INSPECTING PHOTOVOLTAIC (PV) SYSTEMS FOR CODE-COMPLIANCE

Presented by

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Brooks Engineering

PV Codes and Standards 101

What are the applicable codes and standards for PV systems?

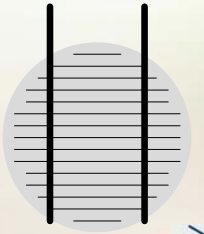
- Electrical codes - NEC Article 690 - Solar Photovoltaic Systems – NFPA 70
- Uniform Solar Energy Code
- Building Codes – ICC, ASCE 7
- UL Standard 1703, Flat-plate Photovoltaic Modules and Panels
- IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems
- UL Standard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

Photovoltaic System ***Basics***

stuff you have to know to understand the NEC

Definitions: PV Cell

- **Cell:** The basic photovoltaic device that is the building block for PV *modules*.

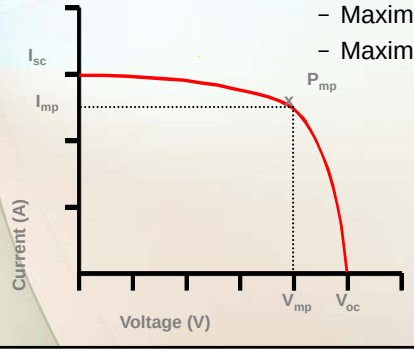


Connect Cells To Make Modules

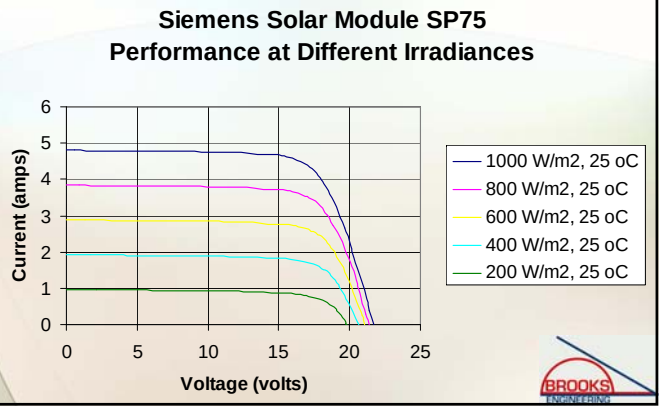
- One silicon solar cell produces 0.5 volt
- 36 cells connected together have enough voltage to charge 12 volt batteries and run pumps and motors
- 72-cell modules are the new standard for grid-connected systems having a nominal voltage of 24-Volts and operating at about 30 Volts.
- Module is the basic building block of systems
- Can connect modules together to get any power configuration

PV Performance Parameters

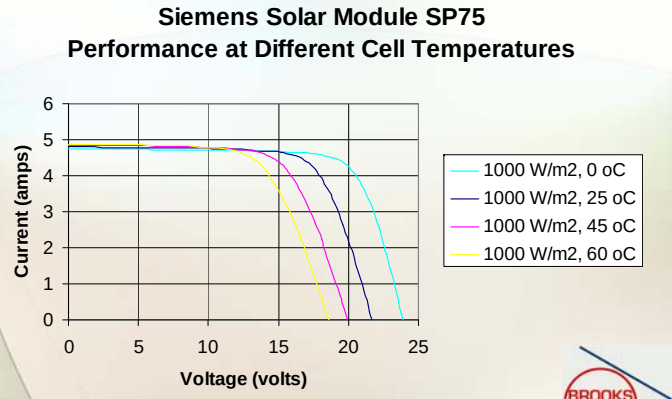
- Open-circuit voltage (V_{oc})
- Short-circuit current (I_{sc})
- Maximum power voltage (V_{mp})
- Maximum power current (I_{mp})
- Maximum power (P_{mp})



Current varies with irradiance



Voltage varies with temperature



Definitions: PV Module

- Module: A group of PV cells connected in series and/or parallel and encapsulated in an environmentally protective laminate.

Polycrystalline Silicon module

Monocrystalline Silicon module

Integrated PV Modules

Definitions: PV Panel

- **Panel:** A structural group of *modules* that is the basic building block of a PV *array*.

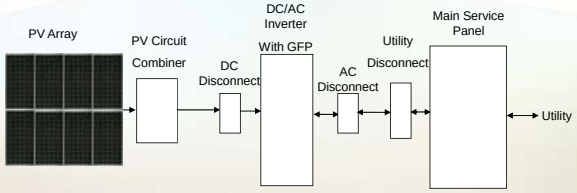
Definitions: PV Array

- **Array:** A group of *panels* that comprises the complete direct current PV generating unit.

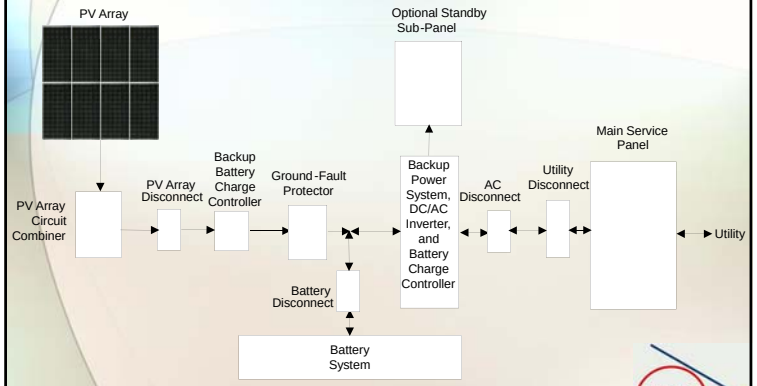
Definitions: Balance of System (BOS)

- **BOS:** The balance of the equipment necessary to integrate the PV array with the site load (building). This includes the array circuit wiring, fusing, disconnects, and power processing equipment (inverter).

