Developments in Accelerated Lifetime Testing

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Accelerated Testing: Concept

Pre-Stress Tests

Modules
- Power (100%)
- Safety (low μA leakage) (dry and wet/rain)

Accelerated Stress Tests

- Sunlight
- Ultraviolet light
- Temperature
- Wind & Snow
- Humidity
- Hail
- Partial Shading
- Handling & Installation

Post-Stress Tests

- Power (>95% of original)
- Safety (low μA leakage) (dry and wet/rain)
Accelerated Testing: Classification

- Qualification Testing
- Comparative Testing
- Lifetime Testing
Accelerated Testing: Qualification Testing

Used for Qualification and Market Introduction
(Major Stress Tests: Fail, for example, if >5% power drop)

TC200   DH1000   HF10
Accelerated Testing: Comparative Testing

Used to select one design among qualified designs
(Major Stress Tests: Stop, for example, when >20% power drop)

Sequential Testing

- DH2000
- TC400
- HF40
- Bypass Diode

Extended Testing

- TC400
- DH2000
- HF40

<table>
<thead>
<tr>
<th>Sequential</th>
<th>Extended</th>
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<td>Multi-variable &amp; variable preconditioning</td>
<td>Single-variable &amp; No variable preconditioning</td>
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Accelerated Testing: Lifetime Testing

Used for Lifetime Determination

PV Module Lifetime Research Program
@ ASU Photovoltaic Reliability Laboratory (ASU-PRL)

Characterization as appropriate:
- I-V (dark & light)
- Spectral response
- IR scan
- Electroluminescence
- Visual
- CTI
- GWI
- Voltage withstand

PV Modules/Materials
(Fresh/Field Aged)

Pre-Characterizations

Characterization as appropriate:
- Hipot (dry & wet)
- WVTR
- UV/Vis/IR
- FTIR
- DSC
- TGA
- Mechanical (tensile, shear etc.)
- Layer/module lamination (if required)

Accelerated Stress

Sequential / extended / combined testing:
- Thermal cycling
- Damp heat
- Humidity freeze
- Static heat
- Voltage bias
- Weathering (UV, T & RH)
- Light soaking

Field Stress

Varied climatic conditions:
- Hot dry
- Hot humid
- Cold dry
- Hot humid/dry with voltage bias

Post-Characterizations

Failure Analysis

Various analysis including:
- Failure modes
- Failure mechanisms

Modeling

Various models:
- Physical models
- Statistical models

Lifetime Prediction
Field Failures vs. Time

Failure Rate Dictated by Design Quality and Production Quality

- Decreasing Failure Rate
- Constant Failure Rate
- Increasing Failure Rate (interaction of multiple degradation mechanisms)

Year
Field Failures vs. Time: Influence of QT, CT and HALT

QT = Qualification Testing; CT = Comparative Testing; HALT = Highly Accelerated Lifetime Testing