IEC 61215: What it is and isn't

2012 PV Module Reliability Workshop

John Wohlgemuth

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Introduction

- The commercial success of PV is based on long term reliability of the PV modules.
- Today's modules are typically qualified/certified to:
    - IEC 61215 for Crystalline Silicon Modules
    - IEC 61646 for Thin Film Modules
    - IEC 62108 for CPV Modules
- These qualification tests do an excellent job of identifying design, materials and process flaws that could lead to premature field failures.
- This talk will provide a summary of how IEC 61215 was developed, how well it works and what its limitations are.

Evaluating Long Term Performance

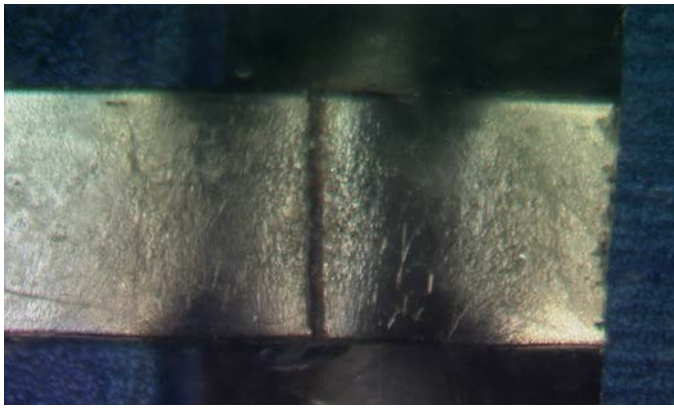
- To evaluate long term performance outdoors we really need outdoor performance data.
- On the other hand we can not wait 25 years to determine if a module is going to have a 25 year lifetime.
- Therefore, we have to utilize outdoor test data to develop accelerated stress tests.
- The first step in this process is to identify the various field failures that have been observed for different types of PV modules.

HISTORY OF FIELD FAILURES for Cry-Si

- Broken interconnects
- Broken cells
- Corrosion
- Delamination and/or loss of elastomeric properties of encapsulant
- Encapsulant discoloration
- Solder bond failures
- Broken glass
- Hot Spots
- Ground faults
- Junction box and module connection failures
- Structural failures
- Bypass Diode failures
- Open circuiting leading to arcing

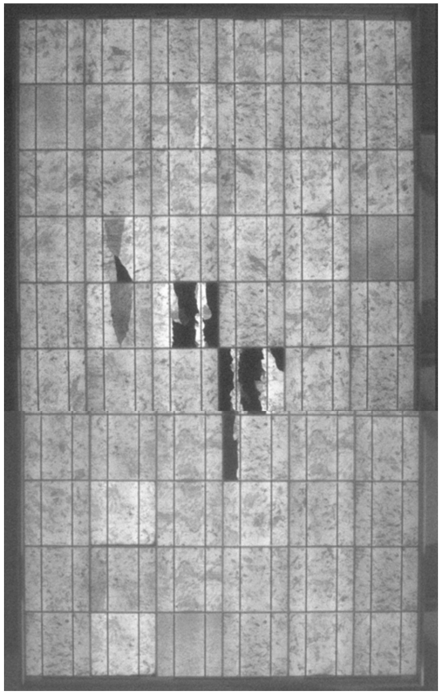
Examples of Field Failures

Broken Interconnects



Ground Fault

Broken Cells



Delamination

Corrosion

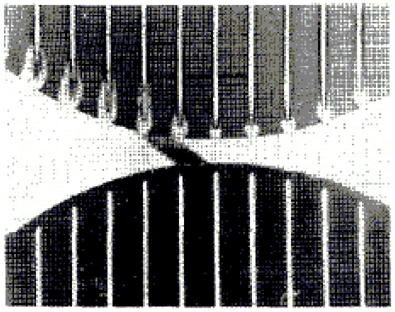


Figure 2. Solar-Cell Electrochemical Corrosion

Accelerated Stress Tests

- Now that we have a list of failures, we can develop tests that duplicate the failures in a fairly short time frame (at least compared to outdoor exposure).
- Our goals should be:
  - To identify accelerated stresses that cause the same types of failures as seen in the field.
  - To determine approximately how long the accelerated stress test must be performed in order to duplicate a reasonable amount of field exposure.
- In developing accelerated stress tests we must cause degradation in order to verify that our accelerated test is duplicating the failure mechanism we saw outdoors.

