

BUILDING & INSPECTING CODE-COMPLIANT PV SYSTEMS

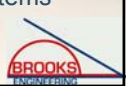
Presented by
Bill Brooks, PE
Brooks Engineering



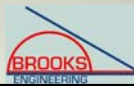
Overview of Presentation

PV System Basics

- Introduction to relevant Codes and Standards
- Summary of PV Electrical Installation Issues
 - DC wiring considerations
 - NEC Article 690 overview
 - Wiring methods
 - System grounding
- Summary of Changes in the 2005 National Electrical Code
- Permit and Field Inspector Guidelines for PV Systems

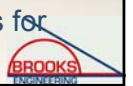


PV Codes and Standards 101



What are the applicable codes and standards for PV systems?

- Electrical codes - NEC Article 690 - Solar Photovoltaic Systems
- Building codes – ICC, UBC
- UL Standard 1703, Flat-plate Photovoltaic Modules and Panels
- IEEE 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems (approved in January 2000)—Now replaced with IEEE 1547 covering all distributed generators.
- UL Standard 1741, Standard for Static Inverters, Converters, and Controllers for Use in Independent Power Systems



IEEE 929-2000

- Represents an excellent primer on PV inverter interconnection issues.
- One area of concern is when building officials have required utility approval before issuing a permit.
- IEEE 1547 is a generic interconnection standard for all distributed generators and is nearly identical to IEEE 929 in its testing requirements for consistency.

P929
Recommended Practice for Utility Interface of Photovoltaic (PV) Systems

Prepared by the Utility Working Group of Standards Coordinating Committee 21, on Photovoltaics

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UL 1741 Standard for inverters, converters, and controllers for use in Independent Power Systems

- First released in May of 1999
- Matched requirements of IEEE 929-2000
- Revised to match the new requirements in IEEE 1547 (new IEEE standard that covers all distributed generation interconnections)

UL Underwriters Laboratories Inc.

333 Pilkington Road
Northbrook, IL 60062
March 3, 1999

Subject: 1741

TO: Industry Advisory Group of Underwriters Laboratories Inc. for Power Conditioning Units for Use in Residential Photovoltaic Power Systems, Electrical Council of Underwriters Laboratories Inc. Subscribers to UL's Listing Services for Photovoltaic Charge Controllers (GSP), Subscribers to UL's Listing Services for Photovoltaic Power Systems Accessories (GPO), Subscribers to UL's Listing Services for Power Conditioning Units for Use in Residential Photovoltaic Power Systems (GRH), and Subscribers to UL's Listing Services for AC Modules (GRY2)

SUBJECT: Request for Comments on the Proposed First Edition of the Standard for Static Inverters and Charge Controllers, UL 1741, PROPOSED EFFECTIVE DATE

Attached as Appendix A for your review and comment are proposed requirements for UL 1741. Questions regarding interpretation of requirements should be directed to the responsible UL Staff. Please see Appendix B of this bulletin regarding designated responsibility for the subject product categories.

Please note that proposed requirements are of a tentative and early nature and are for review and comment only. Current requirements are to be used to judge a product until these requirements are published in final form. **PROPOSED EFFECTIVE DATE**

The proposed requirements will necessitate a review and possible retest of currently listed products. Therefore, UL proposes that the new requirements become effective 18 months after publication. This is intended to provide manufacturers with sufficient time to adjust modified products for investigation and to implement the necessary changes in production. Please note that this also includes the time that will be needed by UL to conduct a review of the modified product.

RATIONALE

The first edition of the Standard for Static Inverters and Charge Controllers for Use in Residential Power Systems, UL 1741, was proposed in the subject bulletin dated August 1, 1997. The proposed Standard has been significantly revised since then. The revisions are a result of the comments UL received from industry members regarding the proposed draft. In addition, the revisions were made to align the proposed Standard with the North American Recommended Practice for Utility Interface of Photovoltaic (PV) Systems (P929) and IEEE 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems (P929), and IEEE 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems (P929), and IEEE 929-2000, Recommended Practice for Utility Interface of Photovoltaic (PV) Systems (P929).



What is UL 1741 and how does it relate to IEEE 929 and IEEE 1547?

- UL 1741 is the UL test standard that is used for the listing of PV inverters, charge controllers, and other BOS equipment.
- It continues to be updated as all new standards are over the first several years of implementation.
- 1741 incorporates the testing required by IEEE 929 (&1547) (frequency and voltage limits, power quality, non-islanding inverter testing)
- 1741 testing includes design (type) testing and production testing.



Primary Concerns for the Building Official

- Mounting structurally sound
- Roof properly weather proofed
- Electrical equipment correctly specified and installed according to Electrical Code.



Mounting Structurally Sound

- Two main types of loading to consider
 - dead load (typically 3-5 lbs./ft² for standard standoff install and 2-12 lbs./ft² for integrated products)
 - wind load (85mph is typical for California)
- Structure must be capable of supporting dead load and attachment method must be capable of keeping the PV array on the roof (or relevant structure).



Mounting Structurally Sound (cont.)

- Most modern truss roofs are capable of handling the extra 3-5 lbs./ft² dead load provided that the roof is not masonry. Masonry roofs often require a structural analysis or removing the existing product and replace it with composite in the area of PV array.
- Attachment method must be capable of keeping the PV array on the roof (or relevant structure).

