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Proceedings of the 1999 Photovoltaic Performance and Reliability Workshop

T.S. Basso, Editor

Presented at the 1999 Photovoltaic Performance and Reliability Workshop
Vail, Colorado
October 18-21, 1999

National Renewable Energy Laboratory

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Preface

This report compiles the presentations made at the 1999 Photovoltaic Performance and Reliability Workshop, held on October 18-21, 1999, at the Vail Cascade Hotel in Vail, Colorado. Also included are summary notes of the workshop discussion sessions. This was the twelfth such workshop since its inception and was sponsored through the National Center for Photovoltaics, funded by the U.S. Department of Energy. The National Renewable Energy Laboratory hosted this year's meeting.

The focus of the workshop was on testing, test methods, evaluation, and standards. Tutorial presentations and open discussion sessions allowed everyone to contribute and learn from one another. The presentations were followed by discussion sessions, which addressed the needs and requirements expressed by the participants.

All of the 65 PV industry and research workshop attendees contributed during the workshop, and they are acknowledged for their questions and comments. In particular, we acknowledge the workshop presenters and panelists: J. Berdner, W. Bottenberg, W. Bower, S. Chalmers, R. DeBlasio, S. Jochums, D. King, B. Kroposki, W. Marion, C. Osterwald, C. Whitaker, and J. Wohlgemuth. In closing, we also acknowledge the following individuals for their contribution to developing the workshop: the Planning Committee—R. DeBlasio, B. Kroposki, H. Post, and M. Thomas; the Session Chairs—B. Kroposki, C. Osterwald, W. Bower, and A. Rosenthal; Workshop Chairmen—T. S. Basso and P. McNutt; and Workshop Logistics and Coordination—K. Taylor and B. Ferris.

T. S. Basso and P. McNutt, NREL

Workshop Chairmen

Contents

1. Overview

The theme of the 1999 Photovoltaic Performance and Reliability Workshop was "Setting a Standard for PV Performance and Reliability," with the focus on testing, test methods, evaluation, and standards. The workshop plan was to provide a venue for technical discussions on four topical areas: module rating, module qualification, power processing, and systems.

Opening remarks at the workshop were presented by R. DeBlasio, who welcomed participants and introduced the personnel involved in planning and implementing the workshop. Tutorial presentations and open discussion on individual concerns, issues, and solutions both served as the means for all to contribute and learn from one another. Morning presentation sessions were followed by afternoon standards development meetings to address the needs and requirements established in the morning. The afternoon panel discussions included representatives from IEEE SCC21, ASTM E44.09, IEC TC82 U.S. TAG, the NEC, UL, and others, who discussed potential new projects identified in the morning and the need to revise published standards or develop new standards project authorization requests (PARs).

In addition, co-located with the workshop, there were three topical meetings on: lead-free solder for PV modules, ASTM solar simulator considerations, and PowerMark Corporation technical meeting that addressed system certification and module performance testing. These topical meetings were not formally part of the workshop and are not reported in these proceedings.

In the four topical areas of the workshop, a repeated theme was that we need to ensure that the U.S. PV industry is in concert with, and at the forefront of, international PV module and systems technology activities. An overview of the outcome of the workshop includes the following.

I) Module Performance Rating. IEEE PAR 1479 "Draft Recommended Practice for the Evaluation of Photovoltaic Module Energy Production" – proceed with validating the models, inputs, and the standard's clauses; complete the draft by the IEEE working group; look closely at the need to develop a similar activity for system energy rating.

II) Module Qualification Testing. IEEE Std.1262 "Recommended Practice for Qualification of PV Modules" – establish a PAR for 1262 test program revisions; continue validation of proposed new qualification tests at NREL, ISPRA, and U.S. PV industry and test lab facilities. How do we ensure that new products and potential new failure mechanisms are included in qualification program? And, a repeated statement was that reliability testing should be done and that it should include module qualification.

III) Power Processing. It was recommended to pursue new IEEE PARs for inverters and for charge controllers. The most pressing concerns expressed by individuals included system design and system components integration aspects; reliability assurance; interconnection and the need for a uniform, national approach; testing; and, infrastructure development, e.g., outreach/education, qualification, accreditation, certification, and national/international standards development.

IV) Systems Evaluation. The most pressing concerns stated primarily reiterated the concerns in the power processing session, and additional concerns were about installation. There was much discussion about packaged systems and appliance-level approaches to PV systems and their validation.

IEEE PAR 1373 "Draft Recommended Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems." There was much discussion of the appropriate levels of recommended testing; it was recommended to complete this IEEE Draft Std 1373 and to focus on the need to develop an IEEE PAR activity for system energy rating.

IEEE PAR 1526 – "Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems" – it was recommended to build on the completed initial testing validation at four U.S. sites by conducting a validation of the revised practices, and aggressively pursue the previously initiated international testing validation involvement.

2. Module Performance Rating – October 18, 1999

Subsection 2.1 lists the planned agenda, which identifies the topical areas. Subsection 2.2 presents summary notes, after which we include the compilations of the presentations made at the workshop. The titles of the presentations do not necessarily match the exact wording of the agenda topics.

2.1 Agenda – Session I - Module Performance Rating

Session I: 8:45 AM – 5:00 PM – Workshop Chair: T. Basso

General Session (8:45 AM – 12:15 PM): Organizer and Session Chair - B. Kroposki

- Module Performance Ratings Tutorial (1 hour) - W. Bottenberg
- Photovoltaic Module Performance Modeling (30 minutes) - D. King
- Validation of Module Energy Ratings Procedure at NREL (30 minutes) - W. Marion
- Open Discussion (1 hour) - Facilitator: B. Kroposki
- Session Summary (15 minutes) - T. Basso

Standards Panel/Discussion (1:30 PM – 5:00 PM): Facilitator - T. Basso

- IEEE WG P1479 - B. Kroposki – P1479 Draft *Recommended Practice for Evaluation of Photovoltaic Module Energy Production*
- ASTM E44.09 - C. Osterwald – American Society for Testing and Materials (ASTM) Committee E44 on Solar, Geothermal and Other Alternative Energy Sources Subcommittee E44.09 on Photovoltaics
- IEC TC82 US TAG - S. Chalmers and J. Wohlgemuth IEC TC83 WG2 – International Electro-technical Commission (IEC) Technical Committee 82 (TC82) *Solar Photovoltaic Energy Systems* U.S. Technical Advisory Group (TAG), and Modules Working Group (WG2)

2.2 Module Performance Rating Session Summary Notes

The session started with W. Bottenberg's presentation on the history and industry needs for module performance rating. He provided an overview of the basics of a number of the more well-known module rating models; for the current methods, he stated a number of the problems/unfinished business aspects. He concluded with several points: excellent progress has been made; we are closer to developing consistent module methods that can increase the accuracy for system sizing and help reduce performance risk; and while the consensus method is slow, it appears to allow for achieving scientifically sound methods for module rating.

In his presentation, D. King stated that the objectives were to develop integrated tests and a performance model based on outdoor field measurements; adequately address systematic influences on performance; and demonstrate for modules and arrays, for clear and cloudy operating conditions, a system design based on power or energy. He concluded the following: the performance measurement and modeling procedures were verified for many technologies and are applicable to cells, modules, and arrays; outdoor field-test methods were documented and being submitted as proposed standards; and design comparisons based on annual energy production are now possible.

The purpose of the module energy rating methodology presentation by W. Marion was to validate a procedure for incorporation into IEEE PAR 1479 "Recommended Practice for the Evaluation of Photovoltaic Module Energy Production." By comparing model estimates with outdoor measurements, he concluded that the uncertainty in relative performance included a reproducibility limit of 6.7% for different test facilities. And further, he stated "because of errors in measurements and energy rating methodology, differences of 8% or less in the energy rating of two PV modules are not significant. If one of the PV modules is amorphous silicon, differences of 13% or less are not significant."

The group discussions included recommendations that a future need is to take this module work to the next level for systems integration, but first, to reach a completion level for module energy rating. The group discussions included concerns that upcoming focus should be on completing the additional work to bring IEEE P1479 to ballot, and similarly, for addressing potential revisions to the related existing standards under the American Society for Testing and Materials. There were also concerns about the international arena and the potential impact or role that the IEEE/U.S. consensus module energy rating standard would have in a world market.

Module Performance Ratings

Tutorial on
History and Industry Needs

William Bottenberg
Photovoltaics International, LLC

Presented at
PV Performance, Reliability and Standards Workshop
Vail, CO
October 18, 1999

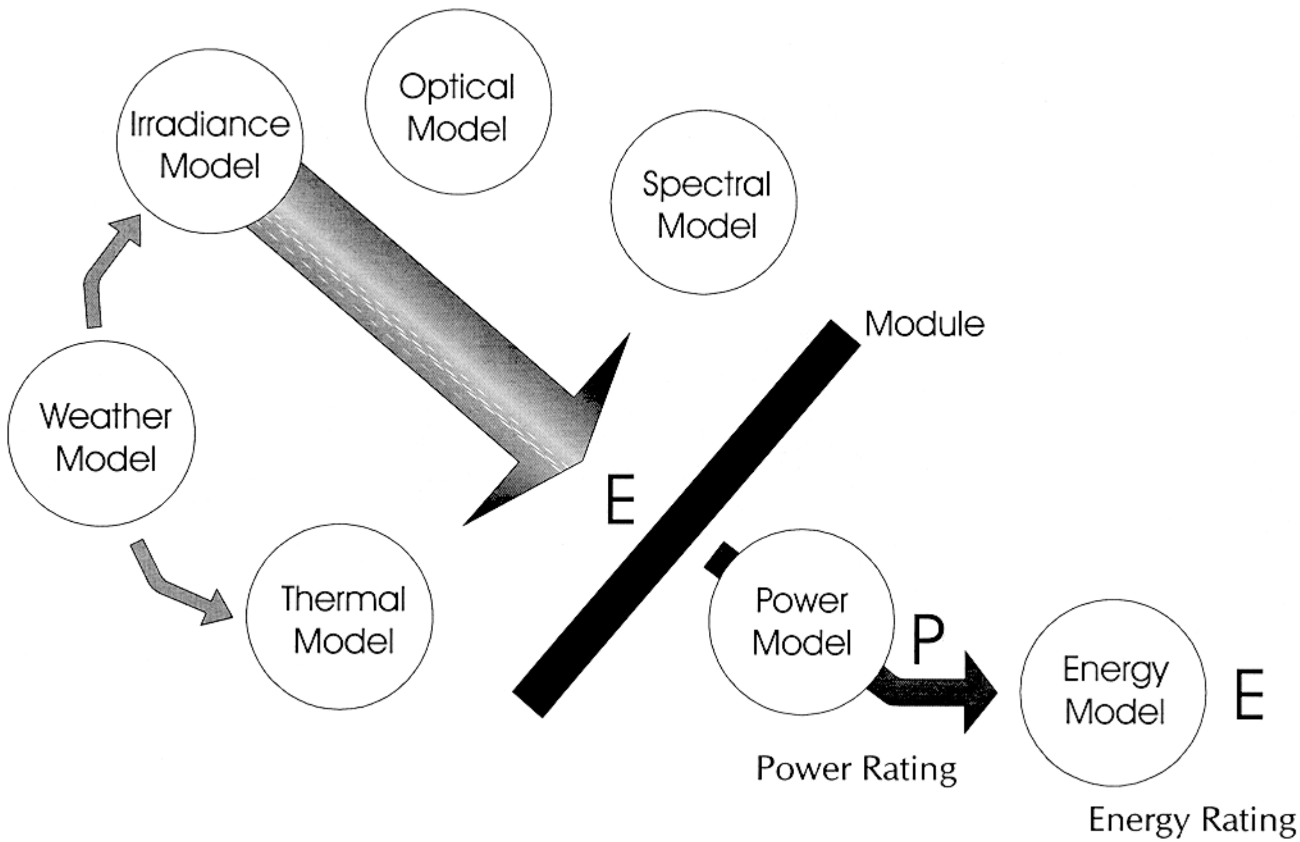
Module Rating Schemes

- Instantaneous Power
  - Amenable to Factory Testing
- Module Energy Delivery
  - More meaningful to customer

Categorization of Methods
Module Model - Some Fundamentals

- Need at least
  - Irradiance Value, Module Temperature
- May also use
  - Ambient Temperature
  - Wind Speed
  - Radiation Spectral Content

Models In Rating Engine



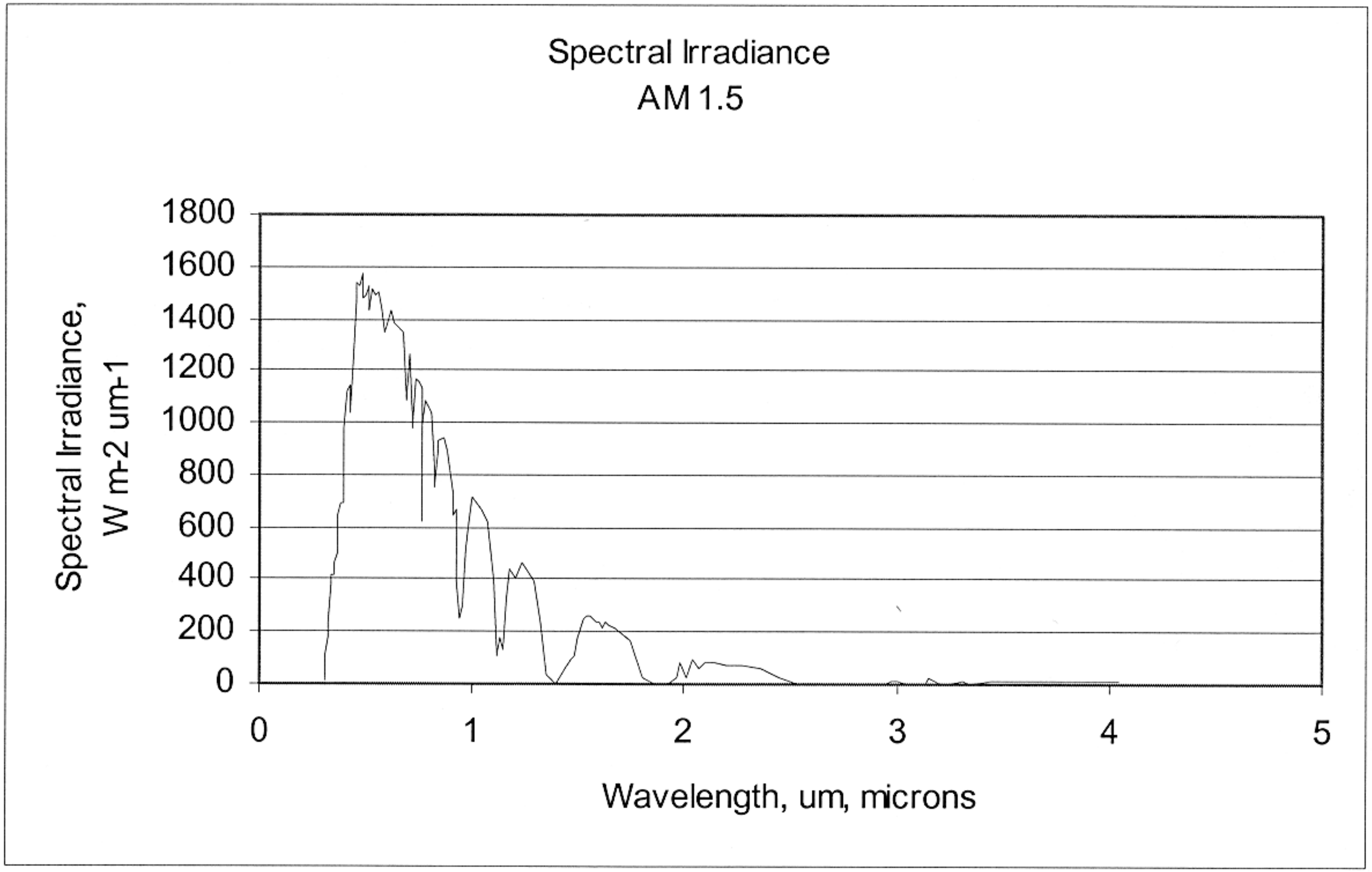
Summary of Standard Conditions

Standard Name	Irradiance, W/m^2	Temp., °C	Wind Speed	Purpose
STC/SRC (Standard Reporting Conditions)	1000 global AM1.5	25 (cell)		Indoor measurement of peak power (used in PV mfgr catalogs)
PTC (PVUSA Test Conditions) flat plate	1000 global AM1.5	20 (ambient)	1 m/s	Outdoor measurement of peak performance
PTC (PVUSA Test Conditions) Concentrator	1000 global AM1.5 850 DNI AM1.5	20 (ambient)	1 m/s	Outdoor measurement of peak performance
NTE (Nominal Terrestrial Environment)	800 global	20 (ambient)		Most common operating conditions
NOCT (Nominal Operating Cell Temperature Conditions)	800 global	20 (ambient)	1 m/s	Outdoor measurement to determine Tcell

From S. Kurtz, 1998 (unpublished)

Source of Reference Conditions and Notation

- 1000 w/m^2 - global irradiance
  - a standard for the flux of solar radiation incident on a plane surface
  - a round number commonly observed in most parts of the world at high solar elevation angles near solar noon
- AM 1.5 global - spectral irradiance
  - refers to a specific spectral irradiance standard - as shown in next slide


Spectral Irradiance
AM 1.5
Spectral Irradiance,
W m-2 um-1
1800
1600
1400
1200
1000
800
600
400
200
0
0
1
2
3
4
5
Wavelength, um, microns

Historical Overview

- JPL/NOCT Method
- SRC - ASTM Standard
- AM/PM Model
- Realistic Reporting Conditions ISE Fraunhofer RRC Model
- PTC - PG&E and PVUSA
- Sandia Models
- NREL Models
- MER

JPL & NOCT

- Instantaneous Power Rating
- Developed as part of the flat plate solar array program
- Uses nominal operating cell temperature concept:
  - Irradiance: 800 w/m2
  - Tambient: 20°C
  - Wind Speed: 1 m/s
  - determine Tcell at these conditions
- 20°C selected because of study by JPL of median ambient temperature after multi-city data analysis

JPL & NOCT

- NOCT was a valuable concept since it emphasized the fact that module rating must recognize temperature of operation
- The NOCT method of deriving the cell temperature as a function of insolation and heat transfer stimulated further work
- However, the typical NOCT temperature of 40-45°C was too low to accurately reflect most modules actual performance.

Standard Reporting Conditions & ASTM

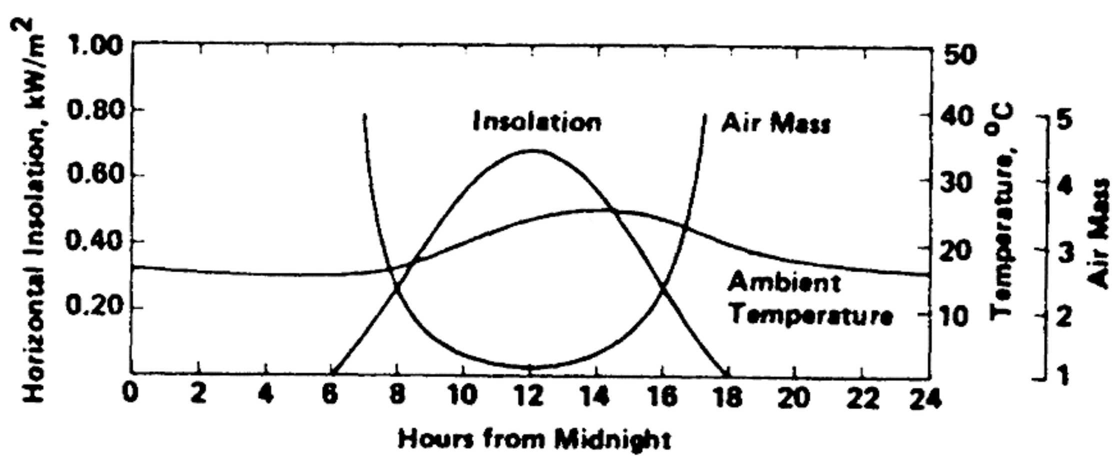
- Instantaneous Peak Power Rating
- Combines NOCT and the concept of Standard Test Conditions (STC)
- STC:
  - Irradiance: 1000 w/m^2 Air Mass 1.5 spectrum
  - Cell temperature: 25°C
- Test and curve translation methods have been memorialized as an ASTM standard 1036-96 for flat plate modules

SRC -- Standard Reporting Conditions

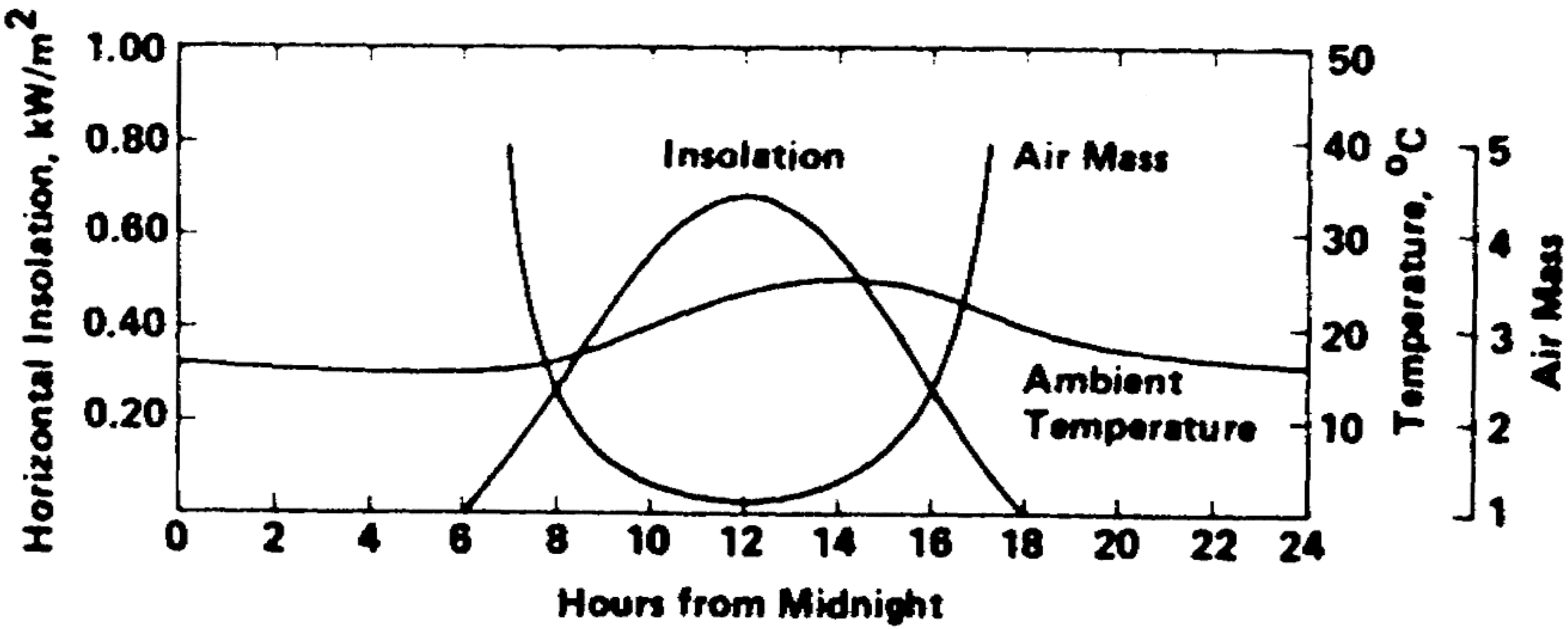
- SRC rating is very convenient for manufacturers since a wide variety of cell and module test machines can be calibrated to give consistent results using ASTM and IEC methods for spectral correction.
- On every module label
- Problems
  - SRC is not representative of operating conditions, since cell temperature is 25 - 40°C higher most of the time under normal operation
  - It has been shown that early curve translation methods were faulty. Because translations had to be made over wide ranges, poor predictions of module performance were obtained.

AMPM -- All-Day Module Performance Model

- Gay et al. recognized that instantaneous power ratings would not clearly tell buyers what the energy generation capability of modules would be
- Among the first module energy rating methods
- Defined a standard day - the 'World Standard Day' based on
  - A horizontal insolation profile with maximum value of 800 w/m2
  - An air mass profile
  - An ambient temperature profile



AMPM -- World Standard Solar Day

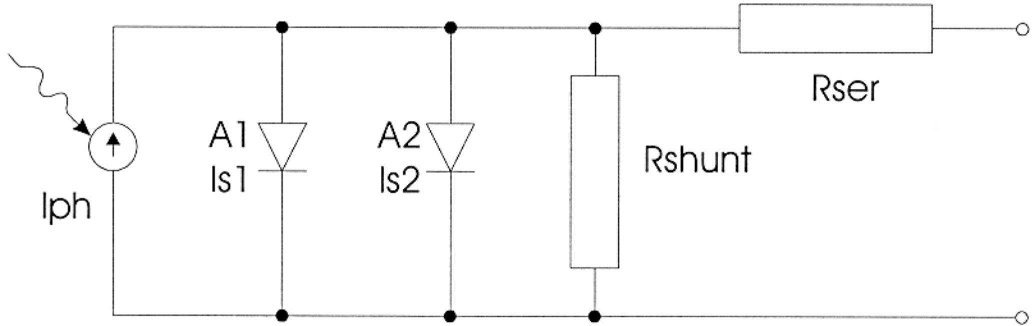


Module Performance Ratings Tutorial
PV PR&S Workshop

10/18/1999
wrb/PVI

Realistic Reporting Conditions - RRC

- Developed at ISE Fraunhofer by Heidler et al. (1990)
- Employs 2 diode model to calculate I-V curve
- Requires evaluating lumped parameters over a wide range of conditions. They found that they needed to stitch together I-V parameter sets over the temperature range. One set of parameters could not be satisfied over the whole range.



Realistic Reporting Conditions - RRC

- The temperature dependence of the cell performance is completely contained in the temperature dependence of the parameters.
- The energy rating model works well when there is a good cell model for its basis. Works best with crystalline Si.

PVUSA Test Conditions - PTC

- PG&E developed a power regression model based on extensive measurements at San Ramon facility and later at PVUSA of installed modules.
- The initial problem was that SRC/STC ratings could not predict power output of installed modules.
- Used a simple 'heuristic' model:

$$P = A_1 \cdot E + A_2 \cdot E^2 + A_3 \cdot E \cdot T_{amb} + A_4 \cdot E \cdot WS$$

E: Irradiance
Tamb: Ambient Temperature
WS: Wind Speed

PVUSA Test Conditions - PTC

- Regression is performed on qualified data over a 30 day period using irradiance values above 500 W/m^2
- Model does not work well for low irradiance values probably because of incidence angle effects
- Energy rating can be obtained by multiplying the power rating by the number of sun hours in the time period. This method works surprisingly well.
- Model needs to be modified to handle 1-axis trackers

Sandia Performance Modeling Efforts

- King et al. have been developing regression models that are intended to apply to arrays, but these models are based on module testing and characterization as well
- Stimulated by inadequacies of STC and PTC ratings, regression methods have been developed to account for angle of incidence effects, spectral effects and to enable validation of outdoor testing
- Model includes different temperature coefficients for Imp and Vmp
- A simplified model for module operating temperature was introduced based on irradiance and wind speed

Sandia Performance Modeling Efforts

- The model predicts the values for Voc, Isc, Vmp and Imp as a function of irradiance, air mass, angle-of-incidence and module temperature
- Typical equation as modified for use in 1-axis low concentrator application:

$$I_{sc}(T_c, E_{DNI}, E_{DIF}, AM_a, AOI) = [(E_{DNI}/850) * f_1(AM_a) * f_2(AOI) + C_6 E_{DIF}/150] * \{[I_{sco} / (1 + C_6)] + \alpha_{isc}(T_c - 50°C)\}$$

- This a non-linear equation, but has proven useful for analyzing rooftop module data for our concentrators

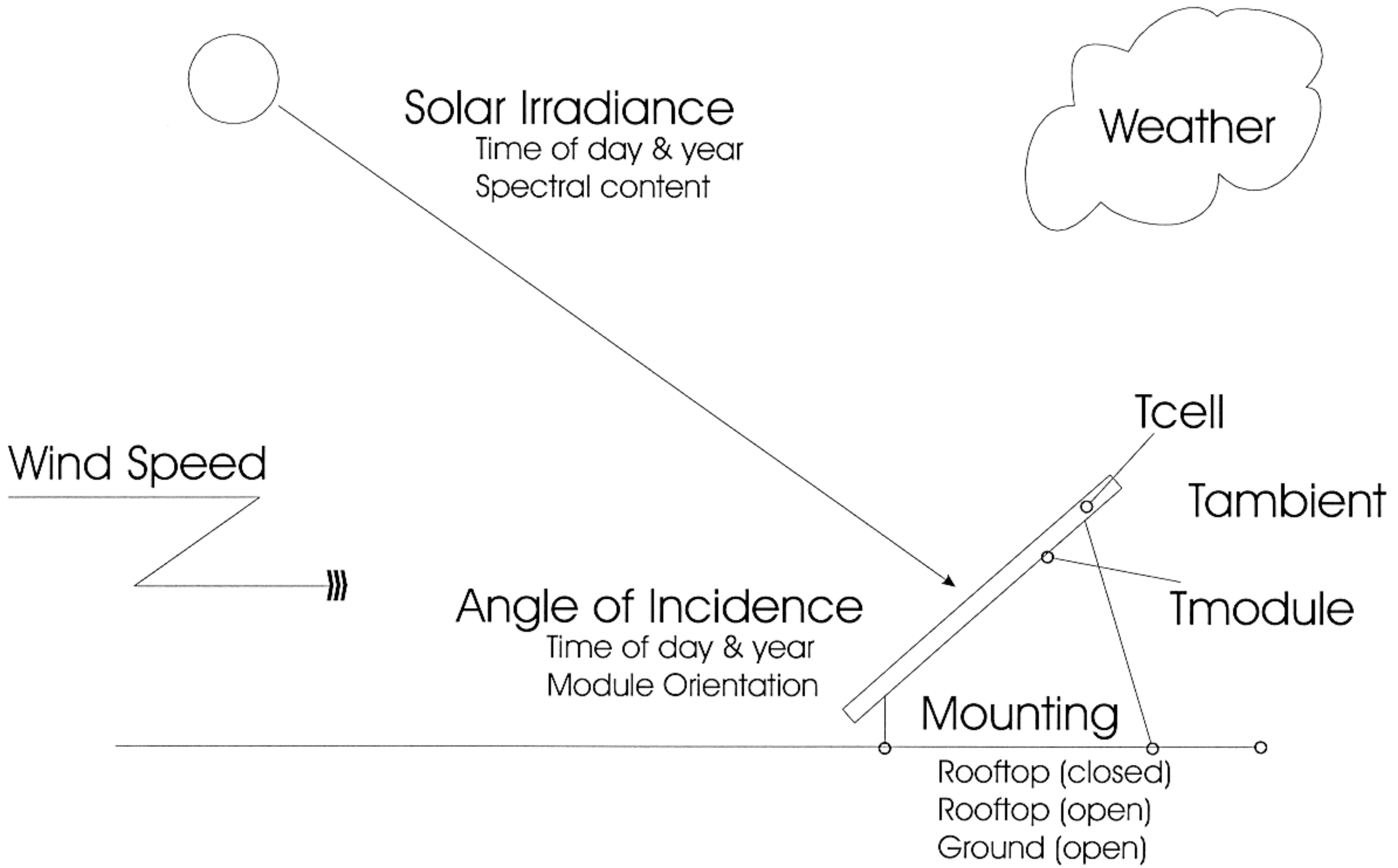
Sandia Performance Modeling Efforts

- Model assumes that all properties of module can be predicted by calculating an effective irradiance and use of an effective module temperature
- Model does not model I-V curve, only Voc, Isc, Vmp, Imp and Pmax
- Results are encouraging for both flat plate and concentrator module modeling.
- Results need to be extended and validated for energy rating purposes

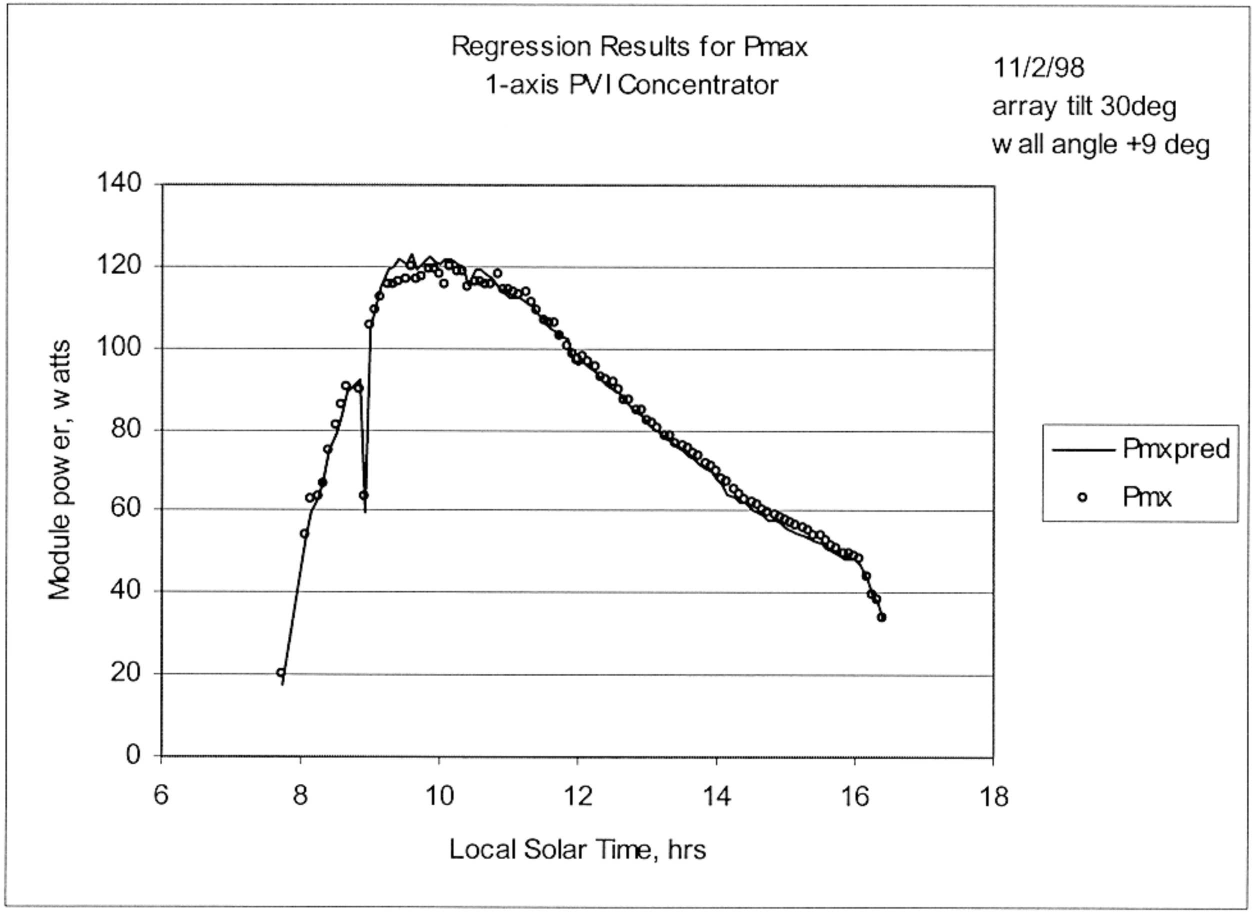
Talk Outline

- Introduction
- Module Rating Schemes
- Historical Overview
- Problems
- Consensus Approach and Industry Requirements
- Conclusion

Module Environment and Factors that Affect Ratings



Model Power Prediction - PVI Concentrator



NREL Performance Modeling Efforts

- One focus of effort over the last five years has been on developing I-V curve translation models to enable effective energy rating procedures
- MER Procedure addresses a variety of standardized days
  - Hot Sunny - Phoenix, AZ
  - Cold Sunny - Alamosa, CO
  - Hot Cloudy - Brownsville, TX
  - Cold Cloudy - Buffalo, NY
  - Nice - Sacramento, CA
- MER Model addresses two 'applications'
  - Peak power operation
  - Battery charging
- Module Energy Rating (MER) is now being validated

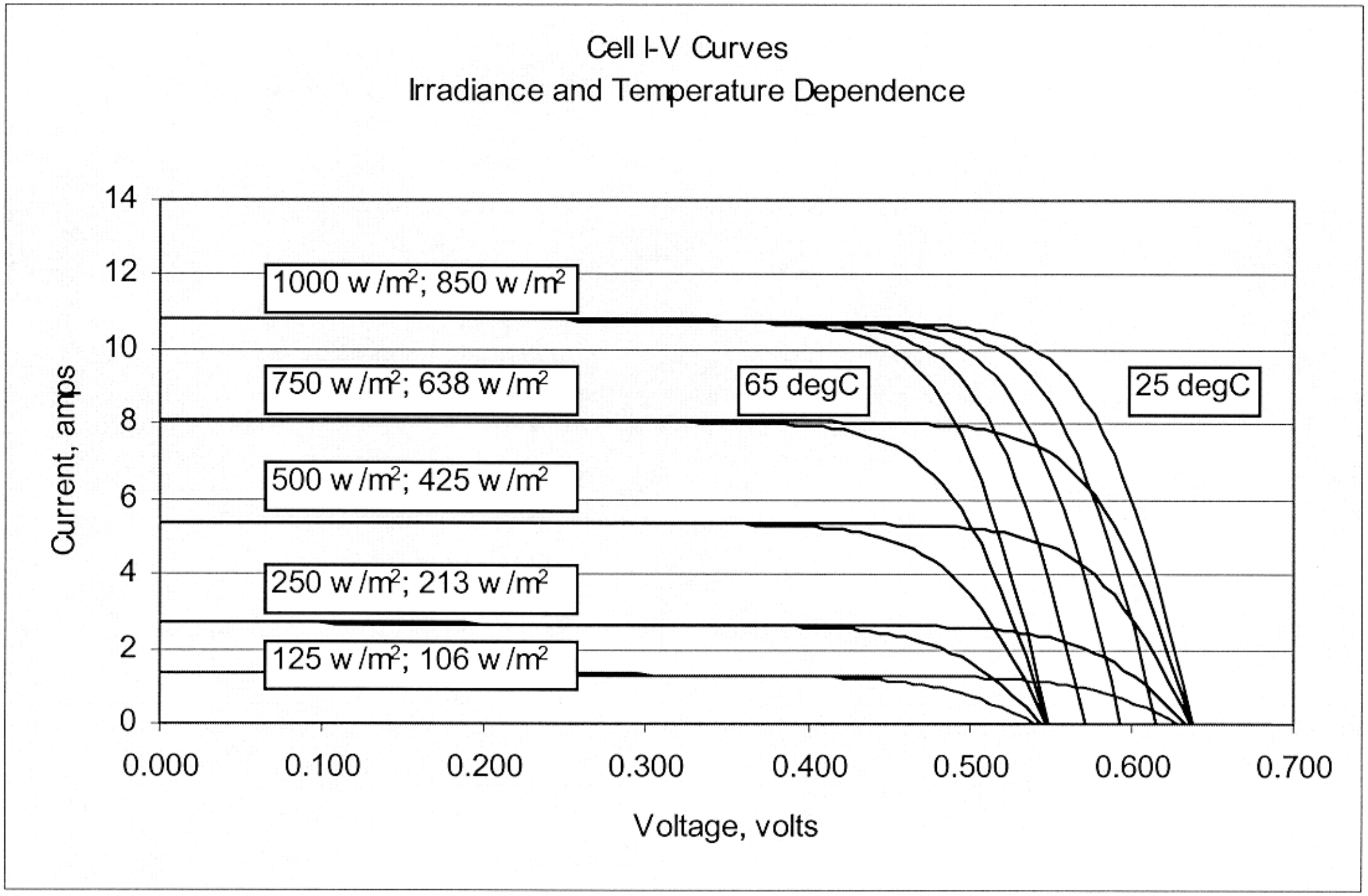
MER Model Flow Diagram

From Whitaker and Newmiller, 1998

Module Power Models

- Linear, Irradiance Only Model
  - Meyers (1998)
- Curve Translation Model
  - Anderson (1994
  - Blaesser (1995)
- Lumped Parameter Models (2 diode)
  - Heidler et al. (1986)
  - Knaup (1998)
  - Whitaker (1998)

Cell I-V Curve Varies Non-Linearly with Temperature and Irradiance



Anderson Curve Translation Model -modified to account for ff effect -

- Includes effects of temperature and irradiance on Voc and Isc
- Uses an array of I-V curves which span the conditions of interest:
  - e.g. Measure module at 5 temperatures and 5 irradiances
  - 25 curves:
  - temperature: 25°C to 55°C
  - irradiance: 125 w/m^2 1000 w/m^2
- Set Reference Condition Curve as 1000 w/m^2 and 25°C
- Determine translated voltage-current pairs by using reference condition ratio and nearest reference curve
- Use newly constructed curve to determine Pmax or P(Vop)

Anderson Curve Translation Model

$Isc = (E / E_o) \cdot Isc_o \cdot [1 + \alpha \cdot (T - T_o)]$

$Voc = Voc_o \; [1 + \beta(E_o) \cdot (T - T_o)] \cdot [1 + \delta(T) \cdot \ln(E / E_o)]$

---

use the reference curve from the matrix of curves with the closest irradiance and then the closest temperature

---

$I = I_R \cdot (Isc / Isc_R)$

$V = V_R \cdot (Voc / Voc_R)$

E, E_o Measured and SRC Irradiances (W/m^2)

α, β, δ Regression coefficients

- Presently the method of choice for MER DC Power model

Problems/Unfinished Business in Module Rating

- Need to develop better determination of module temperature as a function of irradiance and wind speed.
- Need to validate use of Voc to determine cell temperatures (applications for hard to measure modules).
- Need to handle other geometries than fixed latitude tilt.
- Need to develop and validate concentrator models, including: thermal model, angle of incidence and spectral response.
- Need to tie together indoor and outdoor measurement methods.
- Need to validate and settle use of $f_1(AM_a)$ vs. spectral response method.
- Need to validate use of reference cell techniques for flat plate modules and concentrator modules.
- MER still has problems with some thin-film modules.
- Need to continue to relate module performance to array performance.

