



HISTORY OF IEC QUALIFICATION STANDARDS



**International PV Module
QA Forum**

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Introduction

- **The commercial success of PV is based on long term reliability of the PV modules.**
- **Today most PV modules are warrantied for 25 years.**
- **These modules are typically qualified to IEC 61215 or IEC 61646.**
- **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 the qualification tests were developed and a review of their strengths and limitations.**

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.
- Qualification Tests IEC 61215 for crystalline Si and IEC 61646 for Thin Films were developed this way.
- Let's review where the qualification tests came from and what they actually do.
- The first step in this process is to identify the various field failures that have been observed for PV modules.

HISTORY OF FIELD FAILURES

- **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**

Additional Failure Modes for Thin Film Modules

- **Electro-chemical corrosion of TCO.**
- **Light Induced Degradation – Not really a reliability issue as long as it is predictable.**
- **Inadequate Edge Deletion**
- **Shunts at laser scribes**
- **Shunts at impurities in films**

Accelerated Stress Tests

- So 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 for PV

Accelerated Stress Test	Failure Mode
Thermal Cycles	Broken interconnect Broken cell Solder bond failure Junction box adhesion Module open circuit – potential for arcing
Damp Heat	Corrosion Delamination Encapsulant loss of adhesion & elasticity Junction box adhesion Electrochemical corrosion of TCO Inadequate edge deletion
Humidity Freeze	Delamination Junction box adhesion Inadequate edge deletion

Accelerated Stress Tests for PV (cont)

Accelerated Stress Test	Failure Mode
UV Test	Delamination Encapsulant loss of adhesion & elasticity Encapsulant & backsheet discoloration Ground fault due to backsheet degradation
Static Mechanical Load (Simulation of wind and snow load)	Structural failures Broken glass Broken interconnect ribbons Broken Cells Solder bond failures
Dynamic Mechanical Load	Broken glass Broken interconnect ribbons Broken Cells Solder bond failures

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
Hail Test	Broken glass Broken cells
By-pass Diode Thermal Test	By-pass diode failures Overheating of diode causing degradation of encapsulant, backsheet or junction box
Salt Spray	Corrosion due to salt water & salt mist Corrosion due to salt used for snow and ice removal
Ammonia Test	Exposure to farm waste

Qualification testing or Certification

- 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 Qualification Testing

JPL Block Buys I-V (1975-1981) – all crystalline Si
European Union Specifications 501 to 503 (1981-1991)
SERI IQT (1990) – modifications for thin films (a-Si)
IEEE 1262 (1995-2000) – all technologies
IEC 61215 (Ed 1 - 1993, Ed 2- 2005) – Crystalline Si
IEC 61646 (Ed 1 - 1996, Ed 2- 2007) – Thin Films

History of JPL Block Buys

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

Modules had to pass 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.

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 40C (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 $> 15 \mu\text{A}$ to $> 50 \mu\text{A}$ 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.**
- **JPL began recommending paralleling of cells, but modules built this way suffered from shunt related power loss and hot spot problems.**

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.

Hot Spot Test Added in Block V

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)**

European PV Community

Through ESTI the European Community worked on a PV Qualification Standard at the same time that JPL was working on Block Program.

European Standards 501 and 502 had some similarities to the Block V document with:

- Addition of UV Exposure Test
- Addition of Outdoor Exposure Test
- Reduction of thermal cycling maximum from 90 to 85

EU 503 was a draft of IEC 61215, utilized to begin testing to the new standard before it had completed voting by National Committees.

IEC 61215

International Standard incorporating the best ideas from around the world.

Blocks 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.

SERI work on thin film modules (mostly a-Si) led to new “interim standard” for these modules

Biggest new issue was the high leakage current resulting from inadequate edge isolation of the TCO on the glass.

IQT added a Wet Insulation Resistance Test to test for this problem.

IQT also added:

- Ground continuity from UL 1703**
- Cut Susceptibility Test from UL 1703**
- Bypass diode Test from Block VI**

Thin Film PV Testing – IEEE 1262

IQT led to IEEE 1262 and then to IEC 61646.

IEEE 1262

- Was a hybrid having components from IQT and IEC 61215.
- It used the 61215 backbone of tests but incorporated the additions from IQT
- It introduced annealing steps to address light induced degradation in a-Si.

IEEE 1262 served its purpose as the first consensus qualification test standard for thin film modules.

Once IEC 61646 was approved there was no reason to have 2 standards so IEEE 1262 was withdrawn.

IEC - 61646

Written for the thin film modules available in 1996 – they were mostly a-Si.

Combined ideas of IEC 61215 and IEEE 1262.

IEC 61646 added new concept of using thermal annealing and light soak in an attempt to characterize the power loss caused by the different accelerated tests.

Changes from IEC 61215

- Added wet leakage current test.
- Added light soak and anneal cycles.
- Added maximum output power at STC after final light soak as a pass/fail criteria

IEC 61215 Edition 2

Twist test was eliminated

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 61646 Edition 2

An attempt to adapt IEC 61646 to different types of thin film modules.