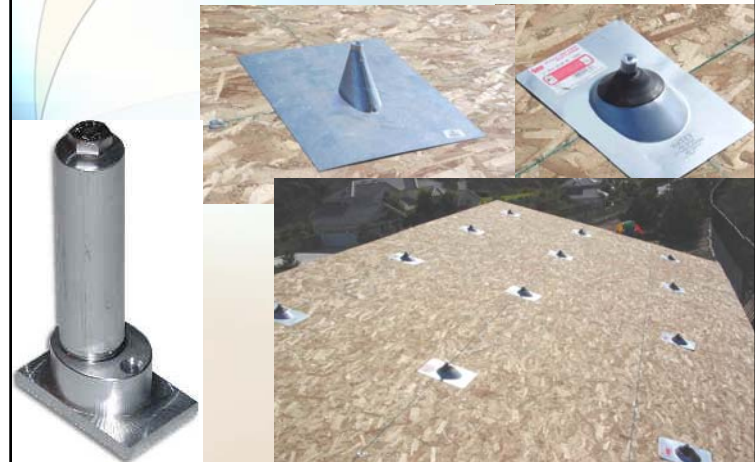


Weather Proofing of Roof

- Attachments must be properly sealed to preclude leakage.
- Urethane caulks such as Sikaflex 1a are both temperature and UV resistant. Silicones and roofing tars are less durable and can leak over time.
- Post and flashing method provides excellent weather proofing



Post and flashing method



Electrical Safety is no joke...



No Picture

funny electricity joke guy plays on friend



NEC Article 690 overview



PV Systems and the NEC

- **Article 690** addresses safety standards for the installation of PV systems.
- Many other articles of the NEC may also apply to most PV installations.



NEC Sections Applicable to PV Systems

- Article 110: Requirements for Electrical Installations
- Chapter 2: Wiring and Protection
 - Most of the chapter--especially
 - Article 250: Grounding
- Chapter 3: Wiring Methods and Materials
 - Most of the chapter—especially
 - Article 300: Wiring Methods
 - Article 310: Conductors for General Wiring
- Article 480: Storage Batteries
- Article 690: Solar Photovoltaic Systems



NEC Article 690: Solar Photovoltaic Systems

- I. General (definitions, installation)
- II. Circuit Requirements (sizing, protection)
- III. Disconnect Means (switches, breakers)
- IV. Wiring methods (connectors)
- V. Grounding (array, equipment)
- VI. Markings (ratings, polarity, identification)
- VII. Connection to Other Sources
- VIII. Storage batteries
- IX. Systems over 600 Volts



NEC Article 690: Solar Photovoltaic Systems

- I. General (definitions, installation)
 - 690.1 Scope—PV Systems (only)
 - 690.2 Definitions—PV Output Circuit, Inverter Input Circuit—1 ½ pages of PV-specific jargon
 - 690.3—"Wherever the requirements of other articles of this Code and Article 690 differ, the requirements of Article 690 shall apply"
 - 690.4—Installation "Equipment: ... shall be identified and listed for the application"
 - 690.5—Ground-Fault Protection—to reduce fire hazards
 - 690.6—AC Module—dc wiring is considered internal



Electrical Equipment Listing

- AHJs generally require listing for components and electrical hardware.
- Some components available for PV systems may not have applicable or any listing.
- Recognized testing laboratories include:
 - UL
 - ETL Semko (Intertek)
 - CSA
 - TÜV



NEC Article 690: Solar Photovoltaic Systems

- II. Circuit Requirements (sizing, protection)
 - 690.7 Maximum Voltage—Table 690.7 and manufacturers data. Max. 600Vdc for residential.
 - 690.8 Circuit Sizing and Current
 - 690.8(A) Max current = rated I_{sc} x 1.25 = I_{max}
 - 690.8(B) Min ampacity and overcurrent = I_{max} x 1.25
 - 690.9 Overcurrent Protection
 - 690.9(A) Generally required on all source circuits—exception: a.) no backfeed; and, b.) total I_{max} less than conductor ampacity.
 - 690.10 Stand-Alone Systems
 - Inverter output need only meet demand.
 - No multi-wire circuits on 120V inverters.



NEC Article 690: Solar Photovoltaic Systems

- III. Disconnect Means (switches, breakers)
 - 690.13—Need to disconnect all conductors connected to building. No disconnect in grounded conductor
 - 690.14—Location—details and options (more to come)
 - 690.17—Switch or Circuit Breaker—Warning sign when line and load energized in open position.



NEC Article 690: Solar Photovoltaic Systems

- IV. Wiring methods
 - 690.31(A) FPN—PV modules get HOT
 - 690.31—single conductors outside conduit allowed in array.
 - Table 690.31—temp. correction must be applied to conductors.
 - 690.33—requirements for connectors.
 - 690.35—Ungrounded PV Power Systems



NEC Article 690: Solar Photovoltaic Systems

- V. Grounding (system, equipment)
 - 690.41 System Grounding
 - Over 50Vdc must be grounded or comply with 690.35
 - 690.42 Point of System Grounding Connection—one point, at GFP device if provided.
 - 690.43 Equipment Grounding—metal likely to become energized must be grounded—listed equipment can be used to bond modules to support structure..
 - 690.45 Size of EGC—Table 250.122 with GFP
 - 690.47 Size of GEC—ac use Table 250.66; dc use Table 250.166



NEC Article 690: Solar Photovoltaic Systems

- VI. Markings (ratings, polarity, identification)
 - 690.53—DC PV Power Source—4 items; rated current, rated voltage, max voltage, max current
 - 690.54—Interactive System Point of Interconnection—rated ac current and voltage
 - 690.56—Sign at service entrance when PV disconnect not located at the service disconnect.



