Comparison of Degradation Rates of Individual Modules Held at Maximum Power

C.R. Osterwald, J. Adelstein, J.A. del Cueto, B. Kroposki, D. Trudell, and T. Moriarty

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Outline

• Purpose
• Published degradation rates
• NREL measurement procedure
• Degradation rate results
• Discussion and conclusions
Purpose

- Module degradation rates ($R_D$) needed for accurate PV system energy delivery calculations
- Time-consuming measurement
- $R_D$ data are generally unavailable
- System sizing software PVWATTTS:
  - Has an input for aging loss, but defaults to no loss
  - Recommends using the common rule-of-thumb 1% per year
- Attempt to quantify PV module $R_D$
Published Degradation Rates

- PV literature search for published $R_D$ values
- Only nine references since 2000 found
- Indication of measurement difficulties
- All but two are from modules exposed in systems
- $R_D$ values derived from system data can include factors unrelated to modules, such as:
  - Inverter operation; max. power tracking
  - Wiring degradation
- System exposures provide more statistics
Published $R_D$ — Systems

- Eurosolare M-SI 36 MS (poly-Si)
- ARCO M-75 (x-Si) †
- ARCO ASI 16-2300 (x-Si) †
- USSC SHR-17 (a-Si)
- Siemens M55 (x-Si)
- [not given] (CdTe)
- [not given] (a-Si)
- AEG PQ40 (poly-Si)

† Based on individual module performance measurements
Published $R_D$ — Modules

- BP Solar BP555 (x-Si)
- Siemens SM50H (x-Si)
- BP Solar MSX64 (poly-Si)
- Kyocera KC70 (poly-Si)
- Ateras APX90 (poly-Si)
- Shell RSM70 (poly-Si)
- Solarex MSX10,20 (poly-Si)
- Ateras A60 (x-Si)
- Isofoton I110 (x-Si)
- Siemens M10 (x-Si)
- Photowatt PW750 (poly-Si)
- Würth WS11007 (CIS)

† N. Cereghetti, et. al., 3rd WCPEC, Osaka, May 2003
NREL $R_D$ Measurements

- Performance & Energy Ratings Testbed (PERT) on roof of Outdoor Test Facility
- Operational since 1994
- Currently 35 modules under test
PERT Data Acquisition

- 3 Raydec Multi-Tracer II max-power tracking loads
- 15 module channels each
- I-V curves every 15 min.
- Irradiance and back-of-module temperature measurements
PTC Power Rating Calculations

• $P_{\text{max}}$ extracted from I-V curves and combined with $E$, $T$, and $s$

• For $E > 800 \text{ W/m}^2$, 1 month of data fit to Performance Test Conditions (PTC)

• Using regression results, power rating @ STC calculated

\[
P = E \left( a_1 + a_2 E + a_3 T + a_4 s \right)
\]

PTC: $E = 1000 \text{ W/m}^2$, $T = 20^\circ\text{C}$, $s = 1 \text{ m/s}$
**R_D Determination**

- PTC ratings plotted versus time
- Slope of linear fit gives $R_D (-0.35 \%/yr)$
Pitfalls

- a-Si initial stabilization
- Seasonal variations
### PERT $R_D$ Results — Crystalline

<table>
<thead>
<tr>
<th>Year</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.6 yr</td>
<td>Solarex SX40U (poly-Si)</td>
</tr>
<tr>
<td>6 yr</td>
<td>Photowatt PWX500 (poly-Si)</td>
</tr>
<tr>
<td>7 yr</td>
<td>BP Solar BP 585F (x-Si)</td>
</tr>
<tr>
<td>8 yr</td>
<td>BP Solar BP 270F (x-Si)</td>
</tr>
<tr>
<td>9.5 yr</td>
<td>Siemens PC-4-JF (x-Si)</td>
</tr>
<tr>
<td>4.5 yr</td>
<td>Kyocera KC40 (poly-Si)</td>
</tr>
<tr>
<td>2.6 yr</td>
<td>Sanyo H124 (a-Si/x-Si HIT)</td>
</tr>
<tr>
<td>7 yr</td>
<td>Siemens ST40 (CIS) †</td>
</tr>
<tr>
<td>10 yr</td>
<td>Solar Cells Inc. (CdTe) †</td>
</tr>
</tbody>
</table>

† Non-commercial prototype modules
PERT $R_D$ Results — a-Si

- Uni-Solar US-32
- Uni-Solar UPM-880
- Solarex SA5
- Solarex MST-22ES
- ECD Sovonix †
- EPV EPV40 †
- APS EP55
- BP Solarex MST-50MV

† Non-commercial prototype modules
Discussion and Conclusions

- Many Si $R_D$ values < 1%/year
- Some thin-film $R_D$ values < 1%/year
- Recommend 0.5% per year for Si
- $R_D > 2\%/year$ likely indicative of serious module or system problems
- $R_D$ values vary over wide range; accurate data should be available for system designers