PV Quality and Minimization of Risks for PV Plant Operation
Florian Reil, TÜV Rheinland
Global market leader in testing & certification of photovoltaic and solar thermal components

- TÜV Rheinland operates 7 accredited solar laboratories (Cologne/Germany, Bangalore/India, Daya/Taiwan, Yokohama/Japan, Shanghai/P.R. China, Gyeongsan/South Korea and Tempe/Arizona, USA)

- More than 30 years experience in the field of photovoltaic at the head quarter in Cologne.

- Global market leader in testing & certification of solar components

- Team of 60 engineers and technicians in Cologne, worldwide 200 solar experts

- Active participation in the important standardization committees

- More than 4 GW inspected PV power plants

- Research and development in the area of characterization and lifetime assessment

TÜV Rheinland overall figures | 2013
---|---
Sales in Mio. € | 1,600
- abroad in % | 48,4
EBIT in % | 7,3
Employees | 18,000
- abroad in % | 59
Locations: more than 500 in 66 countries
Photovoltaic Modules: Fault Statistics from Module Certification

**Percentage of certification projects with test failures**

2,000 certification projects in Germany from 2002 to 2013
(from 2007 c-Si and TF are presented separately)

- **From 2008**: primarily European products shown (opening of TÜV Rheinland laboratories in Japan, China, USA, Taiwan, India, Korea)
- **From 2007**: separate presentation of thin-film and crystalline modules
- **2004–2007**: high percentage of new Chinese manufacturers
- **From 2007/2008**: many thin-film technology start-ups

Today, modules are being constructed to fulfill the standards.
Continuous quality control not always in focus

- Manufacturers organize market entry with minimal effort (only the certificate is important)

- Continuous quality assurance (processes, materials, qualified personnel, etc.) is often not in place

- There are differences among the certifiers
  - With/without factory inspections
  - With/without validity date
  - Active/no participation in standardization
  - Reputation among investors
  - Documentation of materials

IEC certification is only a minimum requirement and is unsuitable as proof of quality; it must be possible to distinguish between different qualities. Quality requires constant control.
Module failures in the field
Loss of Revenue, Risks
Types of risk

On-Site Risks
- Wind and lightning
- Snow, hail and ice
- Pollution
- Dust
- Rock fall
- Land sliding
- Earthquake
- Flood
- Shading
- Animals

Technical Risks
- Performance and yield
- Malfunction
- Degradation
- Aging
- Maintenance costs
- Reparation
- Replacement
- Static
- Visual appearance
- Accessibility

Safety Risks
- Electric shock
- Electric arc
- Fire
- Static
- Mechanics
- Ergonomics
- Theft
- Vandalism

Logistical Risks
- Production delays
- Shipping
- Supply
- Raw materials
- Damages during transport

Political Risks
- Modifications of allowance, permissions and social aspects
- Financial market risks

Financial Risk
Operating Risks Require Inspection and Maintenance of Photovoltaic Systems

Study on system quality 2012/2013: results from 125 inspected large-scale systems

- 30% show serious defects (need for action) or high frequency of errors
- Approximately 50% of defects in the individual segments are installation errors

More than 4 GWp inspected so far

Inspection and maintenance of systems are necessary

- Planning: 18%
- Modules: 25%
- Cabling: 14%
- Grounding, lightning protection: 5%
- Mounting structures: 11%
- Inverter, connection boxes: 13%
- Miscellaneous: 14%
Installation Failures
Installation Failures
Fire Risk for Photovoltaic Systems

- 2014: > 1.5 million PV systems in operation in Germany
- 210+ cases of heat and fire damage caused by PV / 220+ fires involving PV

![Graph showing number of fire damages and breakdown of damage by PV building applications.]

Source: Research project on preventive fire protection in photovoltaic systems

At least 50% of errors resulted from installation defects

More Information [www.pv-brandsicherheit.de](http://www.pv-brandsicherheit.de)
Results of investigations into the origin of fires in PV systems

Fire damage occurs during installation year and in subsequent years!

