Module and Array Testing at the Outdoor Test Facility

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Relevance/Objectives

FY2007 Solar AOP — NREL-Sandia PV System Test and Evaluation Project:

- "Collaborative R&D with industry on module, array, inverter, BOS components, and system requirements related to system design, performance reliability, safety, diagnostics, and failure analyses…"
- "Accredited, unbiased, internationally recognized cell, module, array, inverter, and system performance measurements for U.S. industry…"
- "Coordinated implementation of accelerated testing and long-term field aging of PV arrays from TPP partnerships to determine failure mechanisms, performance degradation rates…"

Relevance/Objectives (cont.)

FY2007 Solar AOP — Module and Array Testing Agreement:

- Indoor accelerated stress testing using consensus standard protocols such as damp heat, thermal cycling, hot spot endurance, and humidity-freeze cycling
- Module mechanical integrity tests such as hail impact, mechanical loading, robustness of wiring terminations, and junction box integrity
- Outdoor stress testing with accelerated solar UV exposure and/or high-voltage bias.

Relevance/Objectives (cont.)

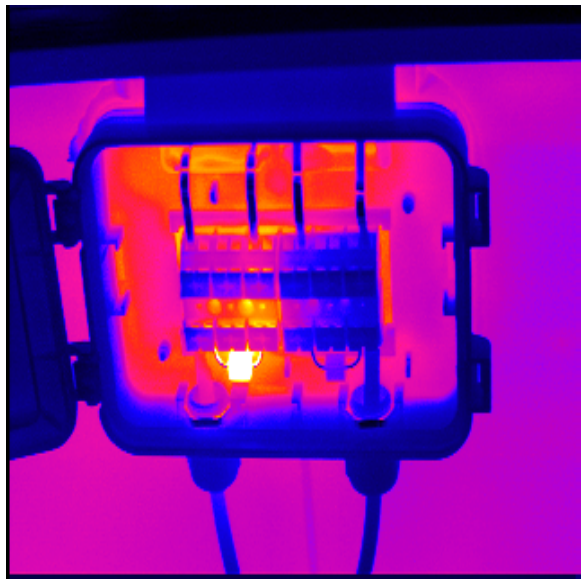
FY2007 Solar AOP — Module and Array Testing Agreement:

- Determination of module energy ratings and outdoor performance degradation rates using the Performance and Energy Ratings Testbed (PERT)
- Technical support and participation with committees (ASTM, IEEE, IEC, UL) developing consensus standards for performance, reliability, and safety of modules
- Standardized module safety testing in collaboration with Underwriters Laboratories, assisting manufacturers to obtain UL certification.

Relevance/Objectives (cont.)

FY2007 Solar AOP — Module Failure Analysis Agreement:

- [Address] module reliability, and thereby system-level performance, through elimination of failure modes that are identified from a failure investigation.
- Attempt to identify the causes of failures observed during testing at the national laboratories, or in modules deployed in the field.
- Diagnostic tools:
  - infrared imaging cameras
  - light and dark I-V measurements
  - quantum efficiency measurements
  - core sampling
  - polymer and adhesion diagnostics
  - surface analysis
  - laser spot scanning.



Summary of Activities

- Major technical focus is support of PV industry with module and system reliability.
- Most important outcome with regard to cost of PV-generated electricity is determination of module degradation rates.
- Personnel:
  - C.R. Osterwald, B. Sekulic, D. Trudell, P. McNutt, J. del Cueto, T.J. McMahon, J. Pruett, B. Marion, R. Hanson, G. Jorgensen, B. von Roedern, H. Ullal

Budget History

Project Task(s)	Total Value
PVB6.7101: Exploratory Reliability & Performance R&D	$1,269K
PVC6.7101: PV System Performance and Standards	$967K
PVB7.7101: Module and Array Testing	$2,240K
PVB7.7201: Module Failure Analysis	$500K
Grand Total	**$4,976K**

