TEST LAB REPORTS TO SUPPORT BANKABLE ENERGY ESTIMATES
100+ Countries where UL customers are located

FORECAST PROVIDER for 60+ GW of renewable energy projects

Investor/Owner’s Engineer on 450+ wind & solar projects*

*since 2012

ADVISED 90% of the industry’s top PROJECT DEVELOPERS and PLANT OWNERS

500+ UL Renewable Energy Experts

200,000+ MW Total renewable energy megawatts (MW) assessed

35 years Continuous renewable energy consulting experience
PRESENTATION OVERVIEW

• Motivation for Module Testing
• Module Performance Parameters
• Test Criteria and Uncertainty
• Example 1: Incident Angle Modifier Factor Profile
• Example 2: Initial Light Induced Degradation
MOTIVATION FOR MODULE TESTING

• Publicly-available specifications sheets may be conservative in their representation of module performance

• If warranted, module definitions in PVsyst (PAN files) and loss assumptions may be created/edited to more accurately represent performance

• Test results always inform the analysis, but certain requirements are needed for a P50 adjustment

• Integration of AWST with UL results in:
  • More meaningful module testing
  • More meaningful IE opinions
    • Internal firewall to protect confidentiality of test lab customers ("safe place to fail")
    • General learning can be shared
# MOTIVATION FOR MODULE TESTING

<table>
<thead>
<tr>
<th>Area of Interest</th>
<th>Independent Engineers</th>
<th>Module Suppliers and Developers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Efficacy</strong></td>
<td>Are lab test standards sufficient to capture future field performance?</td>
<td>If current test lab results are not used for bankable energy estimates, what is the value of performance testing?</td>
</tr>
</tbody>
</table>
| **Sample Size**  | Do lab test results have lower uncertainty than public spec sheets?  
• Calibration/precision of measurements and test equipment  
• Sample size (no. modules, number of measurements per module) | How can testing be optimized to accommodate project schedules?  
• Some tests require significant chamber time  
• By the time testing is complete, supply agreements may be final |
| **Relevance**    | What makes a particular module test relevant?  
• Related modules with a different in bill of materials?  
• What constitutes independent module selection? | How can testing be optimized to be more economic?  
• Testing large sample sizes not financially viable  
• Are previous tests from similar modules relevant for newer products? |
## Module Performance Parameters

<table>
<thead>
<tr>
<th>Performance Characteristic</th>
<th>Relevant Test Standard(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Conversion (I-V Curves)</td>
<td>IEC-61853</td>
</tr>
<tr>
<td>Module Quality Adjustment</td>
<td>IEC-61853</td>
</tr>
<tr>
<td>Module Mismatch (within Bin)</td>
<td>IEC 61853-2</td>
</tr>
<tr>
<td>Incident Angle Modifier Factor</td>
<td>IEC 60904-8</td>
</tr>
<tr>
<td>Spectral Response</td>
<td>IEC 60891</td>
</tr>
<tr>
<td>Temperature Coefficient of Power</td>
<td>IEC 60891</td>
</tr>
<tr>
<td>Initial Light-Induced Degradation</td>
<td>IEC 61215-1 (general), IEC 61215-1-1 (crystalline), IEC 61215-2 (procedure)</td>
</tr>
<tr>
<td>Long-Term Degradation</td>
<td>IEC-61853 at project start, after 3-6 months, then every year for first five years</td>
</tr>
<tr>
<td>DC Performance Loss</td>
<td>IEC-61853 along with systems-level testing</td>
</tr>
</tbody>
</table>
## ACCEPTANCE CRITERIA

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Provider</td>
<td>• Recognized and reputed test laboratory</td>
</tr>
<tr>
<td>Standards</td>
<td>• Tested to relevant standard(s)</td>
</tr>
<tr>
<td>Relevant Module Definition</td>
<td>• Relevant bill of materials for particular test category</td>
</tr>
<tr>
<td></td>
<td>• Consistent manufacturing process</td>
</tr>
<tr>
<td></td>
<td>• Independent “blind” selection</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>• Sufficient number of:</td>
</tr>
<tr>
<td></td>
<td>• Iterations (minimize test error)</td>
</tr>
<tr>
<td></td>
<td>• Samples (quantify variance)</td>
</tr>
<tr>
<td>Reporting</td>
<td>• Sufficient detail to demonstrate adherence to relevant standard(s)</td>
</tr>
<tr>
<td></td>
<td>• Confirm test instrument calibration</td>
</tr>
<tr>
<td></td>
<td>• Uncertainty assessment</td>
</tr>
</tbody>
</table>
CONTRIBUTORS TO TEST UNCERTAINTY

Measurement Accuracy
- Equipment accuracy
- Calibration

Environmental Factors
- Outdoor testing
- Indoor testing

Test Error
- Module variation
- Test protocols
- Human operator error
- Reporting accuracy
SAMPLE SIZE AND UNCERTAINTY

- Number of iterations helps reduce test error
- Number of samples helps reduce variance
- Where’s the sweet spot?
EXAMPLE 1: INCIDENT ANGLE MODIFIER FACTOR
EXAMPLE 1: INCIDENT ANGLE MODIFIER FACTOR

