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SUMMARY OF COLLABORATIVE PHOTOVOLTAIC INDUSTRY WORK TO PROACTIVELY IMPROVE CODES AND STANDARDS FOR PHOTOVOLTAIC POWER SYSTEM APPLICATIONS

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ABSTRACT

Several important milestones in codes and standards pertaining to the design, installation and operation of photovoltaic (PV) systems have recently been completed with collaboration of participants from all sectors of the PV industry, utilities and the US Department of Energy's National Photovoltaic Program. Codes and standards that have been proposed, written or modified include changes and additions for the 1999 National Electrical Code® (NEC®), standards for fire and personnel safety, system testing, component qualification, and utility interconnect. Project authorization requests with the Institute of Electrical and Electronic Engineers (IEEE) have resulted in standards for listing PV modules and balance-of-system components. Industry collaboration with Underwriter Laboratories, Inc. (UL), with the American Society for Testing and Materials (ASTM), and through critical input and review for international standards with the International Electrotechnical Commission (IEC) have resulted in domestic and international standards for PV. Work related to the codes and standards activities through the International Energy Agency (IEA) is also being supported by the PV industry and the US DOE. This paper will concentrate on and summarize the important new NEC proposals for PV systems and will also describe and show the bonds between the activities in other standards writing activities. The paper will also provide an analysis of changes and resulting impacts of selected proposed NEC changes on PV designs, installations and performance.

INTRODUCTION

The PV industry has been proactive in writing codes, standards, and guidelines in the domestic and international arena. Several key codes, standards and guidelines are now being changed, written or drafted to reach a projected 1999 convergence. The 1999 NEC proposals, written and agreed on by the PV industry, have been submitted and are well on their way to bringing Article 690 -Solar Photovoltaic Systems- of the NEC up to a level commensurate with today's PV technology

and applications.

Underwriter Laboratories Standards (UL1741 and UL1703) are being coordinated and reviewed to be compatible with the new 1999 NEC. The UL1741 Standard for listing inverters is being expanded to include charge controllers and AC modules, and will emerge from its draft format late this year, with the effective date projected at January 1, 1999. The UL1703 Standard for listing PV modules is being reviewed and will be changed to reflect new industry needs and the needs of the 1999 NEC.

Many IEEE standards for PV related topics are being reviewed, re-certified or rewritten. A very critical IEEE standard, now designated P929, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems, is currently being rewritten with a targeted publication date also near the end of 1997. Other IEEE Guides, now PAR 1374, IEEE Guide for Terrestrial Photovoltaic Power Systems Safety and PAR 1373 "IEEE Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems," are in process. Par 1374 is scheduled for re-ballot in June and it is expected that this safety document, written to harmonize hardware availability and system design with the NEC, will also be published this year.

Other critical IEEE Standards and Recommended Practices for PV module qualification, battery applications for PV systems, and field measurements for systems acceptance are all completed or in process with targeted publication dates also before 1999.

Testing methods and materials issues are being addressed through the ASTM, with topics ranging from PV terminology, standard references, materials, and test methods for determining grounding integrity.

The IEC standards for PV applications are also being written in the international arena with critical reviews and input being supplied by the US Technical Advisory Group members with PV industry and utility participation.

Another international activity is the IEA. The IEA is not formally in the standards writing arena, but is reviewing critical utility interconnection issues on an international scale and providing survey reports on utility interconnect requirements,

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PV commercialization, research and developments and utility issues and system configurations used in member countries. The IEA Task V committee is planning collaborative international testing on critical "islanding" and interconnect parameters, and is also planning an international workshop in Zurich, Switzerland during September 15-16, 1997 to bring together, on an international scale, inverter manufacturers and utilities to address utility interconnection issues. The IEA activities are also scheduled to be completed by late 1998 with a final meeting and review planned to be held at Sandia National Laboratories in September 1998.

These standards, codes and guidelines activities have been in process for many years. For example, the proposed changes for the 1999 NEC were compiled through seven task group meetings over a period of three years. The 1999 crescendo will mark a time when the NEC, UL, IEEE, ASTM and IEC publications have converged to better equip the PV industry with a set of qualifications, safety guidelines, installation codes, and interconnect guidelines that are acceptable to the PV industry and electric utilities.

PV AND THE NATIONAL ELECTRICAL CODE

Collaborative work to write proposals for changes to bring Article 690 of the 1999 NEC up to the state-of-the-art in PV device and system technology has recently been completed by an industry supported task group. The task group was appointed by the National Fire Protection Association as an *ad hoc* Task Group for Article 690 - Solar Photovoltaic Systems. The task group was supported by the Solar Energy Industry Association, the Department of Energy's National Photovoltaic Program, and, most importantly, by all sectors of the PV industry.