NEC Article 690: Solar Photovoltaic Systems

- VII. Connection to Other Sources
 - 690.60 Listed inverters for grid-connected systems
 - 690.61 inverter deenergize when utility is out (part of listing process)
 - 690.64 Point of Connection
 - 690.64(A) Supply Side—230.82
 - 690.64(B) Load Side—dedicated breaker; 120% of busbar or conductor; 2008 NEC requires sign and breaker location to obtain 120% allowance for all PV systems.
- VIII. Storage Batteries
- IX. Systems over 600 Volts



Summary of Key PV-Related Changes for the 2005 and 2008 National Electrical Code



I. General [2008 NEC] 690.4 (D) Equipment Installation

- “Inverters, motor generators, photovoltaic modules, photovoltaic panels, ac photovoltaic modules, source-circuit combiners, and charge controllers intended for use in photovoltaic power systems shall be identified and listed for the application.”
- Modules listed to UL1703 (soon UL1730); all combiners, controllers, and Inverters listed to UL1741



I. General [2008 NEC] 690.5 Ground-Fault Protection

- “Grounded dc photovoltaic arrays shall be provided with dc ground-fault protection.”
- *Exception No. 1: Ground-mounted or pole-mounted photovoltaic arrays with not more than two paralleled source circuits and with all dc source and dc output circuits isolated from buildings*
- *Exception No. 2: PV arrays installed at other than dwelling units shall be permitted without ground-fault protection where the equipment grounding conductors are sized in accordance with 690.45.*



I. General [2008 NEC]

690.5 Ground-Fault Protection (cont.)

- “Manual operation of the main PV dc disconnect shall not activate the ground-fault protection device or result in grounded conductors becoming ungrounded.”
- GFP must either open all conductors or deenergize the inverter output.



I. General [2008 NEC]

690.5 (C) Labels and Markings

- Inverter and battery (if used) must have a sign
- A warning label shall appear on the utility-interactive inverter or be applied by the installer near the ground-fault indicator at a visible location, stating the following:
- WARNING, ELECTRIC SHOCK HAZARD, IF A GROUND FAULT IS INDICATED, NORMALLY GROUNDED CONDUCTORS, MAY BE UNGROUNDED AND ENERGIZED



II. Circuit Requirements [2008 NEC]

690.7 Maximum Voltage.

- New table and calculation option.
- Table 690.7 is now graduated in 4°C increments.
- “When open-circuit voltage temperature coefficients are supplied in the instructions for listed PV modules, they shall be used to calculate the maximum photovoltaic system voltage as required by 110.3(B) instead of using Table 690.7.”



II. Circuit Requirements [2008 NEC]

690.7 Maximum Voltage.

- Example Calculation
- Shell SQ-175PC has a Voc Temperature Coefficient in their literature of:
- $\alpha_{Voc} = -129 \text{ mV}/^{\circ}\text{C}$; $V_{oc} = 44.6\text{V}$
- Coldest expected Temp = -25°C
- $V_{max} \text{ (per module)} = 44.6\text{V} + [-129 \text{ mV}/^{\circ}\text{C} \times (1\text{V}/1000\text{mV}) \times (25\text{C} - (-25\text{C}))] = 51.05 \text{ Volts.}$
- Table 690.7: $V_{max} = 44.6\text{V} \times 1.20 = 53.52\text{V}$



II. Circuit Requirements [2008 NEC] 690.9(A) Circuits and Equipment

- “Photovoltaic source circuit, photovoltaic output circuit, inverter output circuit, and storage battery circuit conductors and equipment shall be protected in accordance with the requirements of Article 240. Circuits connected to more than one electrical source shall have overcurrent devices located so as to provide overcurrent protection from all sources.
- *Exception: An overcurrent device shall not be required for circuit conductors sized in accordance with 690.8(B) and located where one of the following apply:”*



II. Circuit Requirements [2008 NEC] 690.9(A) Circuits and Equipment

- (a) There are no external sources such as parallel connected source circuits, batteries, or backfeed from inverters.
- (b) The short-circuit currents from all sources do not exceed the ampacity of the conductors.
- FPN: Possible backfeed of current from any source of supply, including a supply through an inverter into the photovoltaic output circuit and photovoltaic source circuits, is a consideration in determining whether adequate overcurrent protection from all sources is provided for conductors and modules.



II. Circuit Requirements [2008 NEC] 690.10 (A) Inverter Output —for Stand-Alone Systems.

- “The ac output from a stand-alone inverter(s) shall be permitted to supply ac power to the building or structure disconnecting means at current levels less than the calculated load connected to that disconnect. The inverter output rating or the rating of an alternate energy source shall be equal to or greater than the load posed by the largest single utilization equipment connected to the system. Calculated general lighting loads shall not be considered as a single load.”



III. Disconnecting Means [2008 NEC] Article 690.13 (All Conductors)

- Clarification on switches in grounded conductor only as part of Ground Fault Protection (690.5).
- “A switch or circuit breaker that is part of a ground-fault detection system required by 690.5 shall be permitted to open the grounded conductor when that switch or circuit breaker is automatically opened as a normal function of the device in responding to ground faults. The switch or circuit breaker shall indicate the presence of a ground fault.”



III. Disconnecting Means [2005 NEC] Article 690.14 (Additional Provisions)

- Clarification on location of PV Disconnecting Means and Location of Inverters in Not-Readily-Accessible Locations
- (1) Location—New Exception: *Installations that comply with 690.31(E) shall be permitted to have the disconnecting means located remote from the point of entry of the system conductors.*
- 690.31 (E) addresses placing PV Output Circuits in a metallic raceways.