Problems/Unfinished Business in Module Rating

- Still have knotty problems in addressing tandem junction modules in a consistent way with other technologies.
- S. Kurtz's discussion of the correct rating point for concentrators need to be discussed more thoroughly.
- Building integrated PV puts a particular strain on these methods since the modules appear at 'architecturally' pleasing orientations rather than 'insolarlationally' pleasing orientations.
- AC modules have not been considered.
- There continues to be a deep and abiding need for useful data for solar resources over the rest of the world.
- Need consensus on battery charging scenarii

Problems/Unfinished Business in Module Rating

- Goal not yet met
  'Define procedures and techniques for measuring module characteristics and estimating module performance at the representative conditions'
- The combined errors are too high: as C. Whitaker said
  'The combined errors in characterizing module performance, in translating indoor measurements to outdoors, in measuring ambient conditions and module performance, and in accounting for all of the various parameters affecting module performance exceed the accuracy required to compare one module to another under a variety of conditions.'

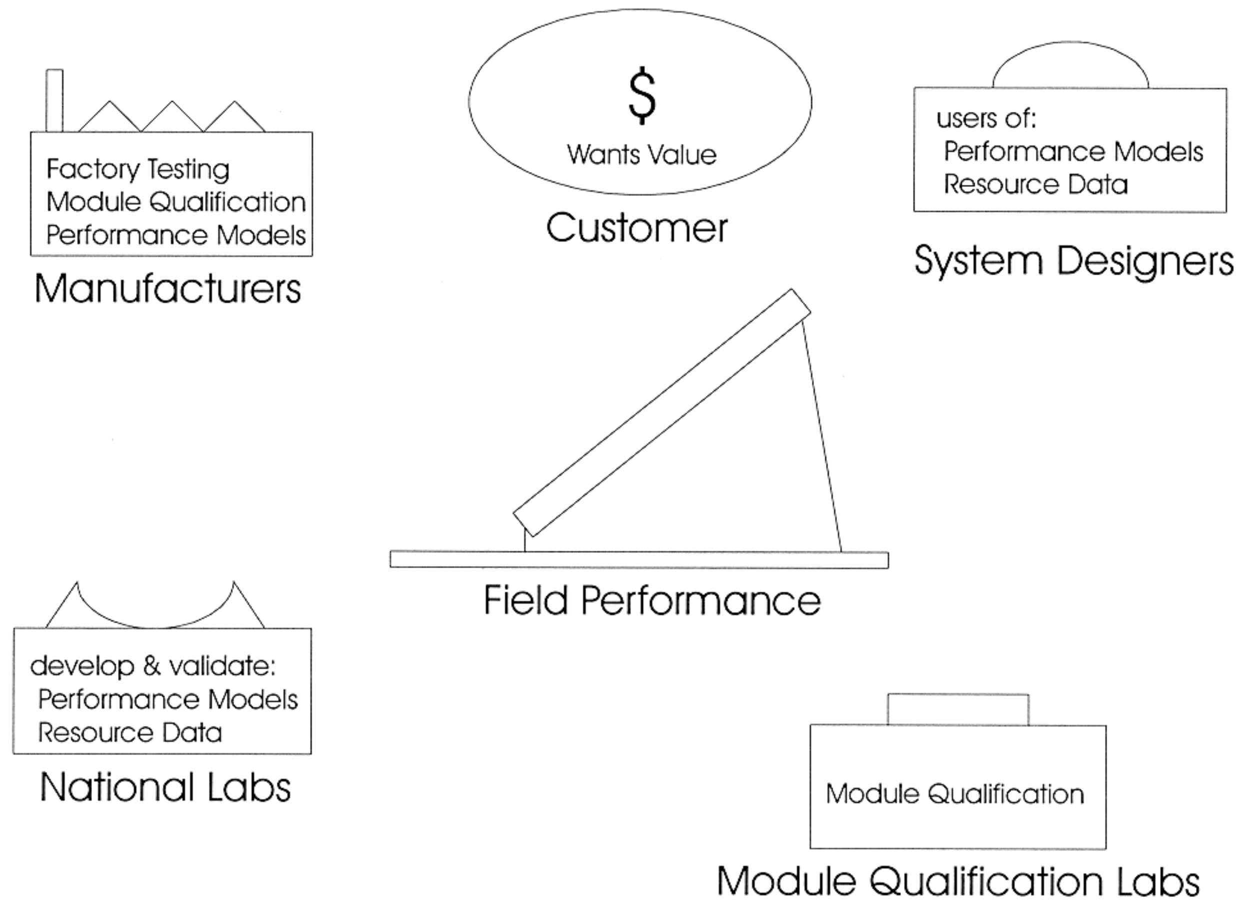
Problems/Unfinished Business in Module Rating

- Still to be done
  - Reach a consensus on the level of accuracy required for the process. This probably requires ±5% over the range of conditions.
  - Current methodolgy yields:

Measurement Scope	Model/Translation Random Errors, %	
	Cell Technology Type	
	Crystalline	Amorphous
All measured days	9	13
Selected reference days	5	11

  - NREL Reports NREL/SR-520-23942 and NREL/TP-520-26909 give an excellent review of the problems and approaches.
  - King's 1998 paper addresses many of the same problems

Roles in Module Rating Method Development



Conclusions

- Excellent progress has been made in the last 5 years on developing the criteria and bases for module rating.
- The development of these methods have greatly cleared the brushwood around older array performance algorithms. Sound array sizing methods require a bedrock of module performance models. We are much closer to developing consistent methods that can increase the accuracy of system sizing and help to reduce performance risk.
- The consensus method, while slow, appears to allow for cross-fertilization of approaches which will produce scientifically sound methods for module rating.

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Photovoltaic Module Performance Modeling

D. L. King, W. E. Boyson, J. A. Kratochvil
Sandia National Laboratories

PV Performance, Reliability, and Standards Workshop
10/18/99

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Where is "modeling" used?

- "Ratings"
  - Standard Reporting Condition (ASTM E 1036)
  - 5 Day:Site Module Energy Rating (IEEE 1479)
  - Array power field test (IEEE 1373)
  - PVUSA Test Conditions (PTC)
- System Design
  - Power at specified operating condition
  - Winter amp-hour production
  - Annual energy production
- System Performance Monitoring

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What is the ideal situation?

- "Integrated" test procedures and models
- Closely related test procedures for cells, modules, and arrays
- Common tests and models for all PV technology types
- Applicable to different system designs

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Our Objectives

- Develop integrated tests & performance model based on outdoor (field) measurements
- "Adequately" address <u>systematic influences</u> on performance. Accept random influences.
- Demonstrate for <u>modules and arrays</u> for clear and cloudy operating conditions
- System design based on power or energy

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What are systematic influences ?

- Incorrect nameplate rating
- Hourly variations in:
  - Solar irradiance
  - Operating temperature (Temp Coefs)
  - Solar spectrum
  - Solar angle-of-incidence

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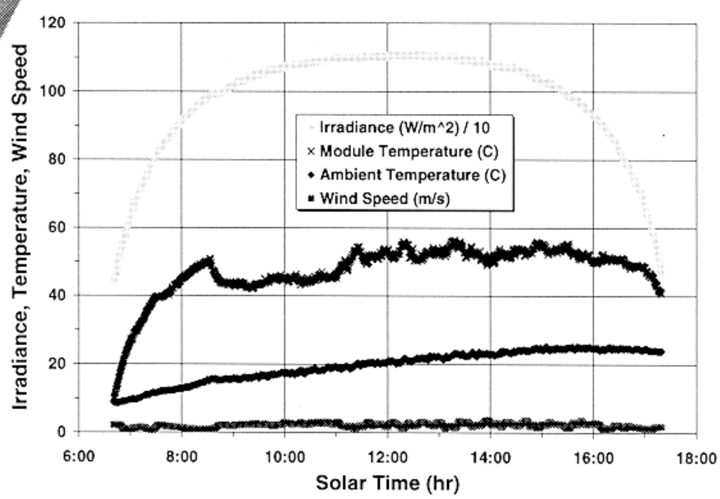
Irradiance & Temperature



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Solar Irradiance

- Factor with greatest influence on performance
- Systematic errors in measurements are common
  - Calibration errors
  - AOI influence and/or misalignment w/ module
  - Solar spectral, temperature, etc.
- Measured for "rating" , modeled for "design"

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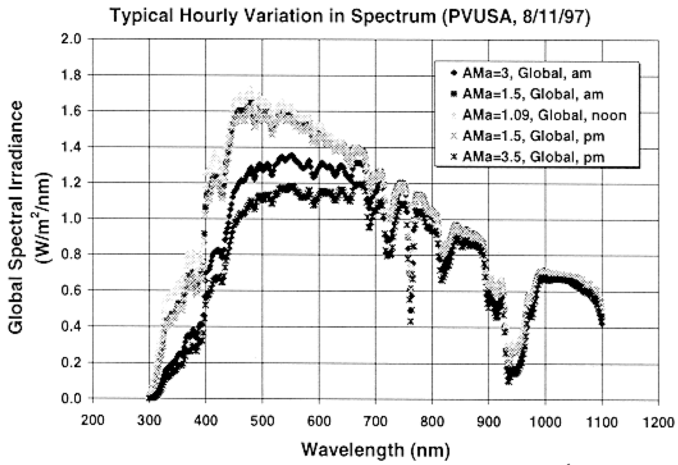
Hourly Spectral Variation



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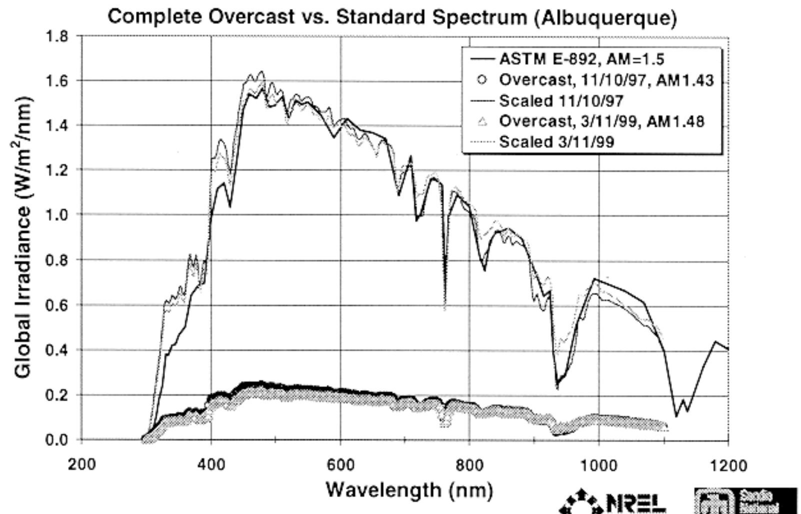
Cloudy vs. Clear Sky



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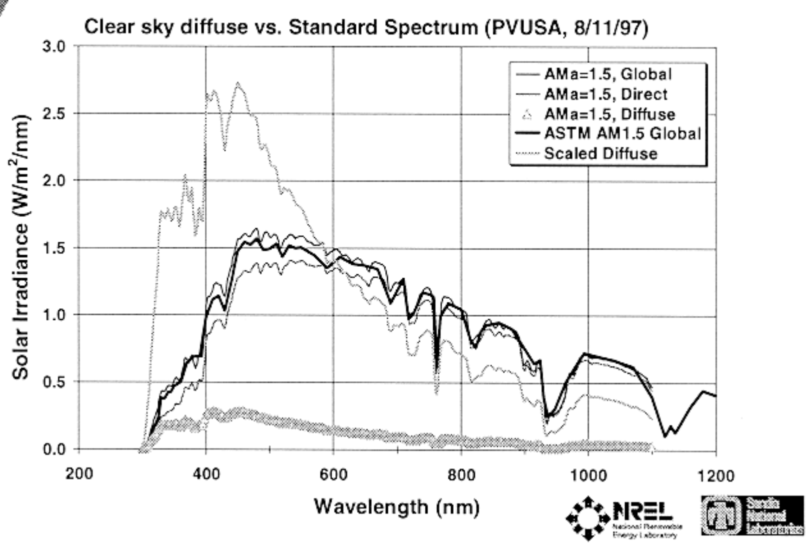
Clear Sky Diffuse



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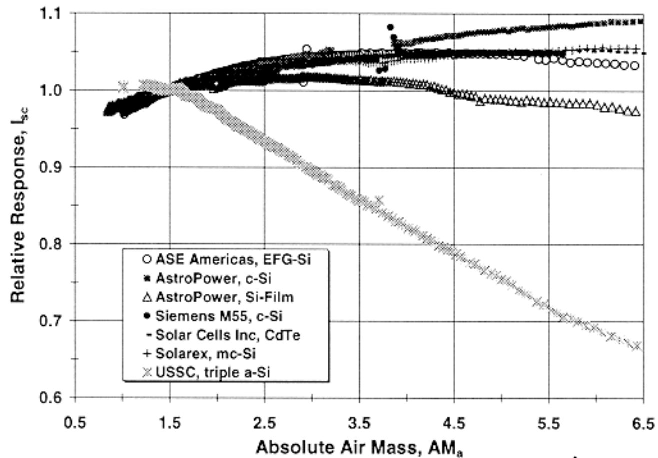
Spectral Influence on Modules



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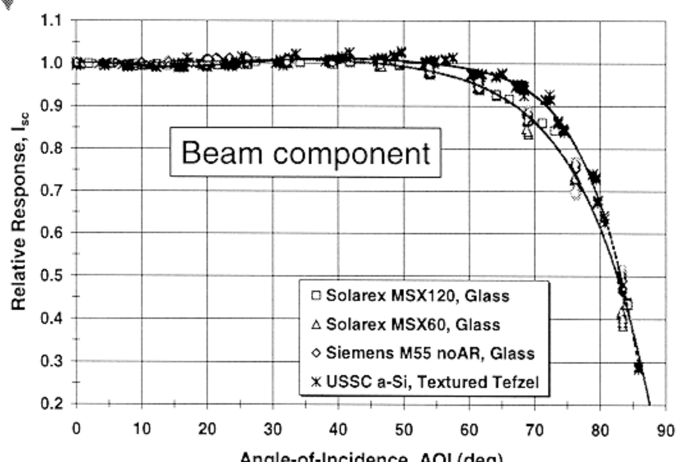
AOI Influence on Modules



NREL National Renewable Energy Laboratory

Sandia National Laboratories

National Center for Photovoltaics

Sandia Performance Model

$$I_{sc} = I_{sco} \cdot f_1(AM_a) \cdot \frac{E_b \cdot f_2(AOI) + f_d \cdot E_{diff}}{E_o} \cdot \{1 + \alpha_{Isc} \cdot (T_c - T_o)\}$$

I_{sc} is most difficult parameter to get right !

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Sandia National Laboratories

National Center for Photovoltaics

Sandia Performance Model

$I_{sc} = I_{sco} \cdot f_1(AM_a) \cdot \{(E_b \cdot f_2(AOI) + f_d \cdot E_{diff}) / E_o\} \cdot \{1 + \alpha_{Isc} \cdot (T_c - T_o)\}$

$E_e = I_{sc} / [I_{sco} \cdot \{1 + \alpha_{Isc} \cdot (T_c - T_o)\}]$

$I_{mp} = I_{mpo} \cdot \{C_0 \cdot E_e + C_1 \cdot E_e^2\} \cdot \{1 + \alpha_{Imp} \cdot (T_c - T_o)\}$

$\delta(T_c) = n \cdot k \cdot (T_c + 273.15) / q$

$V_{oc} = V_{oco} + N_s \cdot \delta(T_c) \cdot \ln(E_e) + \beta_{Voc}(E_e) \cdot (T_c - T_o)$

$V_{mp} = V_{mpo} + C_2 \cdot N_s \cdot \delta(T_c) \cdot \ln(E_e) + C_3 \cdot N_s \cdot \{\delta(T_c) \cdot \ln(E_e)\}^2 + \beta_{Vmp}(E_e) \cdot (T_c - T_o) \cdot$

$P_{mp} = I_{mp} \cdot V_{mp}$

$I_x = I_{xo} \cdot \{ C_4 \cdot E_e + C_5 \cdot E_e^2\} \cdot \{1 + ((\alpha_{Isc} + \alpha_{Imp} \cdot)/2) \cdot (T_c - T_o)\}$

$I_{xx} = I_{xxo} \cdot \{ C_6 \cdot E_e + C_7 \cdot E_e^2\} \cdot \{1 + (\alpha_{Imp}) \cdot (T_c - T_o)\}$

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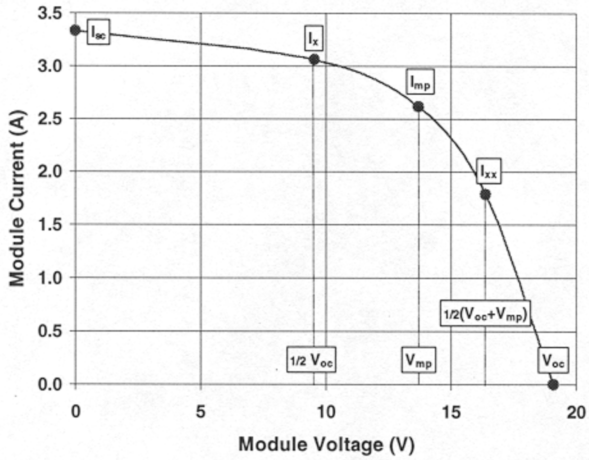
5-Point I-V Model



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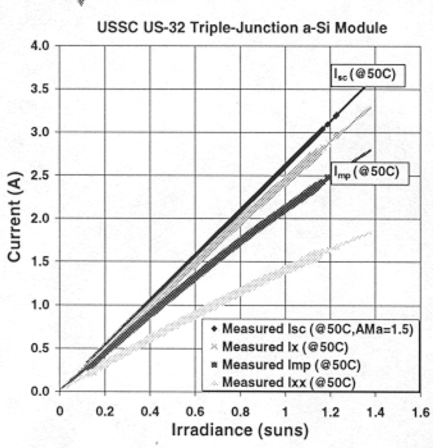
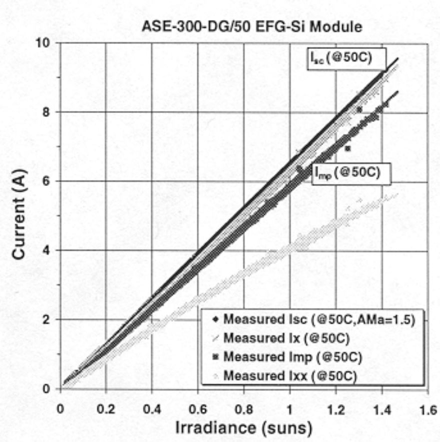
Measured Currents vs. Irradiance
(clear and cloudy days)





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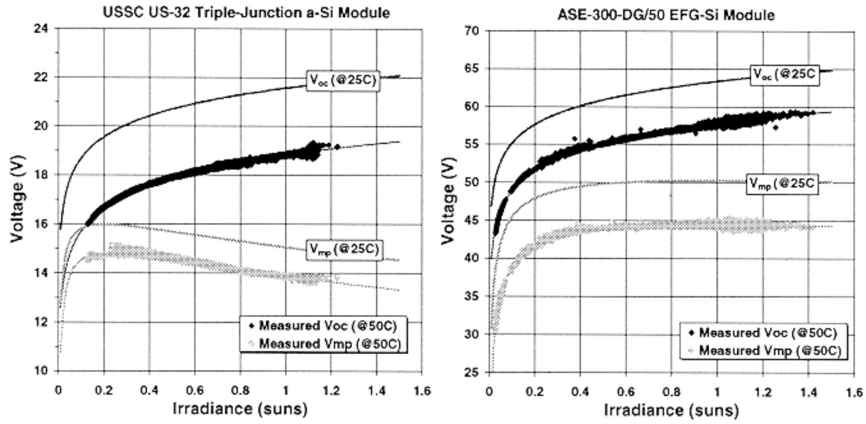
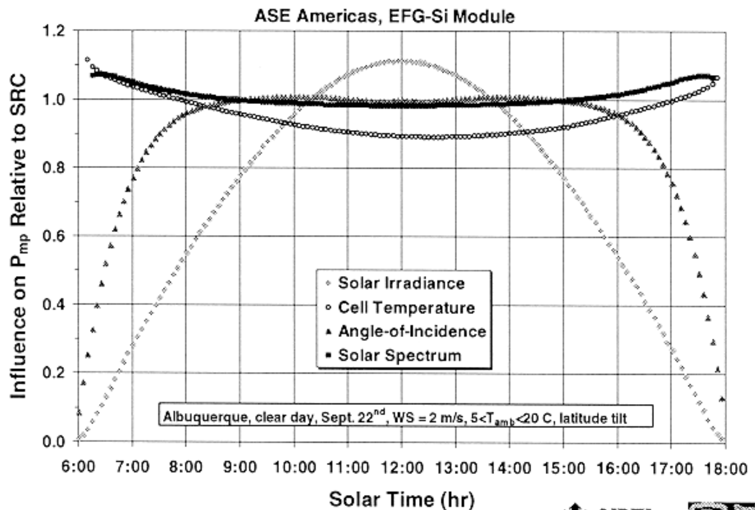
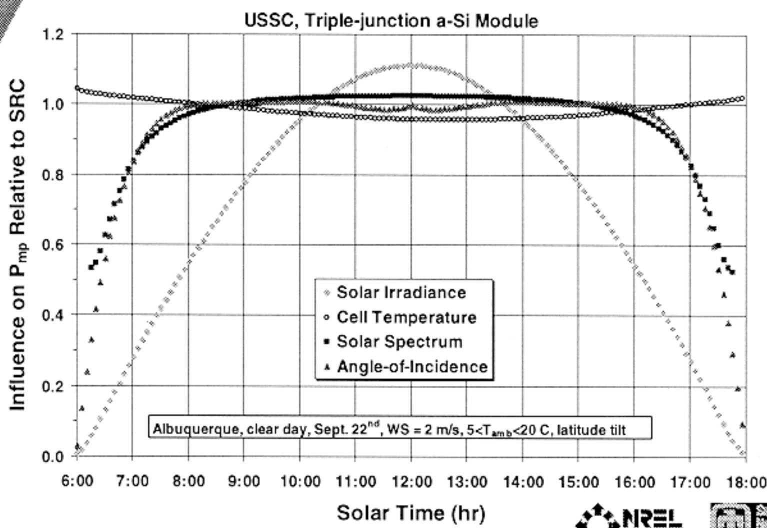
Measured Voltage vs. Irradiance
(clear and cloudy days)



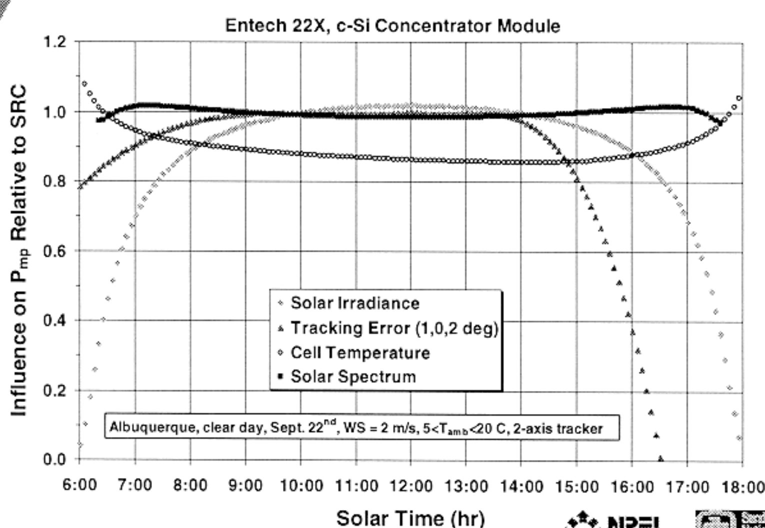
Systematic Influences: Case #1



Systematic Influences: Case #2



Systematic Influences: Case #3



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Operating Temperature

- Field tests for module or array "rating"
  - Module operating temperature measured
- System design for specific site
  - Module operating temperature predicted based on environmental data (TMY2)
  - Thermal model required

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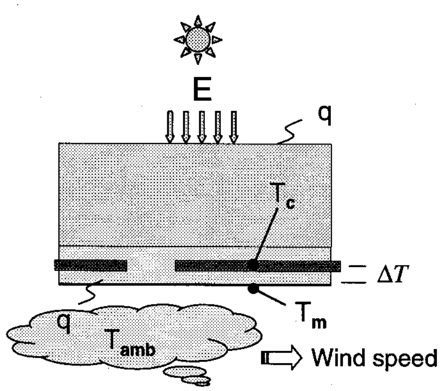
Two Component Thermal Model

$$T_m = E \cdot \left\{ e^{a+b \cdot WS} \right\} + T_{amb}$$

$$T_c = T_m + \frac{E}{1000} \cdot \Delta T_{1000}$$



Simple, adequate, adaptable
Clear day measurements provide a, b coefficients

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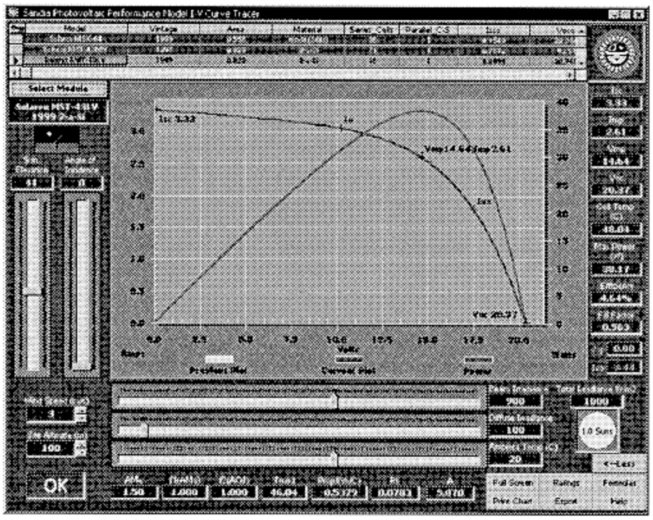
Software Implementations

IVTracer



PV-DesignPro http://www.mauisolarsoftware.com

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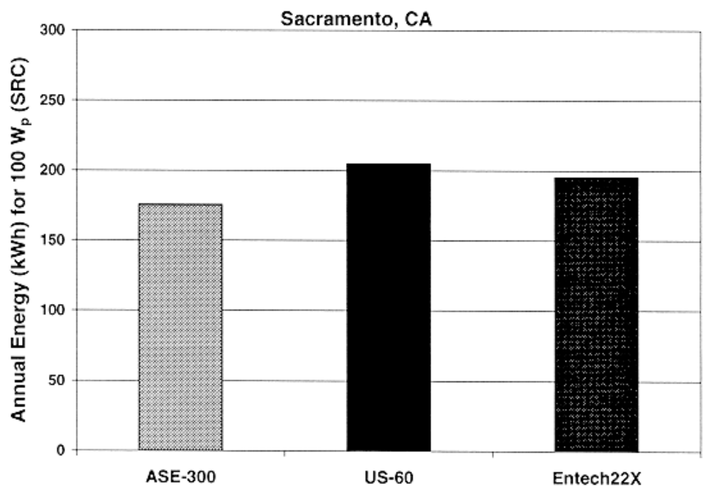
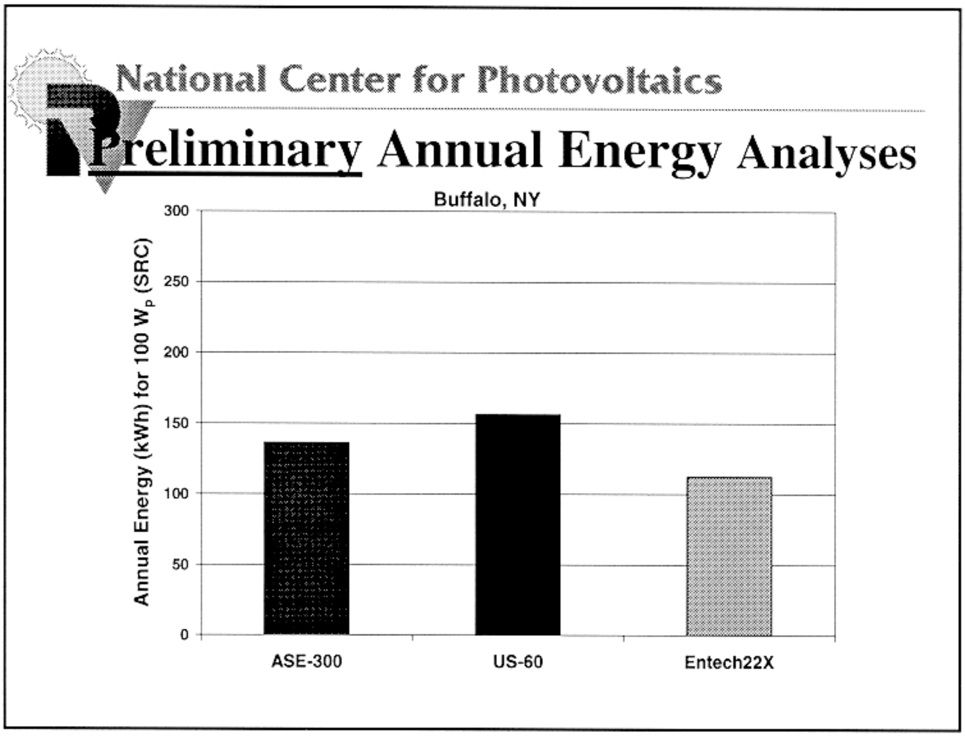
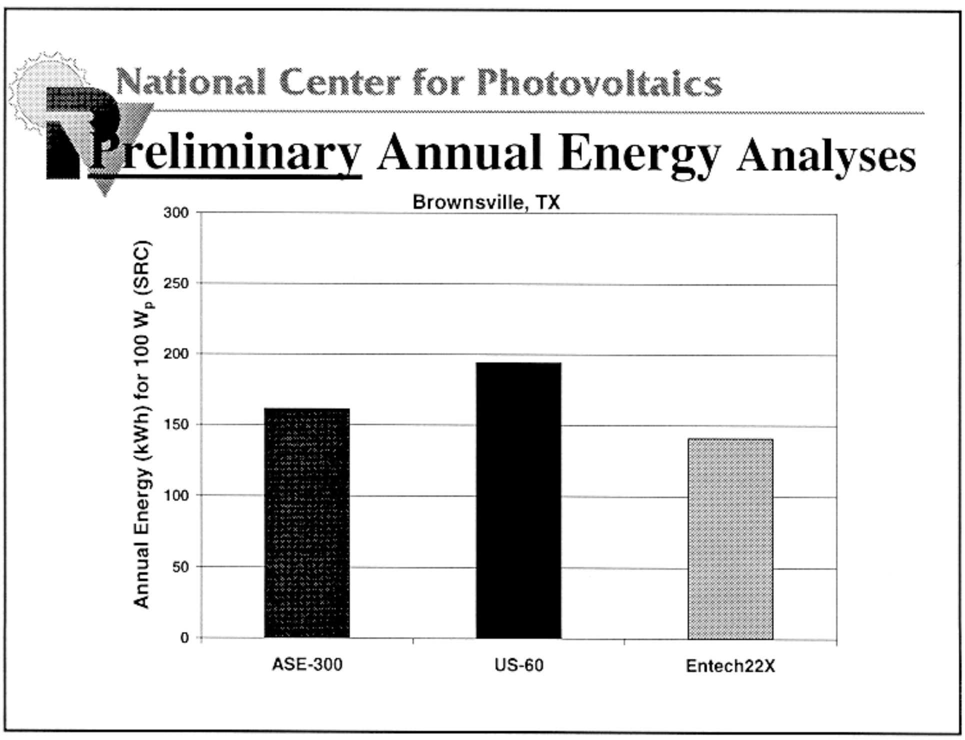
Preliminary Annual Energy Analyses

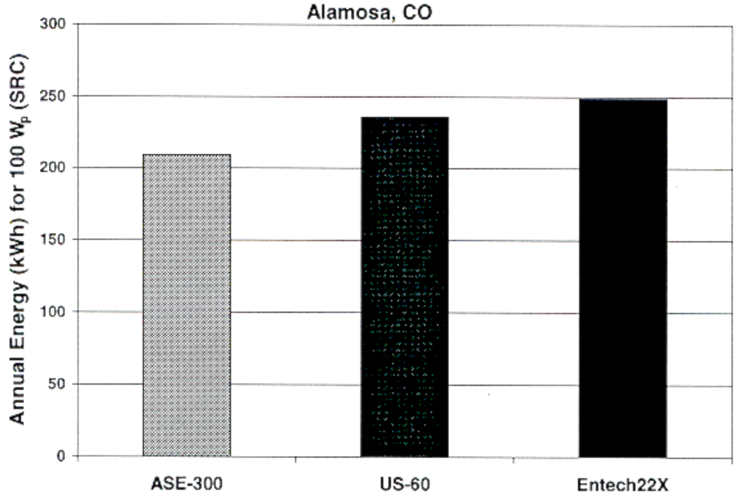



National Center for Photovoltaics
Preliminary Annual Energy Analyses
Buffalo, NY
Annual Energy (kWh) for 100 W_p (SRC)
300
250
200
150
100
50
0
ASE-300
US-60
Entech22X


