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The New 1999 National Electrical Code® Coupled With New Standards Clarify Requirements for Installations of Photovoltaic Systems in the U.S.

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SUMMARY

The National Electrical Code® (NEC®) focuses primarily on electrical system installation requirements in the U.S. The NEC addresses both fire and personnel safety. This paper will describe recent efforts of the PV industry in the U.S. and the resulting requirements in the 1999 National Electrical Code-- Article 690 --Solar Photovoltaic Systems. The Article 690 requirements spell out the PV-unique requirements for safe installations of PV systems in the U.S.A. This paper provides an overview of the most significant changes that appear in Article 690 of the 1999 edition of the NEC. The related and coordinated efforts of the other standards-making groups will also be briefly reviewed.

INTRODUCTION

There are a multitude of guidelines, codes and standards available in the U.S. by which PV systems may be installed or connected to the utility grids, and it is equally true for installations of stand-alone or PV-hybrid systems. Many utilities that were active in early PV

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programs have written their own guidelines for PV and other dispersed generation system interconnections. Where no such utility-generated document exists, a selection of a number of standards, guidelines, codes, and local rules are used. The most universal requirement in the U.S. however, is that PV system installations meet requirements of the National Electrical Code (NEC). The NEC is mandated by law in at least 40 states and by most major cities.[1] In states or municipalities where the NEC has not been adopted as law in whole, it is often used with additional or changed requirements that better fit the local environment.

While installation requirements for fire protection and safety are covered in the NEC, other related issues such as waveform quality, electromagnetic interference, power factor, voltage ranges, PV system anti-islanding, and system performance are covered by a wide variety of other publications. The documents covering these other issues are generated by the Institute of Electrical and Electronic Engineers (IEEE), the American National Standards Institute (ANSI), the American Society for Testing and Materials and the International Electrotechnical Commission. Underwriters Laboratories, Inc. writes standards for recognizing and listing components. The International Energy Agency (IEA) sponsors a Photovoltaic Power Systems Implementing Agreement through which participating countries collaborate internationally to research and report on PV system issues such as interconnect, applications, and building-integration. Although the IEA reports are not standards, they are often used as references as new standards and guidelines are being written.

THE NATIONAL ELECTRICAL CODE

The NEC is published as ANSI/NFPA 70 by the American National Standards Institute/National Fire Protection Agency. It is the most frequently used document for inspecting and approving electrical installations, including PV systems, in the U.S. It is worth emphasizing that the NEC does not directly address the issues of performance, power quality, islanding, operating windows for voltage, current ratings (except for a 600-volt limitation in one- and two-family dwellings).[2] The NEC is primarily a fire protection document, but it also addresses the issue of human safety with requirements for ground-fault interrupters and devices that minimize electrical shock hazards. The 1999 NEC requires the use of components for PV systems that are listed by a qualified laboratory for utility-interconnected systems.[3] The term "listed" refers to equipment tested and approved by a qualified electrical testing laboratory that is recognized as having the facilities described above and that requires suitability for installation in accordance with the NEC. Listed is generally defined in the NEC as "equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction and concerned with evaluation of products or services, that maintains periodic inspection of production of listed equipment or materials or periodic evaluation of services, and whose listing states that either the equipment, material, or services meets identified standards or has been tested and found suitable for a specified purpose."[3] Listed hardware is also required when those components are available for stand-alone and hybrid systems.

The NEC was established in and has been continually revised and expanded since 1897. It deals with the safe installation and use of nearly all electric power components and systems that are outside the utility owned and operated generation or distribution system. Control circuits, computer and data processing circuits, antenna cables and community antenna television (CATV) systems, fire-alarm circuits, and nearly all other low- and high-powered electrical and electronic circuits are included. (Automobiles, railroad cars, ships and self-contained, PV- or battery-powered devices such as wristwatches, calculators, and small toys are not covered by the NEC.)

Nearly all devices with external electrical terminals that must be wired or connected to other powered or power-supplying devices come under the auspices of the requirements established by the NEC. Motor-driven generators are covered, as are systems with voltages less than 50 volts, emergency systems, and legally required standby power systems. Article 690--Solar Photovoltaic Systems--covers PV system requirements. It was added to the NEC in 1984, and has been revised and expanded in 1987, 1990, 1993, 1996 and now 1999. The NEC has a 3-year renewal cycle.

Residential PV systems are limited to single-phase installations by the NEC in the U.S. Intermediate- and central station-size systems that range into the megawatt size are three-phase connections, and are covered by this same Article 690 of the NEC. There is no categorization in the NEC except for the class of equipment that must be used to meet the voltage and power requirements.