Modified the pass/fail criteria

- No longer relies on meeting a plus/minus criterion before and after each test
- Requires meeting the rated power after all of the tests have been completed and the modules have been stabilized

Twist test was eliminated

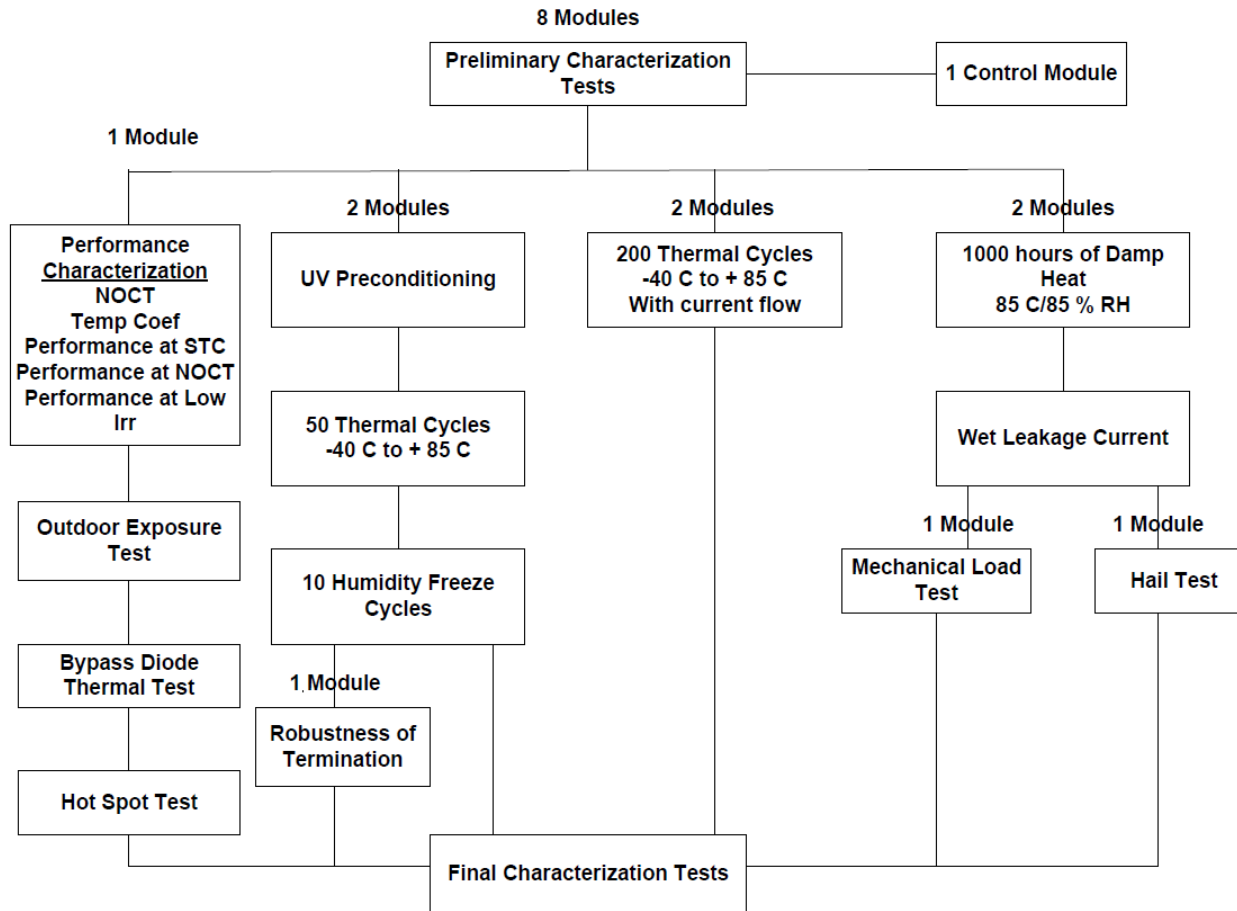
Pass criteria for dielectric withstand and wet leakage current tests were made dependent on the test module area.

Rewrote the Hot Spot Test.

Added by-pass diode thermal test

UV test was clearly labeled a preconditioning test

IEC 61215 Outline



Passing IEC 61215 or IEC 61646

- **So what does it mean if a module type is qualified to IEC 61215 or IEC 61646?**
- **Passing the qualification test means the product has met a specific set of requirements.**
- **Those 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 one of these qualification tests 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.
- The literature survey on degradation rates reported at PVSC by Jordan and Kurtz indicates that the Qualification Tests have been quite successful in identifying and eliminating module types that suffer large degradation rates early in their lifetime.
- There have been many reports of PV modules being the most reliable component in PV systems.

Limitations of Qualification Tests

- **By design the qualification tests have limitations.**
- **They do not test for wear out mechanisms.**
- **Previously reported (23rd EU PVSEC) an experiment where 10 crystalline Si module types (all previously qualified to IEC 61215) were tested for 500 thermals cycles and 1250 hours of damp heat.**
 - **2 out of 10 module types failed 500 TC's.**
 - **8 out of 10 module types failed 1250 hours of DH**
- **Just knowing that a module type passed IEC 61215 doesn't tell you how well it will do in longer term testing or how long it will survive in the field.**

Testing for 25 year Lifetime

- What we would really like is to determine what accelerated stress levels would represent a 25 year lifetime to be consistent with the warranty.
- **But we don't know how to do that today.**
 - ❑ We don't know what combined set of stress tests would be a good predictor of a 25 year lifetime
 - ❑ When those stress levels are determined, they are likely to depend on the geographic location where the module is deployed as well as how it is mounted.
- It was to address this situation that the International PV Module QA Forum was organized.