Block diagram of PV system without battery backup



Block diagram of PV system with battery backup



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)

PV System Electrical Design: Common Problem Areas

- *Insufficient* conductor ampacity and insulation
- Excessive *voltage drop*
- *Unsafe* wiring methods
- *Lack of or improper* placement of overcurrent protection and disconnect devices
- *Use of unlisted*, or improper application of listed equipment (e.g. ac in dc use)
- *Lack of or improper* equipment or system grounding
- *Unsafe* installation and use of batteries

Ain't that purdy....

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

Expedited Permit Process for PV Systems

available at
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÷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÷f)_____ lbs/ft^2

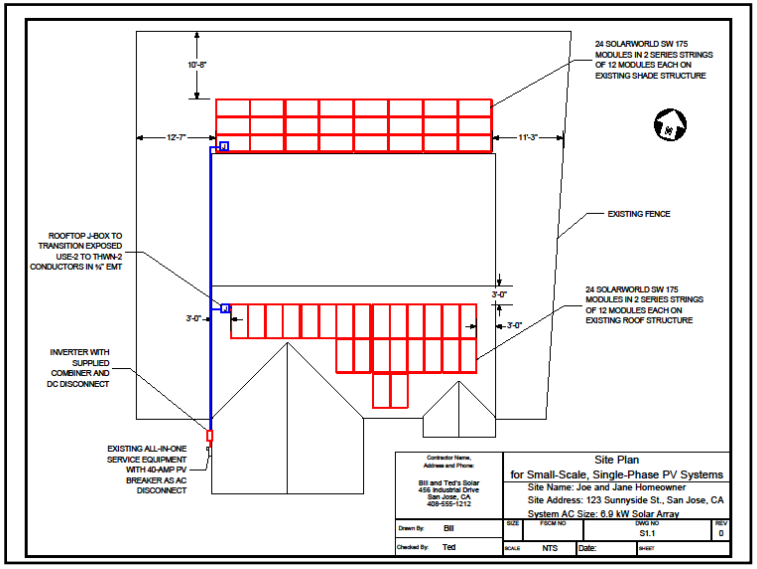
- *If distributed weight of the PV system is greater than 5 lbs/ft^2, see WKS1.*

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.

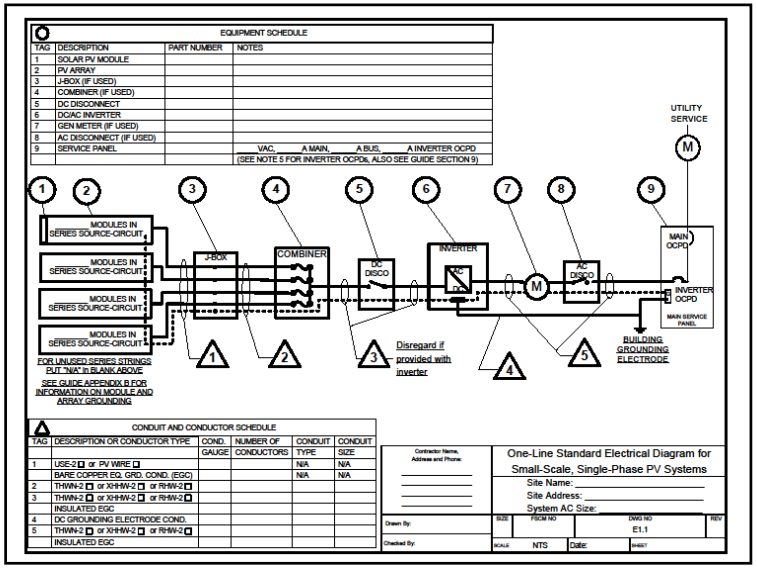
Site Diagram

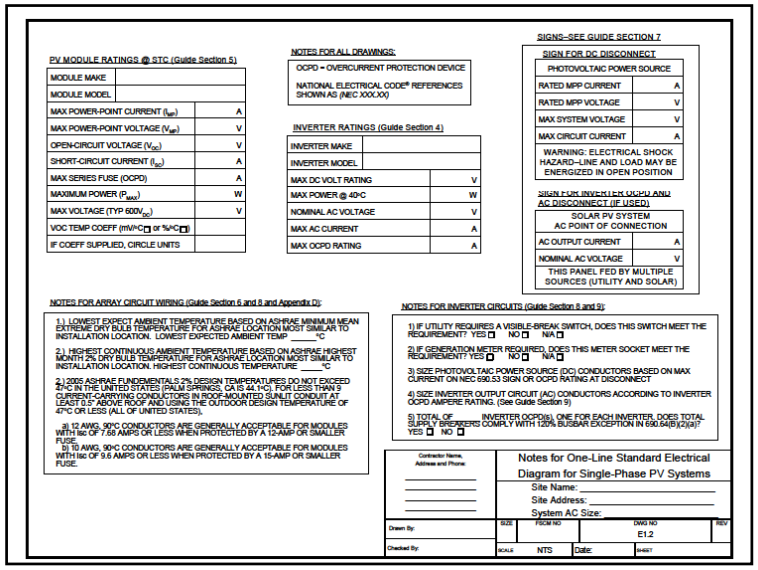
- Drawing does not need to be to scale, but it should basically show were the major components are located.
- If array is ground mounted, it should show that it conforms with allowable setbacks.