III. Disconnecting Means [2005 NEC] Article 690.14 (Additional Provisions)

- Clarification on location of PV Disconnecting Means and Location of Inverters in Not-Readily-Accessible Locations
- New Section (D) Utility-Interactive Inverters Mounted in Not-Readily Accessible Locations. Utility-interactive inverters shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible. These installations shall comply with (1) through (4):
 - (1) A direct-current photovoltaic disconnecting means shall be mounted within sight of or in the inverter.
 - (2) An alternating-current disconnecting means shall be mounted within sight of or in the inverter.
 - (3) The alternating-current output conductors from the inverter and an additional alternating-current disconnecting means for the inverter shall comply with 690.14(C)(1).
 - (4) A plaque shall be installed in accordance with 705.10.



Article 690.31 [2005 NEC] Wiring Methods Permitted

- New 690.31(E) related to PV Output Circuits in metallic raceways.
- **“(E) Direct-Current Photovoltaic Source and Output Circuits Inside a Building.** Where direct current photovoltaic source or output circuits of a utility-interactive inverter from a building-integrated or other photovoltaic system are run inside a building or structure, they shall be contained in metallic raceways or **metal** enclosures from the point of penetration of the surface of the building or structure to the first readily accessible disconnecting means. The disconnecting means shall comply with 690.14(A) through 690.14(D).”



Article 690.31 [2008 NEC] Wiring Methods Permitted

- New language in 690.31(A) “Where photovoltaic source and output circuits operating at maximum system voltages greater than 30 volts are installed in readily accessible locations, circuit conductors shall be installed in a raceway.”



Article 690.31 [2008 NEC] Wiring Methods Permitted

- New language in 690.31(B)
- “(B) **Single-Conductor Cable.** Single-conductor cable type USE-2, and single-conductor cable listed and labeled as photovoltaic (PV) wire shall be permitted in exposed outdoor locations in photovoltaic source circuits for photovoltaic module interconnections within the photovoltaic array. *Exception: Raceways shall be used when required by 690.31(A).*”



Article 690.31 [2005 NEC] Wiring Methods Permitted

- New Fine Print Note in 690.31(A)
 - “FPN: Photovoltaic modules operate at elevated temperatures when exposed to high ambient temperatures and to bright sunlight. These temperatures may routinely exceed 70°C (158°F) in many locations. Module interconnection conductors are available with insulation rated for wet locations and a temperature rating of 90°C (194°F) or greater.”



Side Note on Temperature 310.10 FPN No. 2 [2005 NEC]

- New Fine Print Note (below)
 - “FPN No. 2: Conductors installed in conduit exposed to direct sunlight in close proximity to rooftops have been shown, under certain conditions, to experience a temperature rise of 17°C (30°F) above ambient temperature on which the ampacity is based.”



Side Note on Temperature 310.15(B)(2)[2008 NEC]

- “(c) *Conduits Exposed to Sunlight on Rooftops.* Where conductors or cables are installed in conduits exposed to direct sunlight on or above rooftops, the adjustments shown in Table 310.15(B)(2)(c) shall be added to the outdoor temperature to determine the applicable ambient temperature for application of the correction factors in Table 310.16 and Table 310.18.
FPN: One source for the average ambient temperatures in various locations is the ASHRAE handbook – *Fundamentals.*”



Side Note on Temperature 310.15(B)(2)[2008 NEC]

- **Table 310.15(B)(2)(c) Ambient Temperature Adjustment for Conduits Exposed to Sunlight On or Above Rooftops Temperature Adder**

Distance Above Roof to Bottom of Conduit	°C	°F
0 - 13 mm (1/2 in.)	33	60
Above 13 mm (1/2 in.) - 90 mm (3 1/2 in.)	22	40
Above 90 mm (3 1/2 in.) - 300 mm (12 in.)	17	30
Above 300 mm (12 in.) - 900 mm (36 in.)	14	25



Article 690.31 [2008 NEC] Wiring Methods Permitted

- New language in 690.31(F)
- **“(F) Flexible, Fine-Stranded Cables.** Flexible, finestranded cables shall be terminated only with terminals, lugs, devices, or connectors that are identified and listed for such use.”



Article 690.33 [2008 NEC] Connectors

- New language in 690.33(C)
- **“(C) Type.** The connectors shall be of the latching or locking type. Connectors that are readily accessible and that are used in circuits operating at over 30 volts, nominal, maximum system voltage for dc circuits, or 30 volts for ac circuits, shall require a tool for opening.”



Article 690.33 [2008 NEC] Connectors

- New language in 690.33(F)
- **“(E) Interruption of Circuit.** Connectors shall be either (1) or (2):
- (1) Be rated for interrupting current without hazard to the operator.
- (2) Be a type that requires the use of a tool to open and marked “Do Not Disconnect Under Load” or “Not for Current Interrupting.” ”



Article 690.35 Ungrounded Photovoltaic Power Systems

- Ungrounded systems have not been prohibited, but the 2005 NEC was the first code cycle where the requirements are specifically called out.
- Included is an exception in 690.41 for consistency.



Article 690.35 Ungrounded Photovoltaic Power Systems [2005, 2008]

- “Photovoltaic power systems shall be permitted to operate with ungrounded photovoltaic source and output circuits where the system complies with 690.35(A) through 690.35(G).
 - (A) **Disconnects.** All photovoltaic source and output circuit conductors shall have disconnects complying with 690, Part III.
 - (B) **Overcurrent Protection.** All photovoltaic source and output circuit conductors shall have overcurrent protection complying with 690.9.
 - (C) **Ground-Fault Protection.** All photovoltaic source and output circuits shall be provided with a ground-fault protection device or system that complies with (1) through (3):
 - (1) Detects a ground fault.
 - (2) Indicates that a ground fault has occurred
 - (3) Automatically disconnects **all conductors** or **causes the inverter or charge controller connected to the faulted circuit to automatically cease supplying power to output circuits.**



Article 690.35 Ungrounded Photovoltaic Power Systems (cont.)

