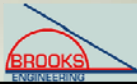
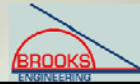


PV System Permitting and Inspection

Presented by
Bill Brooks, PE
Brooks Engineering



PV Codes and Standards 101



What are the applicable codes and standards for PV systems?

- Electrical codes - NEC Article 690 - Solar Photovoltaic Systems – NFPA 70
- Building Codes – ICC, ASCE 7
- 2009 Uniform Solar Energy Code—IAPMO
- UL Standard 1703, Flat-plate Photovoltaic Modules and Panels
- IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems
- UL Standard 1741, Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources



2009 Uniform Solar Energy Code

- Covers solar thermal systems and partially covers photovoltaic systems
- Provisions for installation of single wall heat exchangers
- Requires access to solar collector and its components for maintenance and repair purposes
- Provides protection requirements for freezing temperatures, water hammer, rodents, corrosion, ultraviolet radiation, decay and termites



2009 Uniform Solar Energy Code—Cont.

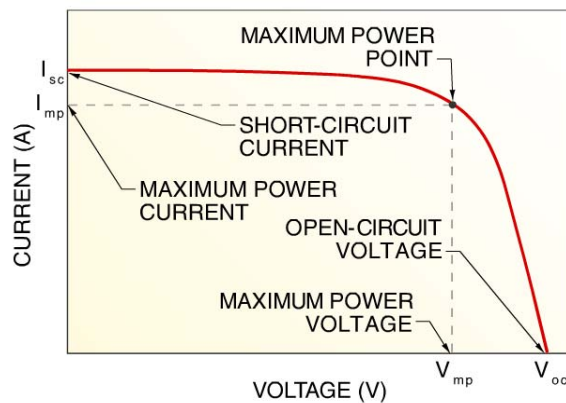
- Waterproofing requirements when solar collector is installed on a building structure to prevent leakage
- The Uniform Plumbing Code© (UPC) sections in this code are taken from the 2009 edition of the Uniform Plumbing Code.
- The Uniform Mechanical Code© (UMC) sections in this code are taken from the 2009 edition of the Uniform Mechanical Code.



Photovoltaic System *Basics*

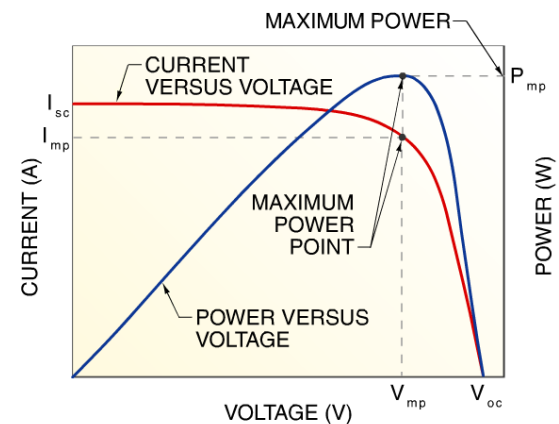


I-V Curve



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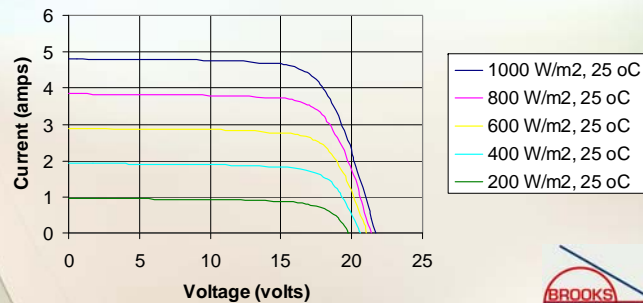
I-V Curve with Power



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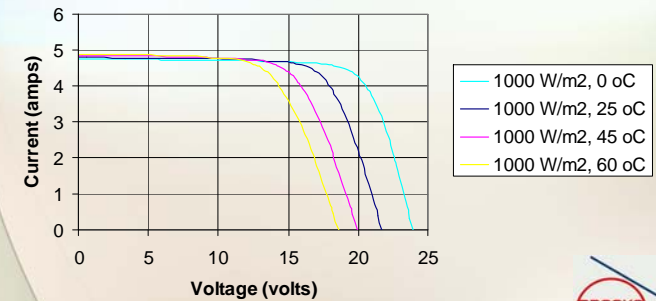
Current varies with irradiance

Siemens Solar Module SP75
Performance at Different Irradiances



Voltage varies with temperature

Siemens Solar Module SP75
Performance at Different Cell Temperatures



Differences Between PV and Conventional Electrical Systems

- PV systems have *dc circuits* that require special design and equipment.
- PV systems can have *multiple energy sources*, and special disconnects are required to isolate components.
- Energy flows in PV systems may be *bi-directional*.
- Utility-Interactive PV systems require an interface with the ac utility-grid and special considerations must be adopted. (utility must be involved-hence utility training)

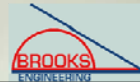
Ain't that purdy....



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



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



Electrical System Grounding

- The NEC defines grounding as a connection to the *earth* with sufficiently low impedance and having sufficient current-carrying capacity to prevent the buildup of voltages.
- Grounding of electrical systems offers personnel safety and minimizes the effects of lightning and surges on equipment.



Electrical Grounding Types (Huge Confusion Over These Terms)

- System Ground (grounding): Connecting the circuit to ground (i.e. the negative of a dc array, the neutral of a split single-phase system, or the neutral of a bi-polar dc system)
- Equipment Ground (bonding): Connecting all non-current carrying metal parts to ground (metal enclosure, module frame, etc...)



Nice Lugs! (poor fasteners)



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.”



Early Improvements for Grounding

UGC-1

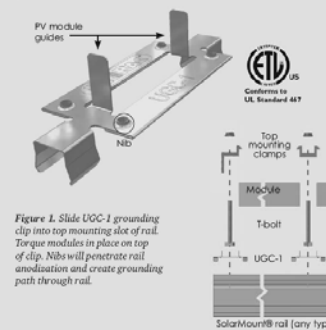


Figure 1. Slide UGC-1 grounding clip into top mounting slot of rail. Torque modules in place on top of clip. Nibs will penetrate rail anodization and create grounding path through rail.