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).





PV MODULE RATINGS @ STC (Guide Section 5)

MODULE MAKE	
MODULE MODEL	
MAX POWER-POINT CURRENT (I_{MP})	A
MAX POWER-POINT VOLTAGE (V_{MP})	V
OPEN-CIRCUIT VOLTAGE (V_{OC})	V
SHORT-CIRCUIT CURRENT (I_{SC})	A
MAX SERIES FUSE (OCPD)	A
MAXIMUM POWER (P_{MAX})	W
MAX VOLTAGE (TYP 600V_{DC})	V
VOC TEMP COEFF (mV/°C☐ or %/°C☐)	
IF COEFF SUPPLIED, CIRCLE UNITS	

NOTES FOR ALL DRAWINGS:

OCPD = OVERCURRENT PROTECTION DEVICE

NATIONAL ELECTRICAL CODE® REFERENCES SHOWN AS (NEC XXX.XX)

INVERTER RATINGS (Guide Section 4)

INVERTER MAKE	
INVERTER MODEL	
MAX DC VOLT RATING	V
MAX POWER @ 40°C	W
NOMINAL AC VOLTAGE	V
MAX AC CURRENT	A
MAX OCPD RATING	A

SIGNS–SEE GUIDE SECTION 7

SIGN FOR DC DISCONNECT

PHOTOVOLTAIC POWER SOURCE	
RATED MPP CURRENT	A
RATED MPP VOLTAGE	V
MAX SYSTEM VOLTAGE	V
MAX CIRCUIT CURRENT	A

WARNING: ELECTRICAL SHOCK HAZARD–LINE AND LOAD MAY BE ENERGIZED IN OPEN POSITION

SIGN FOR INVERTER OCPD AND AC DISCONNECT (IF USED)

SOLAR PV SYSTEM AC POINT OF CONNECTION	
AC OUTPUT CURRENT	A
NOMINAL AC VOLTAGE	V

THIS PANEL FED BY MULTIPLE SOURCES (UTILITY AND SOLAR)

NOTES FOR ARRAY CIRCUIT WIRING (Guide Section 6 and 8 and Appendix D):

1.) LOWEST EXPECT AMBIENT TEMPERATURE BASED ON ASHRAE MINIMUM MEAN EXTREME DRY BULB TEMPERATURE FOR ASHRAE LOCATION MOST SIMILAR TO INSTALLATION LOCATION. LOWEST EXPECTED AMBIENT TEMP _____°C

2.) HIGHEST CONTINUOUS AMBIENT TEMPERATURE BASED ON ASHRAE HIGHEST MONTH 2% DRY BULB TEMPERATURE FOR ASHRAE LOCATION MOST SIMILAR TO INSTALLATION LOCATION. HIGHEST CONTINUOUS TEMPERATURE _____°C

2.) 2005 ASHRAE FUNDEMENTALS 2% DESIGN TEMPERATURES DO NOT EXCEED 47°C IN THE UNITED STATES (PALM SPRINGS, CA IS 44.1°C). FOR LESS THAN 9 CURRENT-CARRYING CONDUCTORS IN ROOF-MOUNTED SUNLIT CONDUIT AT LEAST 0.5" ABOVE ROOF AND USING THE OUTDOOR DESIGN TEMPERATURE OF 47°C OR LESS (ALL OF UNITED STATES),

3a) 12 AWG, 90°C CONDUCTORS ARE GENERALLY ACCEPTABLE FOR MODULES WITH Isc OF 7.66 AMPS OR LESS WHEN PROTECTED BY A 12-AMP OR SMALLER FUSE.

3b) 10 AWG, 90°C CONDUCTORS ARE GENERALLY ACCEPTABLE FOR MODULES WITH Isc OF 9.6 AMPS OR LESS WHEN PROTECTED BY A 15-AMP OR SMALLER FUSE.

NOTES FOR INVERTER CIRCUITS (Guide Section 8 and 9):

1) IF UTILITY REQUIRES A VISIBLE-BREAK SWITCH, DOES THIS SWITCH MEET THE REQUIREMENT? YES ☐ NO ☐ N/A ☐

2) IF GENERATION METER REQUIRED, DOES THIS METER SOCKET MEET THE REQUIREMENT? YES ☐ NO ☐ N/A ☐

3) SIZE PHOTOVOLTAIC POWER SOURCE (DC) CONDUCTORS BASED ON MAX CURRENT ON NEC 690.53 SIGN OR OCPD RATING AT DISCONNECT

4) SIZE INVERTER OUTPUT CIRCUIT (AC) CONDUCTORS ACCORDING TO INVERTER OCPD AMPERE RATING. (See Guide Section 9)

5) TOTAL OF _____ INVERTER OCPD(s). ONE FOR EACH INVERTER. DOES TOTAL SUPPLY BREAKERS COMPLY WITH 120% BUSBAR EXCEPTION IN 690.64(B)(2)(a)? YES ☐ NO ☐

Contractor Name, Address and Phone:

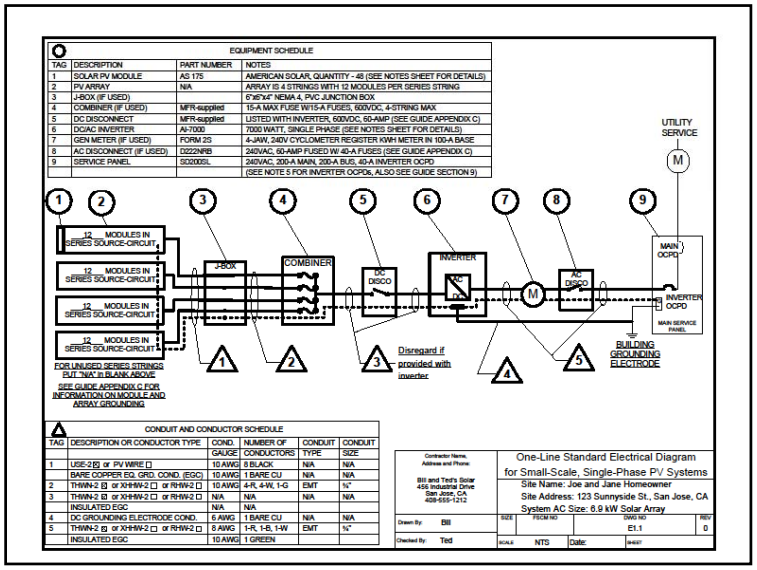
Notes for One-Line Standard Electrical Diagram for Single-Phase PV Systems

Site Name: _____

Site Address: _____

System AC Size: _____

Drawn By:	SIZE	FSCM NO	DWG NO	REV
Checked By:			E1.2	
	SCALE: NTS	Date:	SHEET	



EQUIPMENT SCHEDULE

TAG	DESCRIPTION	PART NUMBER	NOTES
1	SOLAR PV MODULE	AS 175	AMERICAN SOLAR, QUANTITY - 48 (SEE NOTES SHEET FOR DETAILS)
2	PV ARRAY	N/A	ARRAY IS 4 STRINGS WITH 12 MODULES PER SERIES STRING
3	J-BOX (IF USED)		6"x6"x4" NEMA 4, PVC JUNCTION BOX
4	COMBINER (IF USED)	MFR-supplied	15-A MAX FUSE W/15-A FUSES, 600VDC, 4-STRING MAX
5	DC DISCONNECT	MFR-supplied	LISTED WITH INVERTER, 600VDC, 60-AMP (SEE GUIDE APPENDIX C)
6	DC/AC INVERTER	AI-7000	7000 WATT, SINGLE PHASE (SEE NOTES SHEET FOR DETAILS)
7	GEN METER (IF USED)	FORM 2S	4-JAW, 240V CYCLOMETER REGISTER KWH METER IN 100-A BASE
8	AC DISCONNECT (IF USED)	DG222NRB	240VAC, 60-AMP FUSED W/ 40-A FUSES (SEE GUIDE APPENDIX C)
9	SERVICE PANEL	SD200SL	240VAC, 200-A MAIN, 200-A BUS, 40-A INVERTER OCPD
			(SEE NOTE 5 FOR INVERTER OCPDs, ALSO SEE GUIDE SECTION 9)

CONDUIT AND CONDUCTOR SCHEDULE

TAG	DESCRIPTION OR CONDUCTOR TYPE	COND. GAUGE	NUMBER OF CONDUCTORS	CONDUIT TYPE	CONDUIT SIZE
1	USE-2☒ or PV WIRE ☐	10 AWG	8 BLACK	N/A	N/A
	BARE COPPER EQ. GRD. COND. (EGC)	10 AWG	1 BARE CU	N/A	N/A
2	THWN-2 ☒ or XHHW-2 ☐ or RHW-2 ☐	10 AWG	4-R, 4-W, 1-G	EMT	¾"
3	THWN-2 ☒ or XHHW-2 ☐ or RHW-2 ☐	N/A	N/A	N/A	N/A
	INSULATED EGC	N/A	N/A		
4	DC GROUNDING ELECTRODE COND.	6 AWG	1 BARE CU	N/A	N/A
5	THWN-2 ☒ or XHHW-2 ☐ or RHW-2 ☐	8 AWG	1-R, 1-B, 1-W	EMT	¾"
	INSULATED EGC	10 AWG	1 GREEN		

Contractor Name, Address and Phone:

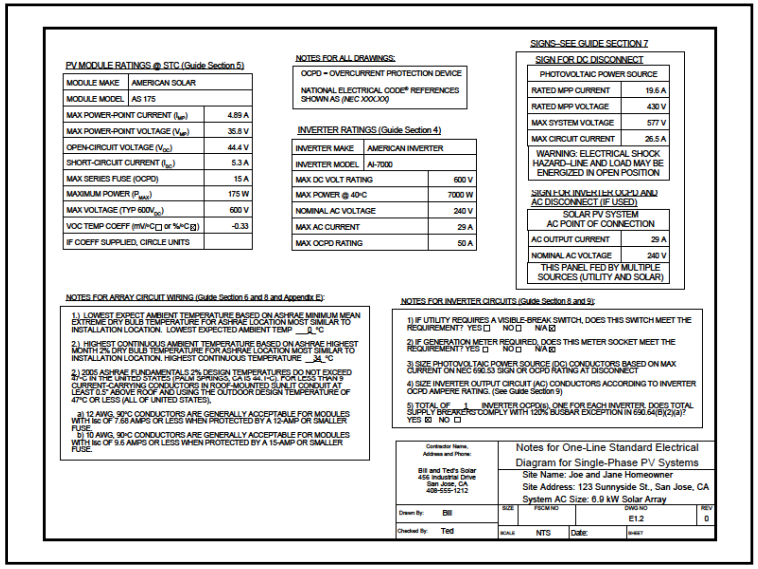
One-Line Standard Electrical Diagram for Small-Scale, Single-Phase PV Systems