Damage occurs particularly during sunny (summer) months

- Damages can be minimized through **qualified installation and regular maintenance**
- Perform maintenance before spring

Source: Research project on preventive fire protection in photovoltaic systems
Fire caused by Photovoltaics
Precise Performance Measurement Secures Returns

Results of performance measurements (2013)

Following doubt about performance (modules that are new or as good as new, operation < one year)

Contractually agreed measurements prior to installation in large-scale systems

**Deviation from the nominal value**

- **Small-scale projects; 51 module types**
- **Large-scale projects; 16 module types**

Investors: (Court-) admissible controls necessary

Investors: Measurements secure module performance

- Critical performance measurement are necessary in projects
- High level of measurement precision required for use in court
Differences in PR > 10%

Determination of suitability for different climates are necessary

Optimize products to achieve maximum energy yields for the locations
Module Requirements from Different Climates
Worldwide Energy Yield Module Benchmark

Module temperature distribution of a c-Si PV module at 4 test locations

- India_29.01.14-13.10.14_Tmod, G=48.8°C
- Arizona_13.12.13-13.10.14_Tmod, G=47.8°C
- Italy_01.11.13-13.10.14_Tmod, G=34.3°C
- Cologne_12.03.14-13.10.14_Tmod, G=33.7°C

Frequency [%]

Module Temperature $T_{mod}$ (2°C Step size)

First Outlook
Module Requirements from Different Climates
Worldwide Energy Yield Module Benchmark

**P_{\text{MAX}}** Temperature Coefficients of various PV Technologies

Distribution of solar radiation at 4 test locations

First Outlook
Module Requirements from Different Climates
Worldwide Energy Yield Module Benchmark

Average module temperature weighted with solar irradiance expected yield differences due to the variation $P_{\text{MAX}}$ temperature coefficients:

<table>
<thead>
<tr>
<th></th>
<th>Arizona</th>
<th>India</th>
<th>Italy</th>
<th>Cologne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average $T_{\text{MOD},G}$</td>
<td>47.8°C</td>
<td>48.8°C</td>
<td>34.3°C</td>
<td>33.7°C</td>
</tr>
<tr>
<td>Expected energy yield impact in periods due to the variation of $P_{\text{MAX}}$ temperature coefficients</td>
<td>4.33%</td>
<td>4.52%</td>
<td>1.77%</td>
<td>1.65%</td>
</tr>
</tbody>
</table>

Expected yield loss due to the variation of performances at low irradiance:

<table>
<thead>
<tr>
<th></th>
<th>Arizona</th>
<th>India</th>
<th>Italy</th>
<th>Cologne</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poor low irradiance behavior</td>
<td>97.5%</td>
<td>98.2%</td>
<td>97.3%</td>
<td>96.6%</td>
</tr>
<tr>
<td>Best low irradiance behavior</td>
<td>100.5%</td>
<td>100.2%</td>
<td>100.2%</td>
<td>100.2%</td>
</tr>
<tr>
<td>Expected energy yield difference in period</td>
<td>3.0%</td>
<td>1.9%</td>
<td>2.9%</td>
<td>3.5%</td>
</tr>
</tbody>
</table>
Precise Energy Yield Prediction as a basis of yield comparison

PAN File Data

IEC 61853-1 → IEC 61853-2 → TUV PAN File

<table>
<thead>
<tr>
<th>Irradiance (W m⁻²)</th>
<th>Module temperature (°C)</th>
<th>Incidence angle</th>
<th>IAM</th>
</tr>
</thead>
<tbody>
<tr>
<td>1100</td>
<td>15</td>
<td>°</td>
<td>0-1</td>
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<tr>
<td></td>
<td></td>
<td>0</td>
<td></td>
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<td></td>
<td></td>
<td>±10</td>
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<td></td>
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<td>±20</td>
<td></td>
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<td></td>
<td></td>
<td>±30</td>
<td></td>
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<td></td>
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<td>±50</td>
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<td>±60</td>
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<td>±80</td>
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<td></td>
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<td>±85</td>
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</tr>
</tbody>
</table>

Efficiencies of base and TUV PAN File

Full set of characterization parameters leads to more **accurate PAN files** and yield prediction of PV power plants.
Precise Energy Yield Prediction as a basis of yield comparison
Angular response of c-Si PV modules

Impact on annual angular EY losses for Cologne:
- Standard float glass: -2.3%
- Float glass with ARC: -1.9%
- Deeply textured glass:
Enhancement of Simulation through Lab Data
Simulation inaccuracies from production-based deviations

- Production-based deviations lead to different output characteristics in:
  - Temperate coefficients
  - Low irradiance factors
  - Series resistances
  - Spectral response (even within the module at different positions)

- Recommendation: Required for more accurate yield predictions are a minimum of 3 modules for the generation of more precise mean values

Results from research showed differences of up to 7% in the energy yield simulation for similar module types caused by performance differences from production.
Special Risk: Potential induced degradation (PID)
Physical Explanation

- Potential difference between grounded frame and solar cells (appr. - 500V)
- Leakage current (several micro-ampere)
- Positive charge carrier, e.g. Sodium (Na+) on the solar cell surface
- PN junction is disturbed 1. by the electrical field --- 2. by ions diffused into PN junction
- Shunt resistance of the solar cells decreases => severe performance loss

