Considerations for a Standardized Test for Potential-Induced Degradation of Crystalline Silicon PV Modules

2012 PVMRW

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February 29, 2012

NREL/PR-5200-54581
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Motivation

“Oh no! our modules are down 40%, we think it is potential–induced degradation”
-anonymous module manufacturer, 2010

- Over the past decade, there have been observations of module degradation and power loss because of the stress that system voltage bias exerts.
  - More sensitive modules
  - Higher system voltage
- This results in part from qualification tests and standards not adequately evaluating for the durability of modules to the long-term effects of high voltage bias that they experience in fielded arrays.
- This talk deals with factors for consideration, progress, and information still needed for a standardized test for degradation due to system voltage stress.
Timeline for system voltage durability

• Need for a better standard for system voltage durability brought up several times in the last decades, but did not get traction. Lack of field data, proposed tests overly harsh.

• I brought this up again in the Fall 2010 Working Group 2 (WG 2) meeting (Köln) and got a small working together, but most people were in the process of getting experience about system voltage effects.

• Spring 2011 WG 2 meeting (Shanghai), indications of increased urgency for a standard, assembled more people for this task team.

• Fall 2011 WG 2 meeting (Montreal), presented an initial draft for comments.

• Present day...
Goals for a standard – two steps

1. Stand-alone test (new standard):
   
   *System voltage durability test for crystalline silicon modules – design qualification and type approval,*

2. Incorporate test into IEC 61215

   Seek to incorporate above stand-alone test with any necessary supplements within IEC 61215
   
   – add test after clause 10.13, Damp Heat Test 1000 h under consideration.
Design standard for a climate: Köppen climate classification

Consider for standard: Humid subtropical, and Humid Oceanic.

Need to design for the market. More stressful environments exist, and that should be noted in the eventual standard.

GROUP C: Temperate/mesothermal climates

Maritime/oceanic climates: (Cfb, Cwb, Cfc)
Humid subtropical climates (Cfa, Cwa)
Experimental Overview

1) HV Test bed in Florida USA
   • 2 module types fielded in February 2011

2) Chamber testing of the same 2 module designs tested in Florida
   • 85% RH; 85°C, 60°C, 50°C
     \[ P_{\text{max}} \text{ vs } t \]

3) Comparison of failure rates for determination of acceleration factors and failure mechanisms for input into standardized test
Definitions

Electrochemical corrosion

c-Si

Mon & Ross

JPL, 1985

Polarization

c-Si

Swanson

SunPower, 2005

Field Performance Decreased 20%
After Several Months Operation

Potential-Induced Degradation

Electroluminescence of mc-Si module strings indicating shunting in the negative portion of a center mounted or floating string


Delamination, corrosion

a-Si

Wohlgemuth

BP Solar, 2000

Other power loss

thin-films

unpublished
Definitions

**Potential-Induced Degradation**

Electrochemical corrosion of c-Si, Mon & Ross, JPL, 1985.

Polarization of c-Si, Swanson, SunPower, 2005.

Field Performance Decreased 20% After Several Months Operation

Electroluminescence of mc-Si module strings indicating shunting in the negative portion of a center mounted or floating string.


Other power loss due to thin-films, unpublished.

Needs an unambiguous name.
Definitions – this standard will cover

Electrochemical corrosion

- c-Si
- Mon & Ross
- JPL, 1985

Polarization

- c-Si
- Swanson
- SunPower, 2005

Electroluminescence of mc-Si module strings indicating shunting in the negative portion of a center mounted or floating string


Delamination, corrosion

- a-Si
- Wohlgemuth
- BP Solar, 2000

Other power loss

- thin-films
- unpublished
Definitions – this standard will cover

Polarization ➔
c-Si
Swanson
SunPower, 2005

Electroluminescence of mc-Si module strings indicating shunting in the negative portion of a center mounted or floating string
System voltage durability

• Designed to cover c-Si

• More than just PID of conventional cells/modules
  - Polarization (like SunPower)
  - Non-reversible elements of PID
  - Rear junction bifacial cells. ECN bifacial/Yingli ‘Panda’
  - HIT cells
  - Framed/unframed modules of various types

• Long term view for harmonization with thin film system voltage durability
Factors for test – leakage current

Voltage potential of active layer, and leakage from that voltage to ground govern degradation in susceptible modules

Circuit resistance factors – cutting relevant series R cuts degradation

Test factors

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

Power Loss vs. Position in String: Polarization, SunPower Modules

R. M. Swanson, The surface polarization effect in high-efficiency solar cells, PVSEC-15, Shanghai
Test factors

- Voltage
- **Mounting/grounding**
- Humidity, surface conductivity
- Temperature

