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Quantifying and Correlating PV Module Defects in the Service Environment

William Gambogi[1], James Kopchick[1], Thomas Felder[1], Steven MacMaster[1], Alexander Bradley[1], Babak Hamzavy[1], Bao-Ling Yu[1], Katherine Stika[1], Lucie Garreau-Iles[2], Chiou Fu Wang[3], Hongjie Hu[3], Yushi Heta4 and T.-John Trout[1]

[1]E.I. du Pont de Nemours and Company, Wilmington, DE, USA, [2]DuPont de Nemours International S.A., Geneva, Switzerland, [3]DuPont (China) Research & Development and Management Co., Ltd., Shanghai, P.R.C., [4]DuPont K.K., Utsunomiya, Japan

Summary

Photovoltaic modules in the outdoor environment are subjected to a wide range of stresses which can operate simultaneously and sequentially and can vary based on climate and installation. These stresses can include temperature, temperature variation, localized heating, humidity, moisture (rain, snow, humidity, condensation), weathering, mechanical stress, abrasion and internal electric fields. These multiple stresses make prediction of service lifetime challenging. Frequently resistance to an extended single stress is improperly used to assess durability.

We have used sequential and simultaneous multi-stress exposure of materials and modules to better predict the synergistic effects of these stresses on module performance. We have also assessed the change in component materials properties to better understand performance changes. Finally, we compare these results to inspection of modules from the field to validate the test methods proposed.

Field Observations

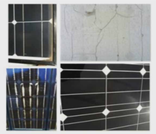
Introduction

- The objective is to quantify and disseminate learnings regarding PV asset management and provide a rationale to reduce risk based on the analysis of PV materials, modules, and systems in the service environment.
- This study involved the inspection of 60 global PV installations equal to 200 MW and consists of approximately 1.5 million modules. Geographic regions included North America (NA), Europe/Middle East (EMEA) and Asia Pacific (AP).
- These systems included both roof- and ground-mounted orientation. System ages ranged from 0-30 years. Crystalline silicon modules using poly, mono, or back contact cells from 45 module manufacturers with Pmax nameplate ratings between 30W and 300W were included.

DuPont Collaborated with Downstream Stakeholders to Assess PV Systems, Modules, and Materials in the Service Environment

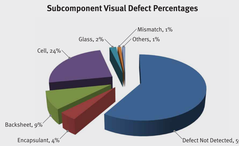
Subcomponent Visual Defects

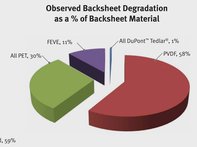
Subcomponent	Visual Defect
Superstrate	Broken, etched, or hazed glass
Encapsulant	Discoloration or delamination
Cell/Interconnect	Corrosion, hot spot (thermal non-uniformity), broken interconnect, snail trail, crack, burn mark
Backsheet	Cracking, yellowing, delamination



Representative visual defects (clockwise): etched glass, cracked backsheet, snail trail, encapsulant discoloration

Visual Defect Percentages by Subcomponent





Discussion

- The combination of extended workmanship warranties and increased system inspections may put a new emphasis on visual defects that are independent of safety and performance degradation.
- Replacement or increased frequency of inspection due to defects may increase the cost of ownership due to unanticipated operational expenses.
- We hope to raise awareness about visual defects that may be indicative of quality issues which can decrease the residual value of a PV asset or require unanticipated operation and maintenance (O&M).

Accelerated Testing

Shortcomings of Current Qualification Tests and Recommendations

- Current IEC qualification standards were designed to identify early failures due to module design; does not predict long-term durability
- IEC qualification standards do not adequately address durability of materials to UV exposure and weathering and synergistic effects of multiple stress
- UV and weathering tests are not applied to modules due to the equipment challenges associated with large area UV and weathering exposure
- DuPont proposes better single stress conditions including UV durability
- DuPont also proposes sequential testing using damp heat (DH), thermal cycling (TC) and UV exposure (UVA) to better predict long-term outdoor performance