Accomplishments

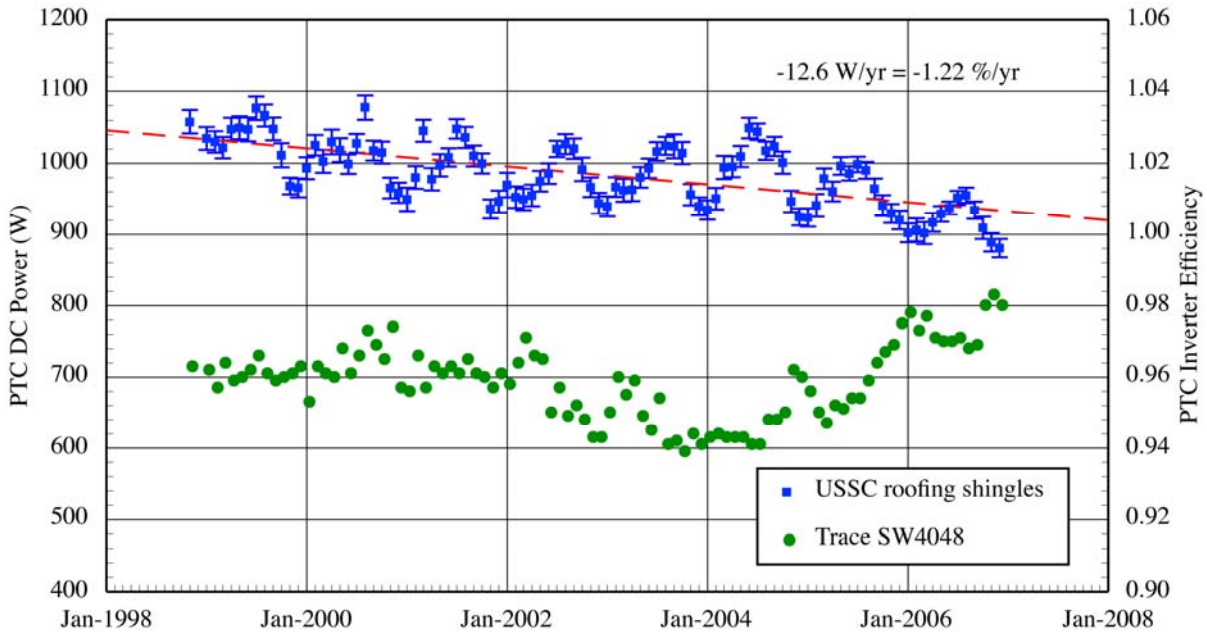
Real-Time Outdoor System Testing:

- Currently 11 grid-tied systems monitored at the OTF — x-Si, ribbon-Si, a-Si, CdTe, and CIGSS.
- New Shell CIGSS thin-film system installed ("Eclipse" 80W modules).
- Two new SunPower high-efficiency x-Si systems installed.

Accomplishments (cont.)

Real-Time Outdoor System Testing:

- Quarterly test reports delivered to module manufacturers
- Linear regressions to Performance Test Conditions (PTC, 1000 W/m^2, 1 m/s wind speed, 20°C ambient), for data blocks one month long
- DC and AC PTC power regressions give PTC inverter efficiency
- System degradation rates in percent per year.



Accomplishments (cont.)

Indoor Module Accelerated Stress Testing:

- Extensive series of thermal cycling and damp heat sequences performed for SunPower
- Thermal cycling and humidity-freeze cycling on Solar Roofing Systems prototype laminate coupons
- Thermal cycling with forward current bias on Advent Solar prototype modules with Emitter Wrap-Through (EWT) Si solar cells.
- Thermal cycling and hot-spot protection performed in support of Underwriters Laboratories (UL) module safety certification.

Accomplishments (cont.)

Indoor Module Accelerated Stress Testing:

- New environmental chamber for damp heat testing of large-area modules procured with FY2006 capital equipment funds
- New qualification/safety tests implemented/upgraded:
  - Ground continuity
  - Bypass diode thermal
  - Hail impact
  - Mechanical load
  - Cut susceptibility
  - Temperature test
  - Robustness of terminations
  - Reverse current overload
  - Accessibility test
  - J-Box securement
  - Wet/dry hi-pot
  - Thermal cycling w/ forward bias.

Accomplishments (cont.)

Performance and Energy Ratings Testbed (PERT):

- 45 module channels in three Raydec Multi-Tracer II electronic loads for continuous maximum power-point loading with periodic I-V curves
- Nearly continuous operation since 1993
- Degradation rates determined with PTC power regressions, comparison report published in 2006 — showed that the common 1% per year rule-of-thumb isn't unreasonable, but varies greatly between modules and manufacturers.
- Major refit currently in progress — new data acquisition computers installed; new outdoor instrumentation installed; aged and cracked module load wiring being replaced.

Accomplishments (cont.)

