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NEW CODES AND STANDARDS FOR UTILTY-INTERCONNECTION OF AC PV MODULES*

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ABSTRACT

Photovoltaic (PV) modules that provide only ac power give new dimensions to the use of, and utility interface of, PV systems because all of the dc issues are virtually eliminated. These AC PV modules offer the important advantage that customers may now purchase a PV system without hiring a design engineer. A qualified electrician will be able to install a complete PV system that performs as expected and meets local electrical codes. Simple installations of additional AC PV modules will be possible once the proper branch circuit wiring and protection have been installed. Codes and standards are currently being written to address the utility-interconnect issues for AC PV modules and other interactive inverters. An industry-supported Task Group has recently written and submitted proposals for changes to bring Article 690 of the 1999 National Electrical Code® (NEC®) up to the state-of-the-art for PV devices such as AC PV modules [1]. This paper summarizes the proposed code changes and standards related to the evolving AC PV module technology in the United States. Topics such as the need for dedicated branch circuits for AC PV modules in residential applications are discussed and analyzed. Requirements for limiting the number of AC modules on a branch circuit and the listing requirements that make safe installations are discussed. Coordination of all standards activities for AC module installations, the building-integrated perspectives, and utility-interface issues is discussed.

INTRODUCTION

AC PV modules combine standard PV modules or standard large-area PV modules with a small, mechanically integrated, utility-interactive module-scale inverter, sometimes called a micro-inverter. Two imminent AC PV module deliverables for the PV Manufacturing Technology Program (PVMaT) in the U.S. are designs using a large-area PV modules and a single module-scale inverter [2]. The designs have no dc circuits that are accessible to installers or users, which eliminates the need for costly dc disconnects and dc ground-fault protection. The entire assembly for each design will be listed as a single AC PV module device intended only for approved utility-interactive operation. In other words, the device produces power only when connected to a utility grid that is operating within a specified voltage and frequency range.

Codes and standards are being written to include the AC PV module concept. Issues such as islanding, voltage set-points, frequency set-points, external disconnects, system disables and environmental conditions are being addressed in each. The NEC is an evolving document that is continually updated in a three-year cycle [1]. The 1999 "code cycle" began for the PV industry

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with the issuance of the 1996 NEC [3]. Collaborative work was completed by a PV industry-supported Task Group 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. The proposed changes include AC PV module and other building-integrated system requirements. The task group was supported by the U.S. Department of Energy's National Photovoltaic Program, the Solar Energy Industry Association (SEIA), and most importantly by all sectors of the PV module and balance-of-system industries.

A number of the changes were needed because of recent advances in PV technology. Several new products and applications have been emerging. They include AC PV modules, other types of modular inverters with multiple modes of operation (utility-interactive, stand-alone, and hybrid), building-integrated PV such as roofing shingles, PV-laminated roofing, window walls, and facades.

The Task Group wrote and submitted 59 proposals for PV system-related changes to the National Fire Protection Association (NFPA). The work concentrated on PV industry-prioritized issues related to safety and installation. AC PV modules were the top priority for writing needed requirements since the 1996 NEC did not address PV systems that have no access to the dc power. Changes related to AC PV modules were proposed for fire and personnel safety, system servicing, integration of PV into building electrical systems, and point-of-connection for building-integrated systems. All proposed changes were based first on safety. Other considerations were PV system installation impacts, good engineering practice, interconnection with the utility grid, availability of hardware, and system cost and performance. Close coordination with Underwriters Laboratories, Inc. (UL) and the Institute of Electrical and Electronic Engineers (IEEE) standards committees have also been an important part of this work.

DEVELOPMENT OF AC PV MODULES IN THE UNITED STATES

Sandia National Laboratories (SNL) and the National Renewable Energy Laboratory (NREL) have teamed to administer the Product Driven System and Component Technology portion of Phase 4A1 of the Photovoltaic Manufacturing Technology (PVMaT) research program [2]. Technical monitoring teams provide monitoring of the individual subcontracts as well as timely reviews, development testing and evaluations for the deliverables.