The 1999 NEC code revision cycle has been completed and the NEC has been published.[3] Fifty-seven proposals for changes in Article 690 were submitted during this cycle by an *ad hoc* task group. The task group was appointed by the National Fire Protection Association as requested by the chairman of Code Making Panel 3 (CMP#3).[4] The task group was asked to provide expertise to determine if the scope of Article 690 was sufficient or if it needed to be rewritten. Once the scope of the Article was determined to be acceptable, the task group was requested to bring Article 690 up to the state-of-the-PV-technology through proposed changes. The task group was also required to provide substantiation for each proposal that it submitted and to study all issues that needed clarification or expansion in Article 690. In addition to the task group proposals, the general public proposed changes to Article 690 through avenues available to the public, and later, through public comments. The approved public proposals also appear as changes in the 1999 NEC.

THE TASK GROUP FOR ARTICLE 690- SOLAR PHOTOVOLTAIC SYSTEMS

A task group, consisting of nine members, was appointed by the National Fire Protection Association as an *ad hoc* Task Group for Article 690, Solar Photovoltaic Systems. The U.S. Department of Energy's National Photovoltaic Program, the Solar Energy Industries Association (SEIA), and, most importantly, all sectors of the PV module and balance-of-system industries supported the task group. Underwriters Laboratories, Inc. (UL) also participated and contributed historical information and coordination with their component and hardware listing standards. Other participants included utility engineers, university leaders, systems installers, and users of PV systems. More than 60 experts participated in formulating the proposed changes for the 1999 NEC.

Seven meetings of the task group served to unify the PV industry participants on code issues. The meetings were held as joint events of the NEC Article 690 task group and the SEIA standards and codes technical review committee. Discussions, information exchange, and industry experience served to greatly clarify the needs and justifications for the proposed code changes. A number of the changes were needed simply because of new products and recent advances in PV and balance-of-system technology.[5] The advances considered for code changes included ac PV modules, modular inverters with multiple modes of operation (utility-interactive, stand-alone, and hybrid), multi-junction PV modules, building-integrated PV such as roofing shingles, PV-laminated roofing, window walls, and facades. Many changes were written to provide clarifications of the current language or to change ambiguous requirements in the existing NEC.

The work concentrated on PV industry-prioritized issues related to safety and installation for the fifty-seven proposals submitted for PV system-related changes to the National Fire Protection Association (NFPA). After industry consensus, changes were proposed to address fire and personnel safety, system servicing, ac PV modules, integration of PV into building electrical systems, point-of-connection for building-integrated systems, and clarifications for hybrid systems, batteries, and charge controllers. All proposed changes made by the task group were based first on safety. Other important considerations taken into account while formulating the proposals were PV system installation impacts, good engineering practices, practicality, interconnection with the utility grid, availability of hardware, cost, and system performance.

Close coordination with Underwriters Laboratories and the IEEE Standards Coordinating Committee 21 have also been an important part of this work.[6,8] All of the proposed changes from the task group were accepted, some with minor changes, during the NEC review process. The 1999 NEC was published in September 1998 and became effective on January 1, 1999 except in localities where legislative approval was required by law.

SIGNIFICANT TOPICS COVERED BY CHANGES IN ARTICLE 690 FOR THE 1999 NEC

Changes in Article 690 for the 1999 NEC are evident throughout the article. One new part, Part I, was added to provide the guidance for systems over 600 volts. Several new sections were added; one completely new section, Section 690-6 *(Alternating Current Modules)* was added to address requirements for the new ac PV module products and their connection to utility lines. Other new sections included 690-10 *(Stand-alone Systems)*, 690-52 *(Marking, Alternating-Current Photovoltaic Modules)*, 690-54 (*Interactive System Point-of-Interconnection)*, 690-60 *(Identified Interactive Equipment)*, and 690-72 *(Charge Control).* Some new sections retained language modified and/or moved from other sections of the 1996 Article 690. The topics covered below include only the most significant changes for the 1999 NEC.

Definitions

A significant number of changes and additions were proposed in the definition section (690-2) of the NEC to assure consistent terminology in the remaining sections of Article 690. They defined new devices, more appropriately cross-referenced the sections of Article 690 to the remainder of the code, and improved consistency in language throughout Article 690. Table 1 lists the new and changed definitions for the 1999 Article 690, along with explanatory details for each.

PV-Unique Components Figure Revised

Revisions of the existing Figure 690-1 of Article 690 were needed to clarify the intent of the figure. Numerous installations have been plagued with uncertainty because designers have tried to use the existing figure for system design, or because electrical inspectors have insisted that the installed system should look like the figure. The revised figures *(now 690-1a and 690-1b)* are clearly labeled 'for component identification only' and are purposely designed to identify PV-unique components, connections, and system options while not resembling an electrical schematic. The new Figures 690-1a and 690-1b are shown as Figure 1 and Figure 2. They include connection and configuration nomenclature and show options for grid-tied, stand-alone, and hybrid PV system applications.