National Center for Photovoltaics
Preliminary Annual Energy Analyses
Brownsville, TX
Annual Energy (kWh) for 100 W_p (SRC)
300
250
200
150
100
50
0
ASE-300
US-60
Entech22X

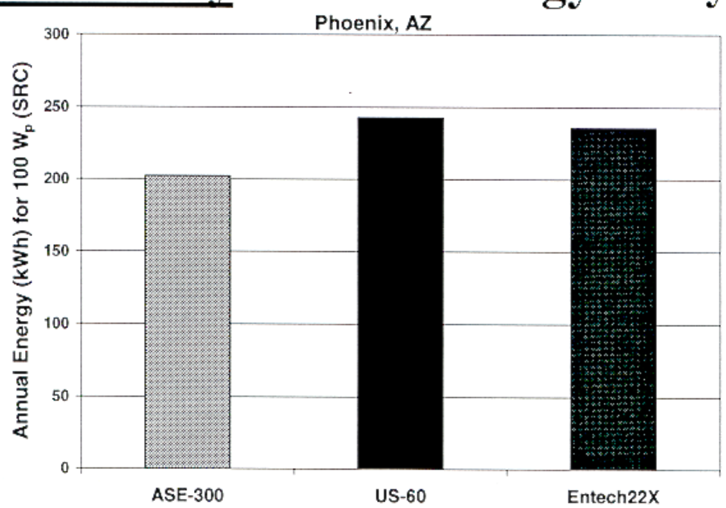
National Center for Photovoltaics

Preliminary Annual Energy Analyses



National Center for Photovoltaics

Preliminary Annual Energy Analyses



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Conclusions

- Performance measurement and modeling procedures verified for many technologies
- Procedures applicable to cell, modules, arrays
- Outdoor (field) test methods documented and being submitted as proposed standards
- Design comparisons based on annual energy production are now possible

NREL National Renewable Energy Laboratory

A Photovoltaic Module Energy Rating Procedure

Bill Marion
NREL

Background

- Purpose of work was to validate a procedure for incorporation into IEEE PAR1479, "Recommended Practice for the Evaluation of Photovoltaic Module Energy Production"
- Follow-on to work performed by Anderson in defining rating concept and Whitaker and Newmiller in outlining the approach

Overview

- Description of MER methodology
- Comparison of model estimates with outdoor measurements

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MER Methodology

- Determine ratings for 5 reference days representative of possible environments
- Indoor module characterization by I-V curves
- I-V curves modeled for reference day conditions to find P_{max} and I_{op}
- Ratings are Wh/day for peak power tracking and Ah/day for battery charging

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Reference Days

- Hot Sunny, Cold Sunny, Hot Cloudy, Cold Cloudy, and Nice.
- Selected based on temperature, wind speed, relative humidity, cloud cover, and global horizontal radiation
- Includes hourly data extracted from the NSRDB

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Reference Day Data

- Hour of day
- Global radiation
- Direct radiation
- Diffuse radiation
- POA radiation
- Ambient temperature
- Wind speed
- Relative humidity
- Air mass
- Angle-of-incidence
- POA spectral irradiance*
- f_1 slope function*
- f_2 y-intercept function*
- Battery voltage*

*data used directly by MER procedure

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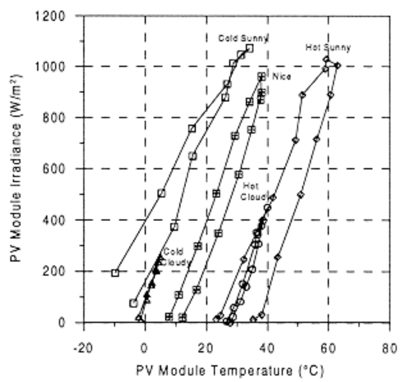
Indoor Module Characterization

- Based on ASTM E1036-96
- I-V curves measured over range of temperatures and irradiances
- Suggested range 5-60°C and 100-1000 W/m²



Reference Day Temperatures and Irradiances

Temperature and Irradiance Correction Functions for Isc and Voc

- Determined from matrix of I-V curves
- Irradiance varied with screens or thin papers
- Temperature varied with chamber setting
- Irradiance when using filters calculated as the ratio of short-circuit currents

$$E_f = E_u \cdot \frac{I_{scf}}{I_{scu}}$$

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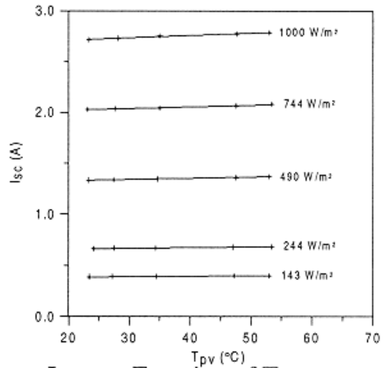
α – Isc Temperature Correction

- Find the slope △Isc/△T at 1000 W/m²
- Normalize slope by dividing by Isc at SRC
- Isc assumed proportional to irradiance for a given temperature



Isc as a Function of Temperature and Irradiance

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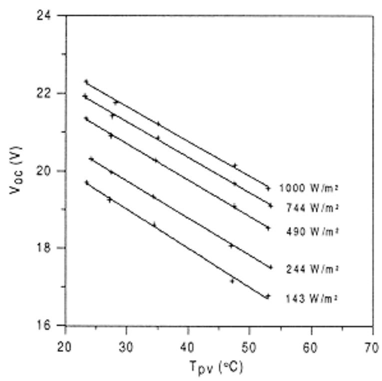
β(E) –Voc Temperature Correction

- Find the slope △Voc/△T for each irradiance level
- Normalize each slope by dividing by the Voc at its irradiance level and 25°C
- Perform least-squares fit of normalized slopes versus irradiance
  $\beta(E) = mE + b$



Voc as a Function of Temperature and Irradiance

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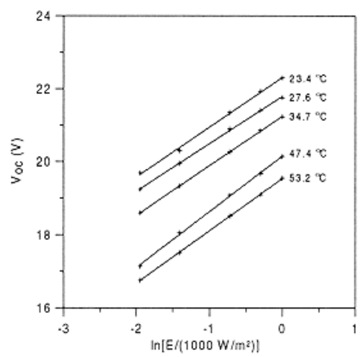
δ(T) –Voc Irradiance Correction

- Find the slope △Voc/△ln(E) for each temperature level
- Normalize each slope by dividing by the Voc at its temperature level and 1000 W/m^2
- Perform least-squares fit of normalized slopes versus Temperature
  δ(T) = mT + b



Voc as a Function of Natural Log of Irradiance for Various Temperature Levels

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Translating from SRC

$$Isc = \frac{E}{E_0} \cdot Isc_0 \cdot [1 + \alpha \cdot (T - T_0)]$$

$$Voc = Voc_0 \cdot [1 + \beta(E_0) \cdot (T - T_0)][1 + \delta(T) \cdot \ln(E / E_0)]$$

Note: SRC denoted by zero subscripts

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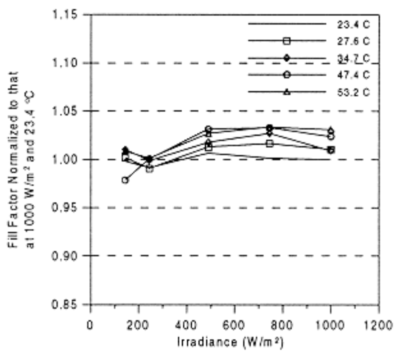
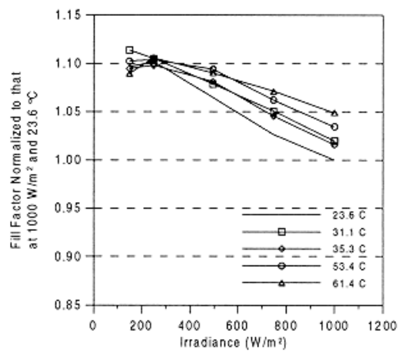
Variations in Fill-Factor



a-Si/a-Si/a-Si:Ge



Cds/CdTe

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Translating the I-V Curve

- Select reference I-V curve from the matrix of I-V curves
- Select I-V curve based on closest to desired irradiance and temperature
- Translate each reference I-V pair by

$$I = I_R \cdot \frac{Isc}{Isc_R} \qquad V = V_R \cdot \frac{Voc}{Voc_R}$$

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Reference Day Irradiances

$$E = \frac{\int_{300}^{1400} E_{INC}(\lambda) SR(\lambda) d\lambda}{\int_{300}^{1400} E_{REF}(\lambda) SR(\lambda) d\lambda} \cdot 1000 \text{ W/m}^2$$

where:

λ = wavelength in nanometers
$E_{INC}(\lambda)$ = MER hour incident spectral irradiance
$E_{REF}(\lambda)$ = reference ASTM E892 spectral irradiance
$SR(\lambda)$ = absolute spectral response per ASTM E1021

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Reference Day PV Module Temperatures

- Equivalent expression to Fuentes model

$T_{pv} = f_1(E_{inc},T_a,w)$ x INOCT + $f_2(E_{inc},T_a,w)$

where:
$f_1(E_{inc},T_a,w)$ = MER hour slope function
$f_2(E_{inc},T_a,w)$ = MER hour y-intercept function
INOCT = NOCT - 3°C

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Validation

- Model estimates compared with measured energy
- 1998 measurements at NREL's Outdoor Test Facility
- 7 modules representing various technologies
- Hourly, daily, monthly, and yearly comparisons

Model Inputs

- Correction factors and functions from indoor PV module characterization
- Spectral irradiances from SEDES2 model and meteorological data
- PV module temperatures from Fuentes model

Pmax RMSEs and MBEs for 1998 Hourly Data

PV Module	RMSE(%)	MBE(%)
a-Si/a-Si/a-Si:Ge	9.7	4.7
CdS/CuInGaSSe	4.9	-0.7
CIS	6.3	2.3
Mono-Crystal Si	5.2	-0.2
Multi-Crystal Si	5.3	-0.1
a-Si/a-Si:Ge	5.6	-1.0
CdS/CdTe	5.6	2.0

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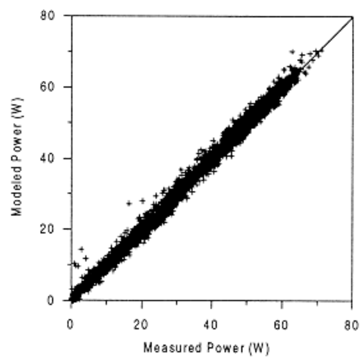
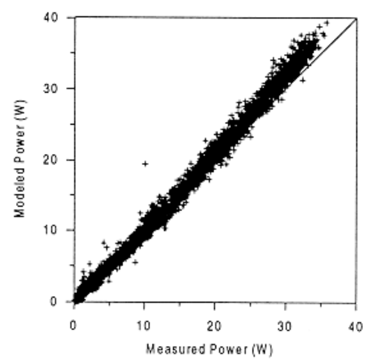
Modeled Versus Measured Pmax



Mono-Crystal Si



a-Si/a-Si/a-Si:Ge

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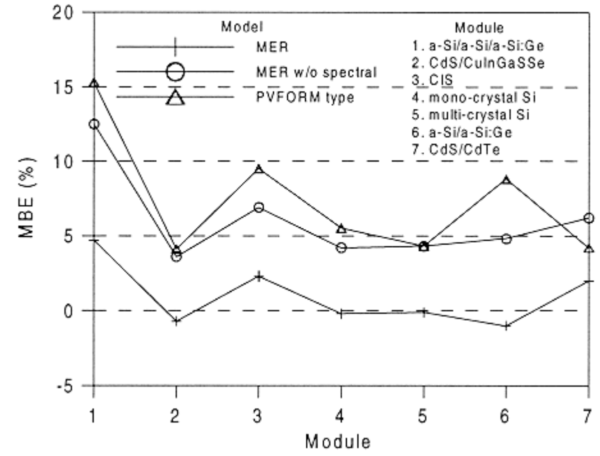
MBEs for Other Methods



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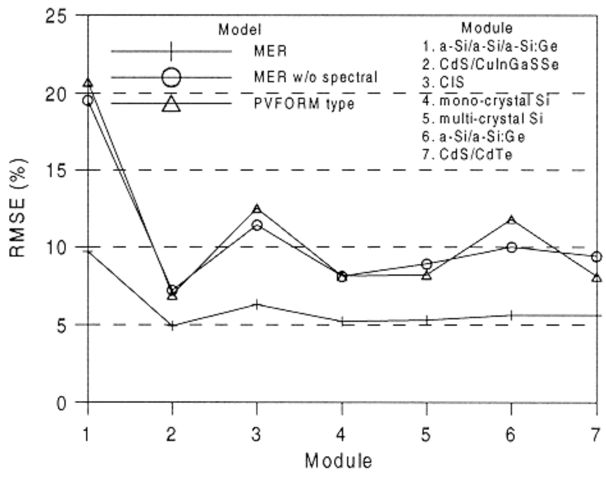
RMSEs for Other Methods



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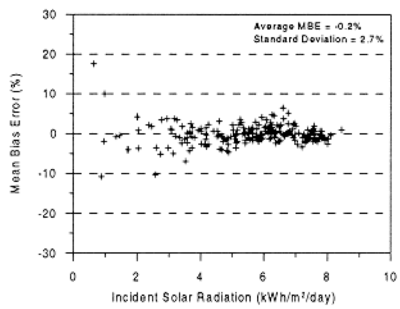
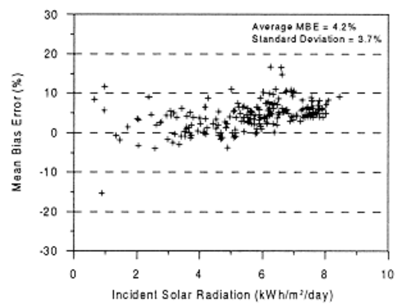
MBEs for Modeled Daily Energy



Mono-Crystal Si



a-Si/a-Si/a-Si:Ge

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MBEs(%) for Selected Days

PV Module	Cold Cloudy	Cold Sunny	Nice	Hot Cloudy	Hot Sunny
a-Si/a-Si/a-Si:Ge	4	**9**	**7**	2	5
CdS/CuInGaSSe	2	-2	-1	1	0
CIS	-1	2	2	1	4
Mono-Crystal Si	0	1	0	0	-1
Multi-Crystal Si	-1	0	0	0	0
a-Si/a-Si:Ge	**6**	0	1	-1	-1
CdS/CdTe	----	-1	1	----	2

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Percent Error in Predicting Relative Performance

PV Modules	Cold Cloudy	Cold Sunny	Nice	Hot Cloudy	Hot Sunny
All	7	11	8	3	6
All except a-Si	3	4	3	1	5

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Uncertainty in Relative Performance of Two PV Modules

- Include reproducibility limit of 6.7% for different test facilities (ASTM E1036)
- "Because of errors in measurements and energy rating methodology, differences of 8% or less in the energy rating of two PV modules are not significant. If one of the PV modules is amorphous silicon, differences of 13% or less are not significant."

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Acknowledgements

Ben Kroposki
Keith Emery
Joe del Cueto
Daryl Myers
Carl Osterwald
Steve Rummel

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Working Group PAR1479 Update – B. Kroposki

PAR 1479 - Recommended Practice for the Evaluation of Photovoltaic Module Energy Production

Scope: This recommended practice establishes a method for determining the energy production of terrestrial photovoltaic power generation modules for different operating conditions. The document defines module characterization procedures, reference days, and performance models used to calculate energy production.

Purpose: Provide a method for evaluating photovoltaic module performance in terms of energy production for different environmental and operating conditions.

Working Group: Ben Kroposki - Working Group Chairman/Technical Editor

Jerry Anderson - Sunset Technology

Gobin Atmaram - FSEC

Bill Bottenberg - PVI

Ron Gonsiorawski - ASE

David King - SNL

Daryl Myers - NREL

Carl Osterwald - NREL

Chuck Whitaker - Endecon

John Wohlgemuth - Solarex

Status:

NREL completed energy ratings study (NREL TP-520-26909) in August 1999

Still on Draft 4. Draft 5 revision will take place after this workshop.

Working on providing test procedures for Annex.

Working Group Meetings:

December 1998 - Washington, DC

June 1999 - Winter Park, CO

October 1999 - Vail CO

Next Meeting TBD

IEC TC 82 SECRETARIAT STATUS

PV PERFORMANCE, RELIABILITY AND STANDARDS WORKSHOP

VAIL, COLORADO
OCTOBER 18 - 20, 1999

INTERNATIONAL ELECTROTECHNICAL COMMISSION
TECHNICAL COMMITTEE 82 – SOLAR PHOTOVOLTAIC ENERGY SYSTEMS

- **Richard DeBlasio (Chairman)**
- **Jerry Anderson (Secretary)**
- **Stephen Chalmers (Ass't Secretary)**

IEC TC 82 STATUS – VAIL, COLORADO – 1999

PURPOSE:

The purpose of this presentation is to describe the present and future plans for the development of PV standards within the International Electrotechnical Commission, Technical Committee 82, (IEC TC 82), *Solar Photovoltaic Energy Systems.*

IEC TC 82 now has a total of 33 member countries (21 of which are P-members), 7 working groups (3 of which are new) and 91 experts:

Working Group 1 (Glossary) – 9 experts;

Working Group 2 (Modules) – 18 experts;

Working Group 3 (Systems) – 25 experts;

Working Group 5 (Quality and Certification) – 11 experts;

Working Group 6 (Components) – 16 experts;

Working Group 7 (Concentrators) – 7 experts;

Joint Working Group TC 21/TC 82 – 5 TC 82 experts.

This represents an approximate doubling of our working groups and expert participation in the past 4 years which illustrates the growing interest and importance of the photovoltaics. When the TAG group participants from the 33 countries are also added to the 91 experts listed above, the total participation probably exceeds 400 people.

The participants from the USA are as follows:

- **WG 1 (Glossary)** - 7 members
  - Steve Chalmers (USA representative)
  - Jerry Anderson (USA representative)
- **WG 2 (Modules)** - 21 members
  - John Wohlgemuth (USA representative)
  - Alex Mikonowicz (USA representative)
  - Steven Jochums (USA representative)
- **WG 3 (Systems)** - 25 members
  - Steve Chalmers (USA representative)
  - Chuck Whitaker (USA representative)
  - Jean Posbic (USA representative)

- **WG 4 (Storage)** – Inactive
- **WG 5 (Quality and Certification)** - 11 members
  - Steve Chalmers (USA representative)
  - Alex Mikonowicz (USA representative)
- **WG 6 (BOS Components)** - 12 members
  - Jean Posbic (Convenor & USA representative)
  - Tim Zgonena (USA representative)
  - Steve Chalmers (USA representative)
  - Chuck Whitaker (USA representative)
- **WG 7 (Concentrators)** - 7 members
  - Bill Bottenberg (Convenor & USA representative)
  - Bob McConnell (USA representative)
- **JWG TC21/TC82 (Batteries)** - 5 of 12 members are from TC 82
  - Jay Chamberlain (USA TC 82 representative)
  - Larry Meisner (USA TC 82 representative)

The work of the JWG on batteries has not progressed well. The Secretary introduced a proposal at the last TC 82 meeting (Denmark, September 1998) to resume work on storage systems (all types ...... not just batteries).

- TC 82 agreed to this and named an ad hoc group to prepare an outline of topics for a New Work Item Proposal (NWIP) for a new project to be called *Requirements for PV Storage Devices.* It would include all types of storage systems.... flywheels, water storage, fuel cells, super capacitors, compressed air, etc.....and batteries;

- Jay Chamberlain was named as the chairman of this ad hoc committee. No outline has been prepared nor has any coordination among the members of this committee occurred as of this date;

Table 1 lists the 33 countries participating in the IEC TC 82.

Table 2 presents a list of the 26 IEC TC 82 documents which have been published.

Table 3 gives a list of the projects currently in progress in TC 82.

TABLE 1

IEC TC 82: SOLAR PHOTOVOLTAIC ENERGY SYSTEM

National Committee Membership of IEC/TC 82

COUNTRY	STATUS	COUNTRY	STATUS
AUSTRALIA	Participating	NETHERLANDS	Participating
AUSTRIA	Participating	NEW ZEALAND	Observer
BELGIUM	Observer	NORWAY	Observer
BRAZIL	Observer	POLAND	Observer
BULGARIA	Observer	PORTUGAL	Participating
CANADA	Participating	ROMANIA	Participating
CHINA	Participating	RUSSIAN FED.	Participating
CZECH REPUBLIC	Participating	SINGAPORE	Observer
DENMARK	Participating	SOUTH AFRICA	Participating
FINLAND	Observer	SPAIN	Participating
FRANCE	Participating	SWEDEN	Observer
GERMANY	Participating	SWITZERLAND	Participating
HUNGARY	Observer	UKRAINE	Observer
INDIA	Participating	UNITED KINGDOM	Participating
INDONESIA	Participating	USA	Participating
ITALY	Participating	YUGOSLAVIA	Observer
JAPAN	Participating		

TABLE 2
PUBLISHED IEC TC 82 STANDARDS

WG 1, GLOSSARY

1. IEC 61836: 1997, *Solar photovoltaic energy systems – terms and symbols*

WG 2, MODULES

1. IEC 60891: 1987, *Procedures for temperature and irradiance corrections to measured I-V characteristics of crystalline silicon photovoltaic (PV) devices. Amendment No 1 (1992)*
2. IEC 60904-1: 1987, *Photovoltaic devices - Part 1: Measurements of PV current-voltage characteristics*
3. IEC 60904-2: 1989, *Photovoltaic devices - Part 2: Requirements for reference solar cells.*
4. IEC 60904-3: 1989, *Photovoltaic devices - Part 3: Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*
5. IEC 60904-5: 1993, *Photovoltaic devices - Part 5: Determination of the equivalent cell temperature (ECT) of photovoltaic (PV) devices by the open-circuit voltage method.*
6. IEC 60904-6: 1994, *Photovoltaic devices - Part 6: Requirements for reference solar modules.*
7. IEC 60904-7: 1995, *Photovoltaic devices - Part 7: Computation of spectral mismatch error introduced in the testing of a photovoltaic device.*
8. IEC 60904-8: 1995, *Photovoltaic devices - Part 8: Guidance for spectral measurement of spectral response of a photovoltaic (PV) device. Second edition (1998)*
9. IEC 60904-9: 1995, *Photovoltaic devices - Part 9: Solar simulator performance requirements*
10. IEC 60904-10: 1998, *Photovoltaic devices – Part 10: Linearity measurement methods*
11. IEC 61215: 1993, *Crystalline silicon terrestrial PV modules - Design qualification and type approval*
12. IEC 61345: 1998, *UV test for photovoltaic (PV) modules*
13. IEC 61646: 1996, *Thin film silicon terrestrial PV modules - Design qualification and type approval*
14. IEC 61701: 1995, *Salt mist corrosion testing of photovoltaic (PV) modules*
15. IEC 61721: 1995, *Susceptibility of a module to accidental impact damage (resistance to impact test)*

WG 3, SYSTEMS

1. IEC 61173: 1992, *Overvoltage protection for photovoltaic (PV) power generating systems*
2. IEC 61194: 1993, *Characteristic parameters of stand-alone photovoltaic (PV) systems*
3. IEC 61277: 1995, *Guide: General description of photovoltaic (PV) power generating systems*
4. IEC 61702: 1995, *Rating of direct coupled photovoltaic pumping systems*
5. IEC 61724: 1998, *Photovoltaic system performance monitoring - guidelines for measurement, data exchange and analysis*
6. IEC 61725: 1997, *Analytical expression for daily solar profiles*
7. IEC 61727: 1995, *Photovoltaic (PV) systems - Characteristics of the utility interface*
8. IEC 61829: 1995, *Crystalline silicon photovoltaic (PV) array - On-site measurement of I-V characteristics*
9. IEC 61883: 1999, *PV systems - Power conditioners - Procedure for measuring efficiency*
10. IEC-PAS 62111: 1999, *Specification for the use of renewable energies in decentralised electrification.*

TABLE 3
IEC TC 82 PROJECTS CURRENTLY IN-PROGRESS

WG 1, GLOSSARY

1. IEC 61836-2 Ed. 1.0, (WD) *Solar photovoltaic energy systems – terms and symbols – Part 2*

WG 2, MODULES

1. IEC 60904-9: Ed. 2.0, (WD) *Photovoltaic devices - Part 9: Solar simulator performance requirements* (Amendment to take into account thin-film silicon and to generally clarify and improve)
2. IEC 61730 Ed. 1.0: (WD) *Safety testing requirements for PV modules*
3. IEC 61853 Ed. 1.0: (WD) *Power and energy rating of photovoltaic (PV) modules*
4. IEC 62145: (WD) *Crystalline silicon terrestrial (PV) modules - Blank detail specification*
5. (NWIP - FAILED) *Thin film terrestrial (PV) modules - Blank detail specification*

WG 3, SYSTEMS

1. IEC 61723 Ed. 1.0: (PWI) *Safety guidelines for grid connected PV systems mounted on buildings*
2. IEC 61728 Ed. 1.0: (PWI) *Safety test procedures for utility grid connected photovoltaic inverters*
3. IEC 61729 Ed. 1.0: (PWI) *Equipment and safety specs. for direct coupled PV-pumping systems*
4. IEC 62124 Ed. 1.0: (WD) *PV stand-alone systems - Design qualification and type approval*

WG 4, STORAGE

1. PWI 82-1 Ed. 1.0: *Photovoltaic electricity storage systems* (Note: an ad hoc committee was created at the TC 82 meeting in Denmark, September 1998. Jay Chamberlain was named to head this committee. This ad hoc committee will prepare a NWIP for *Reqmts. for PV Storage Systems*).

WG 5, QUALITY & CERTIFICATION

1. IEC 62078 Ed. 1.0: (WD) *Certification and accreditation program for photovoltaic (PV) components and systems - Guidelines for a total quality system*

WG 6, BOS COMPONENTS

1. IEC 62093 Ed. 1.0: (WD) *BOS components - Environmental reliability testing – Design qualification and type approval*
2. IEC 62109 Ed. 1.0: (WD) *Electrical safety of static inverters and charge controllers for use in photovoltaic (PV) power systems*
3. IEC 62116 Ed. 1.0: (WD) *Testing procedure - Islanding prevention measures for power conditioners used in grid connected photovoltaic (PV) power generation systems*

WG 7, CONCENTRATORS

1. IEC 62108 Ed. 1.0: (WD) *Concentrator photovoltaic (PV) receivers and modules - Design qualification and type approval*

NOTE: PWI means *Proposed Work Item.*
NWIP means *New Work Item Proposal* (submitted but not yet approved).
WD means *Working Draft* (still in-progress in the Working Group).
CD means *Committee Draft* issued for National Committee comments.
CDV means *Committee Draft For Voting* (and comments).
FDIS means *Final Draft International Standard* (editorial comments only).
APUB means *Authorized for Publication*

DISCUSSION:

Working Group 1 (Glossary) - The WG 1 unit was reactivated in 1995. WG 1 currently has 1 PV standard published, IEC 61836 (1997), *Solar photovoltaic energy systems – terms and symbols.* This glossary incorporates definitions and symbols used in *published* TC 82 standards, and will be a dynamic document in that as new TC 82 documents are published, the Glossary will grow to incorporate any new terms, symbols and definitions. A Part 2 annex to incorporate a more worldwide assortment of terms and symbols is now underway.

Working Group 2 (Modules) - WG 2 has 15 PV standards published. Currently, WG 2 has 4 new standards in-progress; a new safety standard for modules, an IECQ-requested specification for crystalline modules, an updated solar simulator requirements standard and a new standard for rating modules for power and energy.

Working Group 3 (Systems) - WG 3 has 9 PV standards published. They currently have only 1 approved project in progress, a NWIP - *PV stand-alone systems - Design qualification and type approval.* They do have PWI (Proposed Work Items) for 3 additional projects: safety guidelines for grid-connected systems on buildings, safety test procedures for utility-connected inverters and safety for direct-coupled pumping systems.

Working Group 4 (Batteries) - Disbanded and replaced by the JWG TC 21/TC 82. The JWG has one document in progress, project 61427-1, *Secondary cells and batteries for photovoltaic solar energy systems.*

Working Group 5 (Quality and Certification) - This is a newly-approved working group. WG 5 has a NWIP working draft (starting point) of a standard for PV module, component and system qualification and certification and PV test laboratory accreditation. This draft document is based on the work of the NREL-sponsored ASU certification and accreditation program, which in turn is the program upon which PowerMark was founded.

Working Group 6 (BOS Components) - This a new working group. WG 6 has 3 NWIP approved projects, and each has a working draft (starting point). These are:

- BOS components - Environmental reliability testing – Design qualification and type approval;
- Electrical safety of static inverters and charge controllers for use in photovoltaic (PV) power systems;
- Testing procedure - Islanding prevention measures for power conditioners used in grid connected photovoltaic (PV) power generation systems.

Working Group 7 (Concentrators) - This a new working group and project. They currently have one approved project in progress, IEC 62108, *Concentrator photovoltaic (PV) receivers and modules - Design qualification and type approval.* This group is headed by Bill Bottenberg of the USA. They have not yet held their first meeting.

3. Module Qualification Testing – October 19, 1999

Subsection 3.1 lists the planned agenda, which identifies the topical areas. Subsection 3.2 presents summary notes, after which we include the compilations of the presentations made at the workshop. The titles of the presentations do not necessarily match the exact wording of the agenda topics.

3.1 Agenda –Session II - Module Qualification Testing

Session II: 8:30 AM – 5:00 PM - Workshop Chair: T. Basso

General Session (8:30 AM – 12:00 PM): Organizer and Session Chair - C. Osterwald

- Tutorial (1 hour) - J. Wohlgemuth
- Open Discussion (2 hours) - Facilitator: C. Osterwald
- Summary (30 minutes) - T. Basso

Standards Panel/Discussion (1:30 PM – 5:00 PM): Facilitator - Tom Basso

- IEEE WG 1262 - J. Wohlgemuth – IEEE Std 1262-1996 *Recommended Practice for Qualification of Photovoltaic Modules*
- ASTM E44.09 - C. Osterwald
- IEC TC82 US TAG - S. Chalmers

3.2 Module Qualification Testing Session Summary Notes

The session started with J. Wohlgemuth's presentation on module qualification testing. He stated what qualification testing is; how qualification tests evolved for PV modules; and he identified, reviewed, and gave the status of module qualification tests and standards. He then focused on the existing International Electrotechnical Commission (IEC) Standard 1215 and the IEEE Standard 1262 and provided reasons for change and suggested revisions. The conclusions of this qualification presentation were that qualification tests are very useful as screening tests; they are not a substitute for outdoor testing or for reliability testing; and as technology changes, the value of qualification tests must be verified.

The group discussions included the following recommendations. The criteria and requirements of the existing body of PV module qualification standards need to harmonized, and, similarly, the test programs and tests need to be critically reviewed to remove inconsequential clauses, modify others, add new clauses, and develop new tests or standards as appropriate. More general recommendations and concerns included how we ensure that new products and new failure mechanisms are continually addressed, and, that in addition to updating the qualification testing, we need to continue pursuing the more general reliability testing and related activities. It was pointed out that IEEE recently published IEEE Std 1413-1998 *Standard Methodology for Reliability Prediction and Assessment for Electronic Systems and Equipment*, whose scope covers the framework for the reliability prediction process for electronic systems and equipment, including hardware and software prediction at all levels.

The general discussion periods included numerous topics and concerns. They ranged from general concerns such as considerations about low-volume and emerging products and applications (e.g., building-integrated PV, concentrator modules/systems, PV-AC modules) to improving our ongoing approaches, such as light-soaking, UV exposure, annealing, measurement procedures, uncertainty/repeatability, translation of measurements, and indoor and outdoor correlation. And finally, there was lengthy discussion on specific proposed changes to IEEE Std 1262. Those discussions similarly covered a broad spectrum of concerns—from removing inconsequential tests or procedures to establishing new ones.

Slide 1

MODULE QUALIFICATION TESTING

By
John Wohlgemuth
BP Solarex

Slide 2

What is Qualification Testing?

- A well defined set of accelerated environmental tests developed out of a reliability testing program.
- Incorporates strict pass/fail criteria.
- Used by customers to qualify modules for purchase.
- Used by manufacturers as a means of assessing product design, product quality and process control.

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Slide 3

What Qualification is not

- **Qualification testing is not the same as reliability testing.**
- **Qualification testing does not provide a prediction of product lifetime.**
- **Qualification testing should not be independent of module technology.**

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Slide 4

Development of Qualification Tests

- **Based on environmental testing that accelerates the stresses associated with know environmental conditions or a known failure mechanism.**
- **Must be guided by the results of outdoor testing.**
- **Stress levels must accelerate the same failure mechanisms observed in the field.**

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Slide 5

How Module Qualification Tests were developed

- Mostly out of government sponsored procurement activities such as the JPL block purchases and the European demonstration program.
- First step was the procurement of commercial modules. Some went outdoors in various locations, while others were put through accelerated environmental tests.

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Slide 6

Developing module qualification tests

- Initial environmental tests were selected from knowledge of the operating conditions and some experience with space PV.
- Results of the outdoor testing lead to the identification of specific failure mechanisms for these crystalline Si modules.

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Slide 7

Identified failures

- Interconnect failures
- Solder bond failures
- Encapsulant delaminations
- Metallization corrosion
- Cracked and broken cells
- Broken substrates and superstrates
- Hot spots - burn holes
- Discoloration

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Slide 8

Qualification test development

- Identify mechanisms leading to the observed failures.
- Find accelerated conditions that duplicate identified failures.
- Establish tentative test level and compare to field results.
- Modify as needed.

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Slide 9

Failure analysis

- Interconnect failures - thermal cycle
- Solder bond failures - thermal cycle
- Encapsulant delaminations - humidity-freeze
- Metallization corrosion - humidity
- Cracked and broken cells - mechanical load and thermal cycling

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Slide 10

Failure analysis (cont)

- Broken substrates and superstrates - mechanical load and hail
- Hot spots /burn holes - reversed bias due to shadowing, cracked and mismatched cells
- Discoloration - UV degradation of encapsulant or soiling

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Slide 11

History of testing at JPL

Test Year	I 1975	II 1976	III 1977	IV 1978	V 1981
Thermal Cycle	100 -40 to 90	50 -40 to 90	50 -40 to 90	50 -40 to 90	200 -40 to 90
Humidity	70C 90% 68 hrs	5 c 90% 40 to 23	5 c 90% 40 to 23	5 c 90% 54 to 23	10 c 85% 85 to -40
Hot Spots					3 cells 100 hr
Mechanica l Load		100 c 2400 Pa	100 c 2400 Pa	10,000 2400 Pa	10,000 2400 Pa
Hail				¾" 45 mph	1" 52 mph
High Pot		1500 V < 15 μA	1500 V < 50 μA	1500 V < 50 μA	2*V+1000 < 50 μA

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Slide 12

The world of PV after JPL

- NREL developed IQT for thin film amorphous Si.
- IEC worked on international standard for crystalline Si.
- IEEE worked on standard for all PV technologies.

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Slide 13

NREL IQT

- Changes were designed to test for new failure mechanisms not seen before on crystalline Si.
- Major difference was wet high pot test to evaluate corrosion of thin film layers.

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Slide 14

Other test improvements

- Corrosion of contacts assessed using damp heat (85C, 85% RH)
- Combinations of stresses evaluated using UV, thermal cycles and humidity freeze.
- A short outdoor exposure added to screen for really bad designs.

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Slide 15

Glossary of qualification standards

- **JPL Block I,II,III,IV, and V: Developed for block procurements. *Now obsolete*.**
- **CEC 501, 502 and 503: Similar to JPL standards for European procurements. 503 was a preliminary version of IEC 1215. *Now obsolete*.**

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Slide 16

Glossary of qualification standards (cont)

- **IEC 1215: Crystalline Si qualification standard used around the world.**
- **IEC 1646: Thin film (a-Si) qualification standard used around the world.**
- **IEEE 1262: mainly a US standard that is designed to apply to all PV technologies.**
- **UL 1703: A module safety standard**

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Slide 17

Qualification similarities 1215, 1646 and 1262

- All contain 3 legs with
  - ➢200 thermal cycles
  - ➢UV, 50 thermal cycles, 10 humidity freeze
  - ➢1000 hours of damp heat
- All 3 qualify based on power, visual inspection and hi-pot after stress.

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Similarities (cont)

- All contain
  - ➢hail test
  - ➢static mechanical load
  - ➢twist test
  - ➢termination test
  - ➢hot spot test
  - ➢Outdoor exposure test

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Slide 19

Differences

- Between IEC 1215 and 1646: Additions only in 1646:
  - Wet hi-pot test
  - light soaking
  - annealing

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Slide 20

Differences

- Between 1215 and 1262: Tests in 1262, but not in 1215
  - ➢Dynamic mechanical load
  - ➢Bypass diode thermal test
  - ➢Cut susceptibility
  - ➢wet insulation resistance
  - ➢wet hi-pot
  - ➢ground continuity

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Differences

- Between 1215 and 1262
  - Pass-fail criteria in 1215 is 5% power loss per test and 8% per sequence
  - Pass-fail criteria in 1262 is 10% power loss per test.