Seven joint Task Group and SEIA Standards and Codes Technical Review Committee meetings served to unify the participants of the PV industry on code issues. Discussions, information exchange, and industry consensus greatly clarified the needs and justifications for code changes. A number of the changes were needed because of recent advances in PV technology such as the new AC PV module and building-integrated applications. Changes to existing language were also written to provide clarifications of the current language and to better define several requirements currently in the NEC.

This task group provided timely input by submitting 59 proposed PV system-related changes to the National Fire Protection Association. The work concentrated on industry-prioritized issues related to PV system safety, interconnects and performance. Changes for fire and personnel safety, system servicing, AC PV modules, integration of PV into building electrical systems, point-of-connection for building integrated PV systems, clarifications for hybrid systems, batteries, and charge controllers were proposed. Close coordination with UL and IEEE standards committees has been an important aspect of this NEC work.

PROPOSED ADDITIONS AND CHANGES TO THE NEC

Proposed changes related to PV installations covered the entire scope of Article 690. A large number of changes were proposed in the definition section. The new language and definitions

described new devices, improved ties of the sections of Article 690 to the remainder to the code, and provided consistency throughout Article 690. The definitions affected are listed in Table 1.

Other changes included new sections in Article 690 and significant changes to existing language. The changes were based first on safety, then on PV system installation impacts, good engineering practice, interface with the utility, and, lastly, on system cost or performance.

TABLE 1.
PROPOSED DEFINITION CHANGES FOR THE 1999
NEC

Definition	Type of Change	Impact, Consequence or Description
AC Module (AC Photovoltaic Module)	New Definition	Allows AC module applications. Defines AC modules as a complete listed package for Section 690-6 (AC Modules)
Array	Minor Change	Removed the old reference to thermal controller.
Charge Controller	New Definition	Defined the role of charge controller in PV systems
Electric Production and Distribution System	New Definition	Defined a utility grid as one that is not controlled by the PV system. Needed to better differentiate hybrid systems
Hybrid System	New Definition	Defined hybrid systems and energy sources in hybrid systems
Interactive System	Change the Definition	Defined interactive system as tied to the utility grid
Inverter	Change the Definition	Better defined charging functions associated with some inverters
Inverter Input Circuit	Minor Change	Defined inverter input circuit for both stand-alone and interactive inverters
Inverter Output Circuit	Minor Change	Clarified the definition
Module	Minor Change	Clarified definition and helped to differentiate AC modules
Photovoltaic Output Circuit	Minor Change	Changed to make language consistent
Photovoltaic Source Circuit	Minor Change	Changed to make language consistent
Stand-Alone System	Change	Clarified to remove tie to utility interactive systems
System Voltage	New Definition	Added to provide consistency throughout the Article

AC PV Modules

A very significant proposal was the addition of a section to provide circuit and labeling requirements for installation of the evolving AC PV module technology. Although just emerging as a new product, this hardware will very likely find its way to hardware and department stores, architects' manuals, and

builders' product lines by the time the 1999 NEC is issued. There have been more than 100 AC PV modules already installed in the US, and orders exist for almost 1000 more. This new section of the code provides the necessary requirements for safe installation and connection of listed AC PV modules to the utility grid and provides the rules for labeling AC PV modules.

DC Voltages Greater than 600 V

The addition of a new Part I of Article 690 to deal with PV systems with dc voltages greater than 600 volts was proposed. The requirement that installations in single- and two-family homes be limited to 600 volts gives valuable safety installation requirements for PV installations. The addition clarifies the intent of PV system voltage calculations and requirements, and makes it perfectly clear that systems with maximum system voltages over 600 volts use a much more restrictive set of requirements as set down by Article 710 of the NEC.

Temperature Compensation for Crystalline PV Module Voltages Values

A proposed new table (690-7) and the rules for applying the temperature correction for crystalline and multi-crystalline PV applications will more accurately apply the worst-case local temperature corrections to open-circuit voltage in those systems. No longer will installations in tropical locales be subject to the voltage/temperature requirements of installations in locales that experience high latitude temperatures. The table addresses crystalline PV technology which has the greatest temperature coefficient for open-circuit voltage. The temperature break points were carefully selected to match the PV modules that were commercially available. A newly proposed section also gives instructions to refer to manufacturer specifications when other than crystalline PV technologies are being installed. The proposed table is shown here as Table 2.