Sketch of the way of the positive charge carriers

Positive Ions close to the PN junction are the root cause for PID
Special Risk: Potential induced degradation (PID)

- Performance killer number one: potential induced degradation (PID) (occurs in cases of high voltage, sensitive module/material combinations and damp environments – e.g. caused by condensation, high humidity)
- Reversible process through grounding or counter-potential (investments required)
- Knowledge of PID sensitivity of PV modules is necessary

Test results of a PID test of PV modules from large-scale PV systems

![Graphs showing performance degradation](image)

-15%, -75%, -95%

All material combinations of a module must be considered in order to declare it PID-resistant!
Special Risk: Potential induced degradation (PID)
Failure Analysis in the Field

- Monitoring shows slight power losses of module strings (e.g. after one year)
- Infrared thermography shows typical patterns (patchwork or close to the frame)
- Modules are affected close to the negative pole of the module string
- Electroluminescence and Performance measurement

Infrared thermography during operation
Electroluminescence during night

Early detection and recovering is the key to minimize performance losses
Special Risk: Potential induced degradation (PID)

PID- Module Test in the Laboratory

- Standard Draft IEC 62804 (without pass/fail criterion) -1000V, up to 168 hours
  - Test with module in Climatic chamber at 60°C … 85°C and 85% RH
  - Test with module covered with Aluminum foil
- TÜV Rheinland certificate is based on 2PFG (Internal TÜV Rh specification with 5% power loss criteria)

We recommend Aluminum foil test because of a higher reproducibility but we are able to run both
Special Risk: Potential induced degradation (PID)
Actions in the Fab

Disruption of the Failure Chain

1. Cell
2. Module
3. Mounting
4. System

- Cells – More Dense Silicon Nitride (Si3N4) layer (SOLON)
- Cells – Protective Silicon oxide (SiO2) layer between Si3N4 layer and Si Crystal
- Module – Encapsulation: 1 Silicone instead of EVA or PVB, 2 High-resistive EVA
- Module – Glass: 1 PID hindering coating, 2 Na reduction
- Mounting – 1 Frameless Modules, 2 Isolating Clamps

The current of the Ions to the PN junction must be hindered
Special Risk: Potential induced degradation (PID)

Actions in the Field

- Inverter with Trafo: Grounding of the negative Pole
- Transformerless Inverter:
  - Recovery during Night (e.g. SMA PVO-Box, Ilumen PID-Box) by positive voltage
  - Exchange of Inverter (e.g. Sunways AT or OMRON with grounding of neg. pole)
  - High Ohmic Grounding of Central Inverters at the Middle Voltage Transformer

Testing of Anti-PID functionality of Inverters (preventive and recovery)

Recovery takes longer than degradation

16/10/2014

UK Solartrade, Birmingham 2014
Special Risks: System Degradation from Micro-cracks

Example: micro-cracks as defects/damage?

Detected micro-cracks have their origins in:
- Production (soldering process, handling, temperature, etc.)
- Environmental influences (transportation, snow, hail, etc.)
- Mechanical damage (installation)

When is the effect considered to be a defect?

Derivation of necessary, adapted analysis methods
- Determination of damage (potential)
- Derivation of origin
- Statement on further development and impact of the damage on safety and performance

Qualified assessment of the damage/defect necessary
Transportation Risks: Shift transportation distances
Risk Reduction for production, transportation, installation

Means of transportation and conditions influence the goods in transit

- Means of transportation (Ship, train, truck)
- Reloading point (crance, folkift)
- Environmental conditions (road conditions, wave conditions, storm)
- Distance
- Packaging

Transport induced damages can impact the safety and the electrical and monetary yield of a PV plant
Recording of Data Logger (Comparison with Container sensor)
Highest Accelerations during Transshipping and Truck Transport
Example: Time triggered event during truck transport

**Vibration**
- \( G = 0.7 \text{ g} \)
- Duration = 32 msec
- \( \Delta V = -0.11 \text{ m/s} \)

**Shock**
- \( \text{Grms} = 0.133 \text{ g (CH7)} \)

**Maximum Vibration**
- at approx. 12 Hertz
- (Module resonance frequency)
Qualified Shipping Unit
Requirements from International and Internal Standards

Transport Stress Simulation acc. to IEC 62759-1

Acceptance Criteria through TÜV Rheinland Standard (2PfG 2376/02.14):

- Degradation of $P_{MPP}$ < 5 % after each test sequence; < 8 % total
- No deformation of packaging through impact testing
- Compliance check of packaging material against EU guidelines
PVChain
Concept of Quality Assurance Process

Exemplary transportation route