- Outdoor testing introduces environmental error (albedo and diffuse sunlight)
- Uncertainty increases with angle of incidence: most critical part of profile
- Higher latitude sites stand to experience greatest potential energy gain
IAM FACTOR: CONTRIBUTORS TO TEST UNCERTAINTY

Measurement Accuracy
- Pyranometer accuracy
- Calibration, instrument soiling, angularity
- Power measurement accuracy

Environmental Factors
- Temperature, irradiance, wind fluctuations
- Albedo and diffuse (esp. outdoor tests)
- Non-collimated light (indoor tests)

Test Error
- Module variation
- Test angle accuracy
- Test protocols
- Reporting accuracy
## CRITERIA: INCIDENT ANGLE MODIFIER FACTOR

<table>
<thead>
<tr>
<th>Category</th>
<th>DRAFT Criteria</th>
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</thead>
<tbody>
<tr>
<td><strong>Test Provider</strong></td>
<td>• Recognized and reputed test laboratory</td>
</tr>
</tbody>
</table>
| **Standards and Test Requirements** | • Protocols of IEC 61853-2, and  
• 10° intervals as a minimum, 5° intervals strongly preferred between 60°-90° AOI  
• Indoor testing preferred, as this lowers uncertainty and prevents positive bias   |
| **Relevant Module Definition** | • Independent/random selection of test samples  
• Provenance control of modules from production through testing  
• Same series and product line, OR  
• Signed statement from manufacturer indicating:  
  • Same type of glass  
  • Same manufacturing process                                                                                                                                 |
| **Uncertainty**               | • At least three modules, tested separately or together (sample size)  
• At least three measurements for every angular interval (reduce/quantify test error)                                                                                                                                 |
| **Reporting**                 | • Demonstration of testing to IEC 61853-2, showing work  
• Numerical reporting of uncertainty for each measurement interval, including  
  • Calibration of all sensors (meteorological, flash tester, flash reference module)  
  • Uncertainty of temperature correction/adjustment (if relevant)  
  • Assessment of human error                                                                                                                                 |
EXAMPLE 1: IAM FACTOR OBSERVATIONS

- **Opportunities:**
  - Impact on P50 can be 0-1.5% depending on latitude and configuration
  - Relevant module for testing is flexible
  - Adjustments to reporting are easily achievable (uncertainty)

- **Challenges:**
  - Uncertainty is highest in most critical part of the profile
  - Indoor tests are preferred, but still not perfect
EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION
EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION

MANUFACTURER A

• Larger variability than expected
• Stabilization occurred at 100 kWh/m² (about 20 days)
EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION

MANUFACTURER B

- In this location, stabilization was not achieved even after 200 kWh/m²
- Another sample group in another location did stabilize
EXAMPLE 2: INITIAL LIGHT-INDUCED DEGRADATION

MANUFACTURER C

- Stabilization achieved by 80 kWh/m² (about 15 days)
- Gradual return, but final value difficult to determine (site specific)
## CRITERIA: INITIAL LIGHT INDUCED DEGRADATION

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<tr>
<td>Standards and Test</td>
<td>• IEC 61215-1 (general), IEC 61215-1-1 (crystalline), IEC 61215-2 (procedure)</td>
</tr>
<tr>
<td>Requirements</td>
<td>• Test to stabilization: Pmax within 1% for three successive measurements using 25 kWh/m² bins</td>
</tr>
<tr>
<td>Relevant Module</td>
<td>• Independent/random selection of test samples</td>
</tr>
<tr>
<td>Definition</td>
<td>• Provenance control of modules from production through testing</td>
</tr>
<tr>
<td></td>
<td>• Same series and product line required</td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>• At least twenty-module sample size</td>
</tr>
<tr>
<td></td>
<td>• Assessment of uncertainty required (tools, operator, variance)</td>
</tr>
<tr>
<td><strong>Reporting</strong></td>
<td>• Demonstration of testing to standards, showing work</td>
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<td>• Assessment of human error (operator, exposure time, etc.)</td>
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EXAMPLE 2: ILID OBSERVATIONS

• Opportunities:
  • Quick stabilization suggests more confidence ILID assumption
  • Consistent results $\rightarrow$ reduction in ILID uncertainty

• Challenge: universality of test results for P50 adjustment
  • Relevant module is exact same bill of materials
  • Variation within a sample set, from batch to batch
  • ILID rate and magnitude are impacted by environment
CONCLUSIONS: LAB TEST REPORTS

General Observations for Energy Modeling
• Lab performance tests always inform pre-construction energy estimates
• In some cases, additional test/reporting requirements add value
• There is a tradeoff between uncertainty reduction and cost/schedule

Incident Angle Modifier Factor
• Reporting on test uncertainty is an easy win (+)
• Uncertainty is highest in most critical part of the profile (-)

Initial Light-Induced Degradation
• Universality of test results for P50 adjustment? (-)
• If results are consistent → reduction in ILID uncertainty (+)