WEEBLug

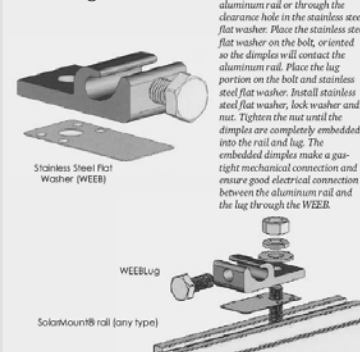


Figure 2. Insert a bolt in the aluminum rail or through the clearance hole in the stainless steel flat washer. Place the stainless steel flat washer on the bolt, oriented so the dimples will contact the aluminum rail. Place the lug portion on the bolt and stainless steel flat washer. Install stainless steel flat washer, lock washer and nut. Tighten the nut until the dimples are completely embedded into the rail and lug. The embedded dimples make a gas-tight mechanical connection and ensure good electrical connection between the aluminum rail and the lug through the WEEB.





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



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 ; Rating @ 25°C (STC)
- V_{max} (per module) = $44.6\text{V} + [-129 \text{ mV/}^\circ\text{C} \times (1\text{V}/1000\text{mV}) \times (-25^\circ\text{C} - 25^\circ\text{C})] = 51.05 \text{ Volts}$.
- Table 690.7 [2008]: $V_{max} = 44.6\text{V} \times 1.20 = 53.52\text{V}$
- Table 690.7 [2005]: $V_{max} = 44.6\text{V} \times 1.25 = 55.75\text{V}$



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(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).*”



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]

- 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 690.33 [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
PHOTOVOLTAIIC POWER SYSTEM ARE
UNGROUNDDED 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



690.45 Size of Equipment Grounding Conductors [2008 NEC]

- “(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.”



690.47(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]

- 2008 NEC has 8 qualifying provisions to “assist” in specifying the grounding requirements.
- Attempt is to reduce the required size of grounding electrode conductor for utility-interactive inverters with GFP.
- The requirements are difficult to follow and do not encourage straightforward enforcement of provisions.
- See 2011 NEC to see the intent of 2008 NEC clarified.



690.47(D) Additional Electrodes for Array Grounding [2008 NEC]

- “Grounding electrodes shall be installed in accordance with 250.52 at the location of all ground- and pole-mounted photovoltaic arrays and as close as practicable to the location of roof-mounted photovoltaic arrays. The electrodes shall be connected directly to the array frame(s) or structure.”
 - GEC from array frames to electrode sized to 250.166
 - No substitute for equipment grounding conductor
 - Ground-mount structure meeting 250.52 complies
 - Roof-mounted may use building steel meeting 250.52(A)(2)
- Exception 1—Arrays with integral loads (area lights)
- Exception 2—If closer than 6' from existing electrode



690.53 Marking: DC PV Power Source[2008 NEC]

- (1) Rated maximum power-point current
 - $I_{mp} \times \text{number of series strings}$
- (2) Rated maximum power-point voltage
 - $V_{mp} \times \text{number of modules in series}$
- (3) Maximum system voltage
 - FPN to (3): See 690.7(A) for maximum photovoltaic system voltage.
- (4) Short-circuit current
 - FPN to (4): See 690.8(A) for calculation of maximum circuit current.
- (5) Maximum rated output current of the charge controller (if installed)



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 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”



Field Inspection



Section 1. Field Inspection Checklist for Array:

- a) Array matches plans
- b) Wire Management
- c) Module and Array Grounding
- d) Electrical enclosures on Roof Accessible and Connections Suitable for the Environment
- e) Array Fastened and Sealed According To Attachment Detail
- f) Conductor Ratings and Sizes



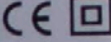

Inspection Checklist for Array:

a) Array Matches Plans

- PV module model number matches plans and spec sheets
- Get a digital photo of module label, if possible



Typical PV Module Label

PHOTOVOLTAIC MODULE				
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	
V _{pmax}	16.9 V	15.2 V	11 A	
I _{pmax}	7.10 A	5.74 A	MASS	
V _{oc}	21.5 V	---	11.9 kg	
I _{sc}	7.45 A	---		
 C UL US LISTED 9PB2	FIELD WIRING		FIRE RATING	
	STANDARD COPPER ONLY 10 - 14 AWG INSULATED FOR 90°C		CLASS C	



Common Installation Mistakes with Array Modules and Configurations

- 1. Changing the array wiring layout without changing the submitted electrical diagram.
- 2. Changing the module type or manufacturer as a result of supply issues.
- 3. Exceeding the inverter or module voltage due to improper array design.
- 4. Putting too few modules in series for proper operation of the inverter during high summer array temperatures.

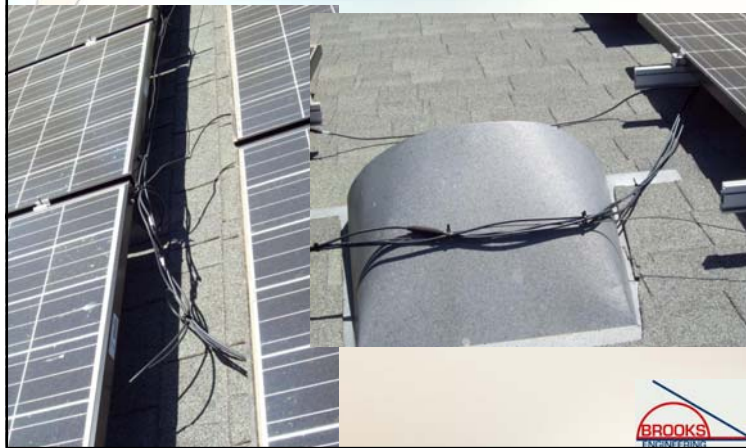


Inspection Checklist for Array: b) Wire Management

- The most important safety issue is proper support and protection of conductors.



Wire Management



Proper Installation of Exterior Cables

- NEC 338.10(B)(4)(b) states how USE-2 is to be installed in exterior locations.
- PV Wire/Cable should follow the same installation methods as USE-2.
- Section 338.10 refers the installer on to Article 334.30 (NM Cable) for support methods



Proper Installation of Exterior Cables—Article 334.30

- 1. Secured by staples, cable ties, straps, hangers, or similar fittings at intervals that do not exceed 4.5 feet
- 2. Secured within 12 inches of each box, cabinet, conduit body, or other termination
- 3. Sections protected from physical damage by raceway shall not be required to be secured within the raceway
- 4. Cable shall closely follow the surface of the building finish or of running boards ((NEC 334.15)—the analogous installation for USE-2 in PV arrays is for the conductors to follow support rails or module extrusions)
- 5. Protected from physical damage by raceway when necessary



Wire Management—Proper



Wire Management—Room for Improvement



Wire Management—Support?