Completing the circuit to ground in a manner representative of mfg. module mounting scheme

Leakage current may be measured as in indicator of module package resistance
Test factors

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

Al foil, carbon film, etc, for surface conductivity
  + Quick/cheap
  + Good screening test
  - Won’t differentiate humidity effects
    (water leaches Na-lime glass)
  - unclear how it connects to textured glass
  - bypasses frame or laminate mount’s ability to reduce degradation, limiting fixes to PID

* Modules that lack a frame and use mounting points bonded to the backsheet glass show no damage [to the extent tested].
* Damage rates can be slowed if leakage currents that are caused by voltage potentials between the frame and the internal circuitry are reduced.

Test factors

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

Because we need to measure the performance of not only the module laminate, but the frame or mounts, the standard as written uses humidity for the circuit to ground.

Surface conductivity of soda-lime glass vs. humidity

Module leakage vs. humidity

P. Hacke et al., 25th EPVSEC, 6-10 September 2010, Valencia, Spain
Test factors

- **Voltage**
- **Mounting/grounding**
- **Humidity, surface conductivity**
- **Temperature**

- Temperature dependence, repeatable
- Arrhenius behavior over temperature range, unless alternate conduction paths exist

Test levels

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature
- System voltage, now effectively governed by IEC 61730-2’s partial discharge test, not PID, generally
- Test at rated system voltage
  - Maximum nameplate value (behind-the-fence/utilities don’t run to UL code)
  - Both polarities (if not polarity is specified)
  - Slight acceleration since actual operating V lower

D. Buemi, Thin-Film PV Powers the Number 1 Global Solar Integrator, davebuemi.com, accessed Feb 22, 2012
Test levels

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

Draft standard:

“For continuous metallic frames encasing the perimeter of the module, the ground terminal of the high voltage power supply shall be connected ... to a module grounding point of the module. “

“If (1) the PV module is provided or is specified for use with means for mounting and (2) the module is designed and specified not to be connected to ground, then such method of mounting the module shall be implemented to the extent possible.”

http://www.solarframeworks.com
SolarFrameWorks Co, BIPV Cool Ply
Accessed Feb 22, 2012
Test levels

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

- 85% RH damp heat chamber, a level that chambers are capable of holding, uniformly
Test levels

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

What level of stress in an accelerated tests reproduces well the failure modes we seek to test for?

How long should it be stressed at that temperature? What is the acceleration factor?
Failure mode in fielded module

Module mounted in Florida, USA after ten months with the active layer biased at -1500 V during the day degraded to 0.35 $P_{\text{max}_0}$

Series resistance losses, as seen in chamber tests, are not yet observed in the field
Step-stress for determination of failure mode

SiN\textsubscript{x} oxidation: not seen in field!

Each step:
−1000 V stress 145 h
+1000 V recovery 145 h
(145 h preconditioning at T & RH level)

Mixed mode –
Series resistance/recombination
Performance of two module types

In Florida, USA
–600 V applied logarithmically with irradiance

In chamber
85% RH
–600 V

More details at 2012 IEEE PVSC
Performance of two module types

In Florida, USA
–600 V applied logarithmically with irradiance

In chamber
85% RH
–600 V

Module Type 1: Acceptable performance in the field survives with less than 5% power drop in chamber with 85% RH, 60°C, rated system voltage, for 96 h
Performance of two module types

In Florida, USA
-600 V applied logarithmically with irradiance

In chamber
85% RH
-600 V

Module Type 1: Acceptable performance in the field survives with less than 5% power drop in chamber with 85% RH, 60°C, rated system voltage, for 96 h

Module Type 2: 5% power drop in 4934 h in Florida and 12 h in chamber at 60°C, (considered a failing module)

More details at 2012 IEEE PVSC
Test levels

- Voltage
- Mounting/grounding
- Humidity, surface conductivity
- Temperature

Draft standard:
“The following conditions shall be applied:
- Chamber air temperature 60 °C ± 2°C
- Chamber relative humidity 85 % ± 5 % RH
- Test duration 96 h
- Voltage: module rated system voltage and polarities”

(one module per polarity)

AF = 427 at 60°C, 85% RH
Test duration, 96 h
Field equivalent: 4.7 y
Next steps: Testing at multiple labs

Determine reproducibility

- **2-3 samples per condition**
  - Presumably 85% RH-60°C, but consider alternates for post IEC-61215 tests

- **5 labs**
  - NREL
  - ASU
  - ...let us know if you are interested!

- Samples from 3 manufacturers
Thank you