Removal of Cross References

Deletion of an old requirement in 690-3 *(Other Articles)* requiring interconnected PV systems to be installed in accordance with the provisions of Article 705 *(Interconnected Electric Power Production Sources),* removed confusion by placing all PV-system installation requirements in Article 690. Justification for this action arises from the fact that PV systems and equipment have characteristics (current-sourced power, for instance) that are different from those of other interactive equipment such as uninterruptible power supplies and emergency generators addressed in Article 705. The deletion allows Article 690 to stand on its own for all PV installations.

Ground Fault Protection

A revised Section 690-5 *(changed from Ground-fault Detection and Interruption to Ground-fault Protection)* for PV arrays on dwellings, was revised extensively to provide clarity and allow alternative methods for satisfying the requirement, while still maintaining system safety. Listed equipment that may be included in utility-interactive inverters, power centers, and as separate components is now available to meet this requirement. The revisions provide rules for fault detection, interruption and further requirements for an indication of ground fault. The ground-fault indicator must be located near the ground-fault device, and in an accessible location with a warning label. Indication is a very important addition here, since ground-fault interruption of grounded PV sources may involve disconnecting (or lifting) the grounded conductor or placing a high resistance in the ground path. The 1996 NEC gave no clear direction on means for ground-fault interruption.[1] The 1996 NEC Handbook attempted to address the issue, but used the term "disable the array" that caused more confusion, since the only way to truly disable an array is to block the sunlight.[9] The revisions spell out the requirements for disconnecting the faulted PV source, interrupting the fault current, indicating the status or condition of the system, and providing a warning label that automatic ground-fault interruption may lift the system ground of a faulted array.

Alternating-Current PV Modules (ac PV Modules)

A significant proposal for building-integrated PV was the addition of Section 690-6 *(Alternating Current Modules).* It provides the requirements for hardware, circuits, and labeling for installation of the new and evolving ac PV module technologies. Although just emerging as a new product, these devices will soon find their way to retail stores, architects' manuals, and builders' product lines.[5] There have been more than 200 ac PV modules installed in the U.S. in the last 18 months.

This new section provides the necessary functional requirements for the safe installation and connection of listed ac PV modules to the utility lines and details the requirements for labeling ac PV modules. The new section 690-6- (*Alternating Current Modules)* is reproduced below for the reader's convenience.[3]

(a) Photovoltaic Source Circuits. *The requirements of Article 690 pertaining to photovoltaic source circuits shall not apply to ac modules. The photovoltaic source circuit conductors and inverters shall be considered as internal wiring of an ac module.*

(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 690-15 and 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. *Alternating-Current 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(b)(2).*

Section (a) acknowledges that ac PV modules have no user-accessible dc circuits and that 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 provided with an accessible disconnect.

Figure 3 shows the world's first UL-listed, complete ac PV module during installation on manufactured Roof Jack™ system. The inverter for the ac PV module is attached at the top-center on the back of the module, and the only electrical connections are through attached and integrated cables and connectors. A licensed electrician normally installs a dedicated branch circuit to which the ac connections are made. An unlicensed user or installer can then attach multiple ac modules, up to the capacity of the branch circuit, at a later time to that circuit.

System Voltage Requires Temperature Compensation

The new section 690-7 *(Circuit Requirements, Maximum Voltage)* begins with new language for determining maximum system voltage (which is temperature dependent) and other circuit requirements. The new Table 690-7, "Voltage Correction Factors for Crystalline and Multi-crystalline PV Modules," and the rules for applying the temperature correction for crystalline and multi-crystalline PV applications more accurately use local temperature corrections to open-circuit voltage in those systems. This table addresses the PV module technology (crystalline) that has the greatest temperature coefficient for open-circuit voltage. The temperature break points for the temperature ranges in the table were carefully selected to match PV modules that are commercially available. Section 690-7(a) also gives instructions referring readers to manufacturer's specifications when other than crystalline PV technologies are installed. The new table is reproduced below as Table 2.[3] Section 690-7 also places the limits of not greater than 600 volts for installations when installed on one- and two-family dwellings.

A comparison of the requirements for 1996 and the new 1999 Section 690-7 is provided here to illustrate the positive impact of the new Table 690-7. This example shows how the change will allow for continued safe installation of PV systems in all climatic regions, while making allowances for regional climatic differences that were previously ignored and which unnecessarily restricted PV system designers and installers. The example is for a PV installation in Phoenix, Arizona where the coldest measured (record) temperature is -9°C (16°F). The example uses crystalline silicon PV modules that are listed to UL Standard 1703.[4] The design requires strings of 24 series-connected modules, each with a rated open-circuit voltage of 22V, to optimize performance and utilization of the inverter. Using the 1996 NEC, the system designer or integrator multiplied the rated open-circuit voltage of the modules by 125% to allow for the worst-case cold-temperature of -40°C under the requirements of the 1996 NEC and using the old UL-1703 listing criteria.[4] No allowance was provided for the fact that the coldest recorded temperature in Phoenix is -9°C. Using the 125% factor allows only 21 modules to be connected in series (21 X 22 X 1.25 = 577.5 Volts) to keep the string voltage less than 600V.