Site Name: Joe and Jane Homeowner

Site Address: 123 Sunnyside St., San Jose, CA

System AC Size: 6.9 kW Solar Array

Drawn By:	SIZE	FSCM NO	DWG NO	REV
Checked By:			E1.1	
	SCALE: NTS	Date:	SHEET	



PV MODULE RATINGS @ STC (Guide Section 5)

MODULE MAKE	AMERICAN SOLAR
MODULE MODEL	AS 175
MAX POWER-POINT CURRENT (I_{MP})	4.89 A
MAX POWER-POINT VOLTAGE (V_{MP})	35.8 V
OPEN-CIRCUIT VOLTAGE (V_{OC})	44.4 V
SHORT-CIRCUIT CURRENT (I_{SC})	5.3 A
MAX SERIES FUSE (OCPD)	15 A
MAXIMUM POWER (P_{MAX})	175 W
MAX VOLTAGE (TYP 600V_{DC})	600 V
VOC TEMP COEFF (mV/°C☐ or %/°C☒)	-0.33
IF COEFF SUPPLIED, CIRCLE UNITS	

NOTES FOR ALL DRAWINGS:

OCPD = OVERCURRENT PROTECTION DEVICE

NATIONAL ELECTRICAL CODE® REFERENCES SHOWN AS (NEC XXX.XX)

INVERTER RATINGS (Guide Section 4)

INVERTER MAKE	AMERICAN INVERTER
INVERTER MODEL	AI-7000
MAX DC VOLT RATING	600 V
MAX POWER @ 40°C	7000 W
NOMINAL AC VOLTAGE	240 V
MAX AC CURRENT	29 A
MAX OCPD RATING	50 A

SIGNS–SEE GUIDE SECTION 7

SIGN FOR DC DISCONNECT

PHOTOVOLTAIC POWER SOURCE	
RATED MPP CURRENT	19.6 A
RATED MPP VOLTAGE	430 V
MAX SYSTEM VOLTAGE	577 V
MAX CIRCUIT CURRENT	26.5 A

WARNING: ELECTRICAL SHOCK HAZARD–LINE AND LOAD MAY BE ENERGIZED IN OPEN POSITION

SIGN FOR INVERTER OCPD AND AC DISCONNECT (IF USED)

SOLAR PV SYSTEM AC POINT OF CONNECTION	
AC OUTPUT CURRENT	29 A
NOMINAL AC VOLTAGE	240 V

THIS PANEL FED BY MULTIPLE SOURCES (UTILITY AND SOLAR)

NOTES FOR ARRAY CIRCUIT WIRING (Guide Section 6 and 8 and Appendix E):

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2.) HIGHEST CONTINUOUS AMBIENT TEMPERATURE BASED ON ASHRAE HIGHEST MONTH 2% DRY BULB TEMPERATURE FOR ASHRAE LOCATION MOST SIMILAR TO INSTALLATION LOCATION. HIGHEST CONTINUOUS TEMPERATURE __34_°C

2.) 2005 ASHRAE FUNDAMENTALS 2% DESIGN TEMPERATURES DO NOT EXCEED 47°C IN THE UNITED STATES (PALM SPRINGS, CA IS 44.1°C). FOR LESS THAN 9 CURRENT-CARRYING CONDUCTORS IN ROOF-MOUNTED SUNLIT CONDUIT AT LEAST 0.5" ABOVE ROOF AND USING THE OUTDOOR DESIGN TEMPERATURE OF 47°C OR LESS (ALL OF UNITED STATES),

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3b) 10 AWG, 90°C CONDUCTORS ARE GENERALLY ACCEPTABLE FOR MODULES WITH Isc OF 9.6 AMPS OR LESS WHEN PROTECTED BY A 15-AMP OR SMALLER FUSE.

NOTES FOR INVERTER CIRCUITS (Guide Section 8 and 9):

1) IF UTILITY REQUIRES A VISIBLE-BREAK SWITCH, DOES THIS SWITCH MEET THE REQUIREMENT? YES ☐ NO ☐ N/A ☒

2) IF GENERATION METER REQUIRED, DOES THIS METER SOCKET MEET THE REQUIREMENT? YES ☐ NO ☐ N/A ☒

3) SIZE PHOTOVOLTAIC POWER SOURCE (DC) CONDUCTORS BASED ON MAX CURRENT ON NEC 690.53 SIGN OR OCPD RATING AT DISCONNECT

4) SIZE INVERTER OUTPUT CIRCUIT (AC) CONDUCTORS ACCORDING TO INVERTER OCPD AMPERE RATING. (See Guide Section 9)

5) TOTAL OF 1 INVERTER OCPD(s). ONE FOR EACH INVERTER. DOES TOTAL SUPPLY BREAKERS COMPLY WITH 120% BUSBAR EXCEPTION IN 690.64(B)(2)(a)? YES ☒ NO ☐

Contractor Name, Address and Phone:

Bill and Ted's Solar
456 Industrial Drive
San Jose, CA
408-555-1212

Notes for One-Line Standard Electrical Diagram for Single-Phase PV Systems

Site Name: Joe and Jane Homeowner

Site Address: 123 Sunnyside St., San Jose, CA

System AC Size: 6.9 kW Solar Array

Drawn By: Bill	SIZE	FSCM NO	DWG NO	REV
Checked By: Ted			E1.2	0
	SCALE: NTS	Date:	SHEET	

