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Statistics of Photovoltaic Module Failure
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Activity 3.4 in IEA TASK13
Degradation Rates of PV Modules/Systems¹

- x-Si mean degradation in the 0.8–0.9%/a range
- HIT and microcrystalline silicon ≈ 1%/a
- Thin-film > 1.4%/a, strong variations depending on technology

![Graph showing degradation rates by climate zone]

- Based on 11029 data points
- Degradation rate: no clear climatic zone dependence²

Structure of the Survey

### PV system basics

<table>
<thead>
<tr>
<th>System ID:</th>
<th>Example ID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Source of data:</td>
<td>Expert</td>
</tr>
<tr>
<td>Country:</td>
<td>Germany</td>
</tr>
<tr>
<td>Climate zone:</td>
<td>Moderate (C-climate)</td>
</tr>
<tr>
<td>Special stress:</td>
<td>Roof top commercial</td>
</tr>
<tr>
<td>Kind of system:</td>
<td>0 (south)</td>
</tr>
<tr>
<td>Orientation:</td>
<td>30</td>
</tr>
</tbody>
</table>

### Integral data

<table>
<thead>
<tr>
<th>Total system power loss [%]</th>
<th>Inverter [%]</th>
<th>Cable and interconnector [%]</th>
<th>PV module [%]</th>
<th>Mounting [%]</th>
<th>Other [%]</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Failure specification for 25% of the system

<table>
<thead>
<tr>
<th>Failed system part</th>
<th>Failure 1 specification [%]</th>
<th>Power loss 1</th>
<th>Failure 2 specification [%]</th>
<th>Power loss 2</th>
<th>Safety failure 1</th>
<th>Safety failure 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No failure</td>
</tr>
<tr>
<td>Cable and interconnector</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No failure</td>
</tr>
<tr>
<td>PV module</td>
<td>Cell cracks [3%-10%]</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No failure</td>
</tr>
<tr>
<td>Mounting</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No failure</td>
</tr>
<tr>
<td>Other system component</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No detectable loss</td>
<td>No failure</td>
<td>No failure</td>
</tr>
</tbody>
</table>

Selected PV Module Failure Examples

- Cell cracks
- Discolouration of laminate
- PIDs
- Defect bypass diode
- Delamination
- Disconnected cell or string interconnect ribbon

- But also information on soiling, snow load, storm …
Database Composition

- Main survey data from Europe
- Moderate climate dominates data
- Technology distribution equal to market distribution
- 144 failure-survey-data sets from 18 countries
Analysis of Failure Occurrence

- Count only failures leading to power loss
- Cell cracks in 1-2 year, PID in 3-4 year
• Defect bypass diodes, in the first years but also later
• Discolouring all years, but accumulate after 18 years
Degradation Rates – Impact on Affected PV Modules

- Degradation rate of PV modules affected by failure $x$ of system $i$:

\[
d_{i,x} = \frac{\Delta P_{i,x}}{\tau_{b,i} - \tau_{a,i}}
\]

**Power of whole system:**

$P_i$ in kW$_p$

**From failure $x$ affected system part:**

$z_{i,x}$ of system $i \Rightarrow d_{i,x}$
Degradation Rates – Impact on Investigated Part of PV System

- Degradation rate of the investigated system part:
  \[ \delta_{i,x} = d_{i,x} \frac{z_{i,x}}{y_i} \]

- Degradation not necessarily linear

- But method allows comparing power loss for different system ages

Power of whole system:
- \( P_i \) in kW

From failure \( x \) affected system part:
- \( z_{i,x} \) of system \( i \) \( \Rightarrow \) \( d_{i,x} \)

For failure \( x \) investigated part:
- \( y_i \) of system \( i \) \( \Rightarrow \) \( \delta_{i,x} \)
All failure modes have high DR variations.
Potential induced shunts (PIDS) (mean 12%/a), PID-corrosion (13%/a) and defect bypass diode (15%/a) are most critical.
Cell cracks lead in some cases to power loss (5%/a), but not as critical as PID.
Discolouring of pottant occurs often, but with low DR (0.4%/a).
Degradation Rates for Investigated PV System Part

<table>
<thead>
<tr>
<th>Degradation Rate (δ, [%/a])</th>
<th>Quantity in database</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delamination</td>
<td>10</td>
</tr>
<tr>
<td>Defect backsheet</td>
<td>5</td>
</tr>
<tr>
<td>Defect junction box</td>
<td>27</td>
</tr>
<tr>
<td>Discolouring</td>
<td>19</td>
</tr>
<tr>
<td>Cell cracks</td>
<td>8</td>
</tr>
<tr>
<td>Burn marks</td>
<td>5</td>
</tr>
<tr>
<td>Potential induced shunts PID</td>
<td>15</td>
</tr>
<tr>
<td>Potential induced corrosion</td>
<td>8</td>
</tr>
<tr>
<td>Disconnected cell or string</td>
<td>5</td>
</tr>
<tr>
<td>Defective bypass diode</td>
<td>8</td>
</tr>
<tr>
<td>Glass breakage</td>
<td>13</td>
</tr>
<tr>
<td>Isolation failure</td>
<td>2</td>
</tr>
<tr>
<td>Failure due to hail</td>
<td>4</td>
</tr>
<tr>
<td>Failure due to snow load</td>
<td>3</td>
</tr>
<tr>
<td>Animal &gt; bite/corrosion/dirt</td>
<td>2</td>
</tr>
</tbody>
</table>

- Most DR are reduced on system level, because not all modules are affected!
- DR of PIDS (8%/a), PID-corrosion (12%/a) and defect bypass diode (10%/a) are reduced on system level
- DR of cell cracks is substantially reduced (2%/a),
- Discolouring DR does not change, mostly all modules in a system are equally affected (0.4%/a)
Degradation Rates of Failure Affected Part of PV System

- Cell crack degradation rate highest (8%/a) in continental climate.
- Mean PID 16%/a for temperate climate but high variations in rates.
- Discolouring highest in tropical climate but mean <1%/a.
LID for PERC modules not in statistic

- P-type multi crystalline PERC cells susceptible for Light and enhanced Temperature Induced Degradation (LeTID) 1.5%-15% degradation in 1-5 years ($V_{mpp}$), proprietär solutions\(^1\)
- P-type mono crystalline PERC cells susceptible for B-O degradation
  1% - 10% degradation multiple days ($V_{mpp}$), industrial solutions available

\[1\] F. Kersten et al., 31st EUPVSEC, Hamburg, Germany (2015), p. 1830
Conclusions

• Cell cracks dominate the early failures during year 1 and 2.
• Degradation rate caused by cell cracks is highest (8%/a) in continental and snow climates.
• PIDs dominates year 3 and 4 in the failure statistic (16%/a) in moderate climate.
• Great variation of degradation rates for bypass diode failure, may cause dramatic power loss.
• In all climates mean degradation rate of discolouring is below 1%/a.
• Be aware of LID degradation
Outlook

- Assessment of PV Module Failures in the Field
- Support us to collect anonymous data
  http://iea-pvps.org/index.php?id=344
- Send to: m.koentges@isfh.de
- TASK13 extension start in September 2018

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