PHOTOVOLTAIC INDUSTRY-PROPOSED CHANGES FOR THE 1999 NATIONAL ELECTRICAL CODE FOR PV APPLICATIONS*

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ABSTRACT

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 in photovoltaic (PV) device and system technology [1]. This paper summarizes the proposed code changes, discusses background on both new and changed code text, and presents examples and analysis of three proposed changes. Topics such as the proposed new temperature compensation table for calculating maximum system voltage are analyzed. Requirements for calculating PV array currents used to size conductors using the proposed changes are presented. Impacts on PV installations, building integrated systems, and AC module installations are reviewed and coordination with other standards writing is discussed.

INTRODUCTION

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 with the issuance of the 1996 NEC [2]. Collaborative work was completed by the 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 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 also supported by the 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.

Seven meetings served to unify the PV industry participants on code issues. The meetings were held as joint events between the NEC Article 690 Task Group and the SEIA, Standards and Codes Technical Review Committee. Discussions, information exchange, and industry consensus also served to greatly clarify the needs and justifications for the proposed code changes. A number of the changes were needed because of recent advances in technology. Several new products and applications have been emerging. They include AC PV modules, modular inverters with multiple modes of operation (utility-interactive, stand-alone, and hybrid), triple junction PV modules, building-integrated PV such as roofing shingles, PV laminated roofing, window walls, and facades. Many changes were also written to provide clarifications of the current language or to change requirements currently included in the NEC.

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. Changes were proposed for fire and personnel safety, system servicing, AC PV modules, integration of PV into building electrical systems, point-of-connection for building-integrated systems, clarifications for hybrid systems, batteries, and charge controllers. 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.

OVERVIEW OF PROPOSED CHANGES

The limited scope of this paper prevents an overview of all changes proposed, however, many of the significant topics are discussed. A complete set of 1999 NEC proposals and code making panel actions are published for public comment in the NFPA Report on Proposals [3].

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. See Table 1 for the affected definitions.

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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).
Array:	Minor Change to clarify and correct.	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 Definition.	Defined an interactive system as tied to the utility grid.
Inverter:	Change Definition.	Better defined charging functions associated with some inverters.
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 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.
Stand-alone System:	Change to Clarify.	Clarified and removed tie to utility interactive systems.
System Voltage:	New Definition.	Added to provide consistency throughout Article 690.

Table 1. List of proposed definition changes for 1999 Article 690, NEC

New Part I Added for PV Systems Greater than 600 V

One new part was written for Article 690 to provide requirements for PV systems operating at greater than 600 Vdc. It was designated Part I and was written at the request of the Code Making Panel #3 Chairperson. It was requested to better organize changes that were made for the 1996 NEC. The addition of Part I, dealing with PV systems with dc voltages greater than 600 volts, and clarification that installations in single- and two-family dwellings be limited to 600 volts, gives valuable safety requirements for PV installations. The addition also clarifies the intent of system voltage calculations and requirements, and makes it perfectly clear that systems with maximum system voltages over 600 volts must use a different set of requirements consistent with Article 710 of the NEC.

New Sections for Article 690

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 included 690-10: Stand-alone Inverter, 690-11: Sizing and Protection, 690-52: AC Photovoltaic Modules, 690-54: Interactive System Point-of-Connection, 690-60: Identified Interactive Equipment, and 690-72: Charge Control. Some of the new sections consisted of language modified and/or moved from other parts of Article 690. Other changes were added for clarification or to address new applications, other new language and/or definitions.

PV-Unique Features Highlighted with Revised Figure and Removal of Cross References

Revisions of the existing Figure 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 proposed new figure specifies that it is for component identification only and is purposely designed to identify PV-unique components, connections and system options.

Deletion of a requirement (690-3) to install PV systems in accordance with the provisions of Article 705 "Interconnected Electric Power Production Sources" clarifies PV system installation requirements. PV systems and equipment often have characteristics that are distinctly different from other interactive 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.

Ground Fault Protection

A revised Section 690-5 provides much needed clarification for ground-fault protection of residential roof-mounted PV installations for fire protection. The revisions provide rules for the detection, interruption and indication of ground faults. Indication is a very important addition 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 direction. The 1996 NEC Handbook tried to address the issue, but used the term "disable the array" that was a topic of more confusion, since the only way to truly disable an array is to block the sunlight [4]. The revisions give requirements for disconnecting the faulted the PV source, interrupting the fault current, and indicating the status or condition of the system.

AC PV Modules

A very significant proposal for building integrated PV was the addition of Section 690-6 to provide the hardware, circuit and labeling requirements for installation of the evolving AC 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 by the time 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 provides the necessary functional requirements for safe installation and connection of listed AC modules to the utility lines and provides the requirements for labeling AC PV modules. The proposed section 690-6-AC Modules is reproduced below [3].

(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) above 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 provided with an accessible disconnect.

System Voltage Temperature Compensation

Section 690-7 begins with new language for determining maximum system voltage and other circuit requirements. Proposed 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 are carefully selected to match PV modules that are commercially available. Section 690-7(a) also gives instructions to refer to manufacturer specifications when other than crystalline PV technologies are installed. The proposed table is reproduced below as Table 2 [3].

