Development of a Rating System for a Comparative Accelerated Test Standard

Sarah Kurtz, representing discussions with Task Group #6 and seeking your input!

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Objective: Develop a Useful Rating System

- Identify field failures that could be reduced by improved accelerated testing
- Analyze how to group types of accelerated tests to best correlate with field performance
- Propose how to structure a useful Rating System
- Propose how to communicate the results of the Rating System
Need for Rating System

Task Groups develop accelerated tests to predict experience in the field

Task Group 2: Testing for Thermal and mechanical fatigue
Task Group 3: Testing for Humidity, temperature, and voltage
Task Group 4: Testing for Diodes, shading and reverse bias
Task Group 5: Testing for UV, temperature and humidity
Task Group 7: Testing for Snow and Wind Loading

How do we communicate the results?

Rating System
Types of Accelerated Tests – This work focuses on Comparative tests, even though we would prefer Lifetime testing

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Qualification</th>
<th>Comparative</th>
<th>Lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum design requirement</td>
<td>Comparison of products</td>
<td>Substantiation of warranty</td>
</tr>
<tr>
<td>Quantification</td>
<td>Pass/fail</td>
<td>Relative</td>
<td>Absolute</td>
</tr>
<tr>
<td>Mechanisms studied</td>
<td>Infant mortality</td>
<td>Wear out</td>
<td>Wear out</td>
</tr>
<tr>
<td>Climate or application</td>
<td>No differentiation</td>
<td>Differentiated</td>
<td>Differentiated</td>
</tr>
</tbody>
</table>
## What failures are seen in the field?

<table>
<thead>
<tr>
<th>Observation</th>
<th>Sample size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laminate internal electrical circuit 36% of failures (~2% of modules failed after 8 yr); glass 33%; j-box and cables 12%; cells 10%; encapsulant, backsheet 8%</td>
<td>21 manufacturers; ~60% of fleet of &gt; 1.5 GW</td>
</tr>
<tr>
<td>16% of systems required replacement of some or all modules because of a variety of failures, with many showing breaks in the electrical circuitry</td>
<td>483 systems</td>
</tr>
<tr>
<td>3% developed hot spot after &lt; 7 years; 47% had non-working diodes</td>
<td>1232-module system</td>
</tr>
<tr>
<td>External wiring, shattered, failed</td>
<td>~70,000 modules</td>
</tr>
<tr>
<td>Early degradation linked to optical transmission losses (through glass and encapsulant) and light-induced degradation; Later degradation from increased series resistance is more dramatic</td>
<td>204 modules from 20 manufacturers</td>
</tr>
<tr>
<td>Encapsulant discoloration 66%; delamination 60%; corrosion 26%; glass breakage 23%; j-box 20%; broken cells 15%*</td>
<td>~2000 reports</td>
</tr>
<tr>
<td>200 thermal cycles corresponded to ~10 y in the field</td>
<td>?</td>
</tr>
</tbody>
</table>

D. Degraaff, R. Lacerda, and Campeau "Degradation Mechanisms in Si Module Technologies Observed in the Field", PV Module Reliability Workshop, 2011
K. Kato "PVResQ!: a research activity on reliability of PV systems from a user's viewpoint in Japan". Proc. SPIE, San Diego
Rating System – First address wear out that is slipping past the qualification tests

1. In response to:
   • Broken interconnections, solder bonds, diodes
   Add:
   - Additional thermal cycling or mechanical stress, plus bypass diode/shading testing

2. In response to:
   • Encapsulant discoloration and/or delamination
   Add:
   - Additional UV stress
### Rating System – Additional testing