**TABLE 2.
PROPOSED TEMPERATURE CORRECTION TABLE
FOR CRYSTALLINE AND MULTI-CRYSTALLINE
SILICON MODULES**

Ambient Temp. °C	For ambient temperatures below 25°C (77°F), multiply the rated open-circuit voltage by the appropriate factor shown below	Approximate Ambient Temp. °F
25 to 10	1.06	77 to 50
9 to 0	1.10	49 to 32
-1 to -10	1.13	31 to 14
-11 to -20	1.17	13 to -4
-21 to -40	1.25	-5 to -40

Deratings for PV Array and Source Circuit Conductors

Clarification of the solar enhancement (125%) factor (currently a UL requirement) and the 80% derating factor (currently an NEC requirement) for continuous current for PV array

conductors and fuses has been needed for many years. There has been much confusion in applying these factors in the past, but the proposed change for 1999 puts everything into the NEC and simplifies calculations. Subsequent coordination with UL will remove their 125% requirement in their standard for listing modules.

Ground-Fault Protection

A proposed revision will provide much needed clarification for ground-fault protection of roof-mounted PV installations for fire protection. The revisions provide requirements for the detection, interruption and indication of ground faults. Indication is extremely important, since the ground-fault interruption of grounded PV sources involves disconnecting (or lifting) the grounded conductor or placing a high resistance in the ground path. The 1996 NEC gave no direction for implementation and the 1996 NEC used the term "disable the array" which is an ambiguous topic, since the only way to truly disable an array is to block the sunlight from the PV modules. The revisions give requirements and options for disconnecting the faulted PV source, allow lifting the ground connection and require indicating the condition of the system.

Points of Connection

Two related proposed changes address the issue of connecting PV inverters to commercially available service entrance panels. They were written to clarify the rules for sizing circuit conductors and supplying power to service entrance hardware at lower-than-service-panel-rated currents. Relevant proposals for using the terminology "maximum system voltage" were also made to provide clarity and consistency.

A proposal was submitted to provide the necessary language in Section 690-64(b) to allow the ac connection of PV systems at the load side of the service disconnecting means or at any distribution equipment on the premises. This serves the practical side of PV systems since the arrays may be located on the roofs of buildings and the service disconnecting means is usually at a lower level in an equipment room. This new language will better facilitate building integrated PV installations.

Interconnection to the Utility Grid

A proposal to delete of the existing requirement to install PV systems in accordance with the provisions of Article 705 entitled (Interconnected Electric Power Production Sources) greatly clarifies utility-interactive PV system installation requirements. PV systems and equipment have characteristics that are distinctly different from the equipment such as uninterruptable power supplies and emergency generators addressed in Article 705. This proposal eliminates a cross-reference in the NEC and allows Article 690 to stand on its own for PV installations.

A New PV System Block Diagram for Component Identification

Modification of the existing Figure 1 of Article 690 was needed

to clarify the intent of the figure. Numerous installations have been plagued with uncertainty because designers have tried to use the figure for system design or because inspectors insist the system should look like the figure. The proposed new figure specifies that it is intended for component identification only, and it is purposely designed to indicate installation configuration options only.

Work to be Completed

A proposal that was rejected by the code making panel for the 1999 NEC was to permit a single phase, 120V inverter to supply power to a single phase 120/240V service entrance panel provided there were no multi-wire branch circuits. There are estimated to be more than 50,000 such installations already, but no allowance is given in the existing code. The multi-wire branch circuits contain a common neutral conductor that may be overloaded when used with single 120V inverters. The task group will provide additional input to the code making panel for this and other proposals that need minor clarification.

IEEE STANDARDS, RECOMMENDED PRACTICES AND GUIDELINES

The IEEE has published seven important standards and guidelines related to PV system components out of Standards Coordinating Committee 21 (SCC21) on Photovoltaics. The latest publication was IEEE 1262, "Recommended Practice for Qualification of Photovoltaic Modules." Other important SCC21 documents include terrestrial PV system criteria, recommended practices for installation of batteries for PV systems, and recommended practices for sizing of batteries for PV systems. The recommended practices for batteries are now in the process of being recertified.

PV System Safety Guideline

The fire safety and personnel safety of installed PV systems is a top priority for designers, installers, inspectors and users. The NEC spells out the installation requirements for installation of all electrical systems, but the 1069 pages are often unfamiliar to those involved with PV systems. A Project Authorization Request (PAR)1374 to write a guideline titled "IEEE Guide for Terrestrial Photovoltaic Power Systems Safety" is in progress. The guideline is currently being updated for a second balloting to take place during 1997. It is written to provide an easily read safety document targeted specifically for PV systems. It is closely correlated with the NEC and other ANSI/IEEE recommended practices and standards.