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Status

- IEC 1215 is being rewritten by WG 2 now.
- IEEE 1262 is being rewritten by SCC21 now.
- IEC 1646 will be rewritten by WG2 once 1215 has been completed.

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Slide 23

Reason for Changes to 1215

- Correction of errors
- Improved wording/remove ambiguities
- Eliminate the unnecessary
- Add tests from other test sequences (1262) as appropriate
- Improve tests based on experience
- Improve tests based on knowledge

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Slide 24

Specific changes to 1215

- Eliminate twist test
- Allow temperature coefficient to be measured outdoors
- Run peak power current during thermal cycling
- Allow power measurement to be made at condition other than STC to improve repeatability.
- Make hi-pot tests area dependent

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Slide 25

Changes to 1215 (cont)

- Rewrite Hot Spot test
- Add Bypass Diode Thermal test
- Change UV conditions to agree with 1262
- Add wet insulation resistance test
- Eliminate requirement to monitor ground faults during environmental tests.

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Slide 26

Changes to 1215 (cont)

- Improve statistical method of dealing with data.
- Indicate that you must measure peak power temperature coefficient as well as current and voltage.
- Indicate that "Blank Detailed Specification" provides details on retest requirements.

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Slide 27

Changes to 1262

- Eliminate Twist Test
- Rewrite Hot Spot
- Run peak power current during thermal cycling
- Eliminate requirement to monitor ground faults during environmental tests.

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Slide 28

Changes to 1262 (cont)

- Allow power measurement to be made at condition other than STC to improve repeatability.
- Improve bypass diode thermal test
- Eliminate intrusive hot spot test.
- How soon after stress tests do we do wet hi-pot?

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Slide 29

Changes to 1262 (cont)

- Clarify wind vs. snow load requirements in mechanical load.
- Assess the need for annealing and light soaking in qualification.
- Should we change power loss criteria to match 1215?
- Do we need 2 wet tests (wet insulation and wet hi-pot)

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Slide 30

Changes to 1262 (cont)

- Is dynamic mechanical load test relevant and/or too severe?
- Do we need a long term high irradiance/high temperature test?
- Should we run damp heat with applied voltage?

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Slide 31

How to use module qualification tests

- Qualify new module design
- Qualify new process
- Qualify new materials
- Qualify new equipment
- Qualify changes to any of above
- Periodic re-qualification to check all process control, workmanship and all of the above.

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Slide 32

Conclusions

- Qualification tests are very useful as screening tests.
- Qualification tests are not a substitute for outdoor testing.
- Qualification tests are not a substitute for reliability testing.
- As technology changes the value of qualification tests must be verified.

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Oct. 1999

4. Power Processing – October 20, 1999

Subsection 4.1 lists the planned agenda, which identifies the topical areas. Subsection 4.2 presents summary notes, after which we include the compilations of the presentations made at the workshop. The titles of the presentations do not necessarily match the exact wording of the agenda topics.

4.1 Agenda – Session III - Power Processing

Session III: 8:30 AM – 5:00 PM – Workshop Chair: P. McNutt

General Session (8:30 AM – 12:00 PM): Organizer and Session Chair - W. Bower

- Tutorial (1 hour) - J. Berdner
- Open Discussion (2 hours) - Facilitator: Ward Bower

  - Presenters: S. Jochums, Underwriters Lab

- Summary (30 minutes) - Peter McNutt

Standards Panel/Discussion (1:30 PM – 5:00 PM): Facilitator - Peter McNutt

- IEEE SCC21 - R. DeBlasio – Standards Coordinating Committee 21 Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage
- IEC TC82/US TAG - J. Wohlgemuth (for G. Posbic IEC TC82) – WG6 (Working Group 6 - Balance of System Components)
- NEC Article 690 - W. Bower/J. Wiles – National Electrical Code (NEC) Article 690 Solar Photovoltaic Systems

4.2 Power Processing Session Summary Notes

Morning Session – Session Chair: Ward Bower - SNL

Speakers: Steve Jochums, UL: "UL 1703 Standards Issues"
John Berdner, Pulse Energy Systems: "Power Processing – From Module to Load"
Steve Chalmers, PowerMark: "IEC TC82 Secretariat Status"

Issues Highlighted:

- UL listing does not ensure that a product operates, only that it is safe to operate.
- U.S. standards currently are not widely enforced.
- Liability should be placed upon distributors and installers, as well as manufacturers.
- A national interconnection standard (IEEE 929) is desirable.
- The need exists for performance and reliability standards.

Afternoon Session – Facilitator: Peter McNutt – NREL

Speakers: Dick DeBlasio, NREL: "Interconnection Standards Development – IEEE SCC21 Status"
Chuck Whitaker, PVUSA/Endecon
Tim Zgonena, UL: "BOS Components – IEC TC82/US TAG WG6 Status"
Ward Bower, SNL
John Wiles, SWTDI/NMSU: "2002 NEC Article 690 Proposed Changes"

Issues Highlighted:

- Interconnection Standards are critical to PV systems acceptance.
- Credible data can "sway the group."
- 2002 NEC 690 – changes must be submitted before November 5, 1999.
- Can we reference existing standards?
- Standards should be aimed at all distributed generation., not just PV.
- U.S. should lead standards.
- Manufacturers can't guarantee their components if components are not installed properly.
- Need a list of failure mechanisms and need to disseminate the list.
- Proposed standard – Inverter performance/qualification.

Power Processing

From module to load what you need and why

NREL Balance of Systems
Reliability Workshop
October 1999

Why Standards

- *Improved Safety of electrical equipment*
- *Standards allow unified design for widespread use*
- *Improved quality and reliability*
- *Standards need teeth to be effective*
  - Present US model does not insure compliance
  - CE model places liability on distribution as well as manufacturers

Safety Standards

- *NEC applies to all electrical systems*
- *Article 90.7, 110.2, and 110.3 require testing for safety*
  - Listing by recognized testing labs for consistency
  - Field testing is available for unlisted equipment
- *Safety Standards do not insure reliability or performance*

Quality & Performance Standards

- *Safety Standards imply performance and reliability*
- *Performance and reliability Standards need to be developed*
- *Large funding agencies are in best position to insure compliance*
- *ISO insures consistency and implies quality*

PV Specific Design Basics

- *Design Current - NEC Article 690-8*
  - Isc vs Continuous vs Design
  - NEC – 1.25 * Continuous Current
  - UL - Continuous Current is 1.25 * Isc
- *Design Voltage - NEC Article 690-7*
  - 1.25 * Voc (temperature related)
  - 2.5 * nominal (rule of thumb)

Elements of a PV Module

- *PV Cells*
- *Internal Wiring*
  - Intercell Connectors
- *Bypass Diodes*
  - Purpose
  - Current Rating

Series Fuses or Breakers

- *Required by UL to validate Listing*
  - Size determined by the module manufacturer and UL during testing
  - Establishes maximum rating for over current device used with module
- *Insures safety of module not reliability*
- *Module failure is an acceptable outcome of the UL test*

Blocking Diodes

- *Allowed but not required by NEC*
- *NEC and UL consider diodes to be unreliable devices - separate over current protection is required*
- *Issues*
- *Alternatives*

Intermodule Wiring

- *Must be protected against back feed faults Article 690-9*
- *Ampacity of inter-module wiring*
  - Use 156% of Isc as minimum ampacity
  - Derate ampacity for temperature, fill factors, etc.
  - Protected by series fuse

Source Circuit Combiner

- *Meets UL series fuse requirements*
- *Meets requirement for disablement of an array Article 690-18*
- *Code requires supplementary protection only*
- *Separate means of disconnect required for PV output circuit*

Charge Control - Purpose

- *Extend battery life*
- *Prevent over charge*
- *Minimize gassing and maintenance costs*
- *Prevent over discharge*
- *Night time reverse current flow*
- *Other functions*

Charge Controller Types

- *Series Type*
  - Disconnect charging sources from battery
  - Typically used with PV Arrays
- *Shunt type*
  - Limit Charging by increasing loads

– Typically used in wind and hydro systems

Relay Based (on/off) Controllers

- Limited charge control accuracy
- MDR types have very long life 10M+ cycles
  - Simple, rugged, reliable
  - High resistance to lightning damage
  - Very low power dissipation
- Electro-mechanical types have limited life - 100-500k cycles

Solid State Type (PWM)

- *Sophisticated algorithms are possible*
- *Switching noise can be a problem*
- *More susceptible to lightning damage*
- *Power dissipation / heat generation can be significant*

Solid StateTopologies

- *High-side series switching*
- *Low side series switching*
- *Shunt (diversion)*
- *MOSFET (12 - 48 Vdc)*
- *IGBT (120 Vdc and higher)*

Sub-Array Switching

- *Used in larger systems*
- *Combination PWM plus MDR' s*
  - Provides benefits of both relay type and PWM type
  - Reduces switching noise issues

– Redundant design possible

Charge Control Algorithms

- *Constant voltage*
- *Multi-stage (Bulk, Float, Equalize)*
- *Ahr counting*
- *Max power tracking*

Inverters

- *Utility interactive*
  - battery less
  - battery based
- *Stand alone*
- *Array direct*
- *Combination designs*

Utility Interactive Inverters

- *Codes and standards issues*
  - IEEE 929 Standard in draft form
  - Presently no National interconnect Standards are available
- *Battery-less*
  - Maximum power point tracking
  - Power output varies with insolation level
  - Typically a current source design
  - No back up capability during outages

Utility Interactive Inverters

- *With Battery*

- Often include integral battery charges (inverter / charger)
- Can provide short or long term outage protection
- Power can be sold back to utility based on several criteria:
  - PV output
  - Time of day
  - Household load

Stand Alone Inverters

- *Typically operate as a voltage source*
- *Self commutated*
- *Inverter charger designs most common*
- *Several Waveforms available*
  - Sine wave (~3 % THD)
  - Modified or quasi sine wave (> 25% THD)

PV Array Direct Inverters

- *Application specific designs*
- *Typically operate motor loads*
  - Water pumping systems
  - Air conditioning systems
- *Large potential market but presently manufactured in low volume*

Combined Inverter / Balance-of-Systems

- *Integrated inverter with PV array control, protection, and disconnect means.*
  - Over current protection
    - Integral fuses
    - Integral breakers
  - Means of disconnection AC and DC side
  - Ground fault protection

- Metering / indicators
- Indoor / outdoor enclosure

Summary

- *Safety Standards exist for present BOS components*
- *Existing Standards may need modification to address next generation products*
- *A National interconnection Standard (IEEE 929) is desirable*
- *Performance and reliability Standards or independent certification body does not exist at this time*

UL 1703 Standards Issues

Steve Jochums
Underwriters Laboratories, Inc.
Northbrook, Illinois

Underwriters Laboratories Inc.®

1999 PV Performance, Reliability & Standards Conference Vail, CO

Introduction

- Overview of basic requirements
- Overview of Manufacturer provided data
- Current issues with installation per NEC.
- Special Field Issues

PV Performance, Reliability & Standards Conference 10/99

UL 1703 "Standard for Safety for Photovoltaic Modules and Panels"

- General Construction Requirements
  Polymers - Flammability, UV, HWI, CTI
- Current-Carrying Parts and Internal Wiring
  Buses, tabbing, lead wires, etc.
- Wireways - Wire routing chambers
- Connection Means - Terminals, leads, etc.
- Bonding and Grounding - Mechanical, electrical

PV Performance, Reliability & Standards Conference 10/99

UL 1703 "Standard for Safety for Photovoltaic Modules and Panels"

- Spacings - Internal/external and terminals
- Wiring Compartments - Mechanical, conduit, etc.
- Corrosion Resistance - Paint or coatings
- Accessibility of Live Parts - Shock risk reduction
- Fire Resistance - Basic Classification, UL 790
- Superstrate - Glazing safety

PV Performance, Reliability & Standards Conference 10/99

UL 1703 "Standard for Safety for Photovoltaic Modules and Panels"

- Typical Requested Data from Client
- Material Information –
  - Component Suppliers and designations
  - Component UL Recognition data
  - Construction dimensions

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UL 1703 "Standard for Safety for Photovoltaic Modules and Panels"

- Typical Requested Data from Client
- Electrical Data -
  - Module –
    - Voc, Isc, Vmp, Imp, Pmp, NOCT, Temp. Coefficients
  - Installation (System) –
    - Mounting style, Max. System Voltage, Wire sizing, ***Series fuse rating***

PV Performance, Reliability & Standards Conference 10/99

UL 1703 "Standard for Safety for Photovoltaic Modules and Panels"

- Intent of the Series Fuse – Protection from fire hazard
  - Module – fire hazard from heating of cells, interconnects, etc.
  - Module Wiring – fire hazard overheated insulation

PV Performance, Reliability & Standards Conference 10/99

UL 1703 "Standard for Safety for Photovoltaic Modules and Panels"

- **Inverse Current Overload Test**
- Assessment of module fire risk in reverse current flow.
  - Cell bypassing, ribbon size, cell matching, etc.
- Determines suitability of fuse rating.

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Inverse Current Overload Test

- Test Method –
- "...a module or panel...is to be placed on a single layer of white tissue paper over a 3/4 inch (19.1 mm) thick pine board and covered with a single layer of cheesecloth...any blocking diode provided as a part of the module or panel is to be defeated...conducted in an area free of drafts...current equal to 135 percent of the module or panel series fuse rating current...is caused to flow in a reverse direction through the module or panel...for 2 hours or until ultimate results are known..."

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Inverse Current Overload Test

- Test Results
  - "...no flaming or charring of the cheesecloth or tissue paper in contact with a module or panel, or flaming of the module or panel itself for 15 seconds or more..."

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Inverse Current Overload Test

- Abnormal test – not "normal" operations
- Electrical performance after test is not a criterion for compliance.

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Inverse Current Overload Test

- Reliance on "Fail-Safe" Operation
  - Failure mode must be repeatable (three tests, same results)
  - No accessibility to live parts (test probe, hi-pot)

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NEC Article 690 PV Source Circuit Overcurrent Protection

- Protect wiring from short-circuit heating
- Based on ampacity of wiring w/ temperature de-rating factors
- May be same value as Module Series fuse to serve single function
- May serve as disconnect device for string

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UL 1703 Component Issues

- Other Component Issues
- Bypass Diodes –
  - Suitability of ratings (temp. testing)
  - Failure-mode testing (IEC Reverse Polarity test)

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UL 1703 Component Issues

- Interconnects & Wiring –
  - Minimum sizing – UL 1703
  - NEC Article 690-31
  - Connectors –
    - Recognized, used for array assembly ONLY
  - Listed
    - If deemed suitable for "disconnect means"

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UL 1703 Component Issues

- Blocking Diodes –
  - Typically not used on system-wired modules
  - Evaluated for adequacy in circuit
  - Some diode packages "Recognized"

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Field Issues

- Paralleling modules / panels –
- Allowed by NEC
  (based on wiring, overcurrent, etc.)
- Creates "PV Source Circuit", defined by NEC
- Wiring systems defined by NEC 690

Field Issues

- Paralleling Arrays –
- Allowed by NEC (based on wiring, overcurrent, etc.)
- Creates "PV Output Circuit", defined by NEC
- Wiring systems defined by NEC 690
- Backfeed issues can be addressed by investigated components

Field Inspections of Products

- Based on currently Listed product construction
- Limited testing in field (temps, P/I/V, hi-pot, etc.)
- Products using “new and unusual” construction, materials, configurations, etc. cannot be field investigated; *too many variables.*

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Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

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INTERCONNECTION STANDARDS DEVELOPMENT

STATUS OF IEEE SCC21

BY

RICHARD DEBLASIO
NATIONAL RENEWABLE ENERGY LABORATORY
GOLDEN, COLORADO

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INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS
STANDARDS COORDINATING COMMITTEE 21 (SCC21)
STANDARDS ASSOCIATION (SA)

IEEE - SA - SCC21

CURRENT STATUS

Standards Coordinating Committee 21
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IEEE SCC21 SCOPE

OVERSEES THE DEVELOPEMNT OF STANDARDS IN THE AREAS OF FUEL CELLS, PHOTOVOLTAICS, DISPERSED GENERATION, AND ENERGY STORAGE, AND COORDINATES EFFORTS IN THESE FIELDS AMONG THE VARIOUS IEEE SOCIETIES AND OTHER AFFECTED ORGANIZATIONS TO INSURE THAT ALL STANDARDS ARE CONSISTENT AND PROPERLY REFLECT THE VIEWS OF ALL APPLICABLE DISCIPLINES.

REVIEWS ALL PROPOSED IEEE STANDARDS IN THESE FIELDS BEFORE THEIR SUBMISSION TO THE IEEE-SA STANDARDS BOARD FOR APPROVAL AND COORDINATES SUBMISSION TO OTHER ORGANIZATIONS.

Approved by the IEEE Standards Board on June 25, 1998

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CURRENT IEEE SCC21 COORDINATING COMMITTEE MEMBERSHIP

OFFICERS

R. DeBlasio, SCC21 Chairman
S. Chalmers, SCC21 Vice Chairman
J. Anderson, SCC21 Secretary

ACTIVE WORKING GROUP LEADERS AND LIAISON MEMBERS

J. Stevens, F. Goodman, J. Koepfinger, T. Basso, J. Wiles, W. Bower, R. Feero, J. Chamberlin, D. Dawson, B. Hornberger, K. Hetch, J. Smyth, J. Wohlgemuth, C. Whitaker, B. Kroposki, C. Osterwald, D. Conover, R. McConnell

OVER 200 PARTICIPATING WORKING GROUP MEMBERS

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IEEE - SA STANDARDS BOARD
IEEE STANDARDS COORDINATING COMMITTEE SCC21 FUEL CELLS, PHOTOVOLTAICS, DISPERSED GENERATION AND ENERGY STORAGE
WORKING GROUPS (WG), STANDARDS (STD.) AND PROJECTS (P)

WG 1547 R. DEBLASIO	**P1547** - STANDARD FOR DISTRIBUTED RESOURCES INTERCONNECTED WITH ELECTRIC POWER SYSTEMS
WG P929 J. STEVENS	**P929** - RECOMMENDED PRACTICE FOR UTILITY INTERFACE OF PV SYSTEMS
WG INACTIVE	**STD. 1001** - IEEE GUIDE FOR INTERFACING DISPERSED STORAGE AND GENERATION FACILITIES WITH ELECTRIC UTILITY SYSTEMS (WITHDRAWN 5/96)
WG INACTIVE	**STD. 1021** - IEEE RECOMMENDED PRACTICE FOR THE UTILITY INTERCONNECTION OF SMALL WIND ENERGY CONVERSION SYSTEMS (WITHDRAWN 5/96)
WG INACTIVE	**STD. 1035** - IEEE RECOMMENDED PRACTICE: TEST PROCEDURE FOR UTILITY INTERCONNECTED STATIC POWER CONVERTERS (WITHDRAWN 5/95)
WG INACTIVE	**STD. 1094** - IEEE RECOMMENDED PRACTICE FOR THE ELECTRICAL DESIGN AND OPERATION OF WINDFARM GENERATING STATIONS (WITHDRAWN 1/97)

WG INACTIVE S. CHALMERS	**STD. 928** - IEEE RECOMMENDED CRITERIA FOR TERRESTRIAL PV POWER SYSTEMS (REAFFIRM BY 5/2000)
WG INACTIVE (SEE P929)	**STD. 929** - IEEE RECOMMENDED PRACTICE FOR UTILITY INTERFACE OF RESIDENTIAL AND INTERMEDIATE PV SYSTEMS (REAFFIRM BY 5/2000)
WG INACTIVE J WOHLGEMUTH	**STD. 1262** - IEEE RECOMMENDED PRACTICE FOR QUALIFICATION OF PHOTOVOLTAIC MODULES (REAFFIRM BY 4/2000)
WG ACTIVE C. WHITAKER	**P1373** - RECOMMENDED PRACTICE FOR FIELD TEST METHODS AND PROCEDURES FOR GRID-CONNECTED PHOTOVOLTAIC SYSTEMS (PLANNED COMPLETION 12/99)
WG INACTIVE J. WILES	**P1374** - IEEE GUIDE FOR TERRESTRIAL PHOTOVOLTAIC POWER SYSTEM SAFETY (REAFFIRM BY 12/2003)
WG ACTIVE B. KROPOSKI	**P1526** - RECOMMENDED PRACTICE FOR TESTING THE PERFORMANCE OF STANDALONE PHOTOVOLTAIC SYSTEMS (PLANNED COMP. 12/2002)
WG ACTIVE B. KROPOSKI	**P1479** - RECOMMENDED PRACTICE FOR THE EVALUATION OF PHOTOVOLTAIC MODULE ENERGY PRODUCTION (PLANNED COMP. 7/98)
WG ACTIVE R. McCONNELL	**P1513** - RECOMMENDED PRACTICE FOR QUALIFICATION OF CONCENTRATOR PHOTOVOLTAIC (PV) RECEIVER SECTIONS AND MODULES (PLANNED COMP. 7/2001)

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WG ACTIVE J CHAMBERLIN	**STD. 937** - IEEE RECOMMENDED PRACTICE FOR INSTALLATION AND MAINTENANCE OF LEAD-ACID BATTERIES FOR PV SYSTEMS P937 - REVISION/REAFFIRMATION BY 12/2002
WG ACTIVE J CHAMBERLIN	**STD. 1013** - IEEE RECOMMENDED PRACTICE FOR SIZING LEAD ACID BATTERIES FOR PHOTOVOLTAIC (PV) SYSTEMS P1013 - REVISION/REAFFIRMATION BY 12/2002
WG INACTIVE J CHAMBERLIN	**STD 1144** - IEEE RECOMMENDED PRACTICE FOR SIZING OF INDUSTRIAL NICKEL CADMIUM BATTERIES FOR PHOTOVOLTAIC SYSTEMS
WG ACTIVE J CHAMBERLIN	**STD 1145** - IEEE RECOMMENDED PRACTICE FOR INSTALLATION AND MAINTENANCE OF NICKEL-CADMIUM BATTERIES FOR PHOTOVOLTAIC (PV) SYSTEMS P1445 - REVISION/REAFFIRMATION BY 12/2002
WG ACTIVE J CHAMBERLIN	**P1361** - GUIDE FOR THE SELECTION, TEST AND EVALUATING OF LEAD ACID BATTERIES FOR STAND ALONE PHOTOVOLTAIC (PV)SYSTEMS (PLANNED COMP. 3/2000)

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NEW IEEE SCC21 PROJECT

P1547

PROJECT TITLE: STANDARD FOR INTERCONNECTING DISTRIBUTED RESOURCES WITH ELECTRIC POWER SYSTEMS

PROJECT SCOPE: THIS STANDARD ESTABLISHES CRITERIA AND REQUIREMENTS FOR INTERCONNECTION OF DISTRIBUTED RESOURCES WITH ELECTRIC POWER SYSTEMS

PROJECT PURPOSE: PROVIDE A UNIFORM STANDARD FOR INTERCONNECTION OF DISTRIBUTED RESOURCES WITH ELECTRIC POWER SYSTEMS, AND REQUIREMENTS RELEVANT TO THE PERFORMANCE, OPERATION, TESTING, SAFETY CONSIDERATIONS, AND MAINTENANCE OF THE INTERCONNECTION

IEEE SCC21 - P1547

DISTRIBUTED RESOURCES AND ELECTRIC POWER SYSTEMS INTERCONNECTING WORKING GROUP

WG CHAIR; R. DEBLASIO (NREL)
WG VICE CHAIR: J. KOEPFINGER (DL)
WG VICE CHAIR: F. GOODMAN (EPRI)
WG SECRETARY: T. BASSO (NREL)

OVER 121 WORKING GROUP MEMBERS TO DATE
(USERS 33%; MANUFACTURERS 26%; GENERAL 41%)

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P1547 STATUS - PROJECT DEVELOPMENT

IEEE SCC21 MEETING 12/98, WASH,DC, OVER 120 PARTICIPANTS; NEW WORKING GROUP FORMED FOR DG INTERCONNECTION; INTERCONNECTION PROJECT DEVELOPED (PAR)

PAR SUBMITTED TO IEEE 1/4/99

WORKING GROUP MEETING-2/24-26/1999 HOSTED BY EPRI, PALO ALTO, CALIFORNIA (ASSIGNMENTS MADE)

IEEE STANDARDS BOARD APPROVES PAR 3/18/99

EPRI RELEASES INTERCONNECTION STUDY TO IEEE SCC21 FOR USE IN P1547 PROJECT 3/29/99

WORKING GROUP MEETING- 4/26-27/1999 HOSTED BY ENTERGY, NEW ORLEANS. LA. (ASSIGNMENT AND EPRI STUDY REVIEW)

Working Group MEETING - 6/28-30/1999, CHICAGO - HOSTED BY ZENITH CONTROLS, GRI, AND COMED. (PRELIMINARY DRAFT DEVELOPED; SECTION WRITER LEADERS ASSIGNED; ASSIGNMENTS MADE)

Next Meeting - 9/26-28/1999, Washington, DC

INTERCONNECTION TECHNOLOGY

STANDARDIZATION

INTRINSIC REQUIREMENTS

EXTRINSIC REQUIREMENTS

Figure 2-1 (EPRI REPORT TR-111489)

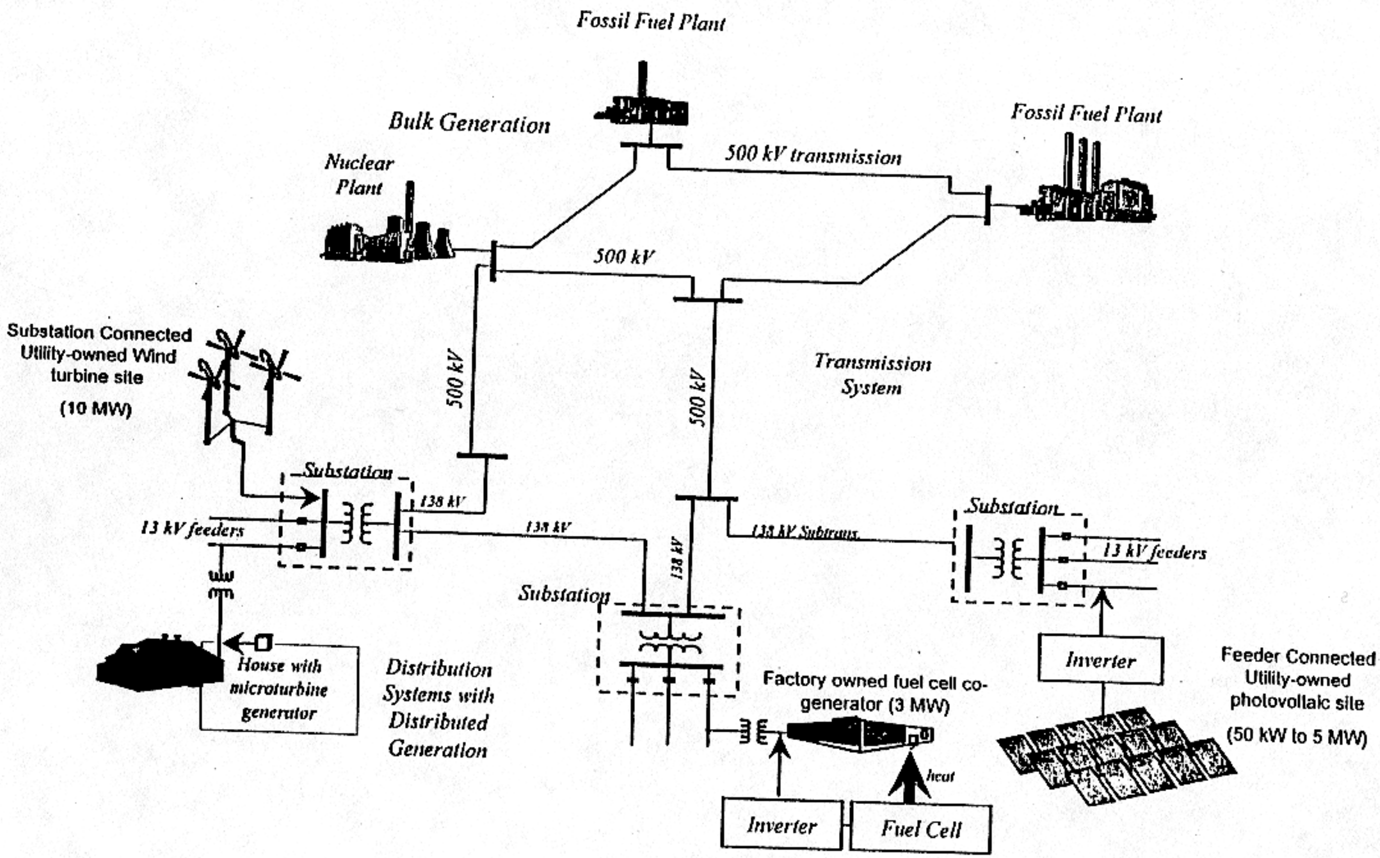


Figure 2-2 (EPRI REPORT TR-111489)

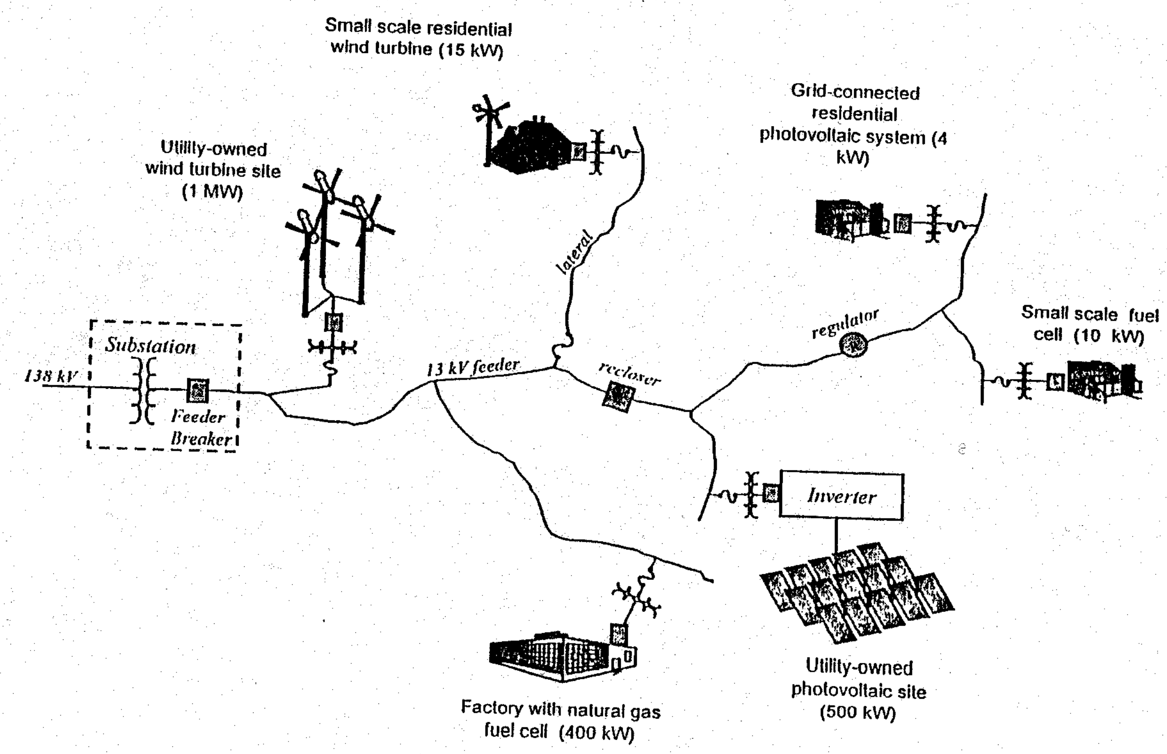


Figure 4-1 (EPRI REPORT TR111489)

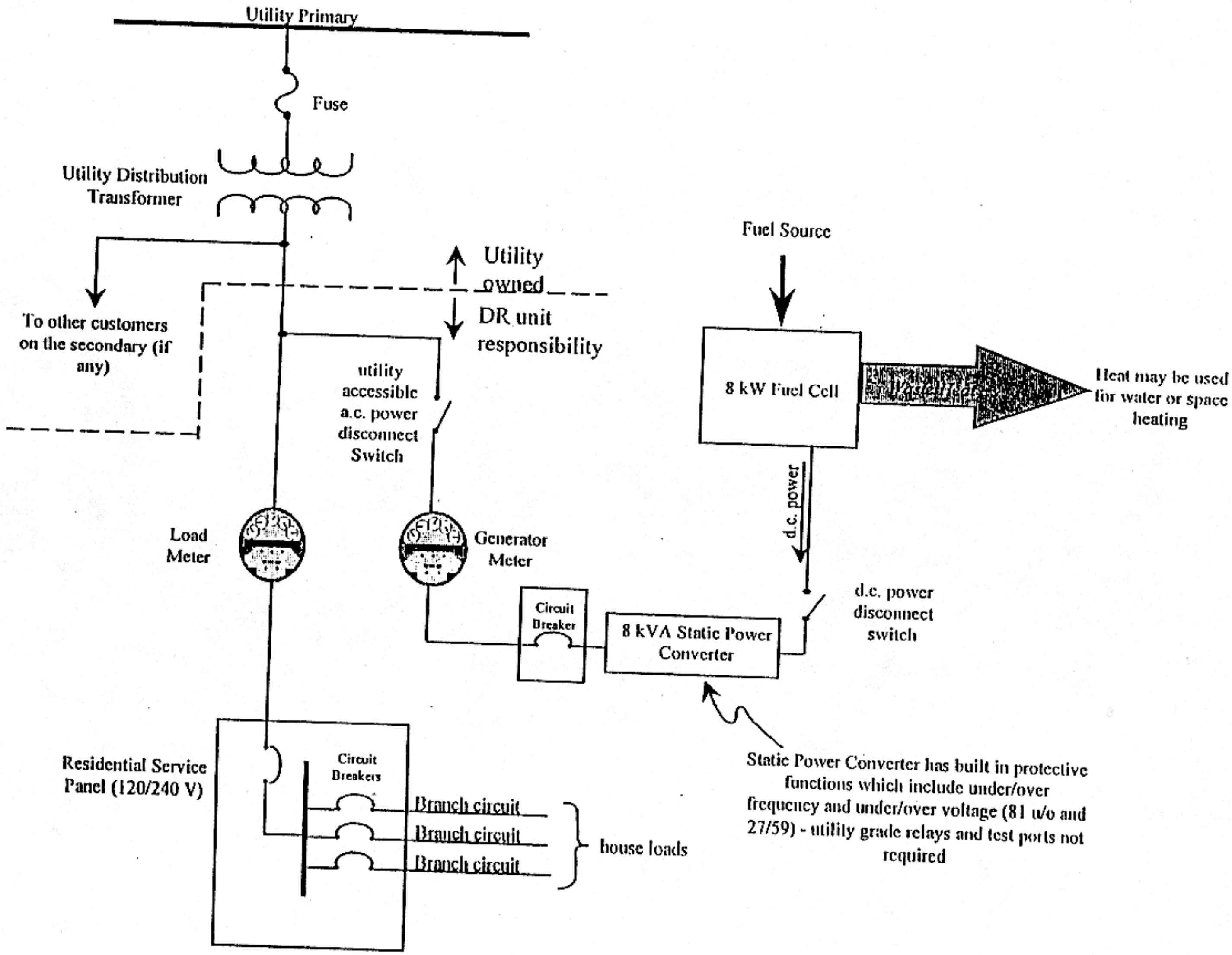
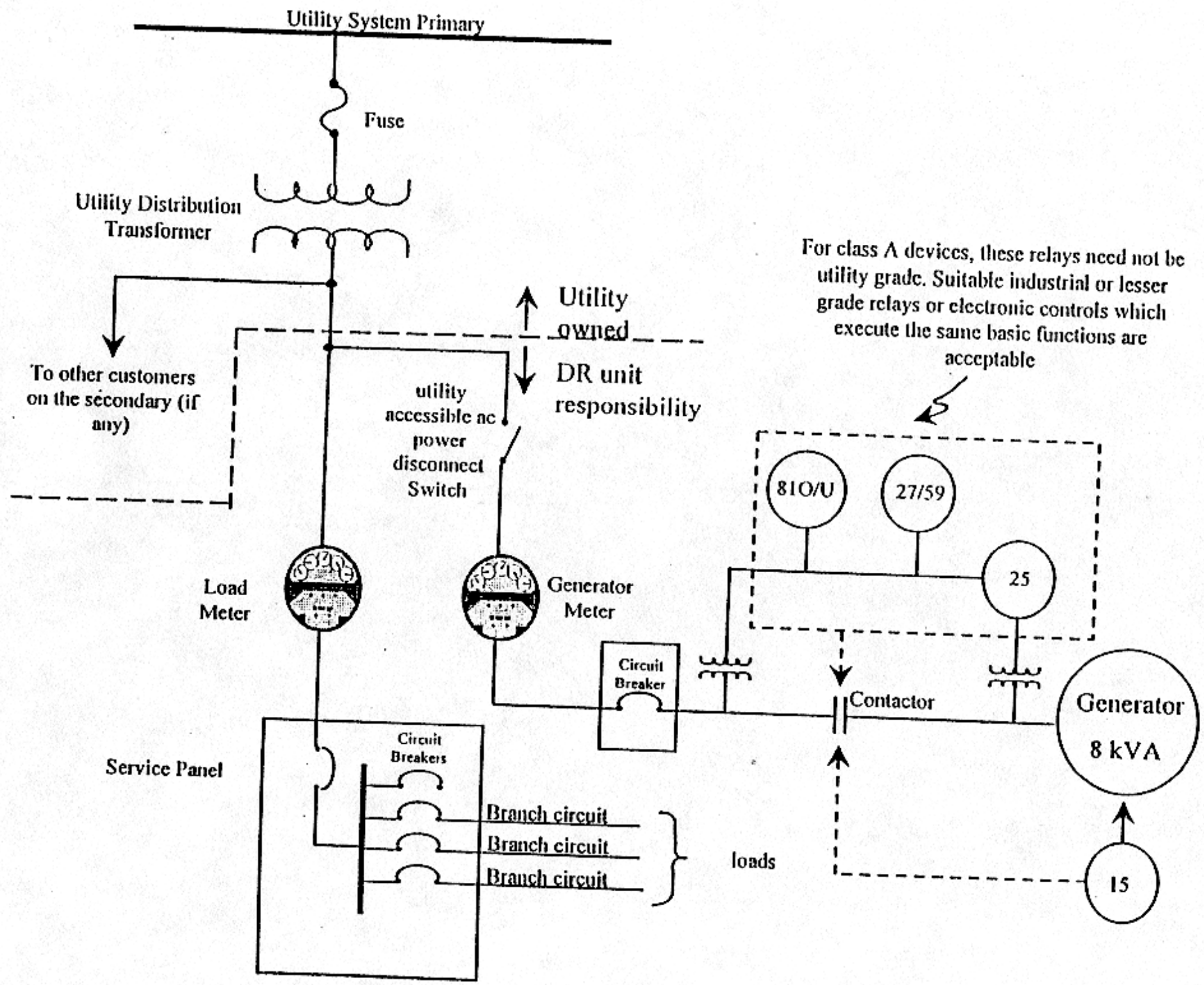


Figure 4-2 (EPRI REPORT TR-111489)



Notes: 81O/U = Under/over- frequency relays

27/59 = Under/over- voltage relays

25 = Synchronizing relay (not required for induction generator)

15 = Speed matching relay (Ind. generator).