Using the 1999 Section 690-7 and the new Table 690-7 allows the designer or system integrator to calculate the system voltage using a temperature-dependent factor more in line with the Phoenix environment. The new calculation allows a multiplication factor of 1.13 from the new Table 690-7 that corresponds to a minimum temperature range of -1 to -10°C (31 to 14°F). With the 1999 NEC, the system can now use 24 modules in series (24 X 22 X 1.13 = 597 Volts) and remains under the 600-Volt limit for a residential application.

Solar Irradiance and Conductor Deratings

Solar irradiance of 1250 W/m^2 is common for brief periods of time in many parts of the U.S. The coordination of the PV module current correction factor of 125 percent for enhanced irradiance, which is currently written as a UL requirement, and the NEC-required 80 percent derating factor for continuous current for all conductors and overcurrent devices, has been needed in the past. Many open fuses and loose connections in early PV systems can be attributed to overheating due to undersized wiring or improper temperature ratings for terminal blocks and fuses. There has been much confusion in applying the solar enhancement and the conductor derating factors because they appeared in different documents. The change in Article 690-8 *(Circuit Sizing and Current)* for 1999 puts all requirements in the NEC and steps through the calculation.

The new NEC language for system voltage and circuit current calculations for wire sizes does require careful coordination with UL Standard 1703.[4] The 1999 NEC requirements will be valid only after the UL Standard 1703 is modified to remove the solar enhancement and voltage temperature requirements from the module instruction manuals. In the meantime, there may be modules in the manufacturer to user supply line that still have the UL requirement in the instruction manual. Those using the 1999 NEC are now cautioned not to duplicate the solar enhancement requirement. The new language for Article 690-8 is reproduced below for the reader's convenience.[3]

690-8. Circuit Sizing and Current.

(a) Computation of Maximum Circuit Current. *The maximum current for the specific circuit shall be computed as follows:*

(1) ***Photovoltaic Source Circuit Currents.*** *The maximum current shall be the sum of parallel module short-circuit currents multiplied by 125 percent.*

(2) ***Photovoltaic Output Circuit Currents.*** *The maximum current shall be the sum of parallel source circuit short-circuit currents as calculated in (1).*

(3) ***Inverter Output Circuit Currents.*** *The maximum current shall be the inverter output current rating.*

(4) ***Stand-Alone Inverter Input Circuit Current.*** *The maximum current shall be the stand-alone continuous inverter input current rating when the inverter is producing rated power at the lowest input voltage.*

(b) Ampacity and Overcurrent Device Ratings. *Photovoltaic system currents shall be considered continuous. The circuit conductors and overcurrent devices shall be sized at not less than 125 percent of the maximum currents as computed in (a). The rating or setting of overcurrent devices shall be permitted in accordance with Sections 240-3(b) and (c).*

Exception: Circuits containing an assembly together with its overcurrent device(s) that is listed for continuous operation at 100 percent of its rating shall be permitted to be utilized at 100 percent of its rating.

(c) Systems with Multiple Direct-Current Voltages. *For a photovoltaic power source that has multiple output circuit voltages and employs a common-return conductor, the ampacity of the common-return conductor shall not be less than the sum of the ampere ratings of the overcurrent devices of the individual output circuits.*

Interconnection Requirements

Two related new sections address connecting inverters to service entrance panels in the 1999 NEC. They were written to clarify the requirements for supplying power in Article 690-10 *(Stand-Alone Systems)* to service entrance hardware at lower than service-panel-rated currents and for sizing conductors. Changes using "maximum system voltage" terminology were also included to provide code language consistency.

Changes were included to provide the necessary language in Section 690-64(b) *(Point of Connection)* 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 a practical means of connecting 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 PV installations. The installer is cautioned to observe maximum current ratings on service panels.

The following is an example for load side connection of a PV-powered electric vehicle charging station on a commercial building that has a main circuit breaker rated at 300 amps at the ac load center. Five 60-amp load circuits and breakers are connected to the load center to supply power to five battery chargers. The owner wants to add a sixth battery charger and a 60-amp PV system to supply the power.

It would seem logical that a 60-amp circuit breaker could be added for the new charger and another to allow the output from a PV utility-interactive inverter to supply PV power to the main panel, hence the new charging station. This new connection however, could cause 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. No circuit breakers would trip, but sections of the internal 300-amp bus bars in the load center could be overloaded by 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, except for dwelling units where 120 percent of the rating is permitted.

The solutions for adding PV to this system are related to reducing the total ratings of the input breakers to be equal to or less than the load center rating.

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.