Ascension Technology, Incorporated has teamed with ASE Americas Corporation to develop and manufacture an AC PV module. Ascension and ASE have refined and integrated a module-scale inverter with a standard, large-area, 300-W_p PV module. Development of an advanced version of the module-scale inverter is based on performance enhancement goals, optimized circuit topology and layout, and more compact construction. The overall design also focused on lower weight, high reliability, and compliance with applicable Underwriters Laboratory (UL) standards that will help to insure code compliant installations.

The combined module-scale inverter and large-area ASE PV module, called the Sunsine300™, has been delivered to Sandia and NREL to be subjected to performance and development testing as well as outdoor performance characterization. Ascension has developed a complete system package that will be installed and evaluated by up to 20 co-funding electric utilities. The system uses a new version of Ascension's "Photovoltaic Source Circuit Protector," an updated "Roof Jack" mounting system and a specialized utility interconnection unit. The complete AC PV module is undergoing final UL tests at this time. Ascension also reports the Sunsine300 AC PV module has met Federal Communications Commission requirements for certification in meeting electromagnetic interference standards.

Solar Design Associates, Inc., teamed with Advanced Energy Systems, Inc. and Solarex to develop standardized, low-cost ac PV systems. The researchers are striving to create standard, certified, modular building blocks utilizing a new Solarex MSX-240 large-area PV module and a micro-inverter developed by Advanced Energy Systems, Inc. Designed as identical units, the AC PV module building blocks can be conveniently combined to create PV systems of virtually any size and capacity.

Solar Design Associates will be incorporating innovative mounting systems, enhanced module-scale inverters, and pre-manufactured wiring systems in a kit. The AC PV modules developed for U.S. applications will be modified as necessary for export to Japan and Europe. Performance data will be collected as units are deployed at utility-team member locations in the U.S.A., Europe, and Japan.

Advanced Energy Systems, Inc. reports that its micro-inverter, developed with Solar Design Associates has undergone UL listing tests and is now a listed micro-inverter. The micro-inverter is also certified by the Federal Communication Commission as compliant with its requirements for use in residential PV applications. Advanced Energy Systems, Inc. has also reported the installation of what is believed to be the world's largest AC-module array with 70 of the micro-inverters attached to Solarex PV modules. The installation is at the Center for Environmental Sciences and Technology Management at the State University of New York.

OVERVIEW OF PROPOSED CODE CHANGES FOR AC MODULES

This paper presents changes proposed for AC PV modules, however, many other significant changes were proposed. A complete set of 1999 NEC proposals and code-making panel actions are published for public comment in the NFPA Report on Proposals [4].

Definitions

Proposed changes addressed all of Article 690. A significant number of changes and additions were proposed in the definition section. They described new devices, tied the Sections of Article 690 to the remainder to the code, and provided consistency in language throughout Article 690. Table 1 lists the proposed definition changes related to AC PV modules.

New Sections for Article 690 That Are Related to AC PV Modules

Several new sections for Article 690 were also proposed for the 1999 NEC. One completely new section (Section 690-6 - AC Modules) was added to address requirements for the new AC PV module products and their connection to the utility lines. Other new sections: AC Photovoltaic Modules, 690-54: Interactive System Point-of-Connection, and 690-60: Identified

Definition	Type of Change	Impact, Consequence or Description
AC Module (AC PV Module):	New Definition.	Allows AC Module applications. Defines AC modules as a complete listed package for Section 690-6 (AC Modules).
Interactive System:	Change Definition.	Defined an interactive system as tied to the utility grid.
Inverter Output Circuit:	Minor Change to Clarify with New Figure 1.	Clarified definition to be consistent with proposed Figure 1.
Module:	Minor Change to Clarify New Definition.	Clarified definition and differentiated AC modules.
Photovoltaic Output Circuit:	Minor Language Change.	Changed to make language consistent.
Photovoltaic Source Circuit:	Minor Language Change.	Changed to make language consistent.

Table 1. Proposed NEC Definitions Related to AC PV Modules

Interactive Equipment are related to AC PV modules as well as other PV installations.