Test	Exposure Condition	Evaluation	Technical Reason
Damp Heat	85° C, 85% RH	1000h	adequate for PET hydrolysis damage
		2000h	assess materials stability
		>3000h	test-to-failure
UV (Junction Box Side)	UV, 70º C BPT, 0.55 W/m²-nm at 340 nm, ~60 W/m² (300-400 nm)	275 kWh/m² (6230 h)	desert climate (25 year equivalent)
		235 kWh/m² (3630 h)	tropical climate (25 year equivalent)
		171 kWh/m² (2630 h)	temperate climate (25 year equivalent)
UV (Encapsulant Side)	UV, 70º C BPT, 1.1 W/m²-nm at 340 nm, ~120 W/m² (300-400 nm), glass/EVA/EVA filter, std. EVA and UV transmissive VA	550 kWh/m² (4600 h)	desert climate (6 - 16 year equivalent)
		550 kWh/m² (4600 h)	tropical climate (7 - 19 year equivalent)
		550 kWh/m² (4600 h)	temperate climate (10 - 26 year equivalent)
Thermal Cycling	-40º C, 85º C, 200cyc	1x, 2x, 3x	assess durability
Thermal Cycling Humidity Freeze	-40º C, 85º C, (50cyc); -40º C, 85º C, 85% RH (10cyc)	1x, 2x, 3x	assess durability

Sequential Stress Testing and Weathering

Basis for Sequential Exposure and Recommended Sequential Tests

- Outdoor environment has multiple stresses operating throughout PV module service life
- DH1000 (85C, 85% RH, 1000h) is considered to be > 25 years equivalent in the harshest climate, based on NREL model
- UVA1000 (UVA, 65W/m², 300-400nm, 1000h) is estimated to be ~ 6 years equivalent exposure on the backsheet side of a module
- TC200 (-40C, 85C, 200 cycles) is a standard thermal stress condition in qualification and recent recommended changes propose extension to multiple exposures
- Sequential DH and UVA exposure results in materials degradation similar to the field; thermal cycling creates mechanical stresses similar to those experienced by modules in the field

Damp Heat → UVA (nX) Thermal Cycling → UVA

Test: Backsheet or Modules — **Observe:** Backsheet Yellowing, Cracking

Damp Heat (nX) Thermal Cycling

Test: Full-Size Laminates or Module — **Observe:** Backsheet Cracking

UVX → Water Spray

Test: Backsheets: weathering (Xe),102m light, 18m light + water spray
Test: Module: resistive loading, weathering exposure (above)
Observe: Backsheet Yellowing, Mechanical Loss
Module: Power Loss

Full-Size Framed Laminate (glass/EVA/EVA/backsheet)

Test 1

Backsheet	DH1000	TC200	TC400
1x PVDF 1	OK	cracks	more cracks
1x PVDF 2	OK	OK	minor cracks
1x PVDF 3	OK	OK	many cracks
TPT	OK	OK	OK
TPE	OK	OK	OK

Test 2

Backsheet	DH1000	TC50HF10	2x(TC50HF10)
1x PVDF 1	OK	OK	cracks
1x PVDF 2	OK	minor cracks	minor cracks
1x PVDF 3	OK	OK	few cracks
TPT	OK	OK	OK
TPE	OK	OK	OK

Full-Size Module (DH1000/UVA1000/TC200)

Test 3

Backsheet	DH1000	UVA1000	TC200
1x PVDF	OK	OK	cracks*
1x PVF	OK	OK	OK

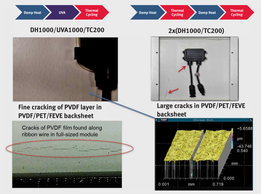
*Cracks are only observed in areas where the backsheet was in contact with the frame

PET Mylar® PET/PET/Tedlar® PET/PE/PET Mylar® PET/PET/Tedlar®

Damp Heat → 2X (Thermal Cycling)

Damp Heat → 2X (TC50HF10)

Damp Heat → UVA → Thermal Cycling



Comparing Extended Single-Stress, Sequential and the Field

- Weathering (UV+ water spray) shows backsheet yellowing, a common failure mechanism in the field
- Sequential exposures (DH -> UV -> TC/UV, DH -> TC) show backsheet cracking, a common failure mechanism in the field
- Power loss and EL imaging of modules after extended damp heat does not match with module performance in the field
- Other extended single-stress test conditions (UV, TC, TCHF) may be more effective in predicting outdoor failure mechanisms
- Work is continuing with other combinations of sequential and/or simultaneous durability test conditions consistent with outdoor

Conclusions

- These results provide the industry with valuable PV system field experience and document PV module defects.
- Risk mitigation techniques can be developed based on field data to eventually help identify and reduce these defects.
- Multiple stress testing procedures are being evaluated to understand the interaction and synergistic effects of outdoor exposure.
- This type of data may be used by insurance agencies to anticipate replacement rates or asset management companies to incorporate into the overall valuation of solar assets.

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