A residential load center rated at 100 amps with a 100-amp main may accept a 20-amp feeder from a PV system (2400 watts of PV at 120 volts or 4800 watts at 240 volts) according the NEC. A load center rated at 200 amps with a 200-amp main may accept a 40-amp feeder from a PV system (4800 watts of PV at 120 volts or 9600 watts at 240 volts). These power levels are sufficient and consistent with the maximum expected sizes of residential PV systems.

Inverters and Multi-Wire Branch Circuits

A change to permit a single-phase, 120-volt inverter to supply power to a split-phase 120/240-volt service entrance panel (provided there are no multi-wire branch circuits) was made in Article 690-10 *(Stand-Alone Systems)* to clarify PV system connections to service entrance panels. It is estimated that there are more than 50,000 such inverter installations already, but no allowance for them was given in the existing code.

The example below is used to illustrate why the multi-wire branch circuit cannot be used with the 120-volt stand-alone inverter. These multi-wire branch circuits are connected so that the 120/240-volt load center supplies a three-wire-with-ground cable from two circuit breakers connected to each (opposite) side of the 120/240-volt service. A common neutral is run with the ungrounded conductors to a remote location in the dwelling. The three-wire 120/240-volt cable is then split into two separate 120-volt branch circuits, and the common neutral conductor is spliced to two separate neutral conductors. The common neutral conductor (between the load center and the point where the circuit splits) carries the difference in currents from the two 120-volt branch-circuits when connected to a 120/240-volt split-phase circuit because the currents are 180 degrees out of phase.

In a stand-alone PV system, a single, 120-volt inverter may be connected to the dwelling load center by connecting one terminal of the output of the inverter to both ungrounded conductors of the main load center. The second terminal of the inverter output is connected to the neutral of the load center. The currents in the two 120/240-volt conductors (which are out of phase when connected to a utility) are in phase when connected to a single inverter, and currents in the common neutral in the multi-wire branch circuit that subtracted (difference) are now in phase and add. When both of the 120-volt branch circuits are fully loaded, the neutral conductor in the multi-wire branch circuit now carries twice its rated current and is not protected by an overcurrent device.

Suggested solutions for connecting the 120-volt inverters to service entrance panels include:

1. Removing the multi-wire branch circuits by rewiring into separate 120-volt branch circuits
2. Connecting both hot conductors of the multi-wire branch circuit to a single circuit breaker
3. Adding a second inverter to provide 120/240-volt power that is phased like the split-phase utility.

Solutions 1 and 2 involve reconfiguration of the electrical system and should be made only if other code requirements, such as exceeding the maximum allowable number of receptacles on a branch circuit, are not violated. Additionally, the output current of a single inverter must be limited by a single overcurrent device rated no higher than the rating of the load center to prevent possible overloading of the neutral bus in the load center.

New Part I Added for Systems Greater than 600 V

One new part was written for Article 690 to provide requirements for PV systems operating at greater than 600Vdc. It was designated Part I *(Systems Over 600 Volts)* and was added to Article 690 to specifically address PV systems operating over 600 volts. Some of the larger utility-interactive systems may operate above 600 volts. The new section directs that systems greater than 600 volts meet the requirements of the new Article 490 *(Equipment, Over 600 Volts, Nominal)* that has been added to collect all parts of the code for over 600 volts into one article. The new Part I includes sections that define the maximum battery voltage as the highest voltage experienced under charging conditions. Maximum system voltage is used for the PV source- and output-circuits.

IEEE STANDARDS, RECOMMENDED PRACTICES AND GUIDELINES

Since the NEC provides installation requirements primarily for PV systems, it is worth noting that other standards should be used to assess system or component performance, other safety requirements, and device characteristics. The IEEE has published eight standards and guidelines related to PV system components out of Standards Coordinating Committee 21 (SCC21) on Photovoltaics. IEEE Standard 1262, "Recommended Practice for Qualification of Photovoltaic Modules," was published in 1997.[10] Other important SCC21 documents include guidelines for terrestrial PV system criteria, recommended practices for installation of batteries for PV systems, and recommended practices for sizing of batteries for PV systems.

PV System Safety Guideline

The NEC spells out the installation requirements for the installation of all electrical systems, but the language in 644 pages of the NEC is often unfamiliar to engineers or designers involved with PV systems. A new guideline, the IEEE Standard 1374, "Guide for Terrestrial Photovoltaic Power Systems Safety," was published in October 1998.[11] It was written to provide an easy-to-read safety document targeted specifically for PV systems and closely correlated with the NEC and other ANSI/IEEE recommended practices and standards.

The guideline addresses PV-specific topics or components related to the design and installation of PV power systems that affect safety. The guideline also suggests good engineering safety practices for PV electrical balance-of-system design, equipment selection and hardware installations. Many PV-unique electrical power requirements are emphasized in the guide. The guide describes easily overlooked wiring and overcurrent protection requirements for PV modules, balance-of-system, and batteries and provides examples for avoiding pitfalls. Particular attention is given to the critical temperature requirements for PV systems at the module and array level. The voltage ratings for cable and insulation types, wiring ampacity, and sizing calculations needed for safe and reliable design are also explained. Other important topics, such as overcurrent protection, required disconnects, grounding, ground-fault protection, surges, transient protection, and instrumentation are also described. Informational examples and recommendations for the selection of the hardware are given in the appendices. The guide is carefully cross-referenced to the applicable articles and sections in the 1996 NEC.[1] This guideline will also be revised once the 1999 NEC is adopted.

