Unexplained Causes of the Most Frequent Degradation mode of Crystalline Silicon photovoltaic Modules

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Introduction
D. Jordan researched more than 2,000 reported degradation rates for photovoltaic (PV) modules [1]. His extensive literature review showed that the majority of crystalline silicon (Si) PV modules degraded most in short circuit current (Isc). And he concluded that Isc degradation could be explained by optical transmission loss caused by such as discoloration of encapsulant and delamination, which are the most frequent visual defects in the field.

However, we have not seen a report that directly links the measured optical transmission loss to PV module performance loss. In addition it is well known that discoloration of EVA, typical encapsulant of Si PV modules, only slightly affects module performance. Is it true that the optical loss is the major cause of Isc degradation? We studied in depth the changes in I-V parameters of Isc degraded PV modules before and after outdoor exposure.

Methods and Results
We studied four reported Isc degradation cases in which I-V parameters of all PV modules were measured before and after outdoor exposure.

Case 1: 29 mono-Si PV modules at Hamamatsu, Japan for 1990-2000. [2]
Case 2: 42 mono-Si PV modules at Southern Spain for 1996-2008. [3]
Case 3: 70 poly-Si PV modules at Northern Italy for 1991-2010. [4, 5]
Case 4: 192 mono-Si PV modules at N. California near the ocean, cool marine environment, for 1990-2001-2010 (measured 3 times). [6]

Case 1
-△Pmax: maximum power decay, -△Isc: short circuit current decay, -△Voc: open circuit voltage decay, -△FF: fill factor decay

Fig. 1 Correlation between -△Pmax and -△Isc, -△Voc, -△FF

Case 2
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Fig. 2 Pmax (a), Isc (b), Voc (c), FF (d)

Case 3
-△Pmax:3.2%, -△Isc:2.8%, -△Voc: 1.6% / 20years

Case 4
-△Pmax:16.13%, -△Isc:10.15%, -△Voc: 0.95%, -△FF: 5.7% / 20years

Outdoor I-V measurements were conducted 3 times at 1990, 2001 and 2010.

Table 1 provides a statistical comparison of module parameters from 1990,2001 and 2010.

<table>
<thead>
<tr>
<th>Year</th>
<th>Pmax(%)</th>
<th>Isc(%)</th>
<th>Voc(%)</th>
<th>Imp(%)</th>
<th>FF</th>
</tr>
</thead>
<tbody>
<tr>
<td>1990</td>
<td>19.30</td>
<td>13.15</td>
<td>17.85</td>
<td>3.26</td>
<td>0.64</td>
</tr>
<tr>
<td>2001</td>
<td>19.20</td>
<td>13.15</td>
<td>17.85</td>
<td>3.26</td>
<td>0.64</td>
</tr>
<tr>
<td>2010</td>
<td>19.20</td>
<td>13.15</td>
<td>17.85</td>
<td>3.26</td>
<td>0.64</td>
</tr>
</tbody>
</table>

It is estimated that the shunt degradation is occurring in the modules.

Table 1 (from table 1 in [6] partially modified)

References

Conclusion
Study of changes in I-V parameters shows that Isc degradation could not be attributed to only optical transmission loss.
It is estimated that some degradation mechanisms of PV cells could affect Isc degradation mode.
One of them is the degradation mechanism which brings on reduction of Voc as well as Isc of PV cells over time.
Yet-to-be-defined degradation mechanisms probably govern the most frequent degradation mode of crystalline Si PV modules.