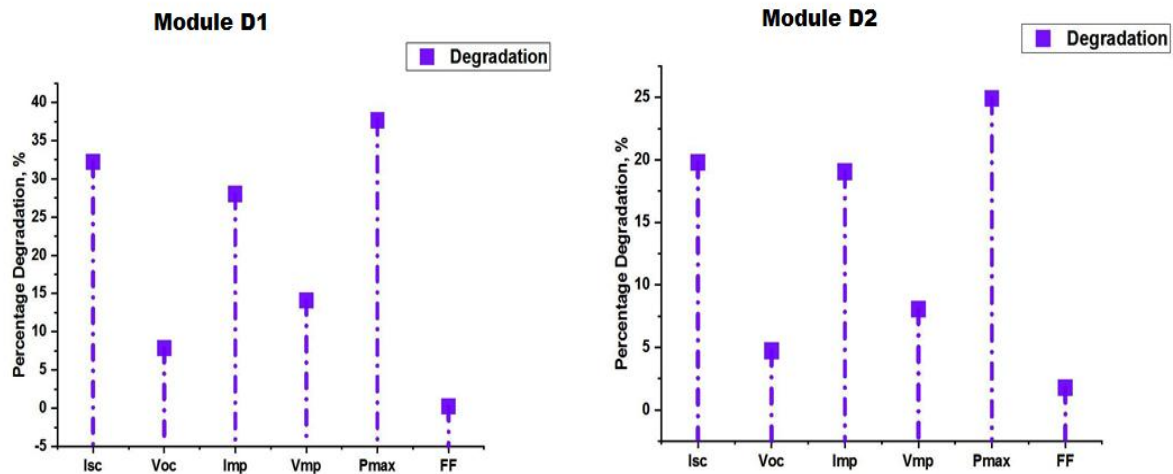


Figure 2: performance parameters degradation of module 1 and 2

IV. CONCLUSION

In this paper, the effect of module discoloration on electrical parameters degradation was analyzed. The discoloration was initially identified through visual inspection method. The visual image shows that the module has changed color to brown, and there is no discoloration on the module metallization. Furthermore, the module discoloration was correlated with the electrical parameters degradation. The analysis shows that Isc and Pmax have degraded high. This indicates that discoloration defect has correlated well with Isc and Pmax degradation. The annual power degradation rate of module 1 and 2 are found to be 2.25/year and 1.56/year respectively.

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