Common Installation Mistakes with Wire Management

- 1. Not enough supports to properly control cable.
- 2. Conductors touching roof or other abrasive surfaces exposing them to physical damage.
- 3. Conductors not supported within 12 inches of boxes or fittings.
- 4. Not supporting raceways at proper intervals.
- 5. Multiple cables entering a single conductor cable gland (aka cord grip)
- 6. Not following support members with conductors.



Proper cable glands into Combiner Box

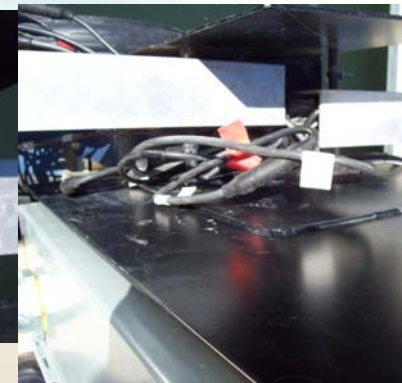


Common Installation Mistakes with Wire Management—cont.

- 7. Pulling cable ties too tight or leaving them too loose.
- 8. Not fully engaging plug connectors.
- 9. Bending conductors too close to connectors.
- 10. Bending USE-2 cable tighter than allowable bending radius.
- 11. Plug connectors on non-locking connectors not fully engaged



Wire Management—Physical Damage



Wire Management count the bad ideas



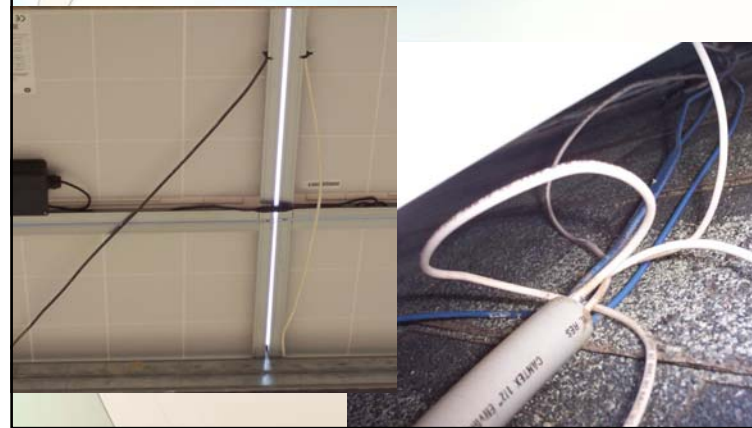
Wire Management —wire bending radius



Wire Management—plug engagement



Wire Management—Follow structural members & What the...?

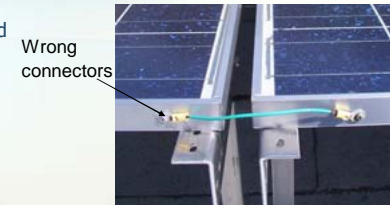


What you can't see won't hurt you??



Inspection Checklist for Array: c) Module and Array Grounding

- Most common concern of field inspectors.
- Ungrounded module frames are a potential safety hazard.
- All array metal “likely to become energized” must be properly bonded together and grounded with lugs on each module and mounting rails or some equivalent equipment grounding method.



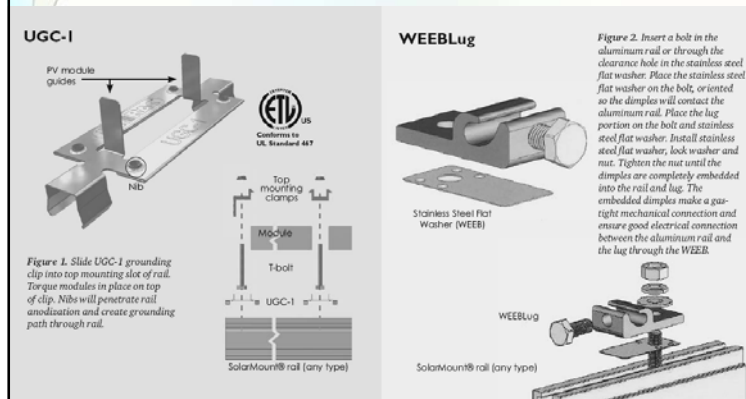
Module bonding and grounding methods

- 1. Some modules are designed to be grounded using a stainless-steel thread-forming screw threaded into the module frame holding the EGC at a grounding symbol. An isolating washer, such as a stainless cup washer is often used to isolate the copper conductor from the aluminum frame to prevent galvanic corrosion.
- 2. Some modules can be grounded to their mounting structures with stainless steel star washers placed between the module and the support structure. This creates an electrical bond while isolating the aluminum frame from dissimilar materials such as galvanized steel. The EGC is attached to an electrically continuous support member with a properly installed grounding lug.

Module bonding and grounding methods—cont.

- 3. Some modules can be grounded by properly installing a properly rated lay-in lug to the either the grounding point on the module, or any unused mounting hole. The EGC is run through this lay-in lug to bond the modules together.
- 4. For specific module mounting products (e.g. UniRac, ProSolar, DPW, etc...), there exists listed grounding clips to bond typical aluminum framed modules to the mounting structure. Only the proper clip can be used with each mounting structure. This allows the EGC to be connected to the electrically continuous rail. This method is consistent the NEC 690.43 and NEC 250.136.
- 5. Some modules can be grounded together using serrated clips that hold the module to the support structure and electrically bond with the module. One lug on any module can ground a whole row.