Utility Interconnect and Interface Guidelines

In addition to the NEC, a critical standard for defining utility interface and interconnects, now designated Project Authorization Request (PAR929, "Recommended Practice for Utility

Interface of Photovoltaic (PV) Systems,") is currently being written to replace an outdated IEEE929.[8] The targeted publication date is 1999. This document is currently being revised by utility and PV industry experts to integrate both the utility and PV system issues into a document that can be used by utilities, designers, and installers for utility acceptance of installations of utility-interactive PV systems.

Important issues that are the focus of the PAR929 revision include defining requirements for inverter shutdown under abnormal utility conditions, anti-islanding protection, reconnect times after a utility disturbance, the need for manual disconnects, power quality requirements, and direct current isolation.[8,12,15]

LISTING STANDARDS

Listing standards for PV components and systems go hand-in-hand with the requirements of the 1999 NEC. Underwriters Laboratories, Inc. is currently in the process of finalizing the first edition of the "Standard for Inverters, Charge Controllers and ac Modules for Use in Residential Photovoltaic Power Systems, UL1741."[7] UL has already conducted an Industry Advisory Group (IAG) meeting to review the latest version of their Subject 1741, which is the draft standard intended for listing inverters and charge controllers and ac PV 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 U.S.

Department of Energy Photovoltaic Program. The UL goal for publishing the completed standard is projected for 1999. This timing also allows UL to incorporate requirements spelled out in the revised IEEE929 into the UL1741 standard. The draft UL1741 now includes new language for testing and listing of ac PV modules, charge controllers, and inverters that meet the revised IEEE929 requirements.[8] The publication dates were established to coincide with adoption of the 1999 NEC in order that code changes might also be reflected in the UL standard. UL has also begun a 1999 code compatibility review of their UL1703 "Standard for Flat-Plate Photovoltaic Modules and Panels."[4]

IEA PV POWER SYSTEMS COLLABORATION

The IEA Photovoltaic Power Systems (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 PV power systems. The mission of the program is to enhance international collaboration efforts through which PV becomes a more significant energy option in the near future. Task V of the IEA PVPS has an overall objective of developing and verifying 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: PV system and utility system review, definition of guidelines, and collaborative testing to address 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.[13] A report on interconnection equipment is also available for distribution to industry.[14] Nine technical topics are under investigation in Task V for addressing utility-interconnect 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 National Laboratories and the IEA in 1999.

Another important milestone for Task V work was an international workshop held in Zurich, Switzerland on September 15 and 16, 1997.[15] The workshop was designed to involve utilities, inverter manufacturers, photovoltaic system suppliers, and engineers in international discussions on interconnect guidelines. Topics included islanding, reclosing, external-disconnect requirements, overvoltage protection, grounding, and dc injection.

CONCLUSIONS

Publication of the 1999 NEC, with a strong and well-developed Article 690 on PV power systems, represents a safety code that enables 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. Coordinated 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. Convergence of the publication of 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.