- (D) The photovoltaic source and output conductors shall consist of the following:
 - (1) **Nonmetallic jacketed multiconductor cables**
 - (2) **Conductors installed in raceways, or**
 - (3) **Conductors listed and identified as Photovoltaic (PV) Wire installed as exposed, single conductors.**
- (E) The photovoltaic power system direct-current circuits shall be permitted to be used with ungrounded battery systems complying with 690.71(G).
- (F) The photovoltaic power source shall be labeled with the following warning at each junction box, combiner box, disconnect, and device where the ungrounded circuits may be exposed during service:

WARNING
ELECTRIC SHOCK HAZARD
THE DC CIRCUIT CONDUCTORS OF THIS
PHOTOVOLTAIC POWER SYSTEM ARE
UNGROUND**ED** **AND** MAY BE ENERGIZED
WITH RESPECT TO GROUND DUE TO
LEAKAGE PATHS AND/OR GROUND FAULTS.
- (G) The inverters or charge controllers used in systems with ungrounded photovoltaic source and output circuits shall be listed for the purpose.



Grounding—Numerous Changes in 2005 & 2008

- 690.42 Point of System Grounding Connection
- 690.43, .45, .46 Equipment Grounding
- Grounding Electrode Systems 690.47—Changed in 2005 and completely rewritten in 2008.
- 690.48 Continuity of Equipment Grounding Systems
- 690.49 Continuity of Photovoltaic Source and Output Circuit Grounded Conductors



690.42 Point of System Grounding Connection [2008 NEC]

- Misleading FPN needed more information:
- *FPN: Locating the grounding connection point as close as practicable to the photovoltaic source better protects the system from voltage surges due to lightning.*
- “Exception: Systems with a 690.5 ground-fault protection device shall be permitted to have the required grounded conductor-to-ground bond made by the ground-fault protection device. This bond, where internal to the ground-fault equipment, shall not be duplicated with an external connection.”



690.43 Equipment Grounding [2008 NEC]

- “Devices listed and identified for grounding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to grounded mounting structures. Devices identified and listed for bonding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to the metallic frames of adjacent PV modules.”



690.43 Equipment Grounding [2008 NEC]

- “Equipment grounding conductors for the PV array and structure (where installed) shall be contained within the same raceway or cable, or otherwise run with the PV array circuit conductors when those circuit conductors leave the vicinity of the PV array”



690.45 Size of Equipment Grounding Conductors [2008 NEC] (Size matters—or maybe not)

- “(A) General. Equipment grounding conductors in photovoltaic source and photovoltaic output circuits shall be sized in accordance with Table 250.122. Where no overcurrent protective device is used in the circuit, an assumed overcurrent device rated at the photovoltaic rated shortcircuit current shall be used in Table 250.122. Increases in equipment grounding conductor size to address voltage drop considerations shall not be required. The equipment grounding conductors shall be no smaller than 14 AWG.”



690.45 Size of Equipment Grounding Conductors [2008 NEC]

- “(B) Ground-Fault Protection Not Provided. For other than dwelling units where ground-fault protection is not provided in accordance with 690.5(A) through (C), each equipment grounding conductor shall have an ampacity of at least two (2) times the temperature and conduit fill corrected circuit conductor ampacity”
- Enjoy reading the FPN.... Faults 3-5 series strings might not blow string fuse so EGC must be oversized when no GFP is provided—generally irrelevant.



690.46 Array Equipment Grounding Conductors.[2008 NEC]

- “Equipment grounding conductors for photovoltaic modules smaller than 6 AWG shall comply with 250.120(C).”
- This matches new language at the beginning of 690.43 that states, “An equipment grounding conductor between a PV array and other equipment shall be required in accordance with 250.110.”



690.47(C) Systems with Alternating-Current and Direct-Current Grounding Requirements [2005 NEC]

- “Photovoltaic power systems with both alternating-current and direct-current (dc) grounding requirements shall be permitted to be grounded as described in (1) or (2):
 - (1) A grounding-electrode conductor shall be connected between the identified dc grounding point to a separate dc grounding electrode. The dc grounding-electrode conductor shall be sized according to 250.166. The dc grounding electrode shall be bonded to the ac grounding electrode to make a grounding electrode system according to 250.52 and 250.53. The bonding conductor shall be no smaller than the largest grounding electrode conductor, either ac or dc.
 - (2) The dc grounding electrode conductor and ac grounding electrode conductor shall be connected to a single grounding electrode. The separate grounding electrode conductors shall be sized as required by 250.66 (ac) and 250.166 (dc).”



690.47(C) Systems with Alternating-Current and Direct-Current Grounding Requirements [2008 NEC]

- “Systems with alternating current and direct-current grounding requirements shall comply with items (C)(1) through (C)(8):
 - (1) Where photovoltaic power systems have both alternating-current (ac) and direct-current (dc) grounding requirements, the dc grounding system shall be bonded to the ac grounding system.
 - (2) A bonding conductor between these systems shall be sized as the larger of the dc requirement in accordance with 690.45, the ac requirements based on the inverter alternating current overcurrent device rating and 250.122, and the system bonding requirements of 250.28.”



690.47(C) Systems with Alternating-Current and Direct-Current Grounding Requirements [2008 NEC]

- (3) A conductor that serves as both an equipment grounding conductor and as part of the bond between ac and dc systems for an inverter incorporating dc ground-fault protection shall meet the requirements for equipment bonding jumpers in accordance with 250.102 but shall not be subject to the requirements for bonding jumpers in accordance with 250.28. A single conductor shall be permitted to be used to perform the multiple functions of dc grounding, ac grounding, and bonding between ac and dc systems.”