Figure 3-1 (EPRI REPORT TR111489)

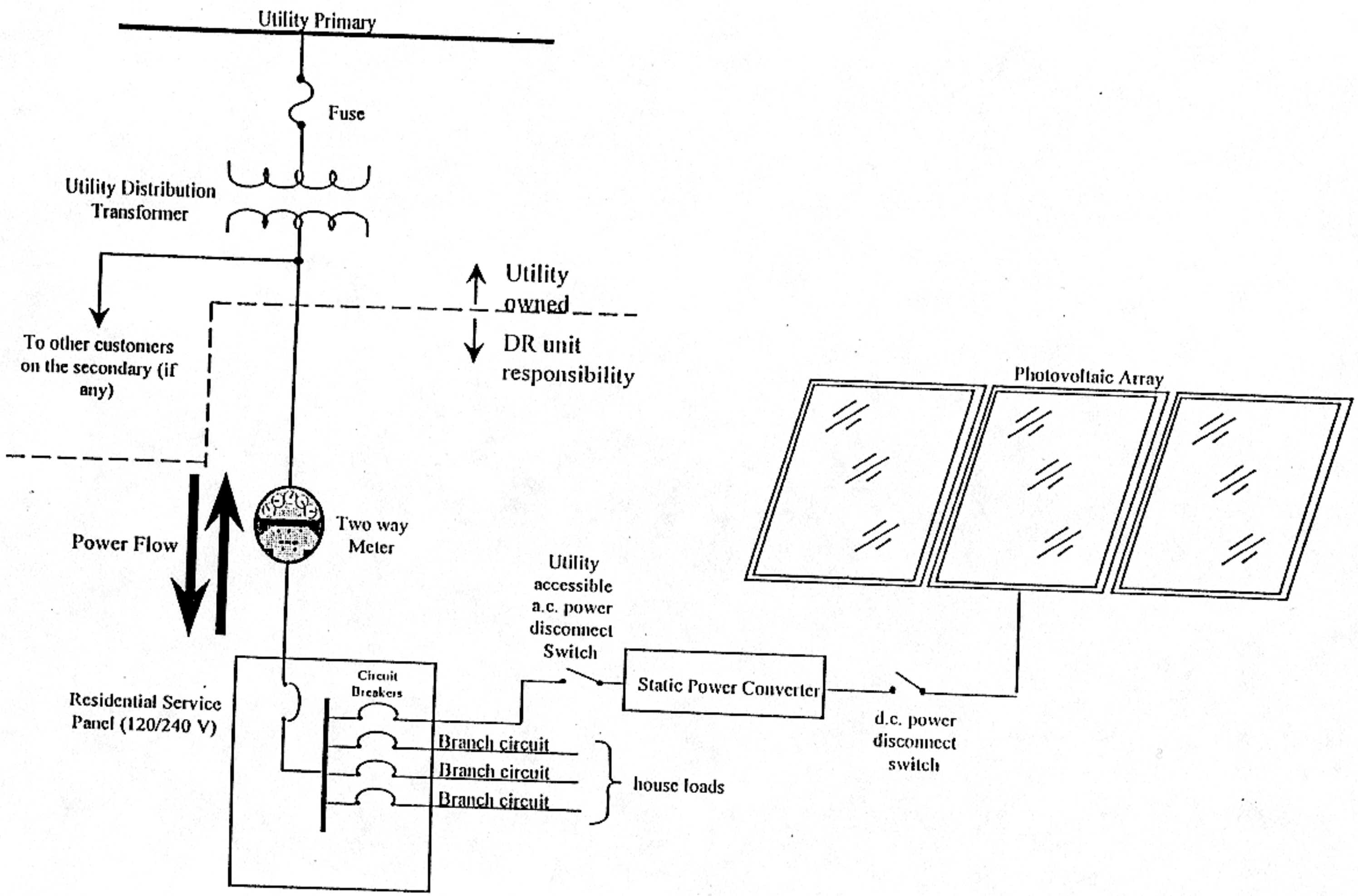
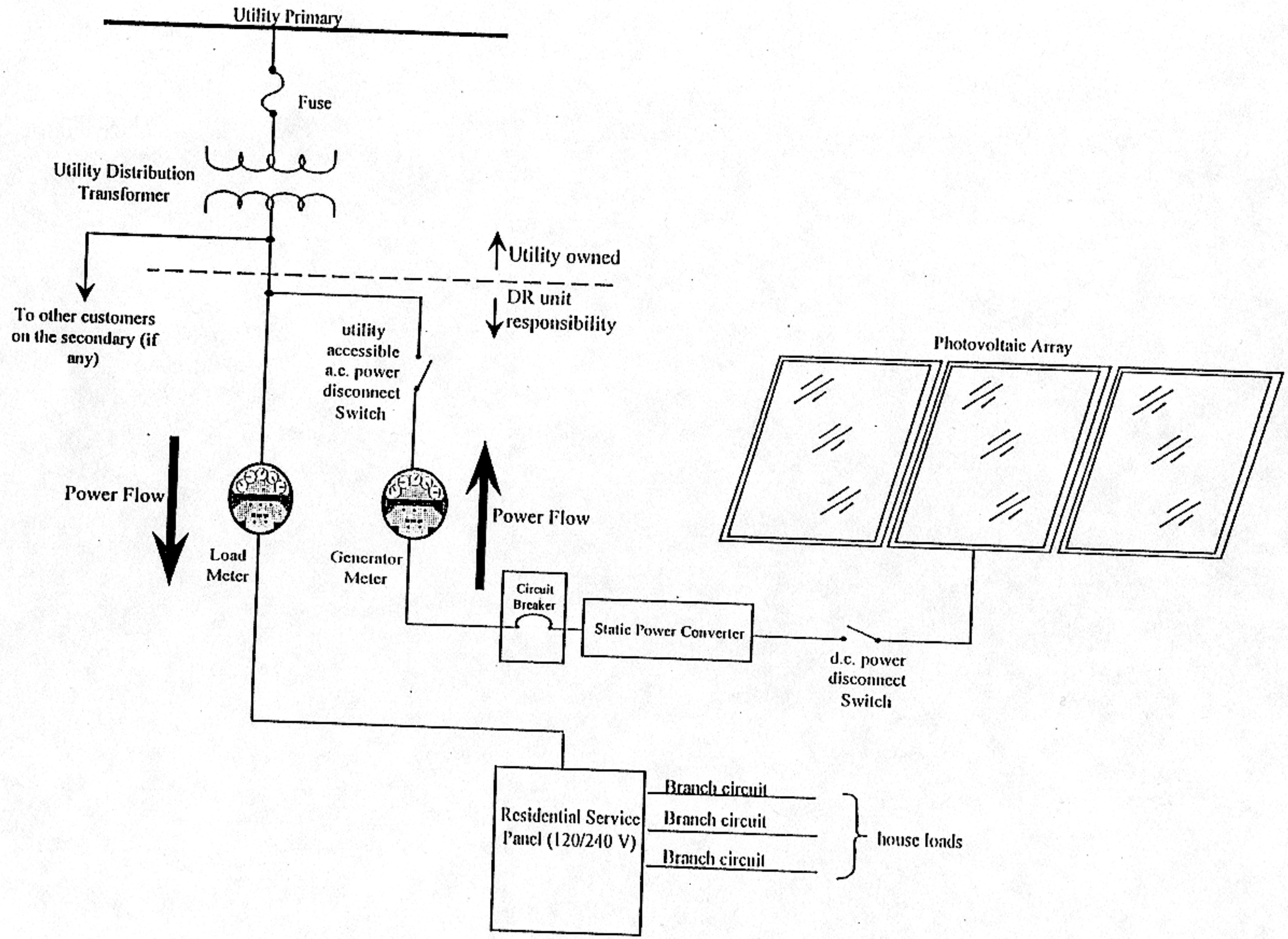
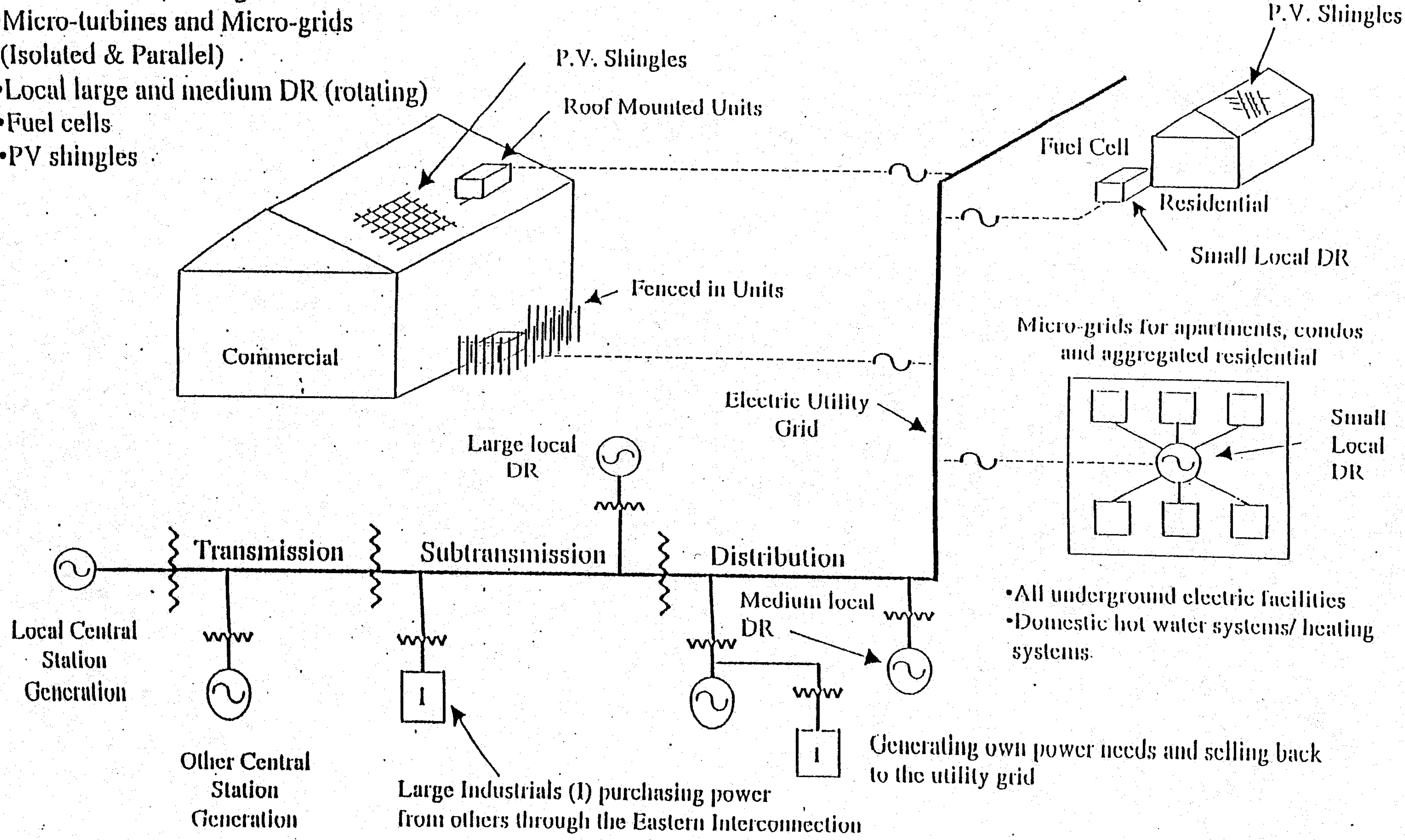


Figure 3-2 (EPRI REPORT TR 111489)

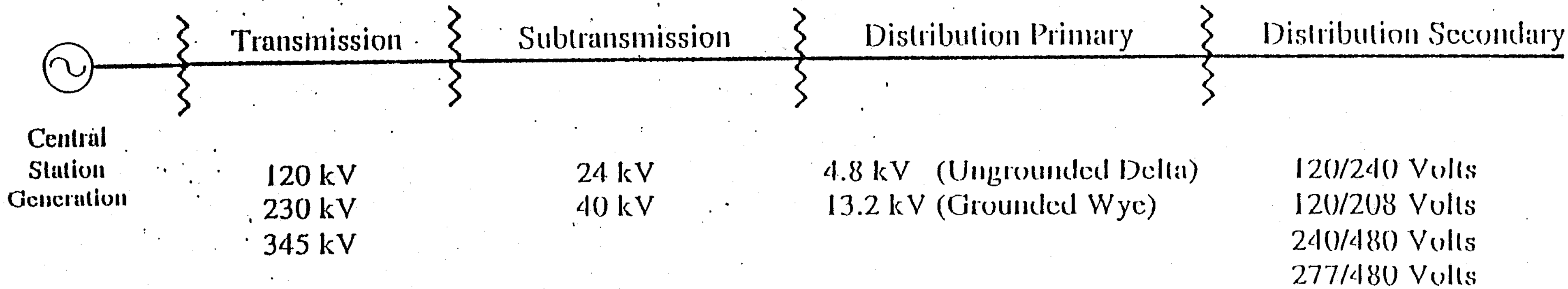


What Could the Power Systems' of the Future look like?

- Large central station generation
- Other central station generation
- Micro-turbines and Micro-grids (Isolated & Parallel)
- Local large and medium DR (rotating)
- Fuel cells
- PV shingles



Transmission & Distribution System Voltages



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INTERFACE/INTERCONNECTION TESTING NEEDS

EXAMPLES - INTERFACE TESTS: DG SHORT CIRCUIT CURRENT OUTPUT AND TOLERANCE - NEEDS TO BE VERIFIED AND CERTIFIED; DG PROTECTIVE SET POINTS (V AND I); VOLTAGE REGULATION - NO LOAD TO FULL LOAD; TESTABILITY - INTERNAL VS EXTERNAL SET POINT AND SIMULATION TESTS; TESTING AND TEST METHOD FOR ISLANDING (ISLANDING AND NON-ISLANDING CHARACTERISTICS); ETC.

EXAMPLES - INTERCONNECTION TEST METHODS: TEST PROCEDURES FOR INTERCONNECTION EQUIPMENT FUNCTIONAL PERFORMANCE; TEST PROCEDURES FOR POWER QUALITY MEASUREMENTS AND EVALUATION; TEST PORCEDURES TO EVALUATE COMMAND AND CONTROL FEATURES OF INTERFACE EQUIPMENT - FOR OPERATIONAL FUNCTIONS AND SAFETY; STANDARDIZED TEST PROCEDURES FOR EQUIPMENT AND INSTALLATION CERTIFICATION; ETC.

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INTERCONNECTION AND TEST STANDARDS DEVELOPMENT INFRASTRUCTURE

DISTRIBUTED RESOURCE POWER SYSTEM (TYPES)	INTERFACE (EQUIPMENT - INCLUDING ASSOCIATED LOCATION) (POINT OF INTERFACE AND ASSOCIATED POINTS OF INTERFACE), WIRING CONFIGURATION, AND TOPOLOGY)	ELECTRIC POWER SYSTEM (VOLTAGE CATEGORIES)
A. TECHNICAL SPECIFICATIONS AND REQUIREMENTS FOR INTERCONNECTION		
FUEL CELLS COMBUSTION TURBINE GENERATOR SETS MICROTURBINE GENERATOR SETS INTERNAL COMBUSTION GENERATOR SETS SOLAR PHOTOVOLTAIC SYSTEMS SOLAR THERMAL-ELECTRIC DISH SYSTEMS WIND SYSTEMS STORAGE (BATTERIES) FOSSIL ETC.	**STATIC INVERTER** **INDUCTION GENERATOR** **SYNCHRONOUS GENERATOR** **TECHNICAL SPECIFICATIONS AND REQUIREMENTS**	**DISTRIBUTION SECONDARY** 120/240; 120/208; 120/480; 277/480 VOLTS **DISTRIBUTION PRIMARY** 4.8 KV(UNDERGROUND DELTA); 13.2KV (GROUNDED WYE) **SUBTRANSMISSION** 20KV;40KV **TRANSMISSION** 120KV;230KV;345KV
B. TESTING SPECIFICATIONS/REQUIREMENTS/PROCEDURES FOR INTERCONNECTION		
A/B TEMPLATE = P1547 STANDARD TECHNICAL APPROACH FOR INTERCONNECTION		

P1547 OUTLINE

INTRODUCTION

1. OVERVIEW

2. STANDARD TECHNICAL APPROACH FOR INTERCONNECTION

3. INTERCONNECTION TECHNICAL SPECIFICATIONS AND REQUIREMENTS

4. TEST SPECIFICATIONS, REQUIREMENTS AND PROCEDURES

5. LIST OF INTERCONNECTION SPECIFICATIONS AND TEST REQUIREMENTS

ANNEXES

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P1547 OUTLINE

(WRITING SECTION COORDINATORS)

INTRODUCTION (R. DeBlasio)

1. OVERVIEW (Lynnda Ell)

2. STANDARD TECHNICAL APPROACH FOR INTERCONNECTION (F. Goodman)

3. INTERCONNECTION TECHNICAL SPECIFICATIONS AND REQUIREMENTS (R. Friedman)

4. TEST SPECIFICATIONS, REQUIREMENTS AND PROCEDURES (J.Koepfinger/D.Leslie)

5. LIST OF INTERCONNECTION SPECIFICATIONS AND TEST REQUIREMENTS (T. Basso)

ANNEXES

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FUTURE IEEE SCC21 MEETINGS

SEPTEMBER 27-30, 1999, INTERCONNECTION P1547 WG
(DOE) Arlington, VA

DECEMBER 1-3, 1999, INTERCONNECTION P1547 WG
(TAMPA ELECTRIC)
TAMPA FLORIDA

JANUARY 26-27, 2000. INTERCONNECTION P1547 WG
(ALLIED SIGNAL)
ALBUQUERQUE, NEW MEXICO

June 18, 1999

P1547 PRELIMINARY DRAFT Standard for Distributed Resources Interconnected with Electric Power Systems

Sponsored by the
IEEE Standards Coordinating Committee 21, entitled,
Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage (IEEE SCC21)
of the
IEEE Standards Association

T. Basso, Secretary of P1547 Working Group of IEEE SCC21
National Renewable Energy Laboratory – MS3411
1617 Cole Blvd
Golden, CO, 80401-3393 USA

P1547 Working Group Resource Document (WGRD) for Draft Standard for Distributed Resources Interconnected with Electric Power Systems

Sponsored by the
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of the
IEEE Standards Association

T. Basso, Secretary of P1547 Working Group of IEEE SCC21
National Renewable Energy Laboratory – MS3411
1617 Cole Blvd
Golden, CO, 80401-3393 USA

Chuck Whitaker – Endecon
Tim Zgonena – UL

10/20/99

IEC TC82 WG6: BOS

New Work Group formed in Sept 98

Three approved activities:

1. IEC 62093 Ed. 1.0: (WD) BOS components - Environmental reliability testing - Design qualification and type approval.

This is the newest project and no documents have yet been produced.

2. IEC 62109 Ed. 1.0: (WD) Electrical safety of static inverters and charge controllers for use in photovoltaic (PV) power systems

This will be an international version of UL 1741.

3. IEC 62116 Ed. 1.0: (WD) Testing procedure - Islanding prevention measures for power conditioners used in grid connected photovoltaic (PV) power generation systems

This is a very hot topic, and the subject of much debate and discussion.

WG6 is an offshoot of WG3 (Systems) and has common membership. As a result we attempt to schedule common meetings. The next joint meeting is scheduled for Dec 1999 in Albuquerque.

National Center for Photovoltaics

2002 NEC Proposed Changes

by

Ward Bower

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PV Performance, Reliability and Standards Workshop

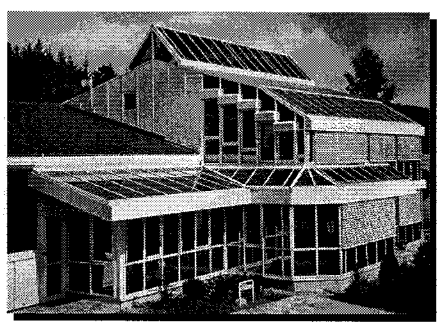
Vail Colorado - October 20, 1999

Sandia National Laboratories

National Center for Photovoltaics

Need for the NEC for 2002

1954, Pearson, Chapin, Fuller at Bell Labs Produce a 6% X-Silicon PV Cell



<u>We've Come A Long Way, Baby!</u>

11/1/99 PV_P&R99.ppt, wibower,snl 4

Sandia National Laboratories

National Center for Photovoltaics

Status of the NEC for 2000

- Thirty-seven Proposals Were Reviewed at the NEC Industry Forum in Tucson.
- The Industry Review Group is Currently Reviewing Proposals until October 29, 1999.
- There are now 28 Proposals.
- Proposals will be sent to NFPA on November 1.
- Code Making Panels Meet January 10-22, 2000.
- Public Comments Can be made until October 27, 2000.

11/1/99 PV_P&R99.ppt, wibower,snl 5

Sandia National Laboratories

National Center for Photovoltaics

2002 NEC Schedule of Events

Nov 5, 1999	Receipt of Proposals
Jan 10-22, 2000	Code-making Panel Meetings
May 15-19, 2000	Correlating Committee Meets
Jul 14, 2000	NEC ROP to Mailing House
Oct 27, 2000	Closing Date for Comments
Dec 4-16, 2000	Code-making Panel Meetings
Mar 12-16, 2001	Correlating Committee Meets
Apr 16,2001	NEC ROC to Mailing House
May 20-24. 2001	NFPA Annual Meeting
July 22, 2001	Standards Council Issuance

11/1/99 PV_P&R99.ppt, wibower,snl 6

Sandia National Laboratories

National Center for Photovoltaics

What's Being Proposed In Article 690 for the 2002 NEC

- **Corrections for Figure 1.**
- **New or Changed Definitions.**
  - Bipolar Photovoltaic Array
  - Diversion Charge Controller
  - System Voltage
- **Conductors of Different Systems.**
- **Module Connection Arrangement.**

National Center for Photovoltaics

What's Being Proposed In Article 690 for the 2002 NEC

- **Disconnection of Conductors.**
- **Ground-Fault Detection.**
- **Devices with Internal Current Limits.**
- **Combined PV Module and Source Circuit Protection.**
- **Overcurrent Protection w/Parallel PV Modules.**

What's Being Proposed In Article 690 for the 2002 NEC

- Additional Provisions.
- Grouping of Disconnecting Means.
- Add USE-2 to Allowable Single Conductor Cable.
- Temperature Correction Factors
- System Grounding.

National Center for Photovoltaics

What's Being Proposed In Article 690 for the 2002 NEC

- Size of Equipment Grounding Conductor.
- Energy Storage Labeling.
- Labeling Stand-alone Systems.
- Load Side Point-of-Interconnection.
- Non-conductive Battery Cases.

National Center for Photovoltaics

What's Being Proposed In Article 690 for the 2002 NEC

- Segmented Batteries for Servicing.
- Floated Batteries for Maintenance.
- Provisions to Allow Ungrounded Battery Systems.
- Diversion Charge Controllers Backup and Overcurrent Protection.

11/1/99 PV_P&R99.ppt, wibower,snl 11 Sandia National Laboratories

National Center for Photovoltaics

Where Do We Go From Here

- Proposals For the 2002 NEC Will be Submitted by November 5, 1999.
- The Industry May Submit Directly, Through Me or John Wiles.
- What Is Not Submitted by November 5, Will Wait Until the 2006 NEC.
- Stay Tuned for Opportunities Through Public Comments.

11/1/99 PV_P&R99.ppt, wibower,snl 12 Sandia National Laboratories

5. Systems Evaluation – October 21, 1999

Subsection 5.1 lists the planned agenda, which identifies the topical areas. Subsection 5.2 presents summary notes, after which we include the compilations of the presentations made at the workshop. The titles of the presentations do not necessarily match the exact wording of the agenda topics.

5.1 Agenda – Session IV - Systems Evaluation

Session IV: 8:30 AM – 5:00 PM -- Workshop Chair: P. McNutt

General Session (8:30 AM – 12:00 PM) – Organizer and Session Chair - A. Rosenthal

- Tutorial (1 hour) - C. Whitaker
- Open Discussion (2 hours) - Facilitator: A. Rosenthal
- Summary (30 minutes) - P. McNutt

Standards Panel/Discussion (1:30 PM – 5:00 PM) – Facilitator - P. McNutt

- IEEE WG P1373 - C. Whitaker
- P1373 Draft Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems
- IEEE WG P1526 - B. Kroposki
- P1526 Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic (PV) Systems
- IEC TC82 US TAG WG3 (Working Group 3 - Systems) - S. Chalmers
- NEC Article 690 - W. Bower/J. Wiles

5.2 Systems Evaluation Session Summary Notes

Morning Session – Session Chair: Andy Rosenthal - SWTDI

Speaker: Chuck Whitaker, Endecon: "Systems Evaluation Tutorial"

Issues Highlighted:

- When 1373 is completed, can we make testing doable by the average electrician/installer?
- Training is key to ensuring proper installation and avoidance of common errors. Checklists exist for installers yet they still don't follow them.
- We are unlikely to see the "appliance" PV system any time soon. As a result, the need exists for extensive field testing.

Afternoon Session – Facilitator: Peter McNutt – NREL

Speaker: Ben Kroposki – NREL: "Performance Testing of PV Systems – PAR 1526 Update"

Issues Highlighted:

- Currently, we are validating the procedures, not the systems.
- The procedures test a system design. They are not intended to field test each individual system.
- Would these procedures point out a marginal or faulty system design?
- Next step is to validate latest procedures with existing systems at the four labs – FSEC, NREL, PVUSA, and SWTDI. Results will be presented by late January 2000 at the 1526 working group meeting in Albuquerque.
- We need to start coordinating our testing efforts with the international community.

PVUSA
System Evaluation Tutorial

Chuck Whitaker
Endecon Engineering

PV Performance, Reliability, and Standards Workshop
October 21, 1999

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Presentation Outline

IEEE P1373:
Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic (PV) Systems

- Acceptance testing
  - Field Inspection
  - Array Tests
  - PCU Tests
  - Instrumentation
- Troubleshooting
- Performance testing
  - Array IV Curves
  - System Rating
  - PCU Performance
- Long-term monitoring

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Who Does System Testing?

- Equipment Manufacturer
- System Installer
- Owner
- ***Endecon Engineering/PVUSA***
  - ***+1 (925) 552-1330***
  - ***info@endecon.com***
- Others

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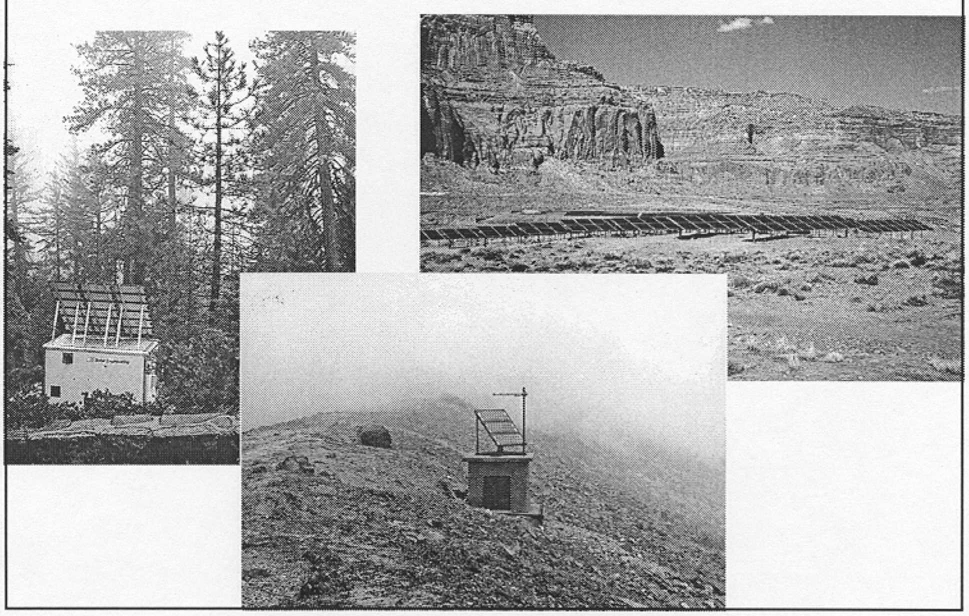
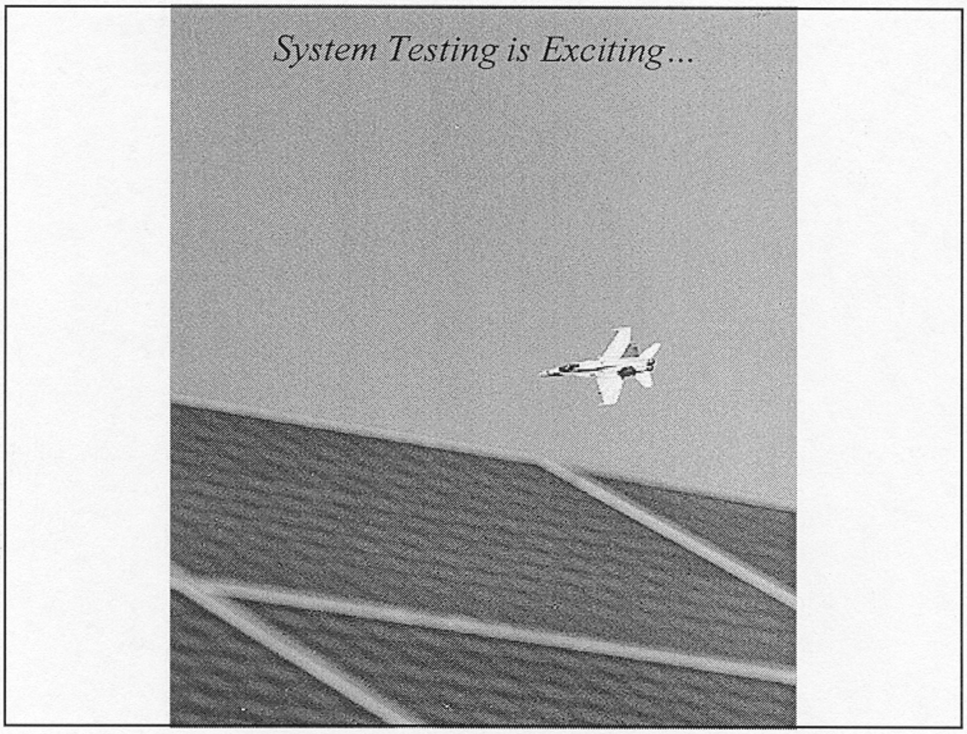
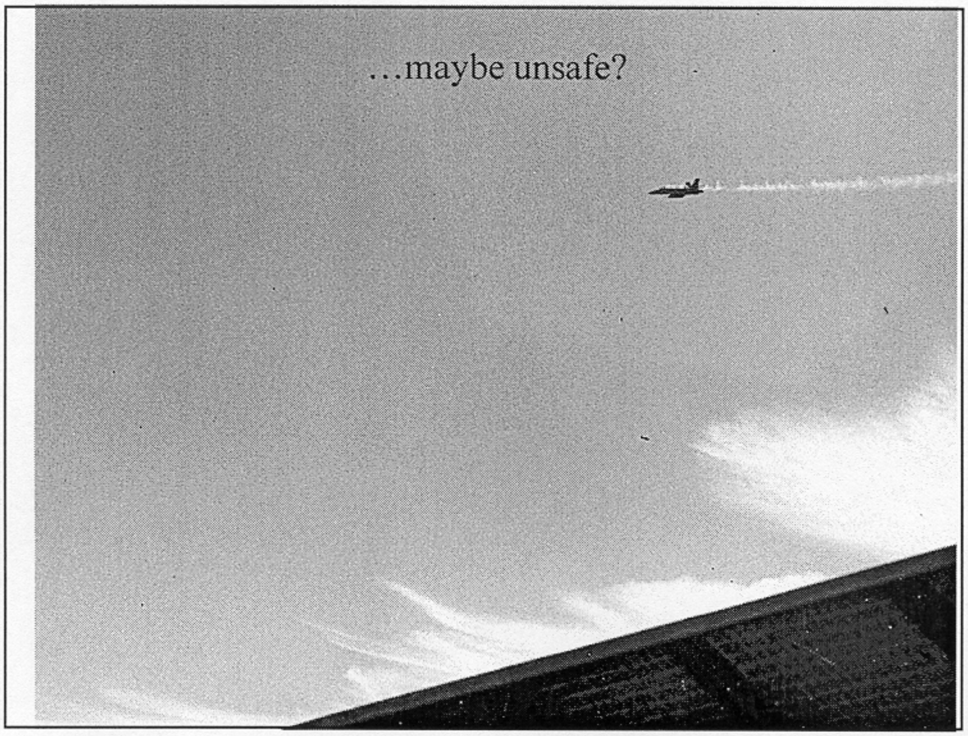
Where do you do System Testing?




System Testing is Exciting...


...maybe unsafe?

P1373 Background

- Recommended Practice for ***Field*** Test Methods and Procedures for ***Grid-Connected*** Photovoltaic (PV) Systems
- Based on PVUSA Acceptance tests plus procedures from SWRES, FSEC, Sandia, NREL,and others.
- Provides test procedures and a basis for selecting tests for specific purposes

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P1373 Purpose

This document provides recommended practices for grid-connected photovoltaic (PV) systems to

- determine that the system is functionally operative and meets the design requirements,
- verify that the system, as installed, is safe for personnel as well as equipment,
- verify that the system meets the utility interconnection requirements for paralleling to the grid, and
- establish or verify system performance.

The tests described are suitable for system acceptance purposes or can be performed at any time for troubleshooting or to evaluate system performance.

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P1373 Scope

This document discusses inspections and tests covering insulation; continuity; grounding; transformer turns ratio; polarity; instrument calibration; relay settings; I- V curves; functional system operation and verification of controls, power protection features, and alarms. Performance tests including output voltage and current harmonics, power factor, and overcurrent are also covered. Finally, a procedure for rating the system is provided.

These tests are applicable to Residential, Intermediate Size, and Central Station PV systems as defined in IEEE 928. However, some of these tests may not be necessary for or applicable to some systems. Utilities having jurisdiction may require different levels of system protection depending on system size or interconnection voltage. These requirements will dictate which components (protective relays, disconnect switches, etc.) and functional characteristics be included in the system. Thus, test selection must be adjusted to match the system requirements and design. Also, the utility may require additional tests or have different criteria or procedures than those listed here. The utility should be contacted to clarify their exact interconnection and testing requirements.