The purpose of the guide is to describe PV-specific topics or components related to the design and installation of PV power systems that affect safety, and to suggest good engineering safety practices for PV electrical balance-of-system design, equipment selection and hardware installations. PV-unique electrical power requirements are emphasized in the guide. The guide describes system types and addresses wiring for PV modules, balance-of-system, and batteries. Particular attention is given to the critical temperature considerations required for PV systems at the module and array level, voltage ratings, cable and insulation

types, wiring ampacity, and sizing calculations needed for safe and reliable design. Other important topics such as overcurrent protection, disconnects, grounding, surge and transient protection, and instrumentation are also described with examples and recommendations for selection of the hardware. The guide is carefully cross-referenced to all applicable articles and sections in the NEC.

Utility Interconnect and Interface Guidelines

A very critical standard for utility interface and interconnects, now designated PAR929, "Recommended Practice for Utility Interface of Photovoltaic (PV) Systems," is currently being revised and rewritten with a targeted publication date also late 1997. This document is being revised by utility and PV industry experts to integrate the utility and PV system issues into a document that can be used by utilities, designers and installers for utility-interactive PV systems.

Important issues that are the focus of the PAR929 revision include defining the requirements for inverter shutdown under abnormal utility condition, islanding protection, reconnect after a utility disturbance, the need for manual disconnects, power quality requirements, and direct current isolation.

Field Test Methods for Grid-Connected PV Systems

Field test methods are being formulated for PV systems through an approved project authorization request designated PAR1373, "Recommended Practice for Field Test Methods and Procedures for Grid-Connected Photovoltaic Systems." The PAR was issued in 1993, and the document has now been reviewed by the committee. The test methods specified in this document could be used for confirming performance of newly installed PV systems or used to obtain data to determine if systems were subject to degradation over time. Tests for inverters, modules, and arrays will be included in the guideline.

PV Module Energy Rating

A project authorization request was submitted for module energy rating in July 96 and was approved in September 1996. The working group includes industry applications groups and was designated PAR1479. Work is progressing and the draft has been submitted to the SCC21 committee for review.

LISTING STANDARDS

Underwriters Laboratories, Inc. is currently in the process of reviewing the proposed first edition of the "Standard for Inverters, Charge Controllers and AC Modules for Use in Residential Photovoltaic Power Systems, UL1741". UL conducted an UL Industry Advisory Group (IAG) meeting in January 1997 to review the latest version of their Subject 1741, the draft standard intended for listing inverters and charge controllers and AC modules for use in PV power systems. The meeting was held to allow IAG members to provide PV industry input during preparation of the draft standard and before public review. The IAG consisted of participants associated with PV module manufacturing, inverter manufacturing, charge controller

manufacturing, ac module development, systems integration and the US DOE Photovoltaic Program. The draft is tentatively scheduled to be ready for public review by June 1997, with the UL goal for publishing the completed standard projected for early December 1997. The draft UL1741 now includes new language for testing and listing of AC modules, charge controllers and inverters. The proposed effective date for the UL1741 standard is January 2, 1999. These dates were established to coincide with the final meeting of code making panels for completion of inputs to the 1999 NEC in order that proposed code changes may also be reflected in the UL standard. The timing also allows UL to incorporate requirements spelled out in the revised IEEE 929 "Guideline for Interconnection of Photovoltaic Power Systems to the Utility Grid."

UL has also begun review of their UL1703 "Standard for Flat-Plate Photovoltaic Modules and Panels." They will hold the IAG meeting for the standard in June 1997 to modify the standard for anticipated changes in the NEC and to include PV technology needs.

ASTM

There are more than 20 ASTM standards related to PV systems, performance, testing, reference cells, insulation integrity, mechanical integrity and corrosion testing for PV components. An additional six documents are being worked on with expected publication dates in the 1999 time frame. Documents being written or revised, as of April 1997, include a test method for electrical performance and spectral response of multi-junction PV cells and modules, a test method for PV array wet insulation resistance, a specification for solar simulation for terrestrial PV testing, test methods for measuring spectral response of PV cells, and a test method for PV modules in cyclic temperature and humidity environments.