New Section for AC PV Modules

A very significant proposal for AC PV modules was the addition of Section 690-6 to provide the hardware, circuit, and labeling requirements for installation of the evolving AC PV module technologies. Although just emerging as a new product, these devices will very likely find their way to hardware and department stores, architect's manuals, and builder's product lines before the 1999 NEC is issued. There have been more than 100 AC PV modules installed in the USA already, and orders exist for almost 1000 more.

This new section of the code provides the necessary functional and installation requirements for safe installation and connection of listed AC PV modules to the utility lines, and provides the requirements for labeling AC PV modules. The proposed section (690-6-AC Modules) is reproduced below [4].

> ***(a) Photovoltaic Source Circuits.*** *The requirements of Article 690 pertaining to photovoltaic source circuits shall not apply to ac modules because the photovoltaic source circuit conductors and inverters are all one integral unit.*
> ***(b) Inverter Output Circuit.*** *The output of an ac module shall be considered an inverter output circuit.*
> ***(c) Disconnecting Means.*** *A single disconnecting means, in accordance with 690-17, shall be permitted for the combined ac output of one or more ac modules. Additionally, each ac*

module in a multiple ac-module system shall be provided with a connector, bolted, or terminal-type disconnecting means.
(d) Ground Fault Detection. *AC module systems shall be permitted to use a single detection device to detect only ac ground faults and to disable the array by removing ac power to the ac module(s).*
(e) Overcurrent Protection. *The output circuits of ac modules shall be permitted to have overcurrent protection and conductor sizing in accordance with Article 240-4, Exception No. 2.*

Section (a) acknowledges that AC PV modules have no user-accessible dc circuits and that other dc requirements of PV source circuits in Article 690 are not applicable. Section (c) allows the combined output of multiple AC PV modules to feed a single, dedicated branch circuit provided that each AC PV module is supplied with an accessible disconnect.

Interconnection Requirements

Two related proposed sections address connecting inverters to service-entrance panels. They were written to clarify the requirements for supplying power (690-10) to service-entrance hardware at lower than service-panel-rated currents and sizing conductors (690-11). Proposals using a "maximum system voltage" terminology were also written to provide code language consistency.

A proposal was also 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 PV arrays may be located on the roof of buildings and the service disconnecting means is usually at a lower level in an equipment room. These changes will better facilitate building-integrated and AC PV module installations.

An example for a commercial PV interconnection is a PV-powered, electric vehicle charging station on a commercial building that has an ac load center with a main circuit breaker rated at 300 amps. Six 60-amp load circuits and breakers are connected to the load center to supply power to six battery chargers.

A 60-amp circuit breaker is added to the load center to allow the output from AC PV modules to also supply PV power to main panel, hence the charging stations. This new connection could allow the bus bars in the load center to be overloaded. If all six charging stations are drawing 60 amps and the PV system is supplying 60 amps, then the grid is supplying 300 amps. Circuit breakers would not trip, but the internal 300-amp bus bars in the load center could be overloaded and carrying up to 360 amps. Section 690-64(b)(2) requires that the sum of the ratings of all overcurrent devices connected to a cable, conductor, or bus bar be less than the ampacity of that conductor.

The requirements for adding AC PV to this system are to reduce the total ratings of the input breakers to be equal to or less than the load center rating. That means:

1. The 300-amp load center could be replaced with a load center having a rating of 360 amps or

higher while retaining the 300-amp main breaker.

2. If the actual power drawn by the charging stations were less than 240 amps, the rating of the main circuit breaker could be reduced to 240 amps while retaining the 300-amp load center.

The restrictions for residential installations (690-64(b)(2) (Exception)) are not as stringent as for commercial applications. The sum of the overcurrent devices in residential applications can be up to 120% of the rating of the load center. A residential load center rated at 100 amps may accept a 20-amp branch circuit from AC PV modules (2400 watts at 120 volts or 4800 watts at 240 volts). A load center rated at 200 amps may accept a 40 amp branch circuit from AC PV modules (4800 watts of AC PV modules at 120 volts or 9600 watts at 240 volts). These power levels are consistent with the maximum sizes of residential roof tops.