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P1373: Array Tests

	≤10 kW			>10 <100 kW			≥100 kW		
	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting
6.1.1 Field Wet Resistance Test		O		O	O		O	O	
6.1.2 Field Dry Resistance Test	O			✓			✓		
6.1.3 Voltage to Ground Test	✓	✓	✓	✓	✓	✓	✓	✓	✓
6.1.4 Open-circuit Voltage Test	✓	✓	✓	✓	✓				
6.1.5 Short-circuit Current Test	✓	✓		✓					
6.1.6 Bypass Diode Shade Test	O	✓		O	✓		O	✓	
6.1.7 Infrared Scan	O	O		O	O		O	O	
6.1.8 Array Tracker Operation	O	✓	✓	O	✓	✓	O	✓	✓
6.1.9 Array I-V Curve		O		O	O	O	✓	✓	

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P1373: PCU Tests

	≤10 kW			>10 <100 kW			≥100 kW		
	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting
6.2.1 PCU Initial Inspection	✓	✓		✓	✓		✓	✓	
6.2.2 Local PCU op & control	✓	✓	✓	✓	✓	✓	✓	✓	✓
6.2.3 Remote PCU op & control	✓	✓		✓	✓		✓	✓	
6.2.4 Wake-up/sleep ops.		✓	O		✓		✓	✓	
6.2.5 Smoke Detector		O		O			O	O	
6.2.6 Door Interlock		O		O			O	O	
6.2.7 Over-temperature		O		O			O	O	
6.2.8 O/U freq, O/U voltage							O		
6.2.9 Loss of control power							O	O	

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P1373: More PCU Tests

	≤10 kW			>10 <100 kW			≥100 kW		
	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting
6.2.10 Loss of array	✓	✓	✓	✓	✓	✓	✓	✓	✓
6.2.11 Loss of Utility:	✓	O		✓	O		✓	O	
6.2.12 Harmonic Distortion				O			O		
6.2.13 Power Factor				O			O		
6.2.14 DC Injection				O			O		
6.2.15 Phase Current Balance				O			O		
6.2.16 Multiple PCU Op				O			O		

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P1373: Instrumentation Tests

	≤10 kW			>10 <100 kW			≥100 kW		
	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting
6.3.1 Instrumentation Check	O	O		O	O		✓	O	
6.3.2 Inst. Xformers, Current		O			O		O	O	
6.3.3 Inst. Xformers, Voltage		O			O		O	O	
6.3.4 Instrumentation Calib.		O		O	O		✓	O	

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P1373: Performance Tests

	≤10 kW			>10 <100 kW			≥100 kW		
	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting
6.4.1 System Power	O	O		O	O		✓	O	
6.4.2 Array Power	O	O	O	O	✓	O		O	✓
6.4.3 PCU Efficiency								✓	
6.4.4 MPPT Accuracy								✓	

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P1373: "Other" Tests

	≤10 kW			>10 <100 kW			≥100 kW		
	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting	Quick Check	Accep tance	Trouble - shooting
6.5.1 Field Inspection	✓	✓	✓	✓	✓	✓	✓	✓	✓
6.5.2 Ground Grid Resistance		O		O	O		✓	✓	
6.5.3 Isolation Transformer		O		O	O		✓	O	
6.5.4 Circuit Breaker (ac & dc)		O			O		O	O	
6.5.5 Disconnect Switch		O			O		O	O	
6.5.6 Protective Functions		O			O		O	O	
6.5.7 Wires, Cables, Busses		O		O	O		✓	O	
6.5.8 DC Grnd-Fault Equip.		O			O		O	O	

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Field Inspection

- Verify system is
  - built as designed
  - installed in workmanlike manner, properly maintained
  - consistent with industry practice, standards, codes, and operational requirements

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Field Inspection

- Torque of electrical and mechanical bolted connections (spot check)
- Condition of finish/corrosion protection
- Integrity of PV module mechanical and electrical connections (random)
- Damage to PV modules
- Damage to support structures
- Integrity of installation and support of electrical cable and conduit systems

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Field Inspection

- Integrity and completeness of equipment and system grounds
- Integrity of seals and bearings (leaking or binding)
- Integrity and completeness of wiring
- Accuracy of as-built documentation
- Installation in compliance with applicable codes and standards

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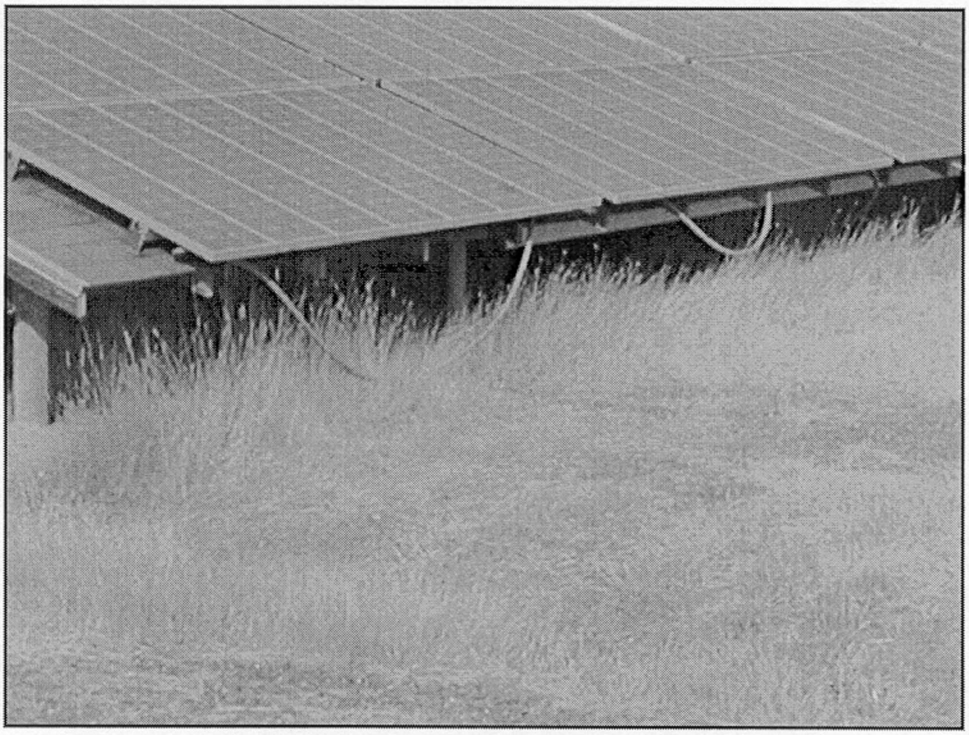

Array Tests

- Voc Test $V_{oc,expected} = n \cdot V_{oc,REF}$
- Isc Test $I_{sc,expected} = n \cdot I_{sc,REF} \cdot \frac{G}{G_{REF}} \cdot 0.95$
- Voltage to Ground

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Array Tests

- IV Curves

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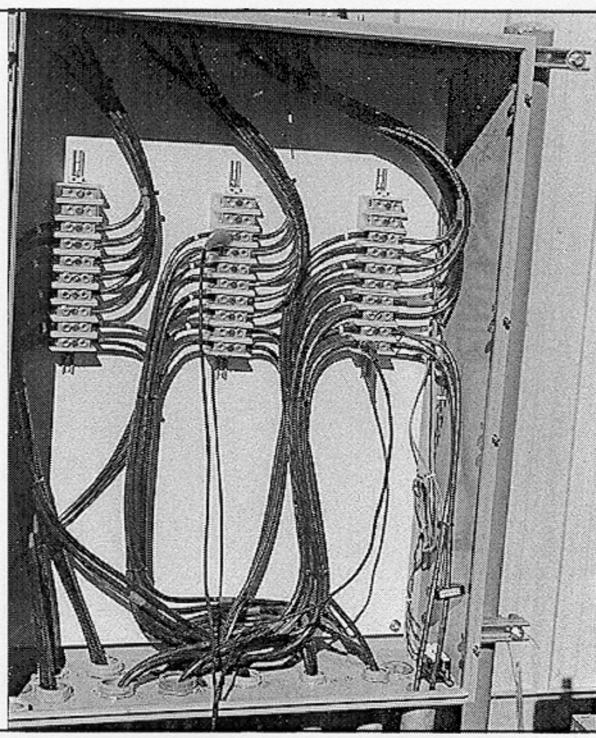
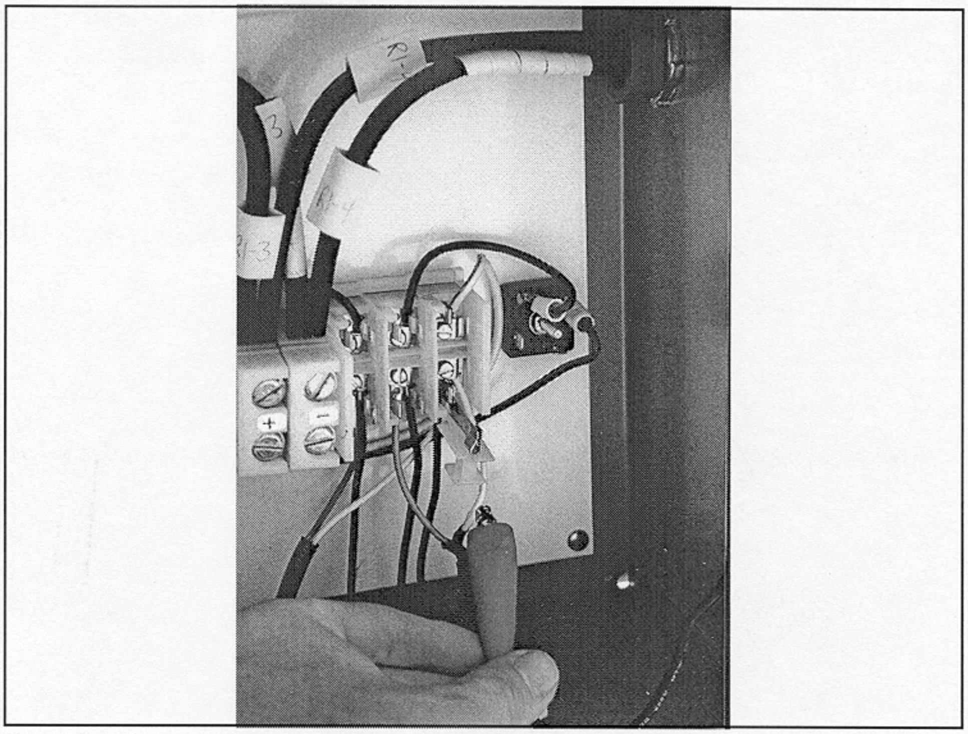
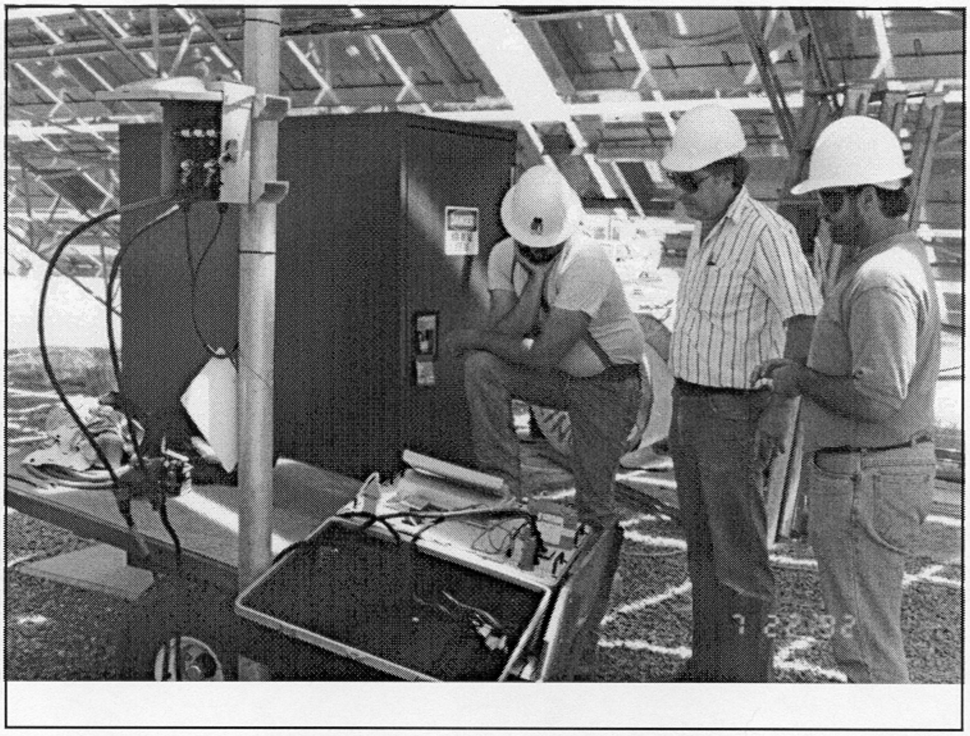
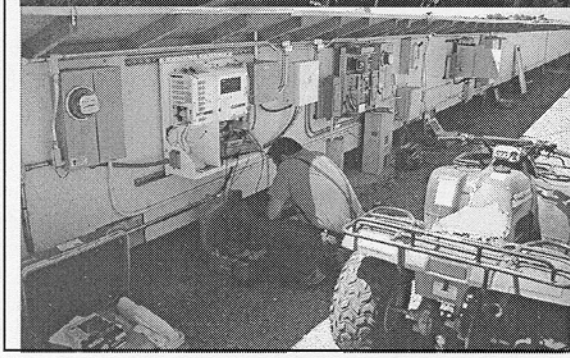
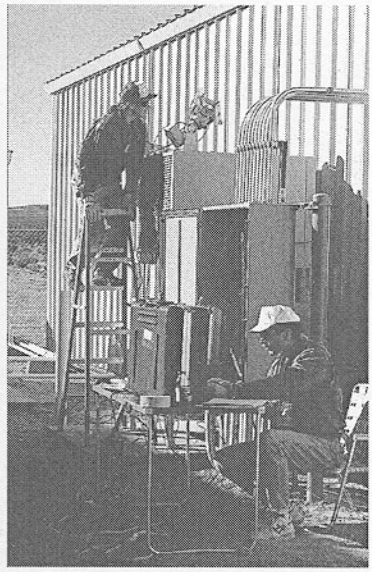
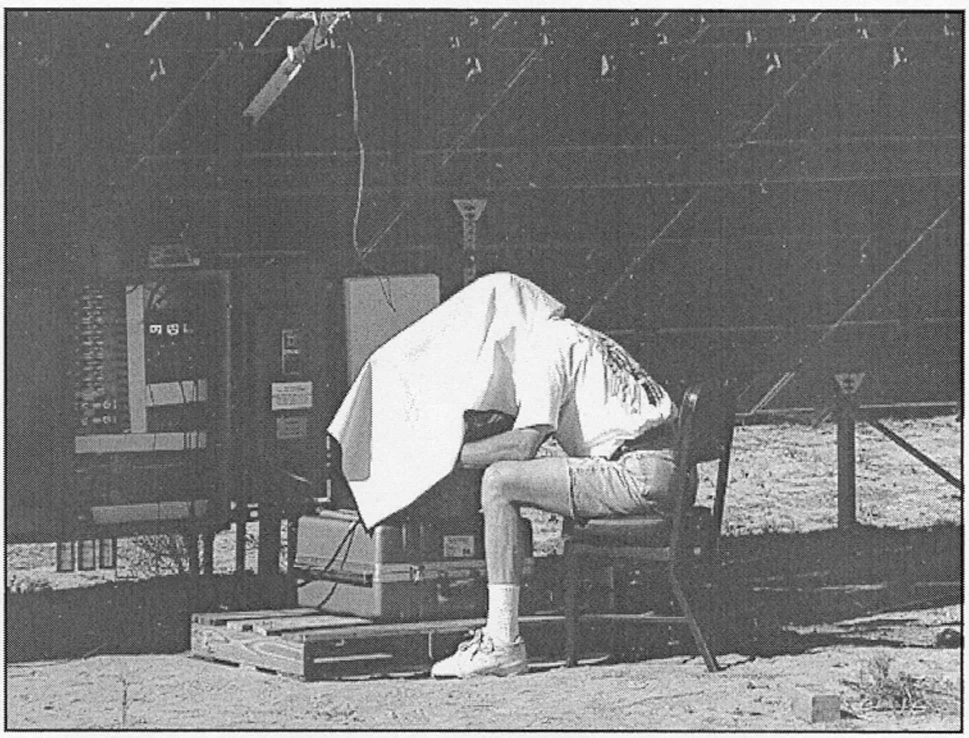


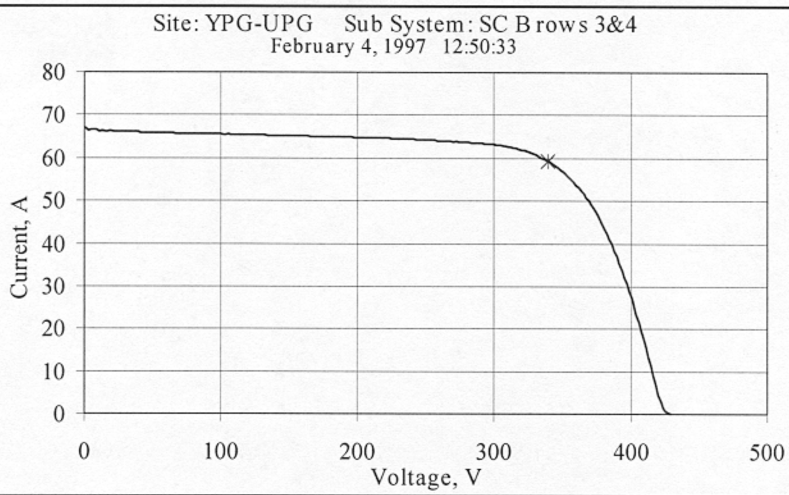








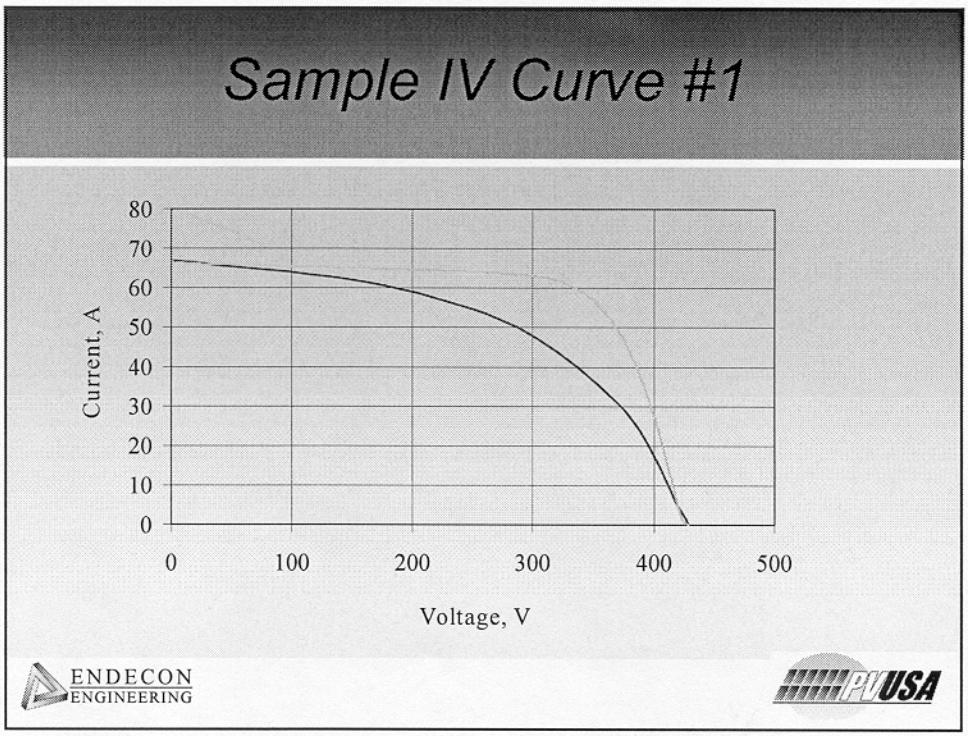


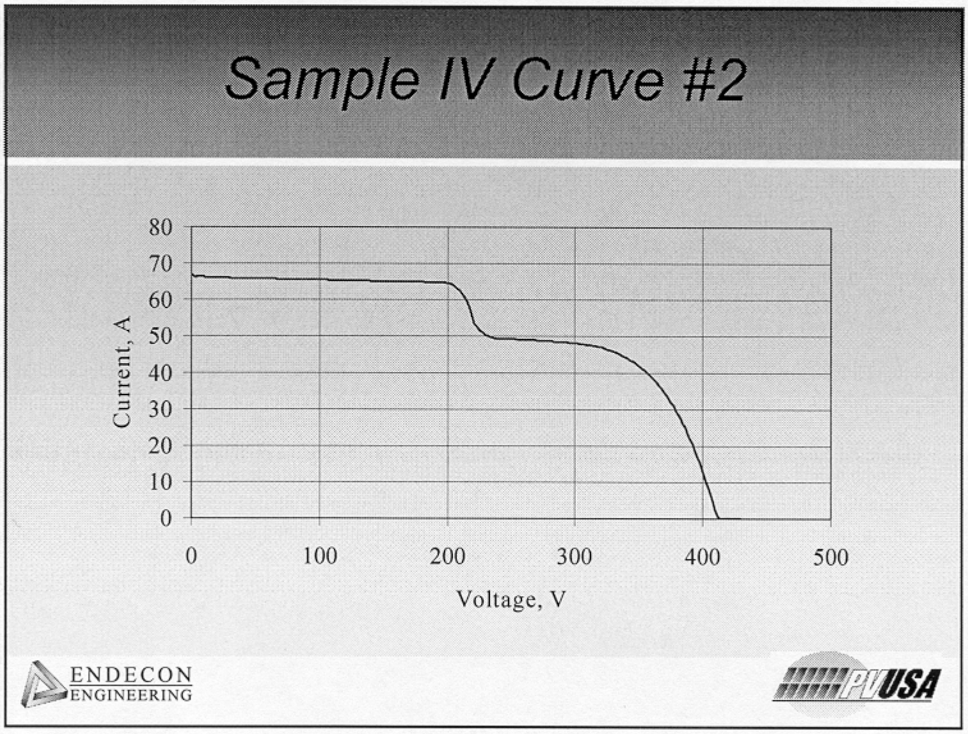


Voc:	429 V	Vpp:	339 V
Isc:	67.0 A	Ipp:	59.4 A
FF:	70.0 %	Ppp:	20,126 W
Corrected Irrad.[(1)]:	526 W/ m^2	Effective Irrad.[(2)]:	0 W/ m^2
Tmod:	43.5 °C	Tamb:	0.0 °C

(1) - Pyranometer reading corrected for incidence angle
(2) - Corrected Irrad. adjusted for module incidence angle and air mass response characteristics

File: ypgb3&4




Sample IV Curve #2
80
70
60
50
40
30
20
10
0
Current, A
0
100
200
300
400
500
Voltage, V
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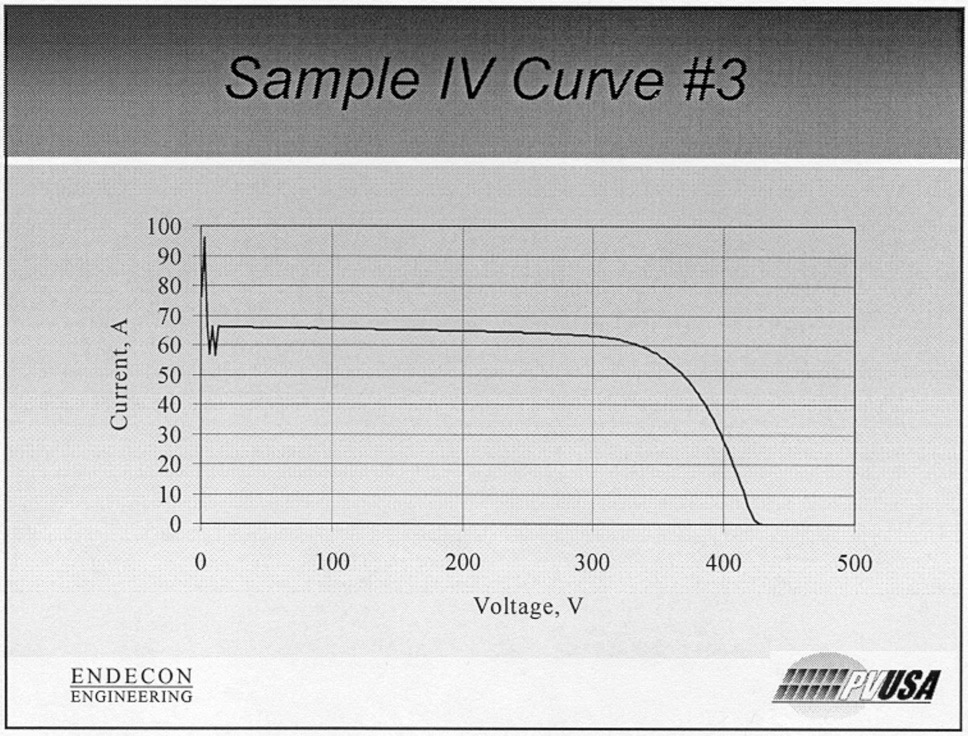
Sample IV Curve #3
100
90
80
70
60
50
40
30
20
10
0
Current, A
0
100
200
300
400
500
Voltage, V
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Array Tests

- Bypass Diode Shade
- IR Scan

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Array Tests

- Field Wet Resistance Test (FWRT)
  - Field version of factory Wet Insulation Resistance Test
  - Developed by PVUSA/JPL/NREL/Bechtel
  - Subject of a current ASTM standard project

Wet Resistance Test ? Wet Hi Pot!!!

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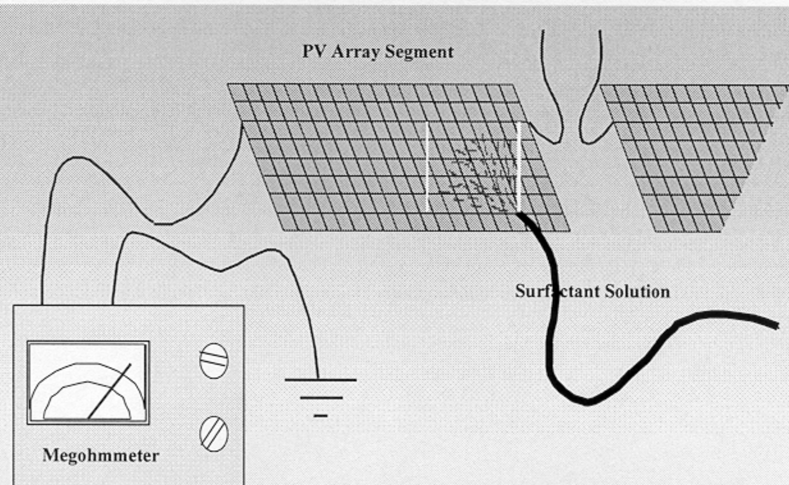
Field Wet Resistance Test Setup



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Wet Resistance Test History

- JPL-developed test to quantify module leakage current
- TCO wrap around on thin film modules: 10^5 MO dry, 0.1 MO wet: Dry Hi-pot does not address adequately
- Pass/fail criteria need to address
  - Safety (1-5 mA)
  - Ground fault arcing (~50µA)
  - Leakage current induced degradation: Corrosion (1-5µA)
- Safety and G.F. based on single incidents. Corrosion based on cumulative leakage over time

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Field Wet Resistance Test Criteria

- Cumulative charge transfer to module failure
- Scaling dependant on type of failure mechanism:
  - Point defect (3 - 30 Coulombs for 30 yr life)
  - Perimeter dependant (0.1 - 1.0 Coulombs/cm)
  - Area dependant (0.03 - 0.3 Coulombs/cm^2)
- For a 1'x4' module with perimeter-related leakage, R_W*= 129 MO to 1314 MO
- 100 MO suggested as indicative but not overly restrictive
- IEEE adopted area related 40 MO-m^2

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Field Wet Resistance Test Issues

- Surfactant
  - Liquinox 1:516
- Module temperature
- Module size
  - 40MO-m^2
- Array segment size (R_W* > 0.2MO = 200m^2)
- Array segment voltage
- Spray pressure
- Open/Shorted
- Speed
- Safety
- Labor intensity
  - ~0.1 mhr/m^2
- Frequency
- P/F Criteria usually irrelevant

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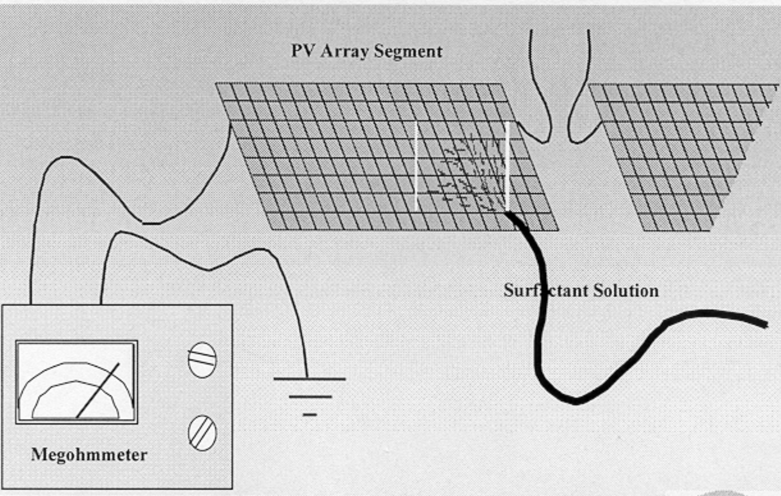
Field Wet Resistance Test Setup



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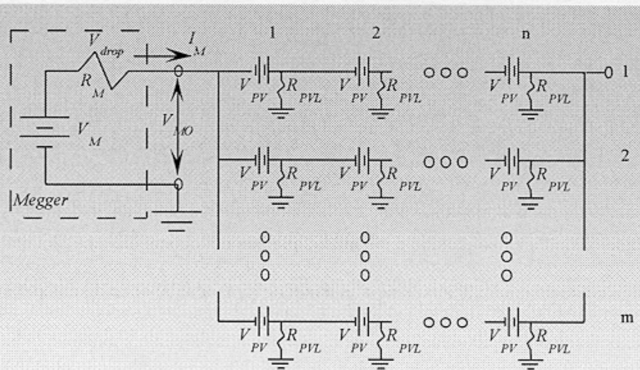
Effect of PV Segment Voltage on Megger Reading



$$R_{MeggerReading} = \frac{2 \times V_M \times \frac{R_{PVL}}{n \times m} - n \times V_{PV} \times R_M}{2 \times V_M + n \times V_{PV}}$$

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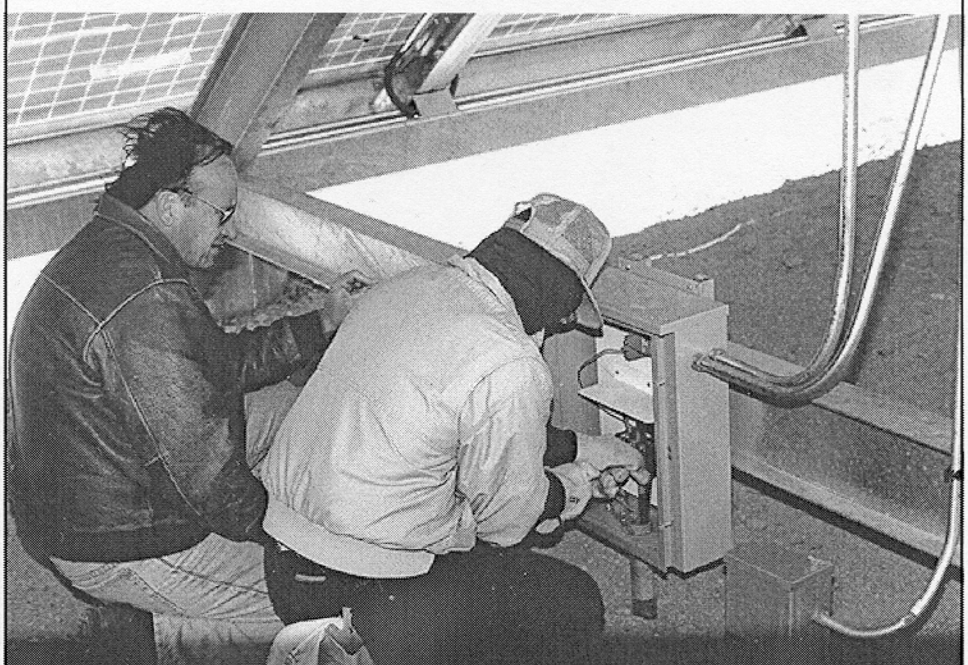