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

Table 2. Proposed Table 690-7 Voltage Correction Factors for Crystalline & Multi-crystalline Silicon Modules.

A comparison of the 1996 and the proposed 1999 NEC is provided here to illustrate the positive impact of the new proposed Table 690-7. This example shows how the proposed change will allow for continued safe installation of PV systems in all climatic regions of the country, while making allowances for regional climatic differences that were previously ignored and which unnecessarily restricted the PV systems designer and installer. The example is for a PV installation in Phoenix, AZ where the coldest temperature is -9°C (16°F). The example system uses crystalline silicon PV modules that are listed to UL Standard 1703 [5]. The design requires strings of 24 series-connected modules, each with a rated open-circuit voltage of 22 V, to optimize performance and utilization of the inverter. The system designer or integrator must multiply 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 current UL-1703 listing criteria. 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. Engineer using only UL label information on the PV module to design the example system have discovered that the inverter operating window no longer matched the PV array output with expensive modifications sometimes required.

Using the proposed Section 690-7 and proposed 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 proposed Table 690-7 that corresponds to a minimum temperature range of -1 to -10°C (31 to 14°F). With the proposed 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 Irradiation and Conductor Deratings

Solar irradiation of 1250 W/m^2 is common in many parts of the country. The integration of the PV module current factor of 125%, that is currently written as a UL requirement, and the NEC required 80% derating factor for continuous current for all conductors and overcurrent devices has been needed. Many opened fuses and loose connections in early PV systems can be attributed overheating due to undersized wiring or improper temperature ratings for terminal blocks and fuses. There has been much confusion in applying these factors because they appear in different documents, but the proposed change (690-8) for 1999 puts all requirements in the NEC and simplifies the calculation. Coordination with UL will remove the 125% requirement from the UL-1703 Standard used for listing PV modules [5]. The new proposed language is reproduced below [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 Circuits.*** *The maximum current shall be the sum of parallel module rated short-circuit currents multiplied by 125 percent.*
(2) ***Photovoltaic Output Circuit.*** *The maximum current shall be the sum of parallel source circuit rated short-circuit currents as calculated in (1).*
(3) ***Inverter Output Circuit.*** *The maximum current shall be the inverter output current rating.*
(4) ***Stand-Alone Inverter Input Circuit.*** *The maximum current shall be the stand-alone inverter input current rating when the inverter is producing rated power at the lowest input voltage.*

(b) Ampacity and Overcurrent Devices. *Additionally, circuit conductors and overcurrent devices in solar photovoltaic systems shall be sized at not less than 125% of the maximum currents as computed in (a) above. 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% of its rating.

(c) Systems with Multiple DC Voltages. *For a photovoltaic power source having multiple output circuit voltages and employing 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 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 PV 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 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 a PV utility-interactive inverter to supply PV power to main panel, hence the charging stations. This new connection could allow the bus bars in the load center to be over loaded. 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 over loaded 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.

Solutions for adding 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.

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 feeder from a PV system (2400 watts of PV at 120 volts or 4800 watts at 240 volts). A load center rated at 200 amps 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 consistent with the maximum expected sizes of residential PV systems.

Inverters and Multi-wire Branch Circuits

The Code Making Panel rejected onee task group proposal to permit a single-phase, 120V inverter to supply power to a single-phase 120/240V service entrance panel provided there are no multi-wire branch circuits. There are estimated to be more than 50,000 such inverter 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 NFPA to insure concerns are addressed in the 1999 NEC.

For example, many newer houses are wired with multi-wire branch circuits to reduce the cost of wiring. These multi-wire branch circuits are connected so that the 120/240V load center supplies a three-wire with ground cable from two circuit breakers connected to each (opposite) side of the 120/240V service. A common neutral is run with the ungrounded conductors to a remote location in the dwelling. The three-wire 120/240V cable is then split into two separate 120V 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 branches) carries the difference in currents from the two 120V branch-circuits when connected to 120/240V because the currents are 180° out of phase.

In a stand-alone PV system, a single, 120V inverter may be connected to the dwelling load center by connecting the output of the inverter to the two ungrounded conductors leading to the main load center disconnects. The two 120/240 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 120V 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 120V inverters to service entrance panels include either:
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 utility.

All solutions 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 buss in the load center.

LISTING AND CERTIFICATION STANDARDS

It was proposed 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. UL conducted an Industry Advisory Group (IAG) meeting in January 1997 to review the latest version of their Subject 1741 [6]. 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.

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 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 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 1997 [8]. This document is being revised by a team of utility and PV industry experts in order to integrate the utility and PV system perspectives into a document that can be used by utilities, and designers and installers for utility-interactive PV systems.

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.

SUMMARY

Publication of the 1999 National Electrical Code, with a strong and well-developed Article 690 on PV power systems, will represent a safety code that will enable future PV systems to be installed using well-understood requirements. An enhanced common understanding among the manufacturers, designers, installers and electrical inspectors has resulted from this work. Good installation practices required by the NEC will improve long-term system performance and reliability. The improved system reliability will also be a natural development that results from complying with the NEC and the construction, component and material requirements needed to pass listing tests. The future installations will be easier to design and inspect, and above all, will provide safety for all concerned.

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