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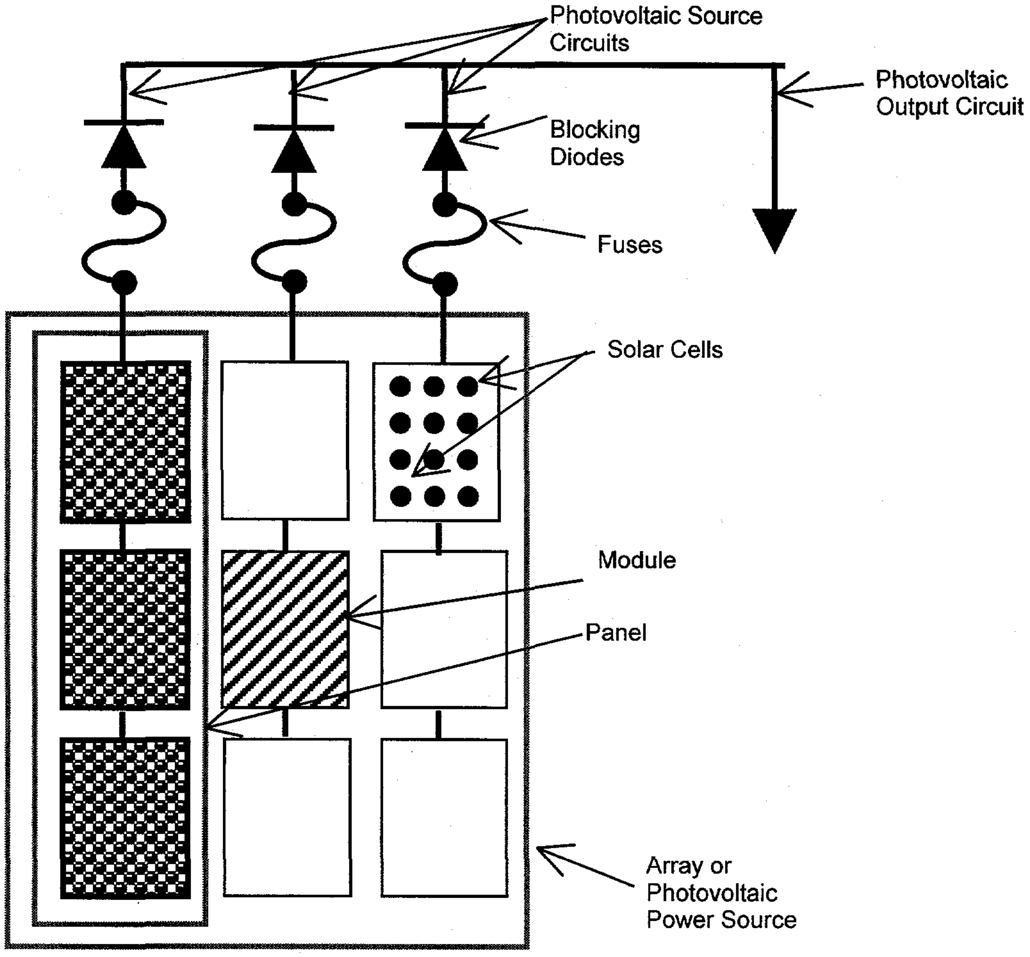
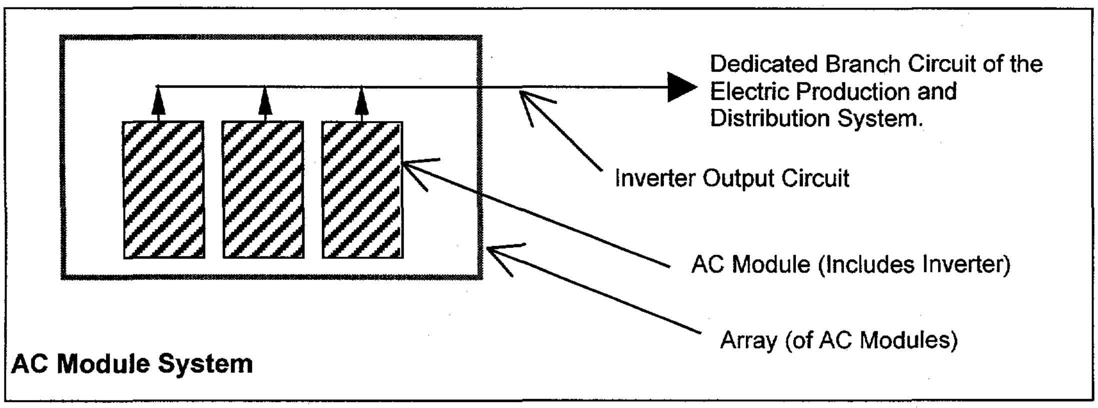
Figure 1. Figure 690-1a, Identification of Solar Photovoltaic System Components as it appears in the 1999 NEC.[3]