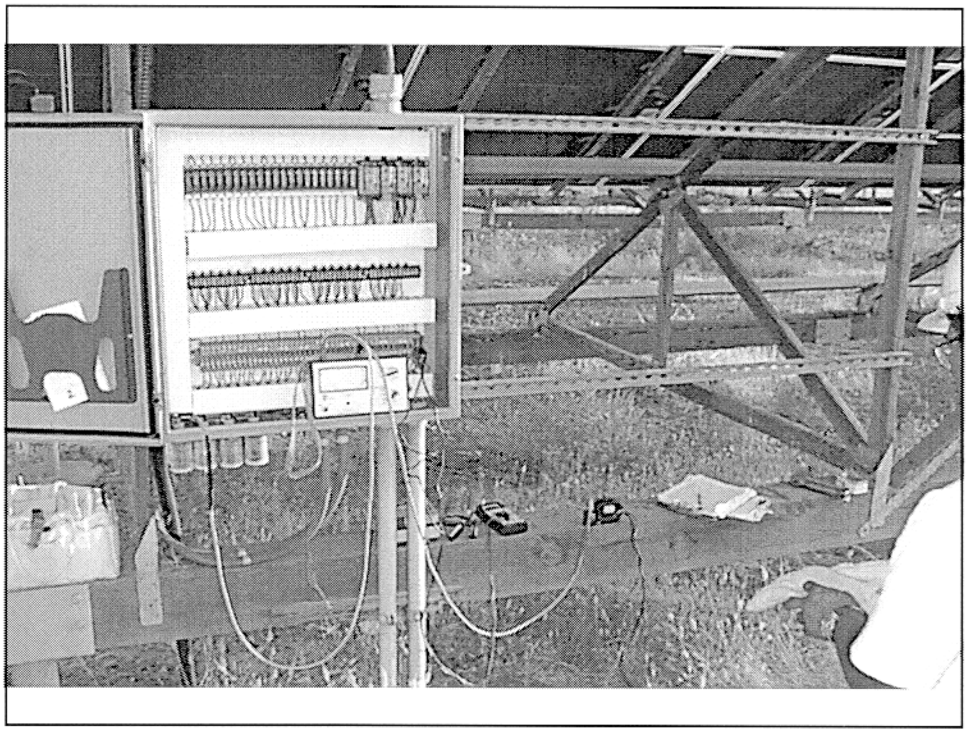

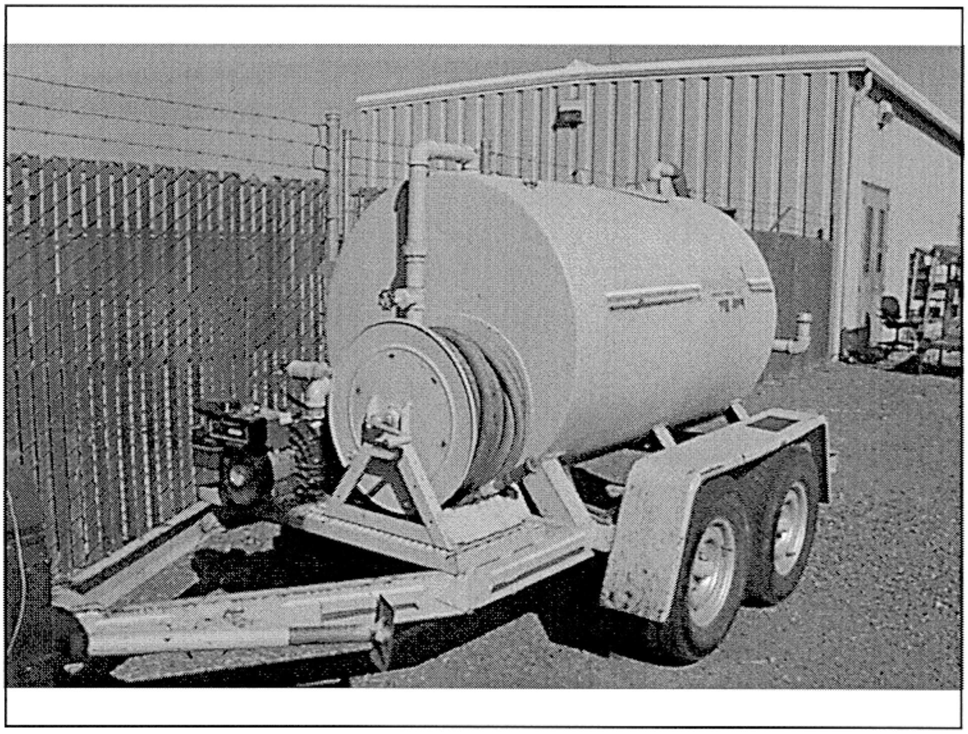

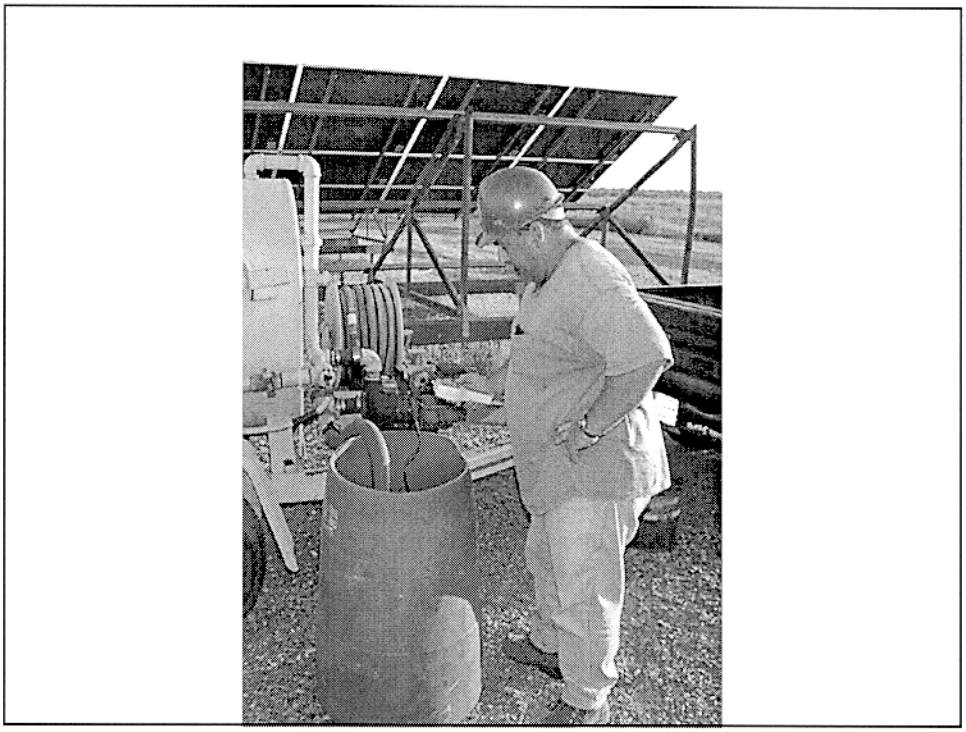

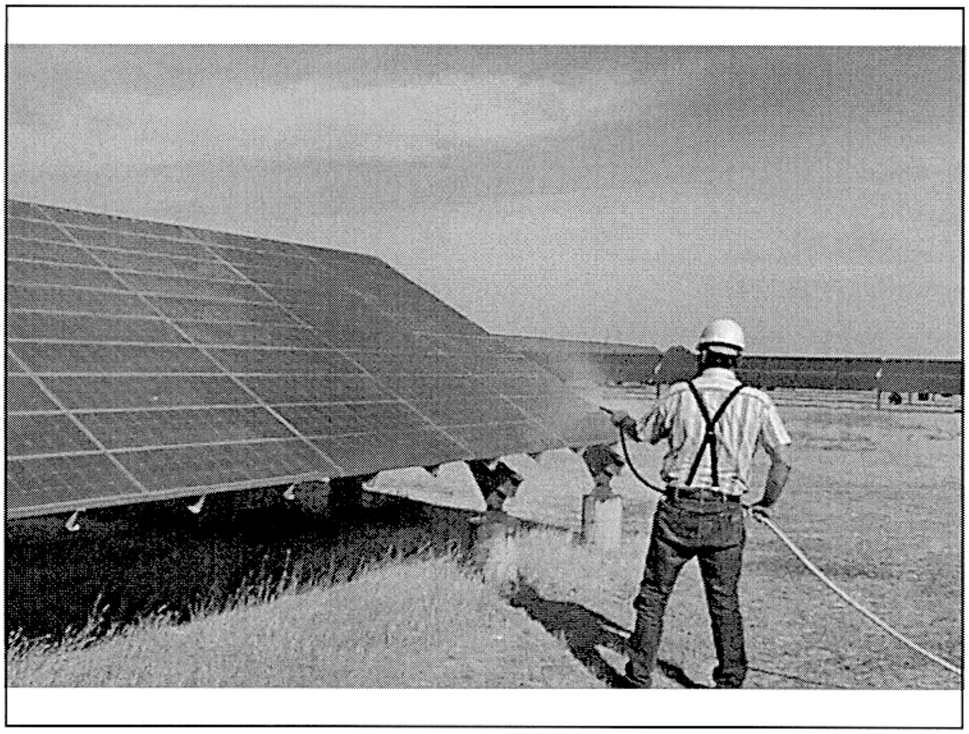

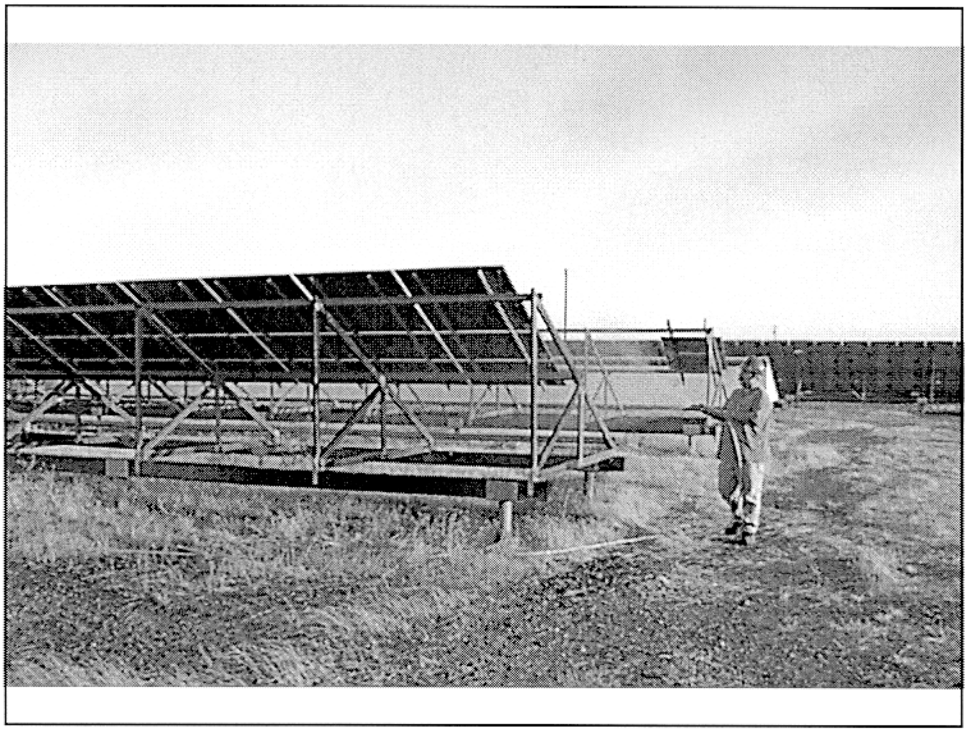

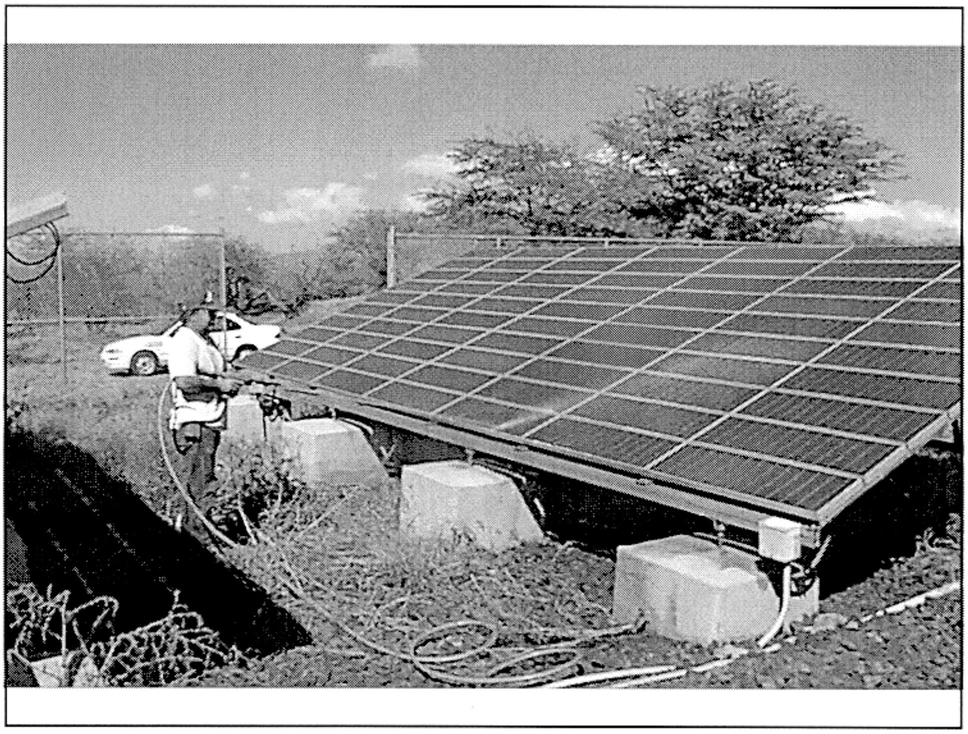

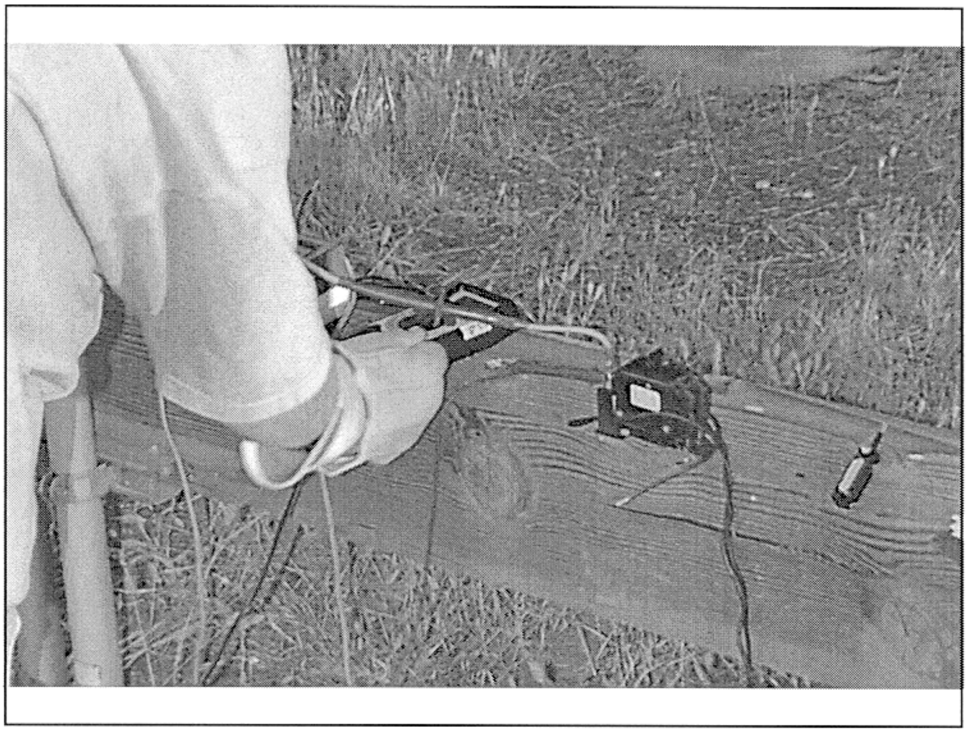

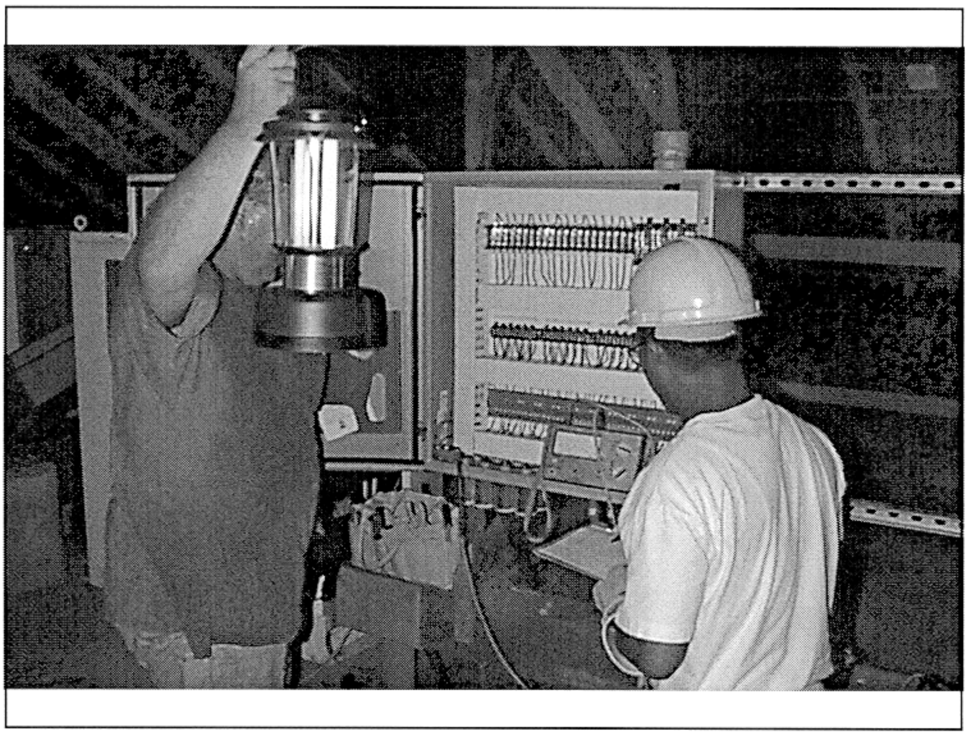

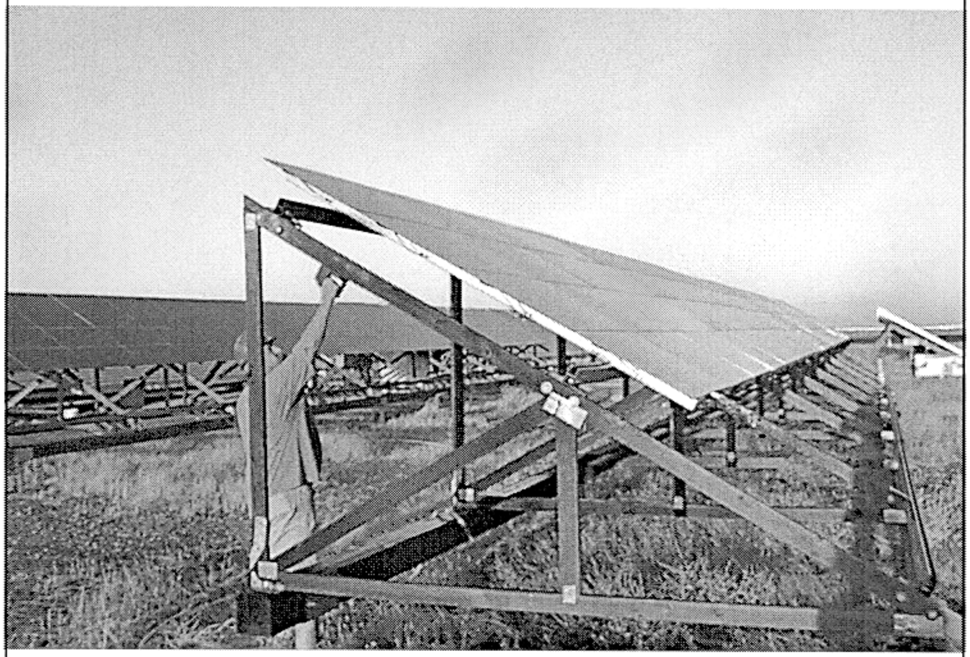

FWRT Results

- FWRT locates
  - Loose module j-box covers
  - Hairline cracks in module junction boxes
  - Nicked/cut wires
  - Improperly sealed/seated connectors and cable clamps
  - module backsheets cut by over aggressive electrician screw drivers
  - other potentially unsafe and unreliable conditions

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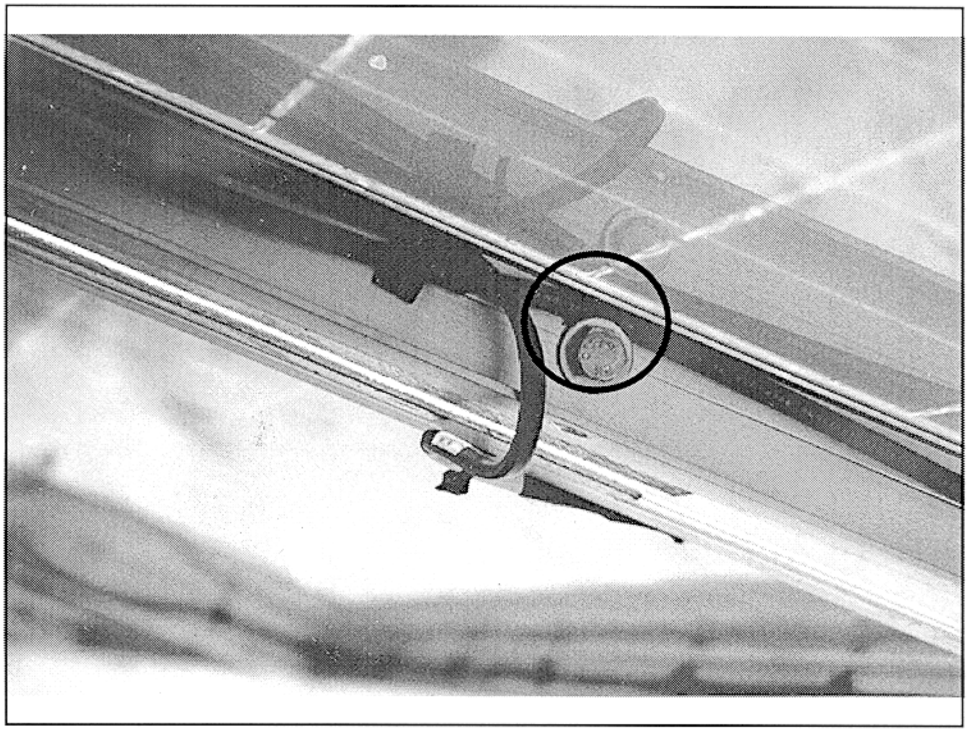

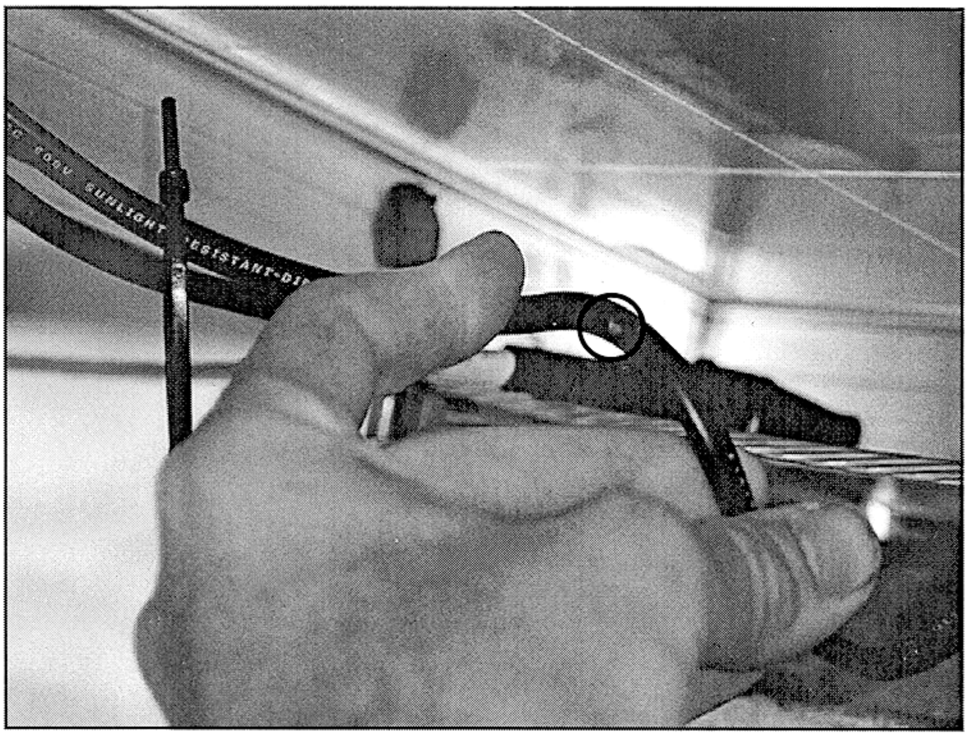
600V SUNLIGHT

PCU Tests

- Initial Inspection
- Local/Remote Operation
- Functional tests
  - Wake-up/Sleep
  - Smoke detector
  - Door Interlock
  - Over temperature
  - O/U Frequency and Voltage
  - Loss of Control Power
  - Loss of Array Power
  - Loss of Utility (Islanding)

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Instrumentation

- Instrumentation Check
- kWh Meter
- CTs and PTs
- Calibration

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Performance Testing: Array IV Curves

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National Center for Photovoltaics

Sandia Performance Model

$$I_{sc} = I_{sco} \cdot f_1(AM_a) \cdot \{(E_b \cdot f_2(AOI) + f_d \cdot E_{diff}) / E_o\} \cdot \{1 + \alpha_{Isc} \cdot (T_c - T_o)\}$$

$$E_e = I_{sc} / [I_{sco} \cdot \{1 + \alpha_{Isc} \cdot (T_c - T_o)\}]$$

$$I_{mp} = I_{mpo} \cdot \{C_0 \cdot E_e + C_1 \cdot E_e^2\} \cdot \{1 + \alpha_{Imp} \cdot (T_c - T_o)\}$$

$$\delta(T_c) = n \cdot k \cdot (T_c + 273.15) / q$$

$$V_{oc} = V_{oco} + N_s \cdot \delta(T_c) \cdot \ln(E_e) + \beta_{Voc}(E_e) \cdot (T_c - T_o)$$

$$V_{mp} = V_{mpo} + C_2 \cdot N_s \cdot \delta(T_c) \cdot \ln(E_e) + C_3 \cdot N_s \cdot \{\delta(T_c) \cdot \ln(E_e)\}^2 + \beta_{Vmp}(E_e) \cdot (T_c - T_o) \cdot$$

$$P_{mp} = I_{mp} \cdot V_{mp}$$

$$I_x = I_{xo} \cdot \{ C_4 \cdot E_e + C_5 \cdot E_e^2\} \cdot \{1 + ((\alpha_{Isc} + \alpha_{Imp} \cdot)/2) \cdot (T_c - T_o)\}$$

$$I_{xx} = I_{xxo} \cdot \{ C_6 \cdot E_e + C_7 \cdot E_e^2\} \cdot \{1 + (\alpha_{Imp}) \cdot (T_c - T_o)\}$$

NREL National Renewable Energy Laboratory

Sandia National Laboratories

Performance Data Translation

$E_e = (E/E_0)\, f_1(AMa-1.5)\, f_2(AOI)$ = Effective Irradiance Ratio (Eqn. 1)

$Isc(E_e, T_C) = nmp * E_e[Isc_0 + \alpha_{Isc}(T_C-T_0)]$; T_C = Measured cell temp, °C (Eqn. 2)

$Imp(E_e, T_C) = nmp * \{C_1 + E_e[C_2 + \alpha_{Isc}(T_C-T_0)]\}$ (Eqn. 3)

$Voc(E_e, T_C) = nms * [Voc_0 + C_4 \ln(E_e) + \beta_{Voc}(T_C-T_0)]$ (Eqn. 4)

$Vmp(E_e, T_C) = nms * \{Vmp_0 + C_6 \ln(E_e) + C_7 [\ln(E_e)]^2 + \beta_{Vmp}(T_C-T_0)\}$ (Eqn. 5)

Location:		
Site	Various Sacramento Homes	
Lat	38	Site latitude, °
Long	121.7	Site longitude, °
Alt	15	Site altitude, m
STM	120	Local Std Time Meridian

Reference Conditions:		
E_0	1000	Reference irradiance, W/ m^2
T_0	50	Reference module temp, °C
AMa_0	1.5	Reference air mass
AOI_0	0	Reference AOI, °

Module Characteristics

Mfg.	Siemens		Model	M55	
ns	36	# of cells in series	np	1	# of cells in parallel
Isc_0	3.34	Isc @reference conditions, A	Imp_0	3.00	Imp @reference conditions = $C_1 + C_2$, A
Voc_0	19.7	Voc @reference conditions, V	Vmp_0	15.2	Vmp @reference conditions, V
α_{Isc}	0.0013	Isc temperature coefficient, A/ °C	α_{Imp}	-0.001	Imp temperature coefficient, A/ °C
β_{Voc}	-0.0857	Voc temperature coefficient, V/ °C	β_{Vmp}	-0.0868	Vmp temperature coefficient, V/ °C
C_1	0.00	Imp regression coefficient, A	C_6	-0.0415	Vmp regression coefficient, V
C_2	3.00	Imp regression coefficient, A	C_7	-0.2921	Vmp regression coefficient, V
C_4	1.024	Voc regression coefficient, V			

f_1 Air mass correction factor: $f_1(AMa-1.5) = 1.0+f_{1,1}(AMa-1.5)+f_{1,2}(AMa-1.5)^2+f_{1,3}(AMa-1.5)^3+f_{1,4}(AMa-1.5)^5$

$f_{1,1}$ 0.0304 $f_{1,2}$ 0.00858 $f_{1,3}$ 0.00114 $f_{1,4}$ 0.0000637

f_2 Angle of incidence correction factor: $f_2(AOI) = 1.0+f_{2,1}(AOI)+f_{2,2}(AOI)^2+f_{2,3}(AOI)^3+f_{2,4}(AOI)^4$

$f_{2,1}$ 4.996E-4 $f_{2,2}$ -2.634E-5 $f_{2,3}$ 1.173E-6 $f_{2,4}$ -1.697E-8

Array Segment Characteristics

nms	28	# of modules in series	Tilt	Various	Array Tilt, °
nmp	3	# of modules in parallel	Azm	Various	Array Azimuth, °

Notes: 1. For array segments multiply β and V_0 by nms and α and I_0 by nmp

2. From Eq. 4, $T_C = T_0 + [Voc(E_e, T_C) - Voc_0 - C_4 \ln(E_e)] / \beta_{Voc}$

Performance Testing: PCU Performance

- Efficiency
- MPPT Accuracy

ENDECON ENGINEERING

PVUSA

Performance Testing: System Rating

- PVUSA Method
  - System performance data collected over a period of time from an on-site data acquisition system.
  - PV system ac output power is determined under Performance Test Conditions (PTC) defined as
    - 20°C ambient temperature,
    - 1 m/s wind speed at 10 meters above grade,
    - 1000 W/m² global plane-of-array irradiance for flat plates
      -or-
      850 W/m² direct normal irradiance for concentrators

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Performance Testing: System Rating

- Parameters are measured and recorded over the data collection period:
  - Plane-of-array irradiance
  - Ambient temperature
  - Wind speed (measured 10 meters above grade)
  - Ac system power output (measured at the point of utility interface)
- Data should be sampled at an interval of no greater than 60 seconds and averaged over an interval of no more than 30 minutes.

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Performance Testing: System Rating

- The measured data are used in equation (3) and a regression analysis performed to determine the coefficients

  P_{sys} = Irr*A + Irr²*B + Irr*Tamb*C + Irr*WS*D (3)

  $$P_{sys} = Irr \cdot A + Irr^2 \cdot B + Irr \cdot Tamb \cdot C + Irr \cdot WS \cdot D \quad (3)$$

  where:
  - P_{sys} = system output power, kWac
  - Irr = irradiance, W/m²
  - Tamb = ambient air temperature
  - WS = wind speed
  - A, B, C, D = regression coefficients
- Derived coefficients and PTC values are entered into the equation and the system ac output power calculated.

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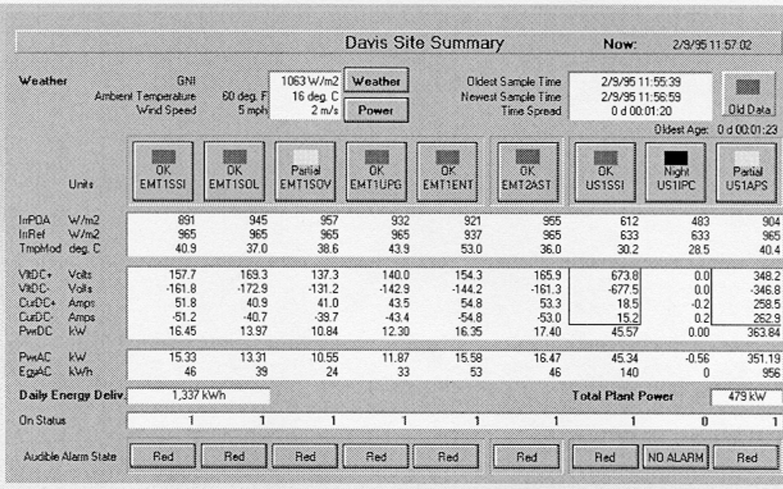
Long Term Monitoring



Davis Site Summary — Now: 2/9/95 11:57:02

Weather: GNI 1063 W/m2; Ambient Temperature 60 deg. F, 16 deg. C; Wind Speed 5 mph, 2 m/s — Weather — Power

Oldest Sample Time 2/9/95 11:55:39; Newest Sample Time 2/9/95 11:56:59; Time Spread 0 d 00:01:20 — Old Data

Oldest Age: 0 d 00:01:23

	Units	EMT1SSI	EMT1SOL	EMT1SOV	EMT1UPG	EMT1ENT	EMT2AST	US1SSI	US1IPC	US1APS
		OK	OK	Partial	OK	OK	OK	OK	Night	Partial
IrrPOA	W/m2	891	945	957	932	921	955	612	483	904
IrrRef	W/m2	965	965	965	965	937	965	633	633	965
TmpMod	deg. C	40.9	37.0	38.6	43.9	53.0	36.0	30.2	28.5	40.4
VltDC+	Volts	157.7	169.3	137.3	140.0	154.3	165.9	673.8	0.0	348.2
VltDC-	Volts	-161.8	-172.9	-131.2	-142.9	-144.2	-161.3	-677.5	0.0	-346.8
CurDC+	Amps	51.8	40.9	41.0	43.5	54.8	53.3	18.5	-0.2	258.5
CurDC-	Amps	-51.2	-40.7	-39.7	-43.4	-54.8	-53.0	15.2	0.2	262.9
PwrDC	kW	16.45	13.97	10.84	12.30	16.35	17.40	45.57	0.00	363.84
PwrAC	kW	15.33	13.31	10.55	11.87	15.58	16.47	45.34	-0.56	351.19
EgyAC	kWh	46	39	24	33	53	46	140	0	956
On Status		1	1	1	1	1	1	1	0	1
Audible Alarm State		Red	Red	Red	Red	Red	Red	Red	NO ALARM	Red

Daily Energy Deliv. 1,337 kWh — Total Plant Power 479 kW

ENDECON ENGINEERING

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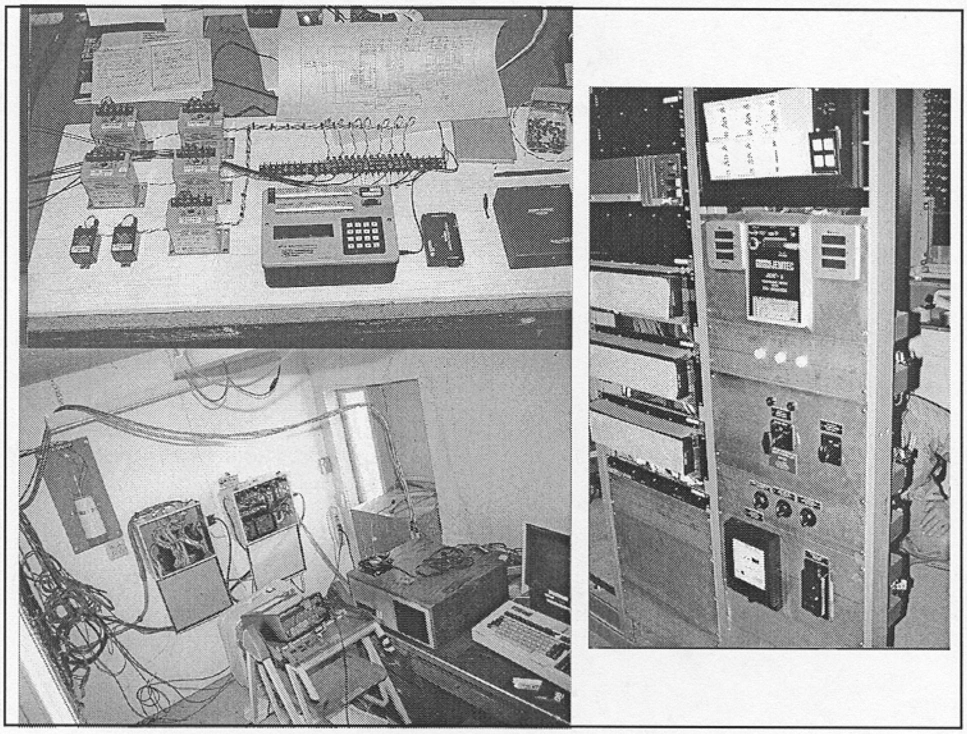
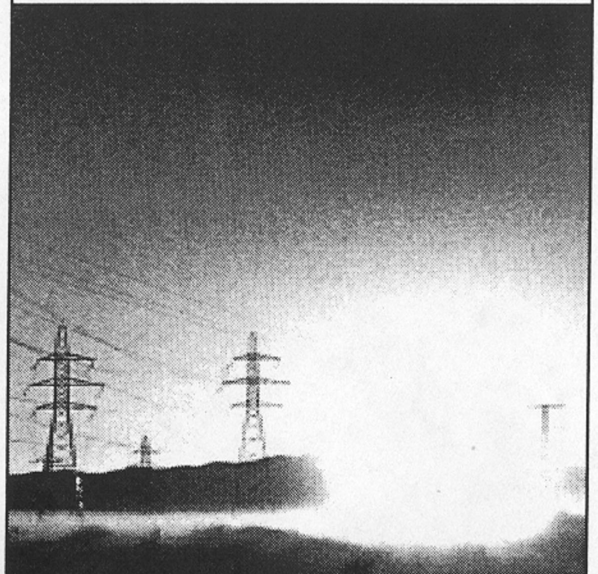


PVUSA

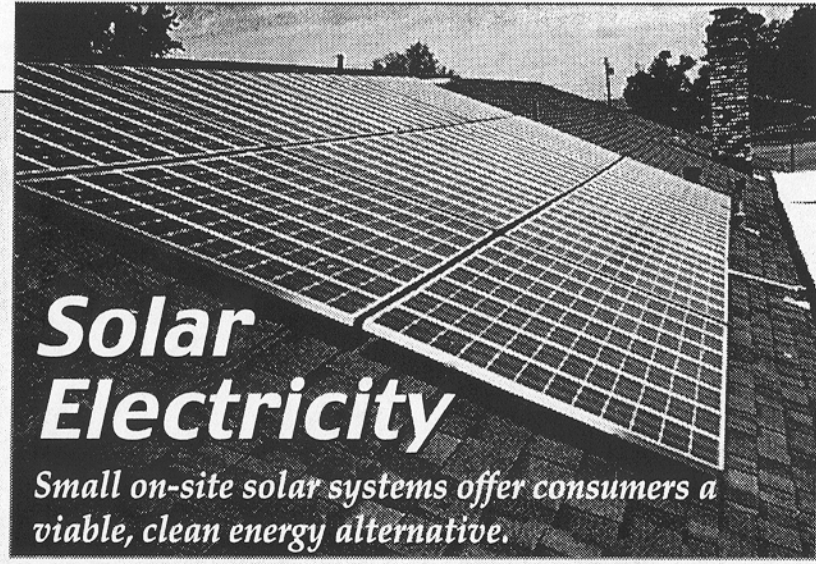
Solar Energy
WORKSHOP SERIES



Designing & Installing Code Compliant PV Systems

STATE OF CALIFORNIA ENERGY COMMISSION

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA



The generation of electric current from the sun, photovoltaics (PV for short), has been used by large utility companies and remote locations for years as a source of clean electricity. Recent government sponsored financial incentive programs, such as the new "Million Solar Roofs" and California's "PV Buydown" programs, have made small scale rooftop generation an appealing option for both commercial applications and private homeowners.

Opportunities and Questions

Many contractors and related specialists in the construction field have already expanded their business to include these new rooftop solar systems. This type of system is unique and can raise questions regarding code compliance, system design, and installation.

Providing Answers

PVUSA (Photovoltaics for Utility System Applications) was established in 1986 to conduct research and development work in the field of solar generated electricity. Long recognized as an authority on the subject of PV systems, PVUSA has teamed up with the California Energy Commission and the Department of Energy to offer hands-on workshops designed to provide the practical knowledge needed to effectively participate in this exciting new market.

Workshop Content

Presented by PVUSA staff and other industry experts, this workshop series provides an intensive overview of small-scale solar electric generation, system design, and installation techniques. Participants will also become familiar with the basic design and installation procedures required to meet the *National Electrical Code (NEC)*. A PVUSA certification of completion will be awarded to those who successfully complete all three days of this course.

Hands-on Experience

Working on actual PV systems at the PVUSA test facility in Davis, California, participants will be involved in several hands-on activities and are encouraged to bring their own tools to use.

Who Should Attend

Construction industry professionals and related trades:

- Building contractors
- Electrical contractors
- Solar contractors
- Inspectors
- Engineers

Designing & Installing Code Compliant PV Systems

Day One

Fundamentals of Grid-Connected PV Systems

Thursday, 8:30 a.m. to 5:00 p.m.

- Basic PV Concepts
- Fundamentals of Solar Energy
- Site Analysis
- Performance Calculations
- Code-Compliant Design
  PV Array Electrical & Mechanical Design
- PV Module Testing
- PV Inverter Characteristics

Day Two

PV System Installation Issues

Friday, 8:30 a.m. to 5:00 p.m.