Early module and structure grounding improvements



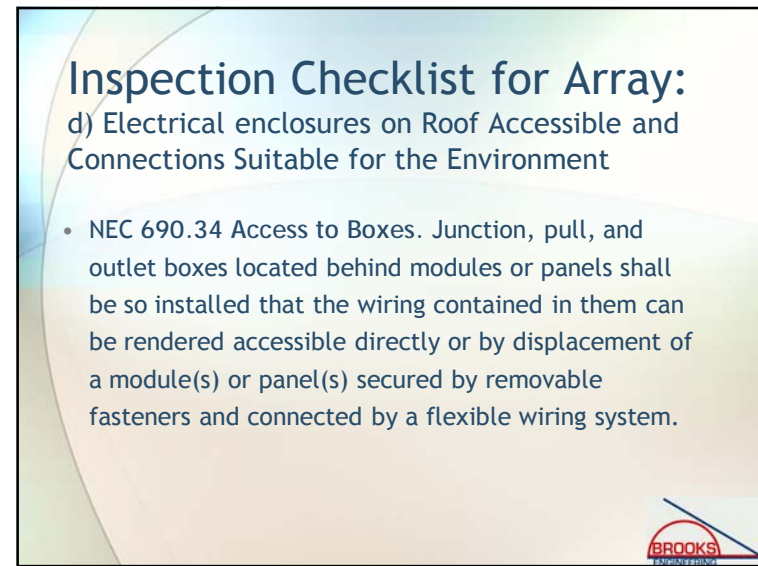
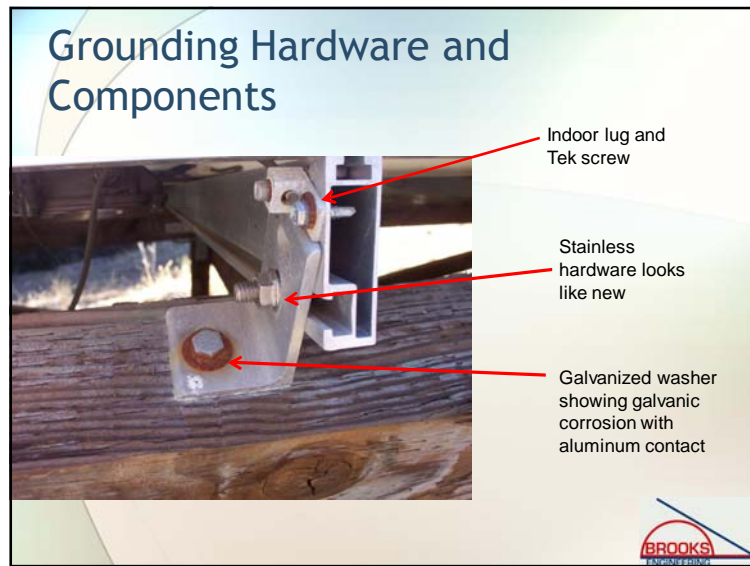
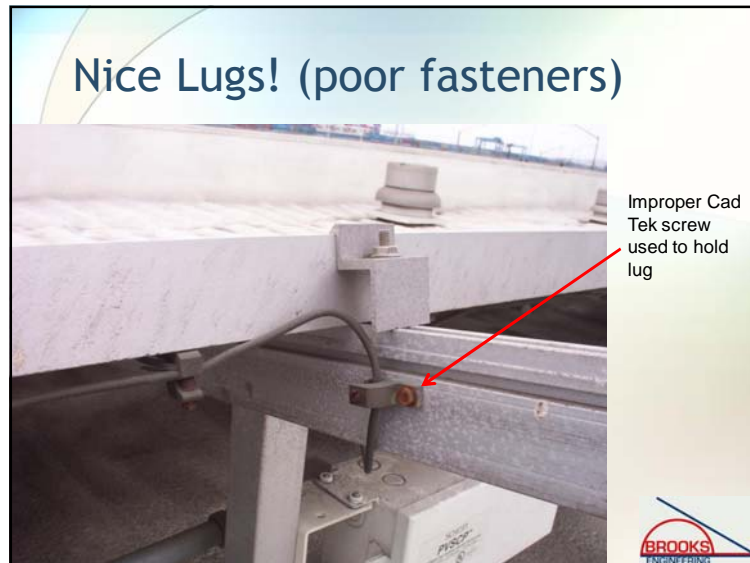
Identifying Grounding Clips



Common Installation Mistakes with Module and Array Grounding

- 1. Not installing a grounding conductor on the array at all.
- 2. Using cad-plated Tek screws to fasten ground wires or lugs to modules.
- 3. Using indoor-rated grounding lugs on PV modules and support structures.
- 4. Not protecting EGCs smaller than 6 AWG from physical damage.
- 5. Allowing copper EGC to come in contact with the aluminum rails and module frames.
- 6. Assuming that simply bolting aluminum frames to support structures provides effective grounding.





Rooftop j-boxes in compliance with 690.34

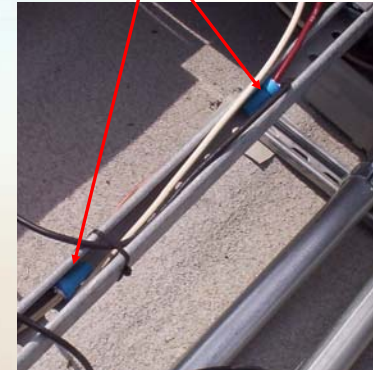


BROOKS
INSPECTION SERVICES

Junction Boxes

- Connection between conductors in an outdoor location generally must be done within a rainproof junction box, NEMA 3R, or 4 (unless with approved connector)
- Junction boxes are commonly used to transition conductors from exterior to conduit conductors and for combining array source circuits.

Waterproof wirenuts must be in j-boxes



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Improper Connections

Wire twisted together, wrapped in tape, and in the sun



Dry wirenut and not in a j-box

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Ratings and locations of Disconnects



NEMA 3R disconnect on sloped roof designed for vertical mounting only

Black cover to shield improperly installed switch only served to make switch invisible

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Ratings and locations of Combiner Boxes



NEMA 4
✓ Combiner Box
with disconnect
built-in. Designed
for horizontal or
vertical mounting



Common Installation Mistakes with Electrical Boxes, Conduit Bodies, and Disconnecting Means

- 1. Installing disconnects rated for vertical installation in a non-vertical application.
- 2. Installing improperly rated fuses in source combiners and fused disconnects.
- 3. Covering boxes or conduit bodies making them nearly inaccessible for service.
- 4. Not following manufacturer's directions for wiring disconnect for 600 Vdc ratings.
- 5. Installing dry wire nuts in wet locations and inside boxes that get wet routinely.
- 6. Using improper fittings to bring conductors into exterior boxes.



Many disconnects like these require the ungrounded conductor to be broken twice in series to get the 600Vdc rating



Incorrect
Breaking of
grounded
conductor

Correct



Correct Fuses



Correct Fuses



Correct Fuses ??



Correct Fuses ??