<table>
<thead>
<tr>
<th>New Tests Will Require Additional Stress</th>
<th>Targeted Meaning of Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure types, loosely grouped</td>
<td>★</td>
</tr>
<tr>
<td>Thermal cycling &amp; diode testing</td>
<td>★</td>
</tr>
<tr>
<td>UV</td>
<td>★</td>
</tr>
<tr>
<td>High Temperature</td>
<td>★</td>
</tr>
<tr>
<td>High humidity</td>
<td>★</td>
</tr>
<tr>
<td>Proposed labels</td>
<td>★</td>
</tr>
<tr>
<td>Infant mortality</td>
<td>★</td>
</tr>
<tr>
<td>Qualification test</td>
<td>★</td>
</tr>
<tr>
<td>Interconnects, discoloration, delamination</td>
<td>★</td>
</tr>
<tr>
<td>Hot-cold</td>
<td>★</td>
</tr>
<tr>
<td>Heat-induced failures</td>
<td>★</td>
</tr>
<tr>
<td>Hot-dry</td>
<td>★</td>
</tr>
<tr>
<td>Humidity-induced failures</td>
<td>★</td>
</tr>
<tr>
<td>Hot-humid</td>
<td>★</td>
</tr>
<tr>
<td>Note: Wind is also a priority in some locations</td>
<td>★</td>
</tr>
</tbody>
</table>

The two primary extremes that have not yet been addressed are:

- **Heat**
- **Humidity**

So add additional stress for these, indicated by ✓
Principles for creating tests/rating system

- Must be predictive
  - (correlate with field experience)
- Must be relevant
  - (predict 10-40 y, not 1 y or 300 y)
- Must be communicated in useful ways
  - (both simple and detailed for different audiences)
- We’ll do our best and communicate uncertainty
  - (when we don’t know, we’ll communicate that we guessed)
- Must be designed so we learn from the results
  - (application of the standard will help improve standard)
- Must be cost and time effective
  - (manufacturers must bring the product to market)
- Must define who is responsible/accountable
  - (customers need confidence in information)
Rating System Proposal – Communicate four ways:

1. **Nameplate:**
   - Pmax: 205 W
   - Durability rating:
     - Hot-cold: ★★★
     - Hot-dry: ★
     - Hot-humid: not rated

2. **Report:**
   - Durability rating: 2400 Pa
   - Snow/wind: 2400 Pa
   - Salt spray: etc.

A high level summary on the nameplate will allow researchers to correlate tested rating with field experience 20 y from now.

3. **Interpretive maps:**
   - Using test results by Test Lab X
   - Estimated minimum ratings needed for:
     - 25 years estimated service life
     - open-rack mounting
     - retention of 80% power and pass high pot testing for 90% of modules

   Numeric ratings for HC (Hot-cold), HD (Hot-dry), HH (Hot-humid):

4. **Climate charts** that link climates with stresses (see next slide):
Climate charts – similar to the interpretative maps: define relationship between climate zones and stress testing needed in these.

Chart can define:
- 25 years estimated service life
- retention of 80% power and safe operation of 90% of modules

<table>
<thead>
<tr>
<th>Use environment</th>
<th>“Hot-dry”</th>
<th>“Hot-humid”</th>
<th>“Hot-cold”</th>
<th>Snow load</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cfa/open rack</td>
<td>★</td>
<td>★</td>
<td>★★★★★</td>
<td>2400 Pa</td>
</tr>
<tr>
<td>Geneva/open rack</td>
<td>★★★</td>
<td>★</td>
<td>★★★★★★</td>
<td>5600 Pa</td>
</tr>
<tr>
<td>Tropical/rooftop</td>
<td>B</td>
<td>A</td>
<td>C</td>
<td>n.a.</td>
</tr>
<tr>
<td>Choose your favorite use environment</td>
<td>?</td>
<td>?</td>
<td>?</td>
<td></td>
</tr>
</tbody>
</table>

Communicate meaning of tests for all climate zones, locations, and applications
Other challenges

Different module constructions will have different acceleration factors. Good science tells us that the test must vary with module construction, but manufacturers will complain if they have to bake longer or shake harder.

The stresses are applied in different combinations and different sequences. We need to simplify a complex problem! Can we simplify and still be meaningful?
Conclusions

• A Rating System is necessary for the success of the QA Task Force

• Building consensus on:
  • Principles: tests must be meaningful/useful
  • Assessing today’s most common wear out mechanisms and those expected in hotter and wetter climates defines our current opportunity to strengthen the standards
  • Must find simple way of summarizing test results to standardize communication of a complicated picture
  • Meaning of test results should be communicated in maps and publications