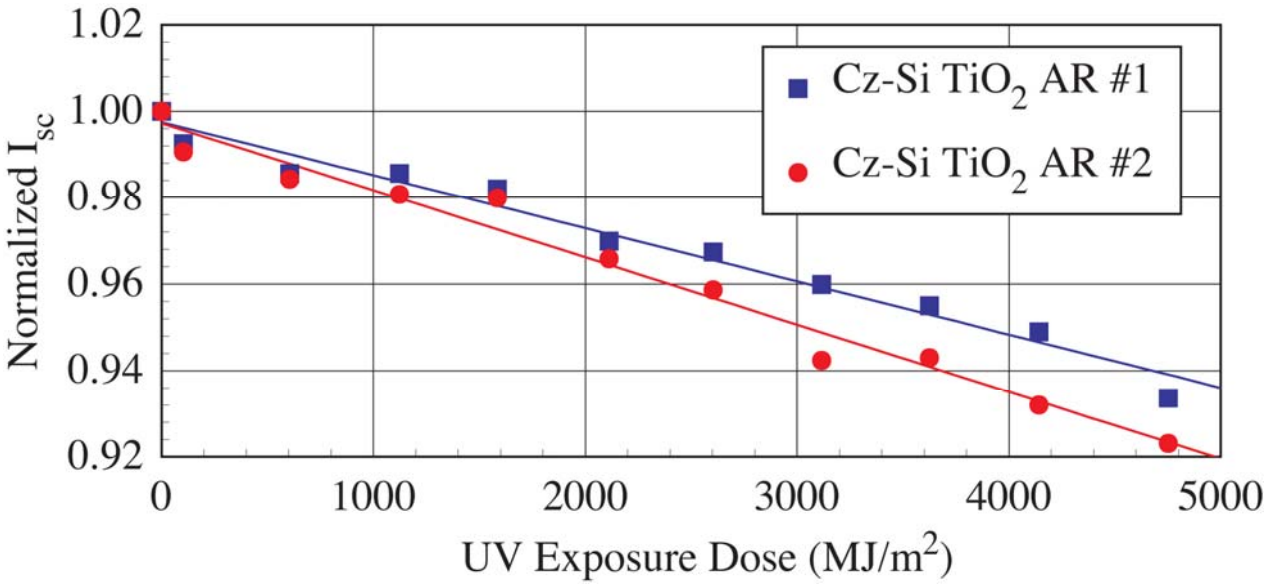
Module Energy Ratings :

- Broad research topic — from IEC 61853-style standard day ratings to one-year ratings at specific locations
- Currently investigating the problems and issues with using PERT data to obtain standard day ratings.
- Analysis of average photon energy (APE) versus air mass has shown that a simple air mass qualifier to model spectral variations is insufficient.
- Research is continuing — will hopefully be used to guide final form of the draft IEC 61853 standard.

Accomplishments (cont.)

Module Failure Analysis:

- New torsional shear measurement of encapsulant materials from module core samples implemented — see poster by Gary Jorgensen and Tom McMahon.
- Long-term study of slow, linear short-circuit current loss in x-Si cells in module packages continues with over 17 years' equivalent UV exposure.
- Thin-film hot & humid exposure subcontracts — testing at FSEC & TAMU continues; both subcontracts extended through FY2007; exposure data delivered to NREL for archiving and analysis.



Accomplishments (cont.)

Outdoor High-Voltage Stress Test (HVST):

- Exposure test with individual modules held at ±600V WRT the frames.
- Leakage currents measured in real time.
- Looks for possible long-term effects of high-voltage bias, especially corrosion.
- New high-voltage test on a Shell CIGSS thin-film array initiated (2006).
- Uses active maximum power-point tracking while array leakage currents are measured; periodic I-V curves.

Schedule of Maj. Events/Milestones

Milestones — Module and Array Testing:

Establish T&E Working Group, coordinate lab activities, and provide T&E support for DOE/TPP participants (with Sandia).	9/30/07
Deliver system performance reports & analyses to module manufacturers.	Quarterly
Obtain UL accreditation at NREL for IEC61215 (qualification) and IEC61730 (safety) testing of modules.	9/30/07
Evaluate modules in Performance and Energy Ratings Testbed, replace with new technologies as needed.	5/31/07
Support test and analysis for thin-film, hot & humid module exposure contracts and other in-house and contract research.	9/30/07
Report on feasibility of using PERT data for module energy ratings, IEC standard.	9/30/07

Schedule of Maj. Events/Milestones

Milestones — Module Failure Analysis:

Continue investigation of I_{sc} degradation in encapsulated c-Si modules.	9/30/08
Develop diagnostic methods to address failure mechanisms that develop with new prototypes or fielded systems.	9/30/07
Support the requirements of SAI/TPP participants for failure analysis.	9/30/07, continuing

Future Directions

- Test & evaluation in support of Stage-Gate reviews for SAI TPPs
- Expansion of indoor accelerated stress test capacity — floor space now available at OTF for two new environmental chambers, but depends on increasing building electrical power service
- Increasing capacity for outdoor degradation rate measurements on large numbers of higher-power modules — will require development of inexpensive maximum power point tracking loads
- Increasing rack space and grid capacity for additional small grid-tied systems in the OTF array field.