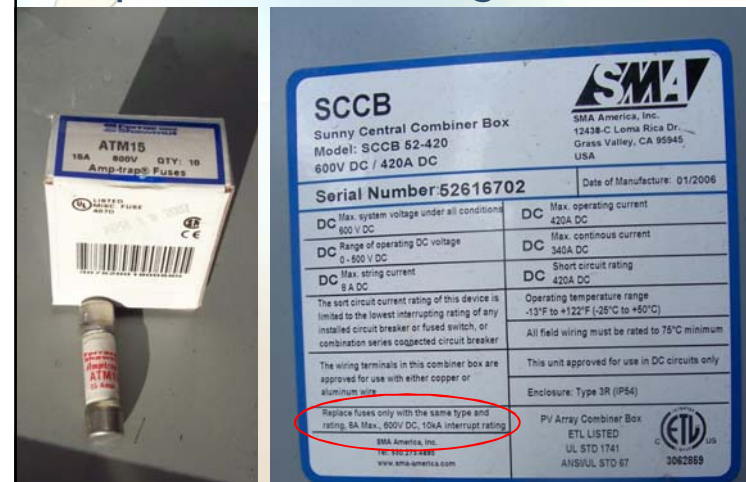
Correct Fuses and Terminals ?



Proper Current Rating?



Proper Current Rating?



Properly Rated Disconnects and Inverters



Inspection Checklist for Array:

e) Array Fastened and Sealed According To Attachment Detail

- Roof penetrations must be properly sealed to preclude leakage.
- Do a hand pull test on a sample of lag screw attachments to make sure they are secured to rafters.
- Look in attic to see if lags are visible.

Proper and Improper Flashing



Common Installation Mistakes with Mounting Systems:

- 1. Not using supplied or specified hardware with the mounting systems.
- 2. Substituting Unistrut for special manufactured aluminum extrusions.
- 3. Not installing flashings properly.
- 4. Not using the correct roof adhesives for the specific type of roof.
- 5. Not attaching proper lag screws to roofing members.
- 6. Not drilling proper pilot holes for lag screws and missing or splitting roofing members.

Inspection Checklist for Array: f) Conductor Ratings and Sizes

- Exposed Array Conductors—The only single-conductor cables allowed in 690.31(B) are USE-2 and PV Wire (Cable).
- Conductors in raceways on rooftops—Table 310.15(B)(2)(a) adds an additional 14°C - 30°C to the ambient temperature. These high temperatures nearly always limit ampacity below the terminal temperature ampacity.

Conduit Exposed to Sunlight Above Rooftops —Table 310.15(B)(2)(a)

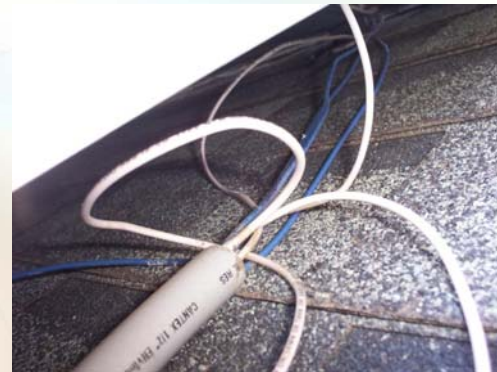


Common Installation Mistakes with Conductors:

- 1. Not accounting for high operating temperatures in rooftop conduit.
- 2. Specifying THHN conductors rather than wet rated conductors in drawings where raceways are clearly located outdoors.
- 3. Specifying or installing THWN conductors in raceways that may exceed 60°C without properly correcting the THWN conductors for this temperature.

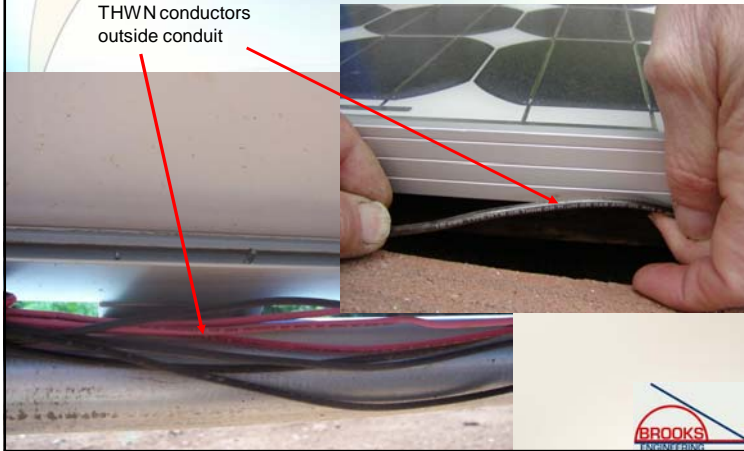


Incorrect conductors and roof plumbing into combiner box



Improperly Rated Conductors

THWN conductors
outside conduit



Section 2. Specifics For Ground-Mounted Arrays

- a) Foundation and mounting structure review
- b) Electrical bonding of structural elements
- c) Additional array electrode [690.47(D)]
- d) Attachment method according to plans
- e) Wiring not readily accessible



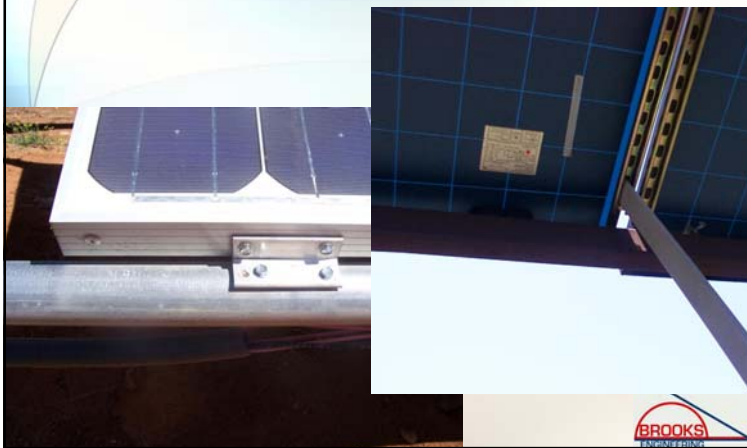
Support Structure and Attachment



Support Structure and Attachment



Support Structure and Attachment



Wiring not readily accessible?



Readily accessible or not?



Common Installation Mistakes with Ground Mounting Systems:

- 1. Not using supplied or specified hardware with the mounting systems.
- 2. Substituting Unistrut for special manufactured aluminum extrusions.
- 3. No bonding of support structure or discontinuous grounding of support structure.
- 4. Dissimilar metals in contact with one another (e.g. aluminum and galvanized steel).
- 5. No bonding of aluminum structural elements to steel structural elements.
- 6. Array wiring readily accessible to other than authorized personnel.