Major Component and Array Electrical Information

- Inverter information
- Module information
- Combiner Box
- Disconnects

Inverter information

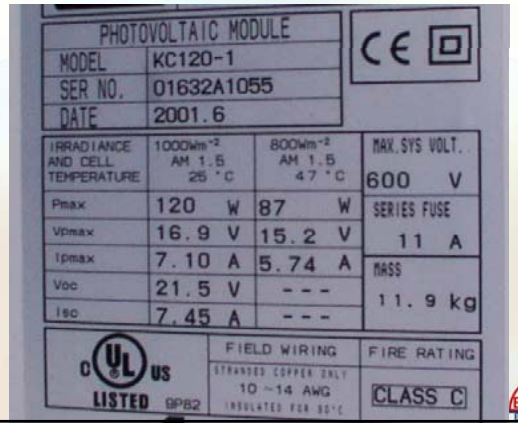
- Model number and manufacturer's "cut sheets" for the specific model.
- Listing—is the inverter listed to UL1741 and labeled "Utility-Interactive"? For a current list of compliant inverters, visit the California Solar Program website. www.gosolarcalifornia.com
- Maximum continuous output power at 40ºC

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



Array electrical information

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

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 Isc x 1.25 = Imax
    - 690.8(B) Min ampacity and overcurrent = Imax x 1.25
  - 690.9 Overcurrent Protection
    - 690.9(A) Generally required on all source circuits—exception: a.)no backfeed; and, b.) total Imax 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)

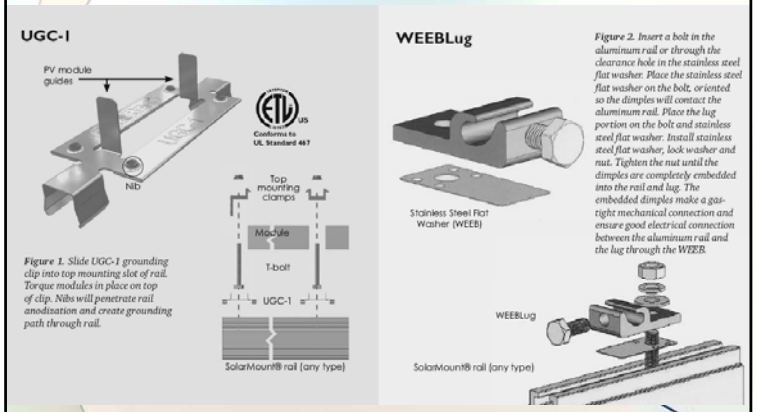
- System Ground (grounding): Connecting the circuit to ground (i.e. the negative of a dc array, the neutral of a split single-phase system, or the neutral of a bi-polar dc system)
- Equipment Ground (bonding): Connecting all non-current carrying metal parts to ground (metal enclosure, module frame, etc…)

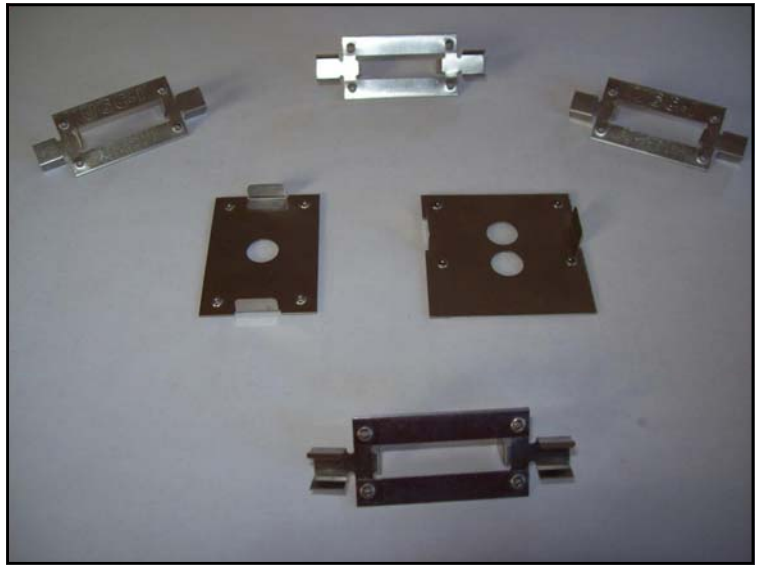
Nice Lugs! (poor fasteners)

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





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 4ºC 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:
  - αVoc = -129 mV/ºC; Voc =44.6V
  - Coldest expected Temp=-25ºC; Rating @ 25ºC (STC)
- Vmax (per module) = 44.6V + [-129 mV/ºC x (1V/1000mV) x (-25ºC-25ºC)] = 51.05 Volts.
- Table 690.7 [2008]: Vmax = 44.6V x 1.20 = 53.52V
- Table 690.7 [2005]: Vmax = 44.6V x 1.25 = 55.75V

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 (31/2 in.)	22 40
Above 90 mm (31/2 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(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 protectioncomplying 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
UNGROUNDED 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]

- "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]

- "(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]

- 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.
- Some have expressed concern over using an equipment grounding conductor to serve the purpose of the grounding electrode conductor given the less-stringent fastening requirements of equipment grounds (2008 NEC Handbook).

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
  - Imp x number of series strings
- (2) Rated maximum power-point voltage
  - Vmp x 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:

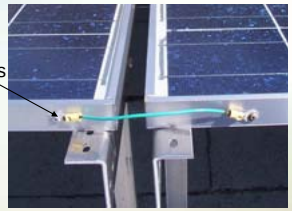
  WARNING

  INVERTER OUTPUT CONNECTION, DO NOT RELOCATE, THIS OVERCURRENT DEVICE"

Field Inspection

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.