Accelerated Stress Tests

Accelerated Stress Test	Failure Mode	Technology
Thermal Cycles	Broken interconnect Broken cells Electrical bond failure Junction box adhesion Module open circuit – potential for arcing	Cry-Si & CPV Cry-Si & CPV All All All
Damp Heat	Corrosion Delamination Encapsulant loss of adhesion & elasticity Junction box adhesion Electrochemical corrosion of TCO Inadequate edge deletion	All All All All TF TF
Humidity Freeze	Delamination Junction box adhesion Inadequate edge deletion	All All TF

Accelerated Stress Tests for PV (cont)

Accelerated Stress Test	Failure Mode	Technology
UV Test	Delamination Encapsulant loss of adhesion & elasticity Encapsulant & backsheet discoloration Ground fault due to backsheet degradation Degradation of Optics	All All All All CPV
Static Mechanical Load (Simulation of wind and snow load)	Structural failures Broken glass Broken interconnect ribbons Broken Cells Electrical bond failures	All Cry-Si & TF All Cry-Si & CPV All
Dynamic Mechanical Load	Broken glass Broken interconnect ribbons Broken Cells Electrical bond failures	Cry-Si & TF All Cry-Si & CPV All

Accelerated Stress Tests for PV (cont)

Accelerated Stress Test	Failure Mode	
Hot spot test	Hot spots Shunts in cells or at scribe lines Inadequate by-pass diode protection	All All All
Hail Test	Broken glass Broken cells Broken Optics	Cry-Si & TF Cry-Si CPV
By-pass Diode Thermal Test	By-pass diode failures Overheating of diode causing degradation of encapsulant, backsheet or junction box	All All
Salt Spray	Corrosion due to salt water & salt mist Corrosion due to salt used for snow and ice removal	All All

Qualification tests

- Qualification tests are a set of well defined accelerated stress tests developed out of a reliability program.
- They utilize stress tests to duplicate failure modes observed in the field.
- They incorporate strict pass/fail criteria.
- The stress levels and durations are limited so the tests can be completed within a reasonable amount of time and cost.
- The goal for Qualification testing is that a significant number of commercial modules will pass.

(If not there will be no commercial market.)

- Qualifies the design and helps to eliminate infant mortality

History of JPL Block Buys

JPL Block buys incorporated a set of qualification tests in each procurement document.

Modules had to pass a test sequence before manufacturer could deliver production quantities of modules.

So where did tests come from?

Block I tests were based on NASA tests utilized on space arrays.

- Thermal cycles extremes selected as -40 and +90 °C based on guesses for worst case conditions in terrestrial environment.
- The humidity test was for a short time because for space arrays exposure to humidity was limited to the time they were exposed before launch.
- These were really the only accelerated stress tests in Block I

JPL Block Qualification Tests

Test	I	II	III	IV	V
Thermal Cycles	100 -40 to +90C	50 -40 to +90C	50 -40 to +90C	50 -40 to +90C	200 -40 to + 90C
Humidity	70C,90% 68 hrs	5 cycles 40 to 23C 90%	5 cycles 40 to 23C 90%	5 cycles 54 to 23C 90%	10 cycles 85 to -40C 85%
Hot Spot (intrusive)					3 cells 100 hrs
Mechanical Load		100 cycles ± 2400 Pa	100 cycles ± 2400 Pa	10000 ± 2400 Pa	10000 ± 2400 Pa
Hail				9 impacts ¾" –45 mph	10 impacts 1" – 52 mph
High Pot		<15 µA 1500 V	< 50 µA 1500 V	< 50 µA 1500 V	< 50 µA 2*Vs+1000

Block Field Experience

The earliest Block modules were typically utilized in small remote site systems.

JPL report stated that “the major cause of module failure to date was by gun shot”.

- Black or blue CZ cells on white background are good targets
- Squares cells on non-white back sheets reduced problem

Many early failures were due to cracked cells:

- Because of module design one cracked cell resulted in total loss of power.

Non glass superstrate modules suffered from significant soiling and delaminations usually due to UV.

Testing Development

Future procurements utilized modified qualification test specifications based on feedback from field failures.

Block II

- **Added 100 mechanical load cycles – once again probably from space experience based on launch damage**
- **Added a High Pot Test to insure electrical isolation**
- **Changed the humidity test from a constant to 5 cycles between 23 and 40 C (Still was too mild a humidity test)**
- **Reduced the number of thermal cycles from 100 to 50**

  This was clearly a mistake. I don't know why they reduced the requirement except to guess that Block I modules had a lot of trouble passing the 100 cycle test.