IEC TECHNICAL COMMITTEE 82 (IEC 82) STANDARDS

The IEC TC 82 has published 19 PV-related standards. PV-related standards already published include procedures for measuring I-V characteristics and using temperature and irradiance correction to the measured I-V characteristics for PV cells and modules, spectral response and mismatch measurements, solar simulator performance requirements, overvoltage protection for PV systems, characteristics of stand-alone PV systems, module design qualification for crystalline and thin-film PV, corrosion testing, impact damage, utility interface characteristics, and on-site measurements of I-V characteristics of PV arrays. Work underway includes a new safety standard for PV modules, a PV module environmental test standard for marine environments, a new method for determining the linearity of PV devices, a new method for defining solar simulator requirements, and new standards for rating PV modules for power and energy delivery.

IEA PV POWER SYSTEMS COLLABORATION

The IEA Photovoltaic Power Systems (IEA PVPS) Implementing Agreement was established in 1993 as an effort by 20 countries to focus on the planning, design, construction,

operation, performance, and promotion of photovoltaic power systems. The mission of the program is to enhance international collaboration efforts through which photovoltaic energy becomes a more significant energy option in the near future. The United States is currently active in five of the seven annexes of the implementing agreement as listed below.

Task I is responsible for the exchange and dissemination of information on photovoltaic power systems (PVPS). Task IV is focused on modeling of dispersed PVPS in support of the utility grid, but currently is limited to an *ad hoc* task group between the USA and Italy. Task V concentrates on the technical issues for grid interconnection of building-integrated and other dispersed PVPS. Task VI focuses on the design and operation of modular photovoltaic plants for large scale power generation. Task VII has just begun and will focus on PVPS in the buildings environment.

US participation concentrates primarily on Task I, Task V and, recently, Task VII. Task I has identified three subtasks. They are to publish a PVPS status survey report to be updated every two years, to provide quarterly newsletters, and to hold an executive conference on strategic photovoltaic business opportunities for utilities. The second bi-annual survey report was published in March 1997 and has been distributed to the US photovoltaics industry through the Edison Electric Institute and Sandia National Laboratories. The Edison Electric Institute participates in Task I by supporting their US expert while Sandia provides technical support for the task. The "Executive Conference on Strategic Photovoltaic Business Opportunities" was held in the US in September 1995 as part of Task I activities.

The US DOE participates directly in Task V and a new Task VII through Sandia and the National Renewable Energy Laboratory. Task V has an overall objective to develop and verify technical requirements that will serve as technical guidelines for grid interconnections for building-integrated and other dispersed power systems. These guidelines focus on safety and reliable interties to the grid at the lowest cost. The work focuses on three categories: review, definition of guidelines, and collaborative testing to demonstrate technical issues such as islanding or control algorithms with solutions to identified problem areas. Task V has already published reports on existing interconnect guidelines for PVPS interconnections and on utility distribution systems. A report on interconnection equipment is under final revision. Nine technical topics are under investigation in Task V for new guidelines. A summary of the findings and proposed guidelines for each will be published as part of the final report for Task V and distributed through Sandia and the IEA.

Another important milestone for Task V work is upcoming as an international workshop that will be held in Zurich, Switzerland on September 15 and 16, 1997. The workshop will be designed to involve utilities, inverter manufacturers, photovoltaic system suppliers, and engineers in international discussions to discuss guidelines that may be used and an international level. Topics will include islanding, reclosing, external disconnect requirements, overvoltage protection, grounding, and dc injection.

Task VII is a new activity, with the first official meeting being held early 1997. Task VII will concentrate on building-

integrated PV systems and issues.

SUMMARY

Publication of the 1999 NEC, with a strong and well-developed Article 690 on PV power systems, will represent a safety code that will enable PV systems to be installed with well understood requirements, to be easier to inspect, and, above all, to be safer for the user and for maintenance. Good installation practices required by the NEC will also improve long-term system performance and reliability. Publication of new IEEE standards and guidelines will serve the PV industry and the utilities by providing clearly defined qualification procedures, interface requirements and design criteria. ASTM standards already in place and scheduled for publication in the near future will provide the means for test methods for components and materials. The IEC international standards will provide the international perspectives and requirements for the manufacturers and designers of PV systems. Convergence of the approved publication of these codes, standards and guidelines in the 1999 time frame will strengthen the PV industry's ability to design, install and apply the technology in a wide range of applications.

This paper summarized the proposed code changes, provided background and analysis for the proposals, and showed collaborative actions with other IEEE, UL, ASTM, IEC and IEA publications.

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Subcommittee chairs working on PARs under the SCC21 include John Stevens of Sandia for PAR929, Chuck Whitaker of Endecon for PAR1373, John Wiles of the Southwest Technology Development Institute for PAR 1374, Ben Kroposki of NREL for PAR 1479, and Jay Chamberlin of Sandia National Laboratories for IEEE1013, IEEE1144, IEEE 1145, and PAR1361.

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