- Allows properly sized single grounding conductor (bonding jumper sized to 250.122) to be used for multiple purposes.



690.47(C) Systems with Alternating-Current and Direct-Current Grounding Requirements [2008 NEC]

- “(4) A bonding conductor or equipment grounding conductor that serves multiple inverters shall be sized based on the sum of applicable maximum currents used in item (2).
- (5) A common ground bus shall be permitted to be used for both systems.
- (6) A common grounding electrode shall be permitted to be used for both systems, in which case the grounding electrode conductor shall be connected to the ac ground system bonding point.
- (7) Grounding electrode conductor(s) shall be sized to meet the requirements of both 250.66 (ac system) and 250.166 (dc system).
- (8) For systems with utility-interactive inverters, the premises grounding system serves as the ac grounding system.”



690.48 Continuity of Equipment Grounding Systems [2005 NEC]

- “Where the removal of equipment disconnects the bonding connection between the grounding electrode conductor and exposed conducting surfaces in the photovoltaic source or output circuit equipment, a bonding jumper shall be installed while the equipment is removed.”
- This clarifies the intent that the array frames must be continuously grounded when any portion of the equipment is removed.



690.49 Continuity of Photovoltaic Source and Output Circuit Grounded Conductors [2005 NEC]

- “Where the removal of the utility-interactive inverter or other equipment disconnects the bonding connection between the grounding electrode conductor and the photovoltaic source and/or photovoltaic output circuit grounded conductor, a bonding jumper shall be installed to maintain the system grounding while the inverter or other equipment is removed.”
- This clarifies the intent that the system grounding of the array circuit must be grounded with a bonding jumper when the inverter is removed.



Article 690.64 (B)(5) [2005 NEC]

- Clarification on not requiring individual clamping of circuit breakers for 690.60 (utility-interactive) inverters. Many inspectors will try to require clamps because they are not familiar with PV systems.
- “Circuit breakers, if backfed, shall be identified for such operation. Dedicated circuit breakers backfed from listed utility-interactive inverters complying with 690.60 shall not be required to be individually clamped to the panelboard bus bars. A front panel shall clamp all circuit breakers to the panelboard bus bars. Main circuit breakers connected directly to energized feeders shall also be individually clamped.”



2008 NEC Complete Rewrites Article 690.64 Point of Connection (B) Load Side

- “Where distribution equipment, including switchboards and panelboards, is fed simultaneously by a primary source(s) of electricity and one or more utility-interactive inverters, and where this distribution equipment is capable of supplying multiple branch circuits or feeders, or both, the interconnecting provisions for the utility-interactive inverter(s) shall comply with (B)(1) through (B)(7).”



Article 690.64(B) (cont.)

- “(1) **Dedicated Overcurrent and Disconnect.** Each source interconnection shall be made at a dedicated circuit breaker or fusible disconnecting means.
- (2) **Bus or Conductor Rating.** The sum of the ampere ratings of overcurrent devices in circuits supplying power to a busbar or conductor shall not exceed 120 percent of the rating of the busbar or conductor. In systems with panelboards connected in series, the rating of the first overcurrent device directly connected to the output of a utility-interactive inverter(s) shall be used in the calculations for all busbars and conductors.”



Article 690.64(B) (cont.)

- “(3) **Ground-Fault Protection.** The interconnection point shall be on the line side of all ground-fault protection equipment.
Exception: Connection shall be permitted to be made to the load side of ground-fault protection, provided that there is ground-fault protection for equipment from all ground-fault current sources. Ground-fault protection devices used with supplies connected to the load-side terminals shall be identified and listed as suitable for backfeeding.
- (4) **Marking.** Equipment containing overcurrent devices in circuits supplying power to a busbar or conductor supplied from multiple sources shall be marked to indicate the presence of all sources.”



Article 690.64(B) (cont.)

- **(5) Suitable for Backfeed.** Circuit breakers, if backfed, shall be suitable for such operation.

FPN: Circuit breakers that are marked “Line” and “Load” have been evaluated only in the direction marked. Circuit breakers without “Line” and “Load” have been evaluated in both directions.

- **(6) Fastening.** Listed plug-in-type circuit breakers backfed from utility-interactive inverters complying with 690.60 shall be permitted to omit the additional fastener normally required by 408.36(D) for such applications.”



Article 690.64(B) (cont.)

- **“(7) Inverter Output Connection.** Unless the panelboard is rated not less than the sum of the ampere ratings of all overcurrent devices supplying it, a connection in a panelboard shall be positioned at the opposite (load) end from the input feeder location or main circuit location. The bus or conductor rating shall be sized for the loads connected in accordance with Article 220. A permanent warning label shall be applied to the distribution equipment with the following or equivalent marking:
 - WARNING
 - INVERTER OUTPUT CONNECTION, DO NOT RELOCATE, THIS OVERCURRENT DEVICE”



Electrical Code Compliance: Issues

- Many PV systems may not comply with the NEC because:
 - Designers, installers, and inspectors have little experience with PV systems—particularly the code requirements.
 - Listed equipment is not widely available for PV components and dc hardware.
 - Suggestions that PV systems are easily designed/installed by untrained personnel.



Inspector Guidelines for PV Systems

available at www.irecusa.org



Overview of Presentation

- Introduction/Rational for Guidelines
- Permit Guidelines for Small-Scale PV Systems
 - Site Diagram
 - One-line Diagram
 - Major Component and Array Electrical Information
 - Provisions for PV Power Source Disconnect
 - Array Mounting Information
 - Costs of Permits
- Field Inspection Guideline
 - Equipment, conduit, and wiring installed according to plans
 - Structure attached according to plans and directions
 - Appropriate signs installed



Funding Source for Guidelines

- Worked with Renewable Energy Technology Analysis Project of the Pace University Law School Energy Project in developing these guidelines for the U.S. Department of Energy.