LISTING AND CERTIFICATION STANDARDS

It was proposed for the 1999 NEC that PV systems connected to the utility grid be required to use listed components. Other proposed changes for the 1999 NEC will require coordination with other standards groups. Underwriters Laboratories, Inc. is currently in the process of reviewing the proposed first edition of the "Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems, UL1741." The draft UL1741 includes new language for testing and listing of AC modules, charge controllers and inverters [5]. UL conducted an Industry Advisory Group (IAG) meeting in January 1997 to review the latest version of its Subject 1741. That 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 was distributed for public review in August 1997. The UL goal for publishing the standard is tentatively set for December 1997. The proposed effective date for the UL1741 standard is January 2, 1999, which was established to coincide with the effective date of the 1999 NEC.

An AC PV module that is listed will be tested in accordance with related UL1741 requirements for inverters and UL1703 requirements for PV modules [6]. An example of some of the tests required include the following:

1) Construction Review
2) Strain Relief of Cables
3) Water Spray
4) Accelerated Aging
5) Temperature Cycling
6) Humidity Cycling
7) Dielectric Strength
8) Grounding Impedance
9) Maximum Voltage
10) Maximum Current
11) Harmonic Distortion
12) Temperature (Overload)
13) Utility Fluctuations
14) Loss of Control
15) Abnormal Tests

COORDINATION WITH OTHER STANDARDS

The IEEE has published important standards and guidelines related to PV system components. These publications were written by the Standards Coordinating Committee 21 (SCC21) on Photovoltaics. SCC21 documents include terrestrial PV system criteria and recommended practices for installation and sizing of batteries for PV systems.

PV System Safety Guideline

Fire safety and personnel safety of installed PV systems are a top priority for designers, installers, inspectors and users. The NEC describes the installation requirements for installation of all electrical systems, but its 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. It is written to provide an easily read safety document targeted specifically for PV systems. It is also closely correlated with the 1996 NEC, other ANSI/IEEE recommended practices or standards, and widely used suggested practices [7]. The guide includes AC PV module installation recommendations

The purpose of the IEEE PV Safety guide is to describe PV-specific topics or components related to the design and installation of PV power systems that affect safety. It suggests good engineering safety practices for PV electrical balance-of-system design, equipment selection and hardware installations. Many system types are analyzed for correct wiring practices for PV modules, balance-of-system hardware and batteries. Particular attention is given to the critical temperature considerations required for conventional 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 applicable language in the 1996 NEC.

Utility Interconnect and Interface Guidelines

A very critical standard for utility interfaces and interconnects, now designated PAR 929, "Recommended Practice for Utility Interface of Photovoltaic (PV) Systems," is currently being revised and rewritten with a targeted publication date 1998 [8]. This document is being revised by a team of utility and PV-industry experts. The utility and PV system perspectives on AC PV modules and other PV systems are being integrated into a document that can be used by utilities, and designers and installers for utility-interactive PV systems. AC PV modules will be subject to the interconnect guidelines outlined in the published IEEE929 standard.

The focus of the PAR 929 revision includes defining a set of guidelines for inverter shutdown under abnormal utility conditions. Islanding protection, reconnects after a utility disturbance, the guidelines for manual and external disconnects, power quality requirements, and direct current isolation from the grid are to be included in the standard.

SUMMARY

Photovoltaic modules providing only ac power do give new dimensions to the use of and utility interface of PV systems. Integrated hardware and components are emerging that is listed and certified that may be safely and effectively installed. Codes and standards are well on the way to addressing the issues associated with the AC PV modules. Publication of the 1999 NEC, with a strong and well-developed Article 690 on PV power systems that includes AC PV module installation requirements, will represent a safety code that will enable PV systems to be installed using well-defined requirements. The UL standards and IEEE standards will also provide the correct paths for design and installation of the components and systems. Future installations will be easier to design and inspect, and above all, will provide safety for all concerned.

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