Section 3. Appropriate signs installed

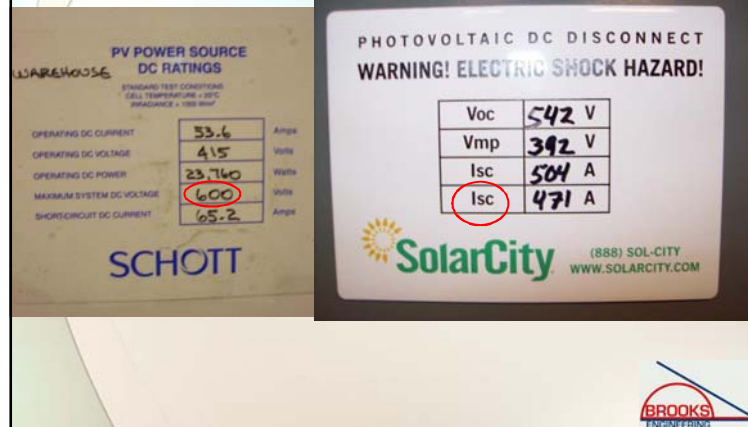
- Sign construction
- Photovoltaic Power Source
- AC point of connection
- alternative power system



Sign Construction

- The NEC is not extremely specific about what signs should be made of.
- NEC 110.21 states, “The marking shall be of sufficient durability to withstand the environment involved.”
- Electrical industry standards for outdoor signs is that signs should be metal or plastic with engraved or machine printed letters, or electro-photo plating, in a contrasting color to the sign background.

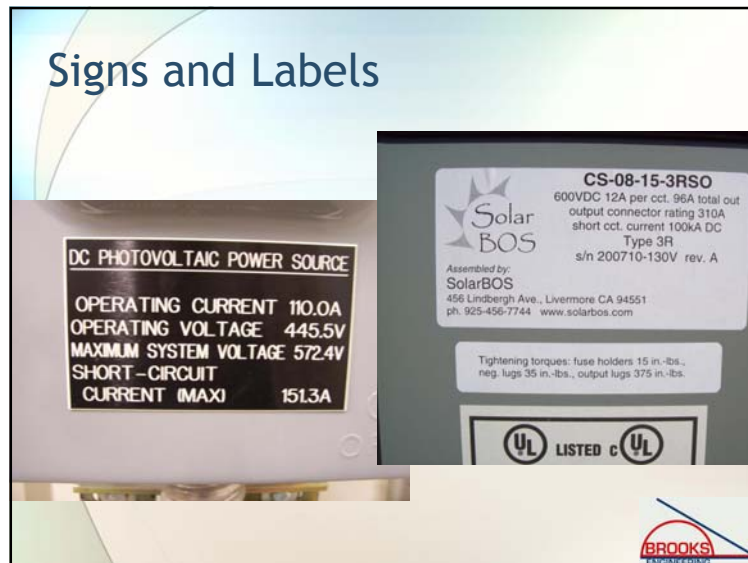
Indoor signs may allow more variety of construction



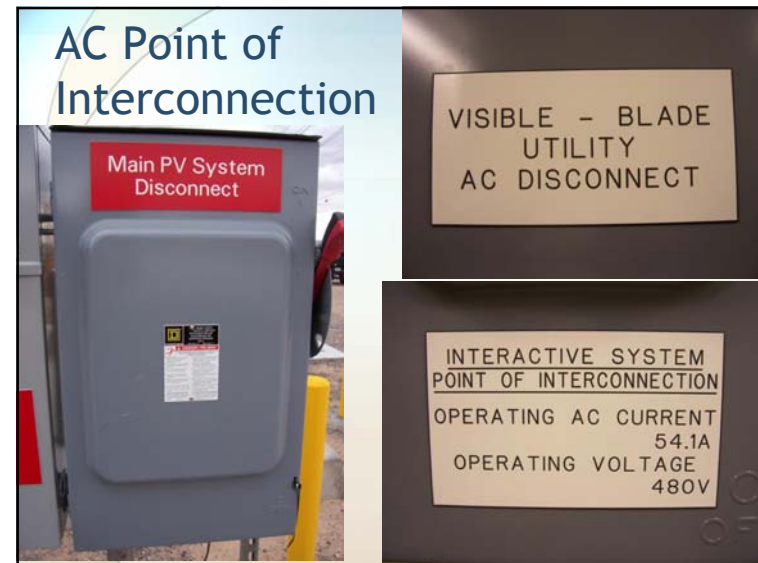
Photovoltaic Power Source Sign



Signs and Labels



AC Point of Interconnection



Signs and Labels
it is possible to
have too many.



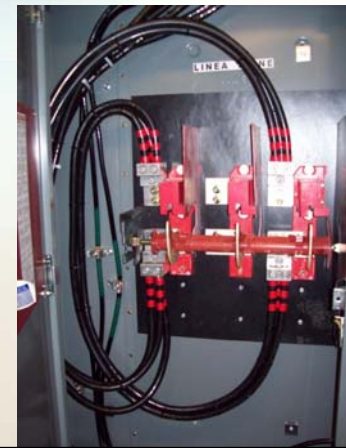
Section 4. Check that equipment
ratings are consistent with
application and signs