Introduction/Rational

- provide a framework for the permitting and inspection of PV systems
- two separate guidelines since jurisdictions normally treat the process in two steps.
 - First is the plan check stage where the information is reviewed for accuracy and completeness
 - Second is the field inspection stage where the installation is reviewed for compliance with the approved plans



Why do we need Inspector Guidelines?

- Variations in compliance requirements—some are insufficient to protect the public, others may not be consistent with established standards.
- Need a predictable process with uniform enforcement of code requirements for jurisdictional authorities and installing contractors.



Ain't that purdy....



...and this is so much prettier...



What are the objectives of the guidelines?

- Facilitate the installation of safe systems at a minimum of cost.
- Provide guidance on what information should be provided for permitting.
- Discourage “fly-by-nights” from the industry by making them do all the steps that a good installer does.
- Raise the professionalism of installing contractors.



What is the basic approach used to develop the guidelines?

- Originally based on the 2002 NEC, Article 690, and various guidelines from a few jurisdictions and using input from several experienced professionals including installers and inspectors throughout the U.S. It has since been updated for the 2005 National Electrical Code.
- In addition to national experts, California has over 25,000 systems that have been inspected by local jurisdictions. This is an experience base not previously available.
- Approach is to establish a set of best practices that will help ensure that the public safety is preserved when an installation meets these guidelines



Who will benefit from these guidelines?

- Jurisdictions in charge of public safety in the built environment (authority having jurisdiction or AHJ).
- Plan checkers and field inspectors tasked with reviewing PV systems.
- Installers who need consistent criteria in which to have their systems reviewed.

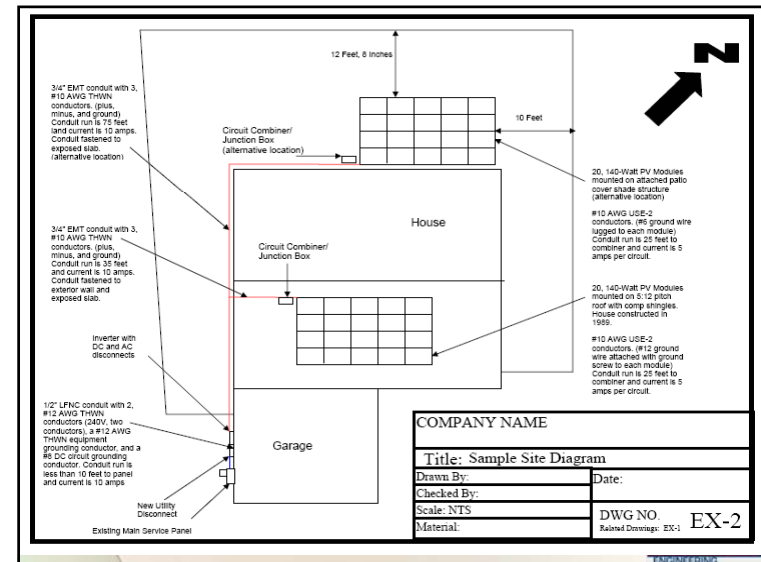


Permit Guidelines for Small-Scale PV Systems



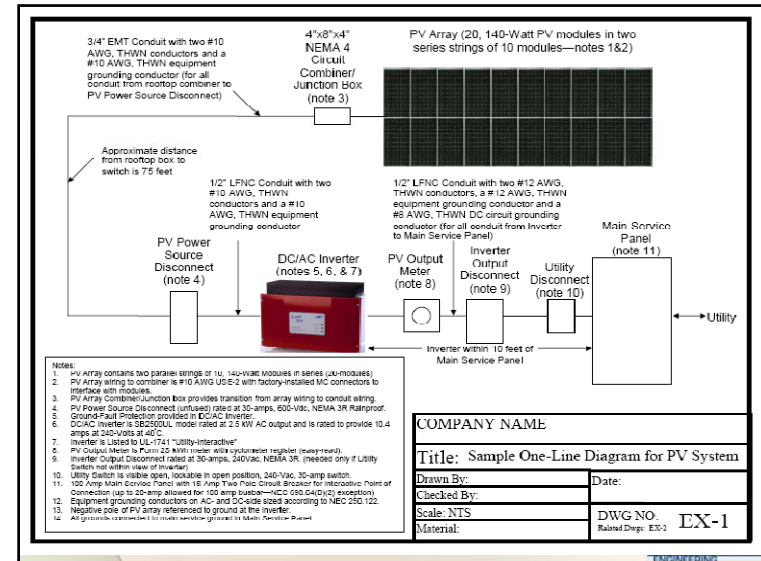
Site Diagram

- Drawing does not need to be to scale, but it should basically show where the major components are located.
- If array is ground mounted, it should show that it conforms with allowable setbacks.
- It can be used to call out conduit and wiring if desired.



One-line Diagram

- Should have sufficient detail to call out the electrical components, the wire types and sizes, number of conductors, and conduit type and size where needed.
- Should include information about PV modules and inverter(s).
- Should include information about utility disconnecting means (required by many utilities).