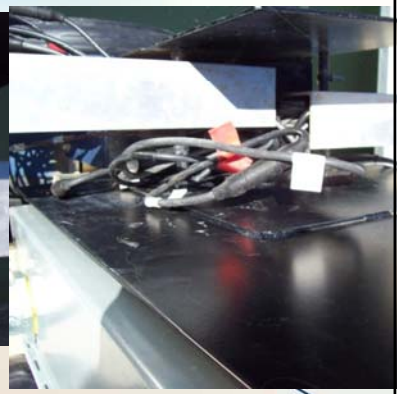
Wire Management

Wire Management

Wire Management

Wire Management

Wire Management



Wire Management

Wire Management

Wire Management

Wire Management

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

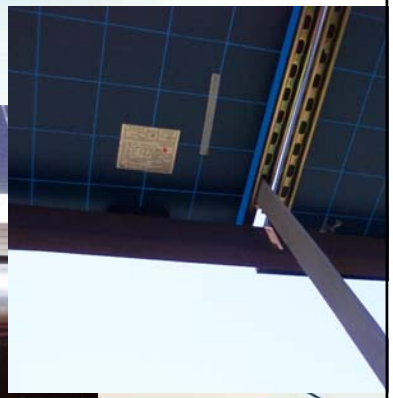
Support Structure and Attachment

Structure attached according to plans and directions

Support Structure and Attachment

Support Structure and Attachment

Support Structure and Attachment



Support Structure and Attachment

Support Structure and Attachment

Hardware and Components

Hardware and Components

Hardware and Components

Hardware and Components

Equipment, conduit, and wiring installed according to plans

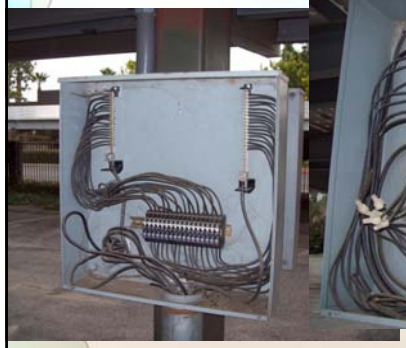
- Check that wiring is consistent with callouts on plans (number and type of modules, correct fuses)
- Check that cable and conduit is properly supported
- Where plug connectors are used for module wiring, inspect a sample of the connections to make sure that connectors are fully engaged

Correct Fuses

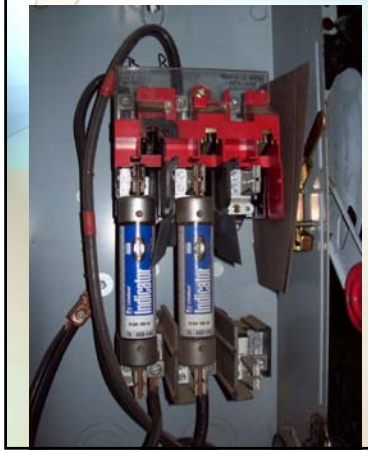
Correct Fuses

Correct Fuses ??

Correct Fuses ??

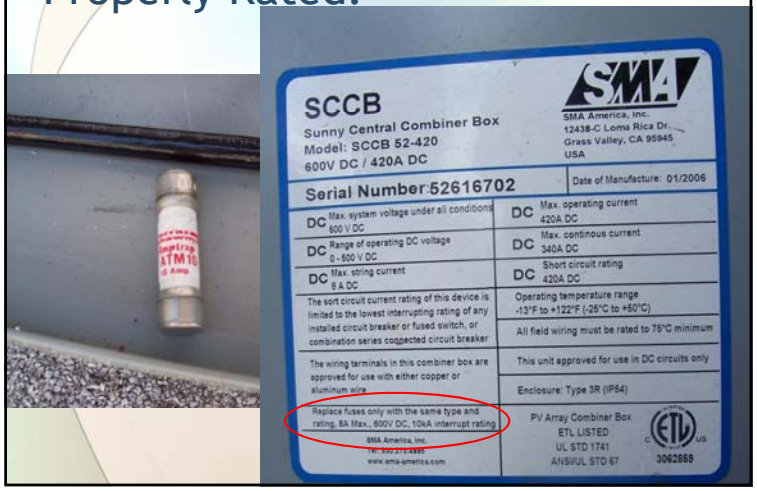


Correct Fuses and Terminals ?



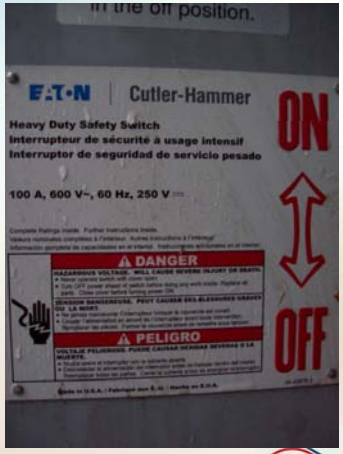
Properly Rated?

Properly Rated?