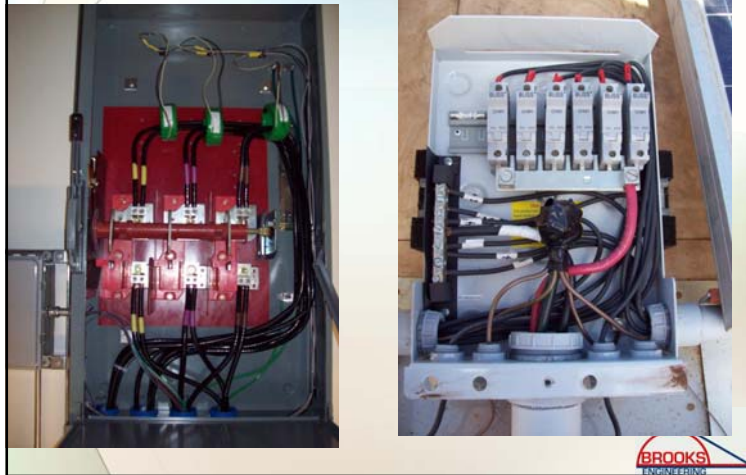
Inverter Labels



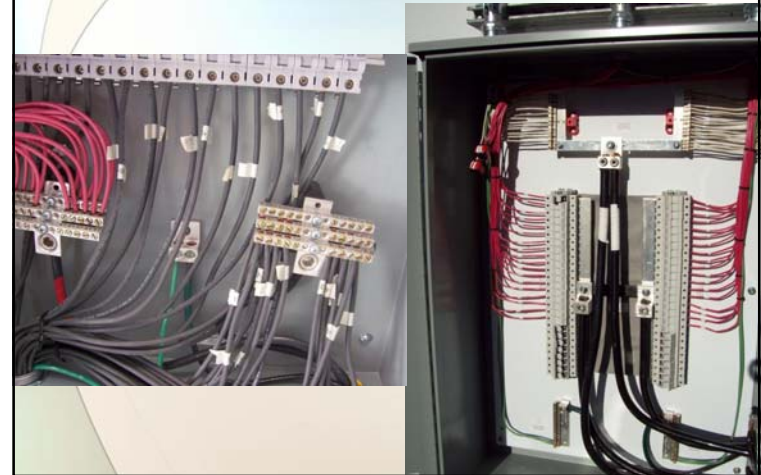
Disconnects consistent with
requirements



Guts—show and tell



Guts—show and tell



Guts—show and tell



Guts—show
and tell



Good Installation Practices



Good Installation Practices



Good Installation Practices



Good Installation Practices





Nice Work



Nice Work

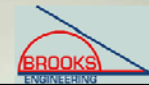


Nice Work



*Expedited Permit Process
for PV Systems*

available at
[www. Solarabcs.org/permitting](http://www.Solarabcs.org/permitting)



Why do we need Permit 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.



Required Information for Permit

- Site plan showing location of major components on the property. This drawing need not be exactly to scale, but it should represent relative location of components at site (see supplied example site plan). PV arrays on dwellings with a 3' perimeter space at ridge and sides do not need fire service approval.
- Electrical diagram showing PV array configuration, wiring system, overcurrent protection, inverter, disconnects, required signs, and ac connection to building (see supplied standard electrical diagram).
- Specification sheets and installation manuals (if available) for all manufactured components including, but not limited to, PV modules, inverter(s), combiner box, disconnects, and mounting system.



Step 1: Structural Review of PV Array Mounting System

- Is the array to be mounted on a defined, permitted roof structure? Yes/No (structure meets modern codes)
- *If No due to non-compliant roof or ground mount, submit completed worksheet for roof structure WKS1.*



Roof Information:

- Is the roofing type lightweight (Yes = composition, lightweight masonry, metal, etc...)_____
- *If No, submit completed worksheet for roof structure WKS1 (No = heavy masonry, slate, etc...).*
- Does the roof have a single roof covering? Yes/No
- *If No, submit completed worksheet for roof structure WKS1.*
- Provide method and type of weatherproofing roof penetrations (e.g. flashing, caulk)._____



Mounting System Information:

- The mounting structure is an engineered product designed to mount PV modules?
Yes/No
 - If No, provide details of structural attachment certified by a design professional.
- For manufactured mounting systems, fill out information on the mounting system below:



Mounting System Information:

- a) Mounting System Manufacturer _____ Product Name and Model# _____
- b) Total Weight of PV Modules and Rails _____ lbs
- c) Total Number of Attachment Points _____
- d) Weight per Attachment Point ($b \div c$) _____ lbs (if greater than 45 lbs, see WKS1)
- e) Maximum Spacing Between Attachment Points on a Rail _____ inches (see product manual for maximum spacing allowed based on maximum design wind speed)
- f) Total Surface Area of PV Modules (square feet) _____ ft^2
- g) Distributed Weight of PV Module on Roof ($b \div f$) _____ lbs/ft^2
 - If distributed weight of the PV system is greater than 5 lbs/ft^2 , see WKS1.



Step 2: Electrical Review of PV System (Calculations for Electrical Diagram)

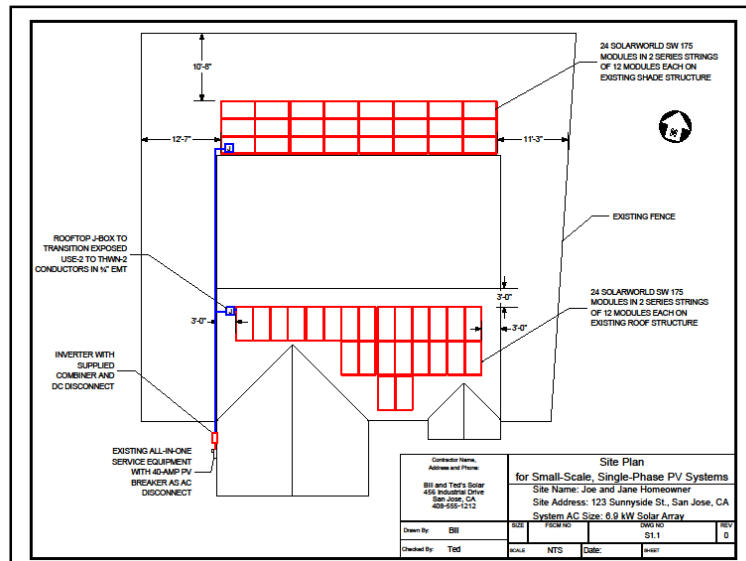
- In order for a PV system to be considered for an expedited permit process, the following must apply:
 1. PV modules, utility-interactive inverters, and combiner boxes are identified for use in PV systems.
 2. The PV array is composed of 4 series strings or less
 3. The Inverter has a continuous power output 13,440 Watts or less
 4. The ac interconnection point is on the load side of service disconnecting means (690.64(B)).
 5. The electrical diagram (E1.1) can be used to accurately represent the PV system.