Major Component and Array Electrical Information

- Inverter information
- Module information
- Battery information (if used)



Inverter information

- Model number and manufacturer's "cut sheets" for the specific model.
- Listing—is the inverter listed to UL1741 and labeled "Utility-Interactive"? For a current list of compliant inverters, visit the California Energy Commission's website.
http://www.consumerenergycenter.org/cgi-bin/eligible_inverters.cgi
- New York Type-Tested Inverters are listed at:
www.dps.state.ny.us/94e0952_11152000.pdf
- Maximum continuous output power at 40°C
- Input voltage range



Module information

- Manufacturer's "cut sheets" for the specific model.
- Listing. The module should be listed to UL 1703. For a current list of modules that are listed to UL 1703, visit the California Energy Commissions website.

http://www.consumerenergycenter.org/cgi-bin/eligible_pvmodes.cgi

- Listing label information



Typical PV Module Label

PHOTOVOLTAIC MODULE				CE
MODEL	KC120-1			
SER. NO.	01632A1055			
DATE	2001.6			
IRRADIANCE AND CELL TEMPERATURE	1000W/m ² AM 1.5 25 °C	800W/m ² AM 1.5 47 °C	MAX. SYS. VOLT.	600 V
P _{max}	120 W	87 W	SERIES FUSE	11 A
V _{pmax}	16.9 V	15.2 V	MASS	11.9 kg
I _{pmax}	7.10 A	5.74 A	FIELD WIRING	STRANDED COPPER ONLY 10 - 14 AWG INSULATED FOR 60V
V _{oc}	21.5 V	---	FIRE RATING	CLASS C
I _{sc}	7.45 A	---		



Battery Information (if used)

- Manufacturer's "cut sheets" for the specific model.
- Nominal battery voltage for the system
(This is 2 Volts per cell for lead-acid batteries. A 24-cell lead-acid battery would have a nominal voltage of 48 volts.)



Array electrical information

- Number of modules in series
- Array operating voltage
- Array operating current
- Maximum system voltage
- Array short circuit current



Wiring and overcurrent protection

- Wire type
- Conductor ampacity
 - The maximum PV Source Circuit Current
 - Minimum Source circuit conductor ampacity
 - Photovoltaic Output Circuit ampacity
 - Inverter Output Circuit ampacity
- Overcurrent protection
 - Inverter Output Circuit overcurrent protection
 - NEC 690.64 (B) covers the requirements for Point of Connection
 - Source circuit overcurrent protection



AC Point of Connection

- 690-64 (B) allows the installation of additional overcurrent devices up to 120% of busbar rating.
 - 100-Amp Panel allows up to 20 Amp breaker.
 - Main breaker can be derated. (e.g. 125-amp busbar can take a 100-Amp and a 50-amp breaker)
 - Connection can also be made on the line side of the main breaker (with double-barrel lugs or bolt-on lugs)



Provisions for the photovoltaic power source disconnecting means:

- 2002 NEC essentially requires that conduit be run exterior to the building or provide a disconnect in a readily accessible location at the nearest point the wires enter the building for a rooftop PV system.
- This requirement is a very real problem especially for integrally-mounted systems and systems being installed on new homes.
- Guidelines provide two alternatives for jurisdictions still on the 2002 NEC:
 - Allow a rooftop disconnect with a sign at the service entrance
 - Require interior wiring to be installed in metal raceways.
- The 2005 NEC has solved this problem by requiring metal raceways for this wiring.



Array mounting information

- If roof mounted:
 - Weight of PV array in pounds per square foot.
 - Age of roof—if older than 30 years, may need to supply additional information.
 - Roof type (comp, tile, metal, thatch, etc....)
 - Provide roof mounting detail.
 - Identify method of sealing penetrations.



Array mounting information

- If ground mounted:
 - Show array supports, framing members, and foundation posts and footings.
 - Provide information on mounting structure(s) construction.
 - Show detail on module attachment method to mounting structure.



Costs of Permits

- Small PV system (up to 4 kW): \$75 - \$200
- Large PV system (up to 10 kW): \$150 - \$400
- For systems above 10 kW, consider a permit cost of \$15 - \$40 per kW.



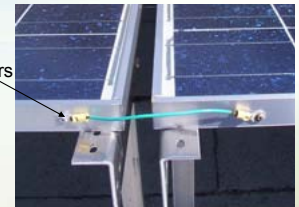
Field Inspection Guideline



Equipment, conduit, and wiring installed according to plans

- PV module model number matches plans and cut sheets
- PV modules are properly grounded with lugs on each module and mounting rails or some equivalent grounding method.

Wrong connectors



Equipment, conduit, and wiring installed according to plans

- Check that wiring is consistent with callouts on plans (number of modules)
- Check that cable and conduit is properly supported
- Where plug connectors are used for module wiring, inspect a sample of the connections to make sure that connectors are fully engaged



Structure attached according to plans and directions



Appropriate signs installed

- Sign construction
- Photovoltaic Power Source
- AC point of connection
- inverter matches one-line
- alternative power system
- Optional Standby System (if battery-backed unit)

PV POWER SOURCE DC RATINGS	
WAREHOUSE	
STANDARD TEST CONDITIONS CELL TEMPERATURE: 25°C IRRADIANCE: 1000 W/m ²	
OPERATING DC CURRENT	53.4 Amps
OPERATING DC VOLTAGE	415 Volts
OPERATING DC POWER	22,140 Watts
MAXIMUM SYSTEM DC VOLTAGE	600 Volts
SHORT-CIRCUIT DC CURRENT	65.2 Amps



What are the next steps needed to propagate these practices?

- A guideline is not law and must be adopted voluntarily by the AHJ.
- Influential building officials and chief electrical inspectors need to understand what is needed for safe PV installations, provide feedback to these guidelines, and then incorporate them into their standard practices.
- Articles in code official newsletters can help spread the word that these guidelines are available and are being used by jurisdictions.