Properly Rated Disconnects and Inverters

Properly Rated Disconnects and Inverters

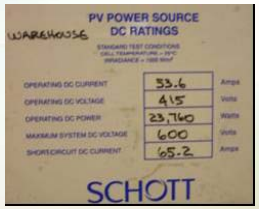


Properly Rated Disconnects and Inverters

Properly Rated Conductors

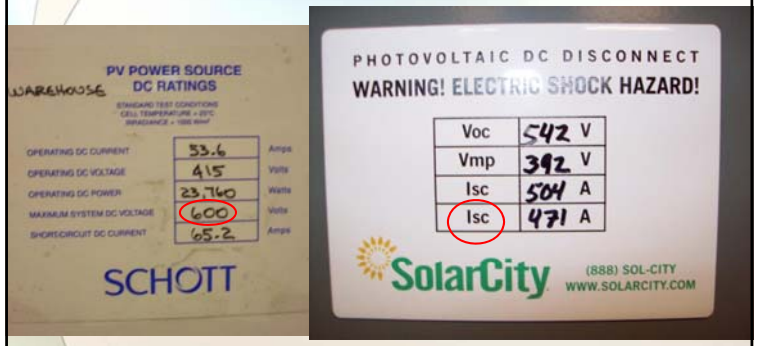
Appropriate signs installed

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

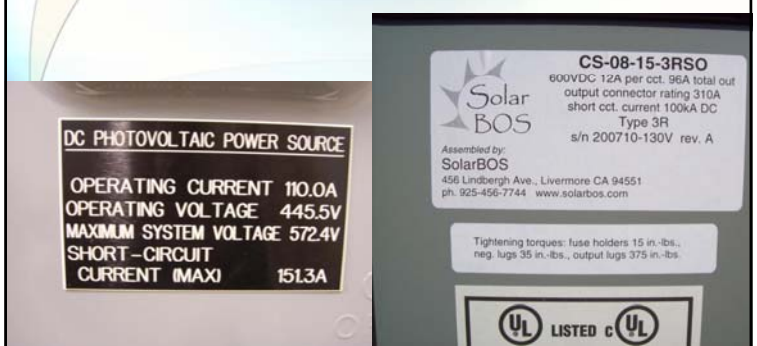


Signs and Labels

Signs and Labels



Signs and Labels

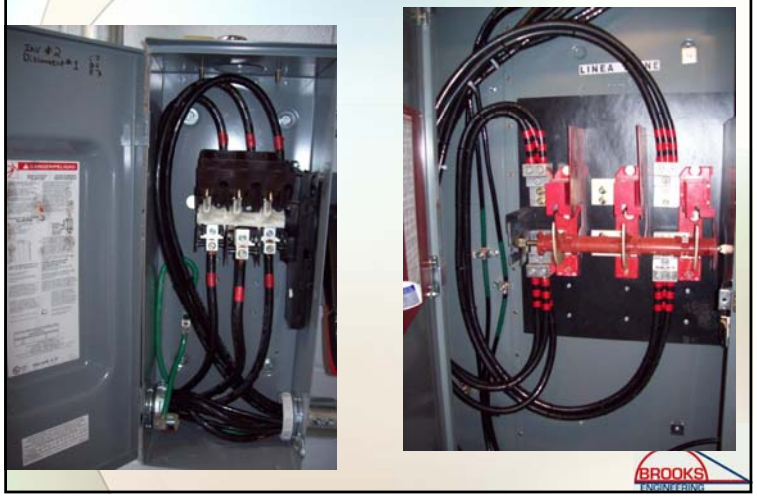


Signs and Labels

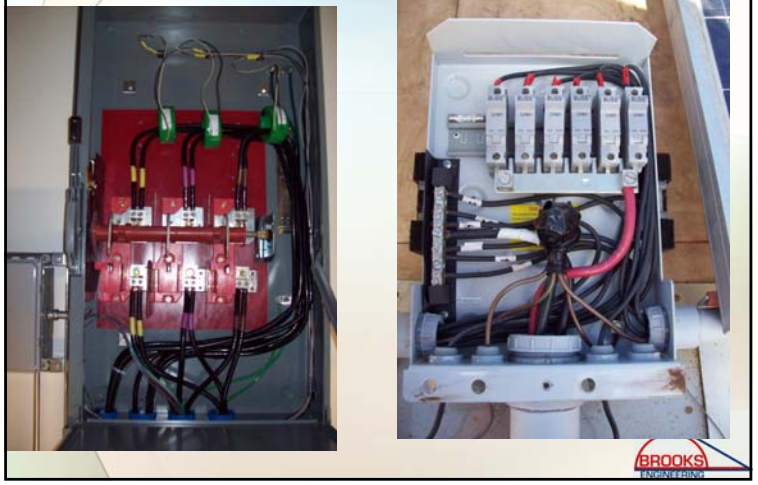
Signs and Labels

Signs and Labels

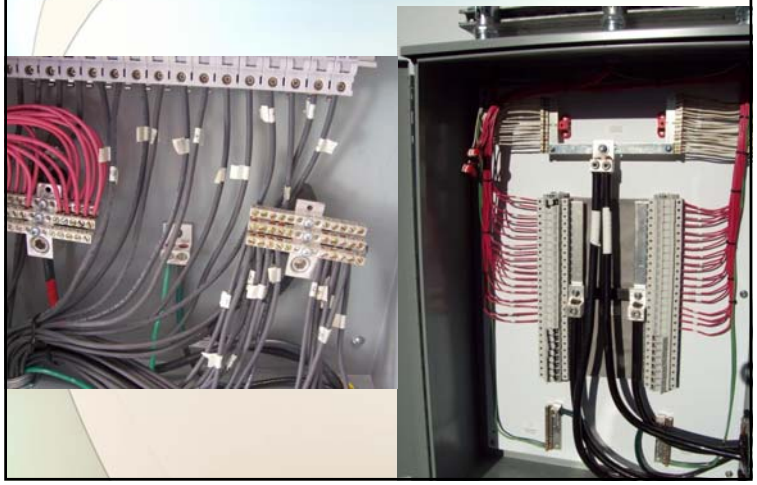
Guts—show and tell



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


Nice Work
BROOKS


Nice Work


Nice Work
BROOKS

Nice Work