- PV Array Installation Issues
- BOS Installation Issues
- Special PV Wiring Considerations
- Conductor Ampacity
- System Voltage Drop
- Final Inspection
- Post-Installation Checklist
- Utility Interconnection Issues

Prerequisite: Fundamentals of Grid-Connected PV Systems

Day Three

Hands-on Installation and System Acceptance

Saturday, 8:30 a.m. to 5:00 p.m.

- Drawings and Documentation
- System Layout
- System Mounting
- Panel Testing
- Array Wiring to Combiner
- Combiner to Inverter Wiring
- AC Inverter Wiring
- Final System Checkout and Acceptance
- Short Exam

Prerequisite: PV System Installation Issues

Training materials, continental breakfast, and lunch will be provided.

About the Lead Instructor:

Bill Brooks: An active member of the technical review committee for NEC Article 690 (Solar Photovoltaic Systems) for the past four years, Mr. Brooks holds B.S. and M.S. degrees in Mechanical Engineering from North Carolina State University and is a registered professional engineer.

Workshop Sponsors:

The **California Energy Commission** has the primary goal of ensuring that California's energy needs are met in a manner which enhances the State's long-term economic competitiveness in balance with health, safety, and environmental concerns.

The **U.S. Department of Energy** (DOE) works together with federal, state and local entities to further the development and application of key domestic energy resources including solar photovoltaics.

PVUSA (Photovoltaics for Utility System Applications) works to promote and coordinate the use of solar photovoltaic technologies in the utility sector in California and the U.S.

Training Program Partners:

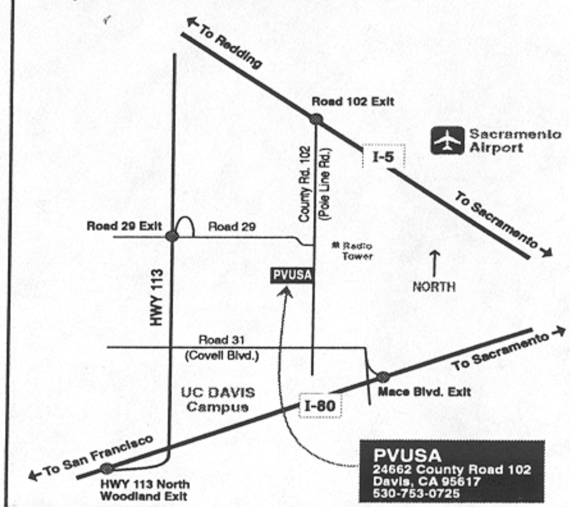
Florida Solar Energy Center (FSEC) is the largest and most active state-supported renewable energy and energy efficiency research institute in the United States. A part of the University of Central Florida (UCF), FSEC has a strong training and education emphasis in its programs.

National Center for Photovoltaics (NCPV) is headquartered at the National Renewable Energy Laboratory (NREL). The NCPV draws on the core expertise of NREL and Sandia National Laboratories to guide operations and coordinate the support of other national resources.

Institute of Sustainable Power (ISP) is a nonprofit organization working with its partners to develop global standards for the accreditation of training programs and competency certifications in areas including PV systems design, installation, maintenance and inspection.

Location:

Located 20 miles west of Sacramento, PVUSA is easily accessible from all directions:



CHECKLIST FOR PHOTOVOLTAIC POWER SYSTEM INSTALLATIONS

PV ARRAYS

- ✓ Check to make sure all panels are attached properly to their mounting brackets and nothing obviously catches the eye as being abnormal.
- ✓ Visually inspect the array for cracked modules
- ✓ Open each combiner box and test open circuit voltage and short circuit current (if possible). Recheck torque on any screw terminals.
- ✓ At final array breakers repeat open circuit voltage and short circuit current tests (if possible) to be sure that all array wiring is properly connected.
- ✓ Perform dry insulation test, at test voltage of 500 V, on array and array wiring. (note: disconnect all SOVs and MOVs BEFORE doing insulation test)
- ✓ Check for NEC-type marking/label on the modules. NEC690-51: Modules shall be marked with identification of terminals or leads as to polarity, maximum overcurrent device rating for protection, and with rated 1] open-circuit voltage, 2] operating voltage, 3] maximum permissible system voltage, 4] operating current, 5] short-circuit current, and 6] maximum power. See NEC 690-52 for ac module requirements.

WIRING

- ✓ Check exposed array wiring for rating and sunlight resistant insulation.
- ✓ Check from the ground to see that all wiring is neat and well supported to stay in place.
- ✓ Check that strain reliefs/cable clamps are properly installed on all cables and cords by pulling on cables to verify [NEC 300-4, 400-10].
- ✓ Make sure that all grounded conductors are white and equipment grounding conductors are green or bare [NEC 200-6(a), Ex 5].
- ✓ DISCONNECT ALL MOVs and SOVs, if any, then perform insulation test on system wiring. Use a test voltage of 500 V for all wiring 600 V and below.
- ✓ Check that all field wiring are tagged at both ends with permanent wire markers.

WIRING METHODS

- ✓ Flexible Metal Conduit is generally suitable for installation in dry locations. Check that supports are no more than 12 inches from boxes (junction box, cabinets or conduit fitting) and no more than 54 inches apart. [NEC 350]
- ✓ Liquidtight Flexible Metal Conduit is generally suitable for installation in wet and dry locations. Check that supports are no more than 12 inches from boxes (junction box, cabinets or conduit fitting) and no more than 54 inches apart. [NEC 351].
- ✓ Liquidtight Flexible Non-Metallic Conduit is generally suitable for installation in wet and dry locations. Check that supports are no more than 12 inches from boxes (junction box, cabinets or conduit fitting) and no more than 36 inches apart. [NEC 351].
- ✓ PVC is not intended for installation in locations subjected to direct sunlight.
- ✓ Long straight rigid conduit runs, 100 feet or more, shall have expansion fittings.

OVERCURRENT PROTECTION

- ✓ The overcurrent device rating of the PV circuit shall be 156% of the rated short circuit current. [125% X 125% = 156%]
- ✓ Make sure dc voltage and current ratings are clearly marked on overcurrent protection or that documentation is on hand for inspector at the final inspection.

CHARGE CONTROLLERS

- ✓ Retorque all terminations.
- ✓ Check that all voltage settings are properly set for the appropriate battery type or system configuration.
- ✓ If the system is connected to a utility-interactive inverter, make sure that the settings of the charge controller(s) do not interfere with the proper operation and dispatch of the inverter system. (Note: If charge controller set points are used to regulate the float voltage of the battery rather than the inverter, power will be wasted from the PV array at the charge controllers before it can be made available to the inverter or battery.)
- ✓ Verify that charge controller operation matches the programmed settings by forcing the system to the set points and making sure that the unit performs the proper control function.

DISCONNECTS

- ✓ Retorque all terminals on disconnect switches.
- ✓ Check voltage drop across switches while operating.

BATTERIES

- ✓ Retorque all battery connections.
- ✓ Coat each terminal with anticorrosive gel.
- ✓ Make sure that access to terminals is limited [NEC Art. 690-71(b)].
- ✓ Make sure that location provides adequate natural ventilation (well-vented areas like garages, basements, out-buildings, not living areas).
- ✓ If battery contains flooded cells, top off cells with distilled water according to the manufacturers instructions.
- ✓ If battery contains flooded cells, be sure an eyewash station is accessible.
- ✓ Once inverter is operational, equalize charge the battery to ensure that the battery is properly connected and functioning properly.
- ✓ Ideally, the installer should run the battery through a few heavy charge-discharge cycles to exercise the battery and potentially cause infant mortality in a defective new battery.
- ✓ Check individual cell or battery voltages after equalization.

INVERTERS (Utility-Interactive Systems)

- ✓ Double-check inverter manual to verify that the array open circuit voltage is acceptable to the inverter.
- ✓ Check utility line voltage to verify that it is within the proper tolerances for inverter. If line voltage is above 124 Volts ac before starting inverter, verify that the maximum voltage drop for the inverter output circuit is less than two volts. (Reason: ANSI C84 requires that the inverter not raise the service voltage at the branch service box above 127 Volts ac. Inverters are therefore required to shut down above this voltage)
- ✓ If inverter measures and reports utility or inverter ac voltage on a display, verify that this voltage agrees with a high quality, true-RMS ac volt meter.
- ✓ Retorque all electrical terminal connections in the inverter to tighten any connections that may have loosened since the initial installation.

- ✓ Follow inverter starting procedure as printed in the owners manuals.
- ✓ For non-battery-based inverters, once inverter has started and is operational, check to see that the maximum power point tracking (MPPT) circuit is operating. This should be done during clear sky conditions if possible by monitoring array voltage from the open circuit condition until it reaches a point where system power peaks and then starts to drop again. Keep monitoring voltage until you note that the system voltage has been adjusted up and down several times.
- ✓ Verify that the operating voltage is near the expected peak power voltage for the conditions of the test (this can be found in most manufacturers literature). If inverter has manual voltage control, move inverter voltage through expected maximum power point voltage to verify actual maximum power voltage and proper operation of MPPT circuit.
- ✓ For battery-based inverters, use the programming features of the inverter to charge the battery and then dispatch the battery to the utility grid to ensure that these functions are operating properly.
- ✓ Check the programming of the inverter to be sure it is set up to operate at the proper voltages for the chosen battery. Inverter should be programmed to perform the constant voltage charge control rather than the charge controller.
- ✓ Temperature compensation probe must be connected to control battery voltage properly.
- ✓ Instruct the homeowner on what to do in the event of an inverter failure.

GROUNDING

- ✓ Verify that only one connection to dc circuits (ungrounded conductor) and one connection to ac circuits is being used for system grounding [NEC Art. 250-21] (referenced to the same point).
- ✓ Check to see that equipment grounding conductors and system grounding conductors have as short a distance to ground as possible and a minimum number of turns.
- ✓ Check that non-current carrying metal parts are grounded properly, note that terminal lugs bolted on an enclosure's finished surface may be insulated because paint/finish at point of contact is not properly removed.
- ✓ Check resistance of grounding system to earth ground, NEC allows 25 ohms or less.

SAFETY SIGNS

✓ Any fuse or circuit breaker that can be energized in either direction must be labeled as such. (NEC 690-17)
✓ Interactive Point of Connection for interactive PV systems (NEC 690-54)
✓ "A sign shall be placed at the service-entrance equipment that indicates the type and location of on-site optional standby power sources." (NEC 702-8)
✓ Provide any additional information that you think would be helpful to the homeowner, inspector, or fire officials

SOLAR PHOTOVOLTAIC SYSTEMS
INSPECTOR CHECKLIST

The following checklist is an outline of the general requirements found in the 1999 National Electrical Code (NEC) — Article 690 for Photovoltaic (PV) Power Systems installations.

This list should be used in conjunction with Article 690 and other applicable articles of the NEC and includes inspection requirements for both stand-alone PV systems (with and without batteries) and utility-interactive PV systems. Where Article 690 differs from other articles of the NEC, Article 690 takes precedence [690-3].

References in brackets [ ] are to the 1999 NEC and other relevant documents.

Questions: Call Bill Brooks, PVUSA/Endecon Engineering, 707-332-0761

This list was originally compiled by John Wiles, New Mexico State University, 505-646-6105

Revised 7/12/99

CHECKLIST FOR PHOTOVOLTAIC POWER SYSTEM INSTALLATIONS

PV ARRAYS

- Listed PV modules are available from 6-7 manufacturers [110-3].

Conductors

- Conductor type—USE-2, UF, or SE if exposed [690-31(b)]; RHW-2, THWN-2, or XHHW-2 in conduit [310-15]. 90°C, wet-rated conductors are necessary. Tray cable (TC) is also sunlight resistant, 90°C, and wet-rated and is seen in UL listed module assemblies with or without connectors.

- Conductor insulation rated at 90°C [UL-1703] to allow for operation at 70°C.

- Temperature-derated ampacity calculations should be based on 125% of short-circuit current (Isc), and the derated ampacity must also be greater than rating of overcurrent device (156% Isc -see below) [690-8,9].

- Suggest derating factors of 60°C for PV modules tilted above roof pitch and 70°C for PV modules mounted parallel to the roof to be used for ampacity calculations.

- Portable cords are allowed only on moving tracker connections [690-31(c), 400-3].

- Strain reliefs/cable clamps or conduit should be used on all cables and cords [300-4, 400-10].

Overcurrent Protection

- DC-rated and listed fuses and circuit breakers are available from several sources. If device is not marked dc, then verify dc listing with manufacturer.

- Rated at 1.25 x 1.25 = 1.56 times short-circuit current from modules [UL-1703, 690-8, module instructions].

- Supplemental devices allowed, but branch-circuit devices preferred [690-9(c)].

- Located near the charge controller or battery [690-9(a) FPN].

- Must protect smallest conductor used to wire modules. Sources of overcurrent are parallel-connected modules, batteries, and backfeed through inverters [690-9(a)].

CHARGE CONTROLLERS

- Listed devices are available separately and inside listed PV load centers [110-3].

- There should be no exposed terminals

DISCONNECTS

- Listed, dc-rated devices are available: Square D QO breakers for 12-volt dc systems, Square D Heavy Duty Fused Safety Switches up to 600 volts dc.

- Listed PV Load Centers by Pulse, Trace, and others for 12, 24, and 48-volt systems contain charge controllers, disconnects, and overcurrent protection for entire dc system.

- Must provide disconnects for all current-carrying conductors [690-13].

- Must provide disconnects for equipment [690-17].

INVERTERS (Battery-Based Systems)

- Listed stand-alone inverters are available from three manufacturers [110-3].

- DC input currents must be calculated for cable and fuse requirements: Input current = rated ac output in watts divided by lowest battery voltage divided by inverter efficiency [690-8(b)(4)].

- Cables to batteries must handle 125% of input currents [690-8(a)].

- Overcurrent devices should be located within 4-5 feet of batteries.

- Overcurrent/Disconnects mounted near batteries and external to PV load centers are suggested if cables are longer than 5-6 feet to batteries or inverter.

- Listed, dc-rated fuses and circuit breakers are available. AIC should be at least 20,000 amps. Littelfuse marks dc rating, Bussmann and others sometimes do not [690-71(c), 110-9]. Verify listed, dc-rating with manufacturer if unmarked.

- 120-volt inverters connected to 120/240 load centers with multiwire branch circuits have the potential for neutral overloading in the branch circuit [100–Branch Circuit, Multiwire].

BATTERIES

- None are listed for PV system use (there some list UPS assemblies that include batteries, but none rated independently for PV systems).

- Cables should be building-wire type cables [Chapter 3]. Welding cables and auto battery cables don't meet NEC. Flexible USE/RHW cables are available. Article 400 cables OK for cell connections, but not in conduit or through walls [690-74, 400-8]. See stand-alone inverters for ampacity calculations.

- Access should be limited [690-71(b)]. Install in well-vented areas (garages, basements, out-buildings, not living areas).

- Cables to inverters, dc load centers, and/or charge controllers should be in conduit [300-4].

INVERTERS (Utility-interactive Systems)

- Listed units are available from four manufacturers and should be used for safety of utility personnel by eliminating the possibility of energizing unenergized utility lines.

- Must be on dedicated branch circuit with back-fed overcurrent protection [690-64].

- Must have <u>external</u> dc and ac disconnects and overcurrent protection [690-15,17].

- Total rating of overcurrent devices connected to ac load center (main breaker plus PV breaker) must not exceed load-center rating (120% of rating in residences) [690-64(b)(2)].

GROUNDING

- Only one connection to dc circuits (ungrounded conductor) and one connection to ac circuits should be used for system grounding [250-21].

- AC and dc grounding electrode conductors may be connected to the same grounding electrode system (ground rod) [690-41,47]. Of course only one ground reference is allowed on a premesis.

- Equipment grounds are required even on ungrounded, low-voltage systems [690-43].

- If a 12-volt system is ungrounded [690-41], then disconnects and overcurrent devices are required in both of the ungrounded conductors in each circuit [240-20(a)].

- Equipment grounding conductors for dc circuits from PV array may be run apart from other conductors [250-57 (b) Ex 2] and this routing is suggested to minimize damage from lightning surges.

CONDUCTORS (General)

- Standard building-wire cables and wiring methods can be used [300-1(a)].

- Wet-rated conductors should be used in conduits in exposed locations [100 Definition of Location, Wet].

- DC color codes should be same as ac color codes—grounded conductors are white and equipment grounding conductors are green or bare [200-6(a), Ex 5]. Look out for black negative conductors that are grounded!

<u>Working Group PAR1526 Update</u> – B. Kroposki

PAR 1526 - Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems

Scope: The test methods and procedures included in this document cover stand-alone photovoltaic systems. Procedures provided are for conducting performance testing of individual components and complete systems. The methodology includes testing the system outdoors in prevailing conditions and indoors under simulated conditions.

Purpose: This recommended practice provides test methods and procedures for determining stand-alone photovoltaic system performance and conducting design verification. Test procedures provided in this document and intended to assist designers, manufactures, system integrators, users, and laboratories in conducting these performance tests.

Working Group:

Ben Kroposki - Working Group Chairman
Peter McNutt - Working Group Secretary/Technical Editor
Steve Chalmers - PowerMark
Jim Dunlop - FSEC
Tom Hund - SNL
Paul Hutchinson - PVUSA
Jerry Anderson - Sunset Technology
Bob Hammond - ASU
Jean Posbic - Solarex
Andy Rosethal - SWTDI
Mike Thomas - SNL
John Wiles - SWTDI
Chuck Whitaker - Endecon

Status:

NREL completed revised test procedures (NREL/TP-520-27031) in September 1999.

This work was done by NREL, SNL, FSEC, SWTDI, and PVUSA.

This tech report is Draft 1 of PAR 1526.

Comments made at WG meetings in September/October will be incorporated for Draft 2 by January 2000.

Working Group Meetings:

June 1999 - Winter Park, CO

September 1999 - Tempe, AZ

October 1999 - Vail, CO

January 2000 - Albuquerque, NM

July 2000 - Location TBD

Annex A Attendee List

Attendee List

PV Performance, Reliability and Standards Workshop
October 18-21, 1999

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PV Performance, Reliability and Standards Workshop
October 18-21, 1999

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PV Performance, Reliability and Standards Workshop
October 18-21, 1999

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PV Performance, Reliability and Standards Workshop
October 18-21, 1999

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October 18-21, 1999

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Annex B Workshop Information

Annex B-1 Workshop Call Letter

NREL
National Renewable Energy Laboratory
National Center for Photovoltaics

May 17, 1999

Dear Colleague,

We are writing to encourage you to come to Vail, Colorado this fall for the PV PERFORMANCE, RELIABILITY AND STANDARDS WORKSHOP. The workshop dates are October 18th-21st.

The purpose of the workshop is to provide a working environment and venue for PV performance, reliability, and standards development technical discussions on four topical areas of interest -- module rating, module qualification, power processing, and systems. Both tutorial presentations, and individual concerns, issues, and solutions on each topic will be encouraged allowing all to contribute and learn from each other's knowledge and experience. Results of the workshop will be to *advance* the PV performance and reliability knowledge base, encourage the transfer of technical expertise to standards development activities, and provide a summary report establishing where we are and where we need to go in advancing PV technology performance and reliability.

Topical Sessions will be held each morning followed by standards development meetings to address the needs and requirements established in the morning session.

Representatives from IEEE SCC21, ASTM E44.09 , IEC TC82 U.S. TAG, etc., will be present to discuss the potential new projects identified in the morning session and need to revise current published standards.

Please note that on Friday, October 22nd, National Renewable Energy Laboratory is hosting an optional tour of the Outdoor Test Facility. Foreign citizens must sign up in advance. Others who are interested may sign up at the Conference Registration Desk in Vail. The tour begins at 10 am. Individuals are responsible for their own transportation.

Enclosed you will find a fact sheet on logistics, content details on the workshop, and a registration form. Early indications of your intent to participate are appreciated and will facilitate our planning.

Sincerely,

Tom Basso
Workshop Chair

Peter McNutt
Workshop Chair

NREL • 1617 Cole Boulevard • Golden, Colorado 80401-3393 • (303) 275-3000
Operated for the U.S. Department of Energy by Midwest Research Institute • Battelle • Bechtel

PV PERFORMANCE, RELIABILITY AND STANDARDS WORKSHOP

Workshop Theme: Setting a Standard for PV Performance and Reliability

Workshop Focus: Testing, Test Methods, Evaluation, and Standards

Workshop Purpose: Provide a working environment and venue for PV performance, reliability, and standards development technical discussions on four topical areas of interest -- module rating, module qualification, power processing, and systems. Both tutorial presentations, and individual concerns, issues, and solutions on each topic will be encouraged allowing all to contribute and learn from each other's knowledge and experience. Results of the workshop will be to *advance* the PV performance and reliability knowledge base, encourage the transfer of technical expertise to standards development activities, and provide a summary report establishing where we are and where we need to go in advancing PV technology performance and reliability.

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Workshop Chairs: T. Basso – PV Module Sessions (Oct. 18 – 19) and, P. McNutt - Power Processing and Systems Sessions (Oct. 20 – 21)

Planning Committee: R. DeBlasio, B. Kroposki, H. Post, and M. Thomas

Organizing Committee: B. Kroposki, C. Osterwald, W. Bower, and A. Rosenthal

Conference Arrangements: NREL Conferences Dept. MS1623
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email: kimberly_taylor@nrel.gov

PV PERFORMANCE, RELIABILITY AND STANDARDS WORKSHOP
October 18 – 21, 1999, Vail, Colorado

FACT SHEET

Location:

The session will be held at the Vail Cascade Hotel & Club.

1300 Westhaven Drive
Vail, Colorado 81657
Phone: 970.476.7111
http://www.vailcascade.com

Lodging:

A room block has been reserved for the nights of October 18-21, 1999 at a special conference rate of $89.00 + 8.5% tax for Main Lodge Rooms. To get this special rate, you must mention the "PV Performance, Reliability & Standards Workshop" and **your reservation must be made by October 1, 1999.** Late room requests will be filled on a space available basis. Reservations can be made by calling 1.800.420.2424.

Transportation:

All major airlines fly into the DIA Airport, located 100 miles East of Vail. Follow I-70 West. Vail is accessible by exit 173. Take exit 173, bearing left around the round-about and heading under the bridge. Head east on South Frontage Road for about 1/4 of a mile. The hotel is on the right hand side. Colorado Mountain Express provides transportation from the Denver Airport to the Vail Cascade Hotel for a fee of $56 one way. Reservations can be made by calling 1-800-525-6363.

Registration Fee:

The registration fee is $200 per person. The registration fee includes meeting attendance and proceedings, four Continental Breakfasts, four lunches, four dinners, four morning breaks, and four afternoon breaks. Please complete the attached Registration Form and return it along with your payment to NREL. **Pre-registration is appreciated.** Questions? Contact Kimberly Taylor. Phone-303.275.4358; Fax-303.275.4320; Email-kimberly_taylor@nrel.gov

Meeting Pattern:

Signs at the Hotel will direct you to PV Performance Reliability and Standards Workshop Registration area. Registration will be open Monday through Wednesday from 7:30 a.m. to 5 p.m. Continental breakfast is available from 7:30 a.m. to 8:30 a.m. each morning, with the meeting beginning at 8:30 a.m.

Deadlines

- The Hotel will not guarantee our rooms or room rate after **October 1st.**
  Call today! 1.800.420.2424.

- The registration fee increases by $50 after September 17th.

PV PERFORMANCE, RELIABILITY AND STANDARDS WORKSHOP

October 18 – 21, 1999, Vail, Colorado

PROGRAM

On-site Registration, and continental breakfast at 7:30 AM – 8:30 AM each day; registration includes continental breakfast, lunch and dinner.

WELCOME and OPENING REMARKS (October 18, 8:30 AM)

R. DeBlasio, NREL

I - Module Performance Rating (October 18, 8:45 AM – 5:00 PM)

General Session (8:45 AM – 12:15 PM)

Organizer and Session Chair – B. Kroposki; Session Summary -- T. Basso.

- Tutorial (1 hour) -- W. Bottenberg.
- Open Discussion (2 hours) -- B. Kroposki – Facilitator.
- Summary (30 minutes) --T. Basso.

Lunch (12:15 PM – 1:30PM)

Standards Panel/Discussion (1:30 PM to 5:00 PM) – T. Basso, Facilitator.

- IEEE WG P1479 - B. Kroposki -- P1479 Draft *Recommended Practice for Evaluation of Photovoltaic Module Energy Production;*
- ASTM E44.09 - C. Osterwald -- American Society for Testing and Materials (ASTM) Committee E44 on Solar, Geothermal and Other Alternative Energy Sources Subcommittee E44.09 on Photovoltaics;
- IEC TC82 US TAG - S. Chalmers and J. Anderson (WG2) -- International Electro-technical Commission (IEC) Technical Committee 82 (TC82) *Solar Photovoltaic Energy Systems* U.S. Technical Advisory Group (TAG), and Modules Working Group (WG2).

Dinner (5:30 PM – 7:00 PM)

II - Module Qualification Testing (October 19, 8:30 AM – 5:00 PM)

General Session (8:30 AM – 12:00 PM)

Organizer and Session Chair -- C. Osterwald; Session Summary --T. Basso.

- Tutorial (1 hour) -- J. Wohlgemuth.
- Open Discussion (2 hours) -- C. Osterwald – Facilitator.
- Summary (30 Minutes)-- T. Basso.

Lunch (12:00 PM – 1:30PM)

Standards Panel/Discussion (1:30 PM – 5:00 PM) – T. Basso, Facilitator.

- IEEE WG 1262 - J. Wohlgemuth: IEEE Std 1262-1996 *Recommended Practice for Qualification of Photovoltaic Modules,*
- ASTM E44.09 - C. Osterwald,
- IEC TC82 US TAG - S. Chalmers and J. Anderson.

Dinner (5:30 PM – 7:00 PM)

PROGRAM (continued)

III - Power Processing (October 20, 8:30 AM – 5:00 PM)

General Session (8:30 AM – 12:00 PM)
Organizer and Session Chair - W. Bower; Session Summary - P. McNutt.

- Tutorial (1 hour) -- J. Berdner.
- Open Discussion (2 hours) -- W. Bower – Facilitator.
- Summary (30 minutes) -- P. McNutt.

Lunch (12:00 PM – 1:30PM)

Standards Panel/Discussion (1:30 PM – 5:00 PM) - P. McNutt, Facilitator.

- IEEE SCC21 - R. DeBlasio – Standards Coordinating Committee 21 *Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage*;
- IEC TC82/US TAG - G. Posbec -- WG6 (Working Group 6 - Balance of System Components);
- NEC Article 690 - W. Bower/J. Wiles – National Electrical Code (NEC) Article 690 *Solar Photovoltaic Systems*.

Dinner (5:30 PM – 7:00 PM)

IV - Systems Evaluation (October 21, 8:30 AM – 5:00 PM)

General Session (8:30 AM – 12:00 PM)
Organizer and Session Chair - A. Rosenthal; Session Summary - P. McNutt.

- Tutorial (1 hour): C. Whitaker.
- Open Discussion (2 hours): A. Rosenthal – Facilitator.
- Summary (30 minutes) -- P. McNutt.

Lunch (12:00 PM – 1:30PM)

Standards Panel/Discussion (1:30 PM – 5:00 PM) - P. McNutt, Facilitator.

- IEEE WG P1373 -- C. Whitaker -- P1373 Draft *Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems;*
- IEEE WG P1526 -- B. Kroposki -- P1526 Draft *Recommended Practice for Testing the Performance of Stand-alone Photovoltaic (PV) Systems*;
- IEC TC82 US TAG WG3 (Working Group 3 - Systems) -- S. Chalmers/J. Anderson;
- NEC Article 690 - W. Bower/J. Wiles.

Dinner (5:30 PM – 7:00 PM)

October 22, 1999 – Optional Tour (10:00 AM or 11:00 AM) NREL Outdoor Test Facility

- Sign up at registration table in Vail; foreign citizens please sign up in advance
- Transportation to and from NREL is on your own

Annex B-2 Workshop General Information Handout

PV Performance, Reliability, and Standards Workshop
October 18 - 21, 1999
Vail, Colorado

General Information

Registration Desk - Barbara Ferris, NREL

Monday, October 18, 1999	7:00 AM – 5:00 PM	Cascade Foyer
Tuesday, October 19, 1999	7:30 AM – 5:00 PM	Cascade Foyer
Wednesday, October 20, 1999	7:30 AM – 5:00 PM	Cascade Foyer
Thursday, October 21, 1990	7:30 AM – 3:00 PM	Rocky Mountain Foyer

Meals

Continental Breakfast

Monday, Tuesday, Wednesday	7:30 AM – 8:30 AM	Cascade Foyer
Thursday	7:30 AM – 8:30 AM	Rocky Mountain Foyer

Breaks
Details are noted in the Final Program

Lunch and Dinner
Details are noted in the Final Program

Optional Tour - NREL Outdoor Test Facility
Friday, October 22, 1999
10:00 AM

Sign up at Workshop Registration Desk by Noon on Wednesday, October 20

- Transportation to and from NREL is on your own
- Upon arrival at NREL, please check in at Site Entrance Building – maps and information available at Workshop Registration Desk
- Photo ID required at check in at NREL Site Entrance Building

Please Note: Final Program will be available at the Registration Desk.

PV PERFORMANCE, RELIABILITY AND STANDARDS WORKSHOP

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Organizing Committee: B. Kroposki, C. Osterwald, W. Bower, and A. Rosenthal

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PV Performance, Reliability, and Standards Workshop
October 18-21, 1999
Vail, Colorado

Final Program

Monday, October 18, 1999

8:30 AM **Welcome and Opening Remarks - Richard DeBlasio** **Cascade Ballroom**

I - Module Performance Rating (8:45 AM – 5:00 PM)
Workshop Chair: T. Basso

General Session: Organizer and Session Chair - B. Kroposki
(8:45 AM – 12:15 with a 15 minute break at 10:15 AM in the Cascade Foyer)

Module Performance Ratings Tutorial (1 hour) - W. Bottenberg

Photovoltaic Module Performance Modelling (30 minutes) - D. King

Validation of Module Energy Ratings Procedure at NREL (30 minutes) - W. Marion

Open Discussion (1 hour) - Facilitator: B. Kroposki

Session Summary (15 minutes) - T. Basso

12:15 PM – 1:30 PM ***Lunch - Rocky Mountain AB***

Standards Panel/Discussion: Facilitator - T. Basso **Cascade Ballroom**
(1:30 PM – 5:00 PM with a 15 minute break at 3:00 PM in the Cascade Foyer)

- IEEE WG P1479 - B. Kroposki
  P1479 Draft *Recommended Practice for Evaluation of Photovoltaic Module Energy Production*

- ASTM E44.09 - C. Osterwald
  American Society for Testing and Materials (ASTM) Committee E44 on Solar, Geothermal and Other Alternative Energy Sources Subcommittee E44.09 on Photovoltaics

- IEC TC82 US TAG - S. Chalmers and J. Wohlgemuth IEC TC83 WG2
  International Electro-technical Commission (IEC) Technical Committee 82 (TC82) *Solar Photovoltaic Energy Systems* U.S. Technical Advisory Group (TAG), and Modules Working Group (WG2)

5:30 PM – 7:00 PM ***Dinner - Rocky Mountain AB***

PV Performance, Reliability, and Standards Workshop
October 18-21, 1999
Vail, Colorado

Final Program

Tuesday, October 19, 1999

8:30 AM **II- Module Qualification Testing** (8:30 AM – 5:00 PM) **Cascade Ballroom**
Workshop Chair: T. Basso

General Session: Organizer and Session Chair - C. Osterwald
(8:30 AM – 12:00 with a 15 minute break at 10:15 AM in the Cascade Foyer)

Tutorial (1 hour) - J. Wohlgemuth

Open Discussion (2 hours) - Facilitator: C. Osterwald

Summary (30 minutes) - T. Basso

12:15 PM – 1:30 PM Lunch - Rocky Mountain AB

Standards Panel/Discussion: Facilitator - Tom Basso **Cascade Ballroom**
(1:30 PM – 5:00 PM with a 15 minute break at 3:00 PM in the Cascade Foyer)

- IEEE WG 1262 - J. Wohlgemuth
  IEEE Std 1262-1996 *Recommended Practice for Qualification of Photovoltaic Modules*
- ASTM E44.09 - C. Osterwald
- IEC TC82 US TAG - S. Chalmers

5:30 PM – 7:00 PM Dinner - Rocky Mountain AB

PV Performance, Reliability, and Standards Workshop
October 18-21, 1999
Vail, Colorado

Final Program

Wednesday, October 20, 1999

8:30 AM **III - Power Processing** (8:30 AM – 5:00 PM) **Cascade Ballroom**
Workshop Chair: P. McNutt

General Session: Organizer and Session Chair - W. Bower
(8:30 AM – 12:00 PM with a 15 minute break at 10:15 AM in the Cascade Foyer)

Tutorial (1 hour) - J. Berdner

Open Discussion (2 hours) - Facilitator: Ward Bower

Summary (30 minutes) - Peter McNutt

12:15 PM – 1:30 PM Lunch - Rocky Mountain AB

Standards Panel/Discussion: Facilitator - Peter McNutt **Cascade Ballroom**
(1:30 PM – 5:00 PM with a 15 minute break at 3:00 PM in the Cascade Foyer)

- IEEE SCC21 - R. DeBlasio
  Standards Coordinating Committee 21 *Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage*

- IEC TC82/US TAG - J. Wohlgemuth (for G. Posbic IEC TC82)
  WG6 (Working Group 6 - Balance of System Components)

- NEC Article 690 - W. Bower/J. Wiles
  National Electrical Code (NEC) Article 690 *Solar Photovoltaic Systems*

5:30 PM ***Dinner - Rocky Mountain* AB**

PV Performance, Reliability, and Standards Workshop
October 18-21, 1999
Vail, Colorado

Final Program

Thursday, October 21, 1999

8:30 AM **IV - Systems Evaluation** (8:30 AM – 5:00 PM) **Rocky Mountain Ballroom**
Workshop Chair: P. McNutt

General Session: Organizer and Session Chair - A. Rosenthal
(8:30 AM – 12:00 PM with a 15 minute break at 10:15 AM in the Rocky Mountain Foyer)

Tutorial (1 hour) - C. Whitaker

Open Discussion (2 hours) - Facilitator: A. Rosenthal

Summary (30 minutes) - P. McNutt

12:15 PM ***Lunch – Mountain View Room***

Standards Panel/Discussion: Facilitator - P. McNutt
(1:30 PM – 5:00 PM with a 15 minute break at 3:00 PM in the Rocky Mountain Foyer)

- IEEE WG P1373 - C. Whitaker
  P1373 Draft *Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems*

- IEEE WG P1526 - B. Kroposki
  P1526 Draft *Recommended Practice for Testing the Performance of Stand-alone Photovoltaic (PV) Systems*

- IEC TC82 US TAG WG3 (Working Group 3 - Systems) - S. Chalmers

- NEC Article 690 - W. Bower/J. Wiles

5:30 PM ***Dinner – Centennial* AB**

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13. ABSTRACT *(Maximum 200 words)*

This report compiles the presentations made at the 1999 Photovoltaic Performance and Reliability Workshop, held on October 18-21, 1999, in Vail, Colorado. Also included are summary notes of the workshop discussion sessions. The theme of the workshop was "Setting a Standard for PV Performance and Reliability," with the focus on testing, test methods, evaluation, and standards. The workshop provided a venue for technical discussions on four topical areas: module rating, module qualification, power processing, and systems. Tutorial presentations and open discussion on individual concerns, issues, and solutions both served as the means for all to contribute and learn from one another. A repeated theme was that we need to ensure that the U.S. PV industry is in concert with, and at the forefront of, international PV module and systems technology activities. An overview of the outcome of the workshop includes the following.

I) Module Performance Rating. IEEE PAR 1479 "Draft Recommended Practice for the Evaluation of Photovoltaic Module Energy Production" – proceed with validating the models, inputs, and the standard's clauses; complete the draft by the IEEE working group; look closely at the need to develop a similar activity for system energy rating.

II) Module Qualification Testing. IEEE Std.1262 "Recommended Practice for Qualification of PV Modules" – establish a PAR for 1262 test program revisions; continue validation of proposed new qualification tests at NREL, ISPRA, and U.S. PV industry and test lab facilities. How do we ensure that new products and potential new failure mechanisms are included in qualification program? And, a repeated statement was that reliability testing should be done and that it should include module qualification.

III) Power Processing. It was recommended to pursue new IEEE PARs for inverters and for charge controllers. The most pressing concerns expressed by individuals included system design and system components integration aspects; reliability assurance; interconnection and the need for a uniform, national approach; testing; and, infrastructure development, e.g., outreach/education, qualification, accreditation, certification, and national/international standards development.

IV) Systems Evaluation. The most pressing concerns stated primarily reiterated the concerns in the power processing session, and additional concerns were about installation. There was much discussion about packaged systems and appliance-level approaches to PV systems and their validation.

IEEE PAR 1373 "Draft Recommended Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems." There was much discussion of the appropriate levels of recommended testing; it was recommended to complete this IEEE Draft Std 1373 and to focus on the need to develop an IEEE PAR activity for system energy rating.

IEEE PAR 1526 – "Draft Recommended Practice for Testing the Performance of Stand-Alone Photovoltaic Systems" – it was recommended to build on the completed initial testing validation at four U.S. sites by conducting a validation of the revised practices, and aggressively pursue the previously initiated international testing validation involvement.

14. SUBJECT TERMS
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