Block III

- **Changed the High Pot failure level from > 15 µA to > 50 µA as modules were getting bigger.**

Block II and III modules were utilized in some larger systems and started to experience new failure modes.

Lessons from Blocks II and III

Many Block II and III modules were used in desert environments

– Pagago Indian Reservation in AZ
– Tanguze, Upper Volta
– Natural Bridges, Utah

Modules that survived 50 thermal cycles began failing in the desert after 3 to 5 years due to broken interconnects and/or broken cells that resulted in total loss of module power.

– Module manufacturers started building in redundant interconnects and stress relief.
– Most new module types used glass superstrate construction, reducing the thermal expansion and contraction.
– In Block V Thermal Cycles increased to 200 to better evaluate module performance.

Lessons from Blocks II and III (cont)

Hail did significant damage to modules built without tempered glass superstrates:

- Broken cells
- Broken annealed glass

Hail test added in Block IV.

Large (60 kW), high voltage system at Mt. Laguna, CA

- Part of array built with Solar Power modules (40 – 4” diameter CZ in series) with no by-pass diodes.
- Modules began suffering from hot spot failures – that is they burned up.

Hot Spot Test Added in Block V

Block V

Major differences in Block V were

- Thermal cycles increased from 50 to 200
- Humidity freeze implemented (before that it was a much milder humidity cycle)
- Addition of hot spot test

Whipple reported on 10 years of field results in 1993 (using data from Rosenthal, Thomas and Durand) that

- Pre-Block V modules suffered from 45% field failure rate
- Post- Block V modules suffered from < 0.1% field failure rate

Clearly the addition of these 3 tests dramatically reduced the infant mortality rate of PV modules.

One can argue that the Block V test made growth of commercial PV possible.

Block VI

JPL was in the process of finalizing a Block VI Specification when the program fell victim to Reagan budget cuts.

Additions they were planning in 1985:

- **Test for bypass diodes**
- **UV exposure test**
- **Damp heat (85C/85% RH) – To simulate the corrosion failures observed in fielded PVB modules.**

IEC 61215

International Standard incorporating the best ideas from around the world – but also remembering that it was developed by international compromise.

Block VI was the basis for 61215.

EU 502 provided UV Test, Outdoor Exposure Test and lower maximum temperature in thermal cycle.

Several tests from Block VI were not included in IEC 61215 – most notably:

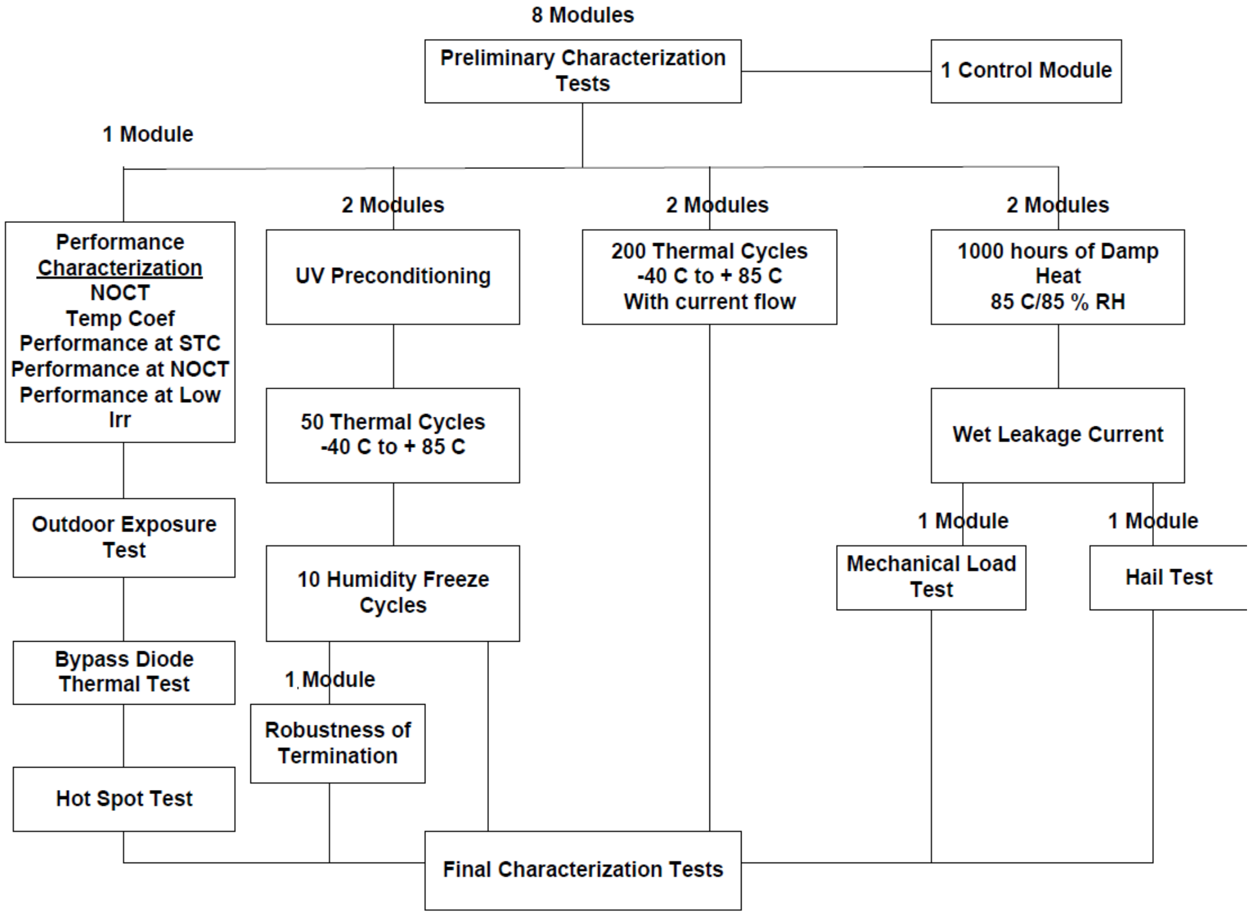
- Dynamic Mechanical Load Test, because the test defined in Block V was unsuitable for large sized modules.
- Bypass Diode Thermal Test, because international community didn't think the test was adequately developed.

IEC 61215 rapidly became the qualification test to pass in order to participate in the PV marketplace, especially in Europe.

IEC 61215 Edition 2

- Twist test was eliminated – no product ever failed it
- Wet leakage current test was added from IEC 61646
- Bypass diode thermal test was added from IEEE 1262
- Pass criteria for dielectric withstand and wet leakage current tests were made dependent on the test module area.
- UV test was clearly labeled a preconditioning test
- Added the requirement to run peak power current through the module during the 200 thermal cycles to evaluate a failure of solder bonds observed in the field.

IEC 61215 Outline



Passing IEC 61215

- So what does it mean if a module type is qualified to IEC 61215?
- Passing the qualification test means the product has met a specific set of requirements.
- Those modules that have passed the qualification test are much more likely to survive in the field and not have design flaws that lead to infant mortality.
- Most of today's commercial modules pass the qualification sequence with minimum change, meaning that they suffer almost no degradation in power output from the test sequence.
- In many markets passing IEC 61215 is a minimum requirement to participate.

How Successful are the Qualification Tests?

- They must be fairly successful because the PV industry has been growing rapidly.
- Reports of Field Failures/ Warranty Returns:
  - ✓ Whipple report of < 0.1% field failures in 10 years
  - ✓ Hibberd from 2011 PVMRW – 125,000 modules from 11 different module manufacturers deployed for up to 5 years with only 6 module failures. (0.005%)
  - ✓ Wohlgemuth et. al. from 20th EU PVSEC – Solarex/BP Solar multi-crystalline Si modules deployed from 1994-2005 with 0.13% warranty return rate (1 failure every 4200 module years of operation)
  - ✓ Wohlgemuth et. al. from 23rd EU PVSEC – Solarex/BP Solar multi-crystalline Si modules from 2005 onward with an annual return rate of 0.01%

Limitations of Qualification Tests

By design the qualification tests have limitations.

They were designed to identify early infant mortality problems, but:

- **Not to identify and quantify wear-out mechanisms**
- **Not to address failure mechanisms for all climates and system configurations**

(PID is an example of something that wasn't addressed because it wasn't important in the JPL deployments and wasn't seen early on in the typical low voltage applications)

- **Not to differentiate between products that may have long and short lifetimes**
- **Not to address all failure mechanisms in all module designs**

(New designs may fail for different reasons - e.g. PCB required different testing than EVA)

- **Not to quantify lifetime for the intended application/climate.**