Site Diagram

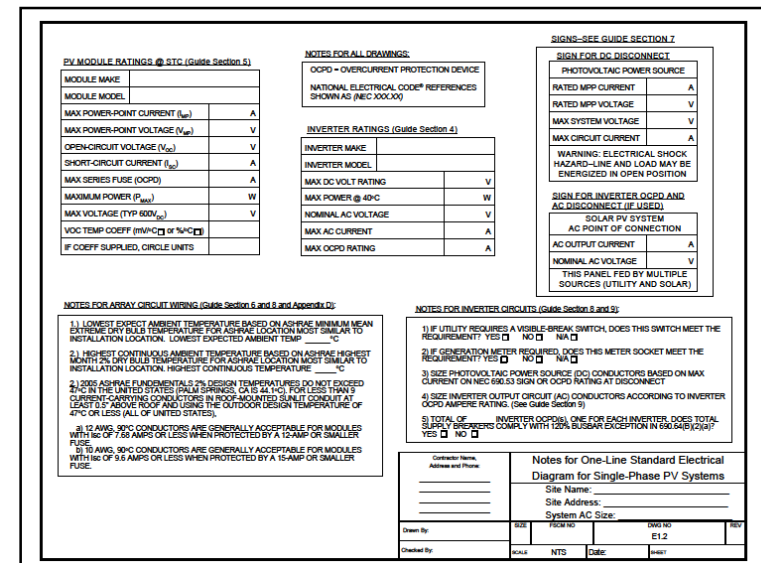
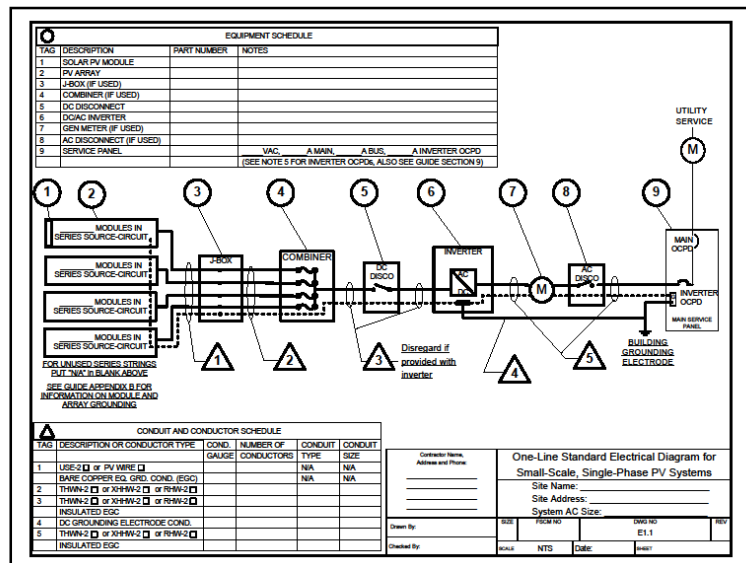
- Drawing does not need to be to scale, but it should basically show where the major components are located.
- If array is ground mounted, it should show that it conforms with allowable setbacks.

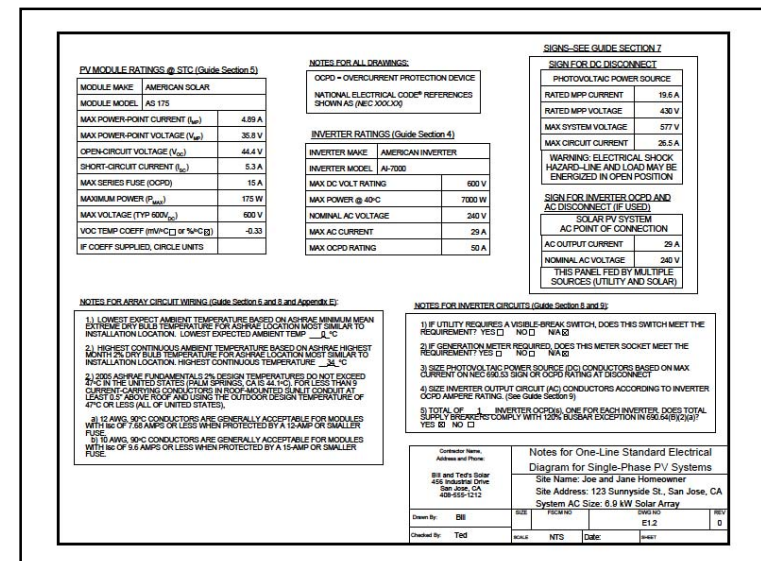
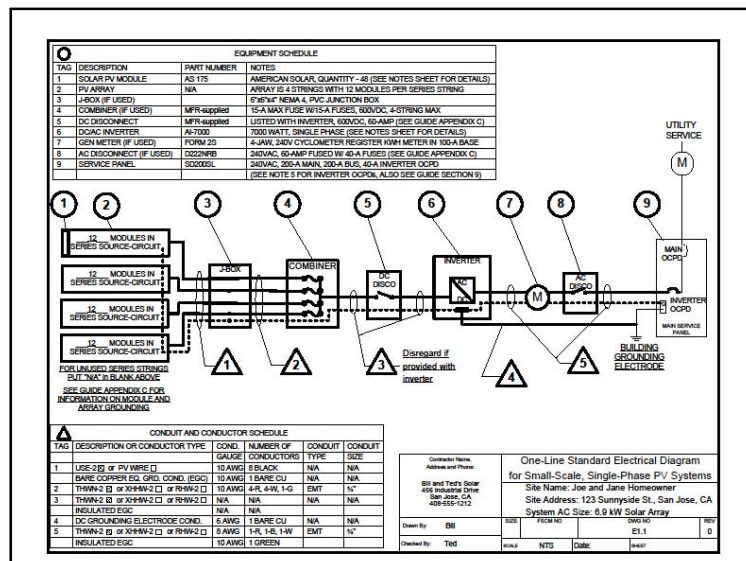




One-line Diagram

- 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
- Combiner Box
- Disconnects

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 Solar Program website. www.gosolarcalifornia.com
- Maximum continuous output power at 40°C

Module information

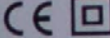

- Manufacturer's "cut sheets" for the specific model.
- Listing. The module should be listed to UL 1703. For a current list of modules that are listed to UL 1703, visit the California website.

www.gosolarcalifornia.com

- Listing label information



Typical PV Module Label

PHOTOVOLTAIC MODULE					
MODEL	KC120-1				
SER NO.	01632A1055				
DATE	2001.6				
IRRADIANCE AND CELL TEMPERATURE	1000Wm ⁻² AM 1.5 25 °C	800Wm ⁻² AM 1.5 47 °C	MAX. SYS VOLT.		
P _{max}	120 W	87 W	600 V		
V _{pmax}	16.9 V	15.2 V	SERIES FUSE		
I _{pmax}	7.10 A	5.74 A	11 A		
V _{oc}	21.5 V	---	MASS		
I _{sc}	7.45 A	---	11.9 kg		
 c UL US LISTED 9P82		FIELD WIRING		FIRE RATING	
		STRANDED COPPER ONLY 10 - 14 AWG INSULATED FOR 90°C		CLASS C	



Array electrical information

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