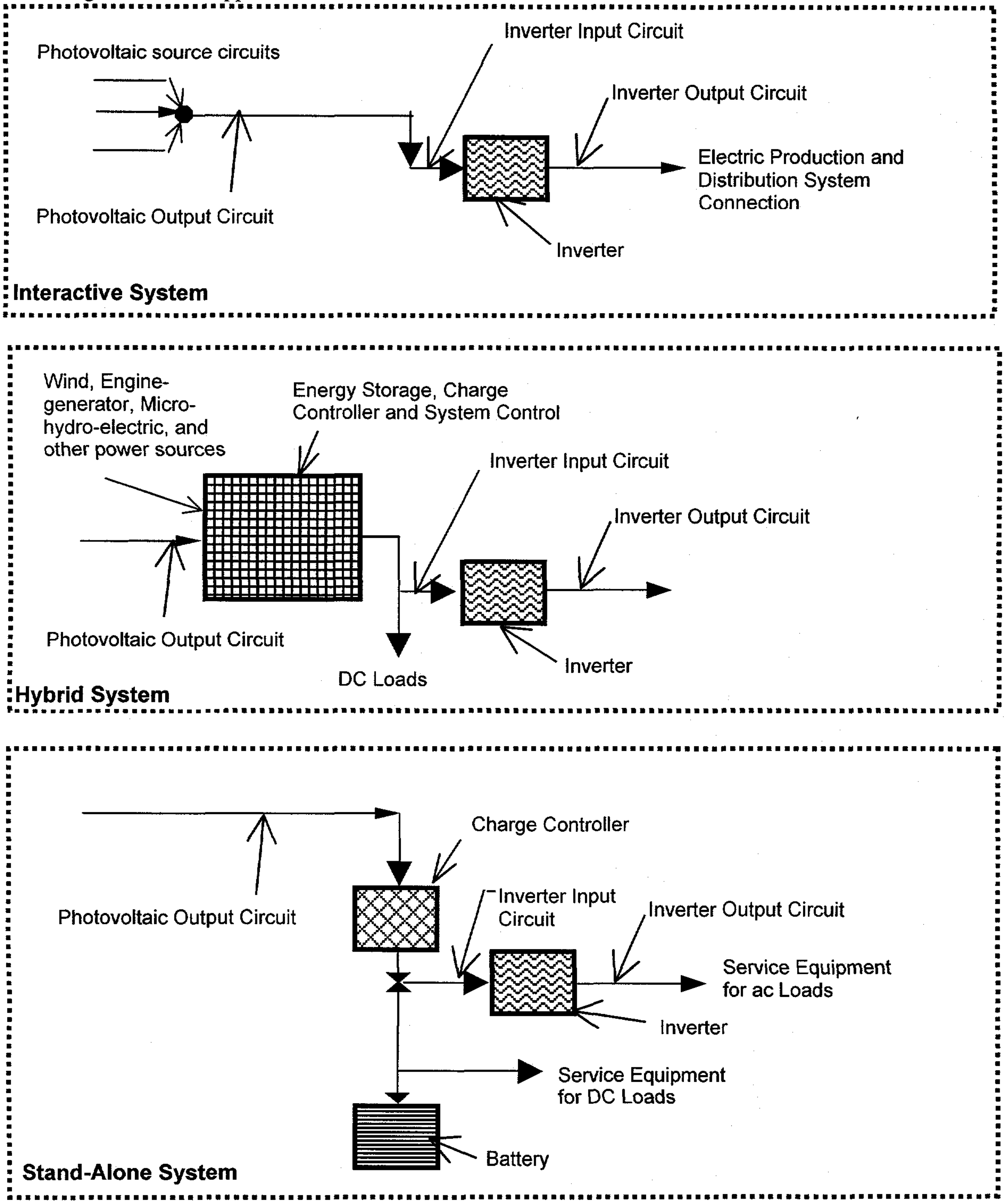


Note 1. These diagrams are intended to be a means of identification for photovoltaic system components, circuits and connections.

Note 2. Disconnecting means required by 690-Part C are not shown.

Note 3. System Grounding and Equipment Grounding are not shown. See 690-Part E.

Figure 2. Figure 690-1b, Identification of Solar Photovoltaic System Components in Common System Configurations as it appears in the NEC.[3]



Note 1. These diagrams are intended to be a means of identification for photovoltaic system components, circuits and connections.

Note 2. Disconnecting means required by 690-Part C are not shown.

Note 3. System Grounding and Equipment Grounding are not shown. See 690-Part E.

Note 4. Custom designs occur in each configuration and some components are optional.

Figure 3. An Installation of a Sunsine 300™ AC PV Module showing the fully integrated inverter mounted to the back surface of the PV module. The integrated connect cables run along the sides of the module.

Table 1. List of definition changes and additions for Article 690 of the 1999 NEC

Definition	Type of Change	Impact, Consequence or Description
AC Module (AC PV Module:	New definition.	Defines AC modules as a complete listed package for Section 690-6 (AC Modules). Allows for code compliant AC module applications.
Array	Minor change to clarify and correct.	Removed the old reference to thermal controllers.
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. This was needed to better differentiate hybrid systems.
Hybrid System:	New definition.	Defined hybrid systems and energy sources in hybrid systems. Defined battery as an energy storage device and not a source of energy for Article 690
Interactive System	Change definition.	Defined an interactive system as tied to the utility grid.
Inverter	Change definition.	Better defined charging functions associated with some inverters. Retained the reference to "power conditioner" but made code language consistent with common usage.
Inverter Input Circuit	Minor change to clarify application definitions.	Defined inverter input circuit for both stand-alone and interactive inverters.
Inverter Output Circuit	Minor change to clarify with new Figure 1.	Clarified definition to be consistent with new Figure 1.
Module	Minor change to clarify new definition.	Clarified definition of a conventional PV modules and differentiated the AC modules.
Photovoltaic Output Circuit	Minor language change.	Changed to make the code language consistent.
Photovoltaic Source Circuit	Minor language change.	Changed to make the code language consistent.
Stand-alone System	Change to clarify.	Clarified and removed the cross-reference to other utility interactive systems.
System Voltage	New definition.	Added to provide consistency throughout Article 690.

Table 2. Table appearing in Article 690-7 of the 1999 NEC--Voltage Correction Factors 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**	**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