Solar PV System Permitting and Inspection

Presented by

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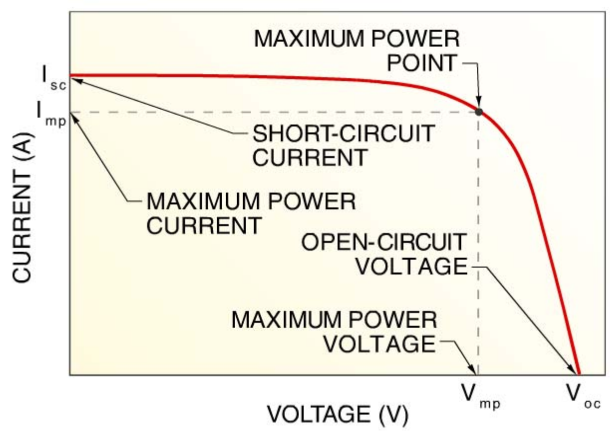
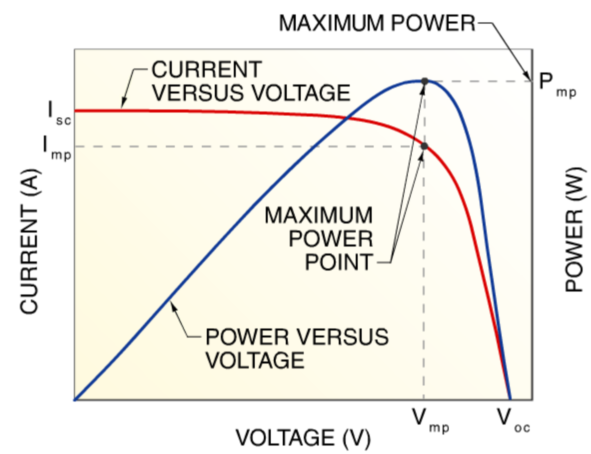
Photovoltaic System
Basics

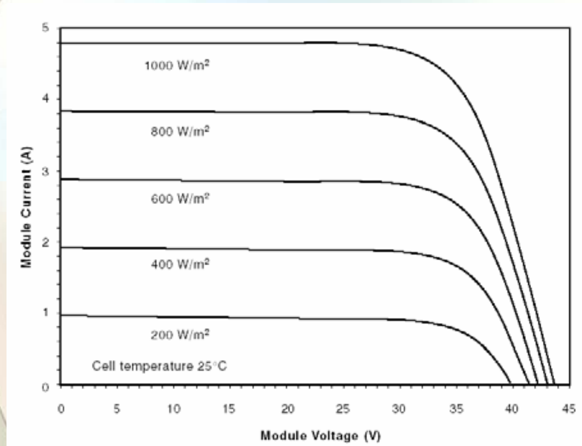
I-V Curve



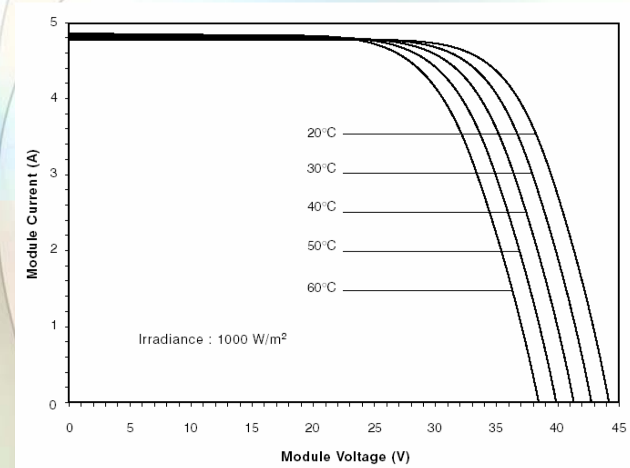
I-V Curve with Power



Current varies with irradiance



Voltage varies with temperature



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)

Expedited Permit Process
for Small-Scale PV Systems

Revised Version Recently Updated:

www.solarabcs.org/permitting

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 designed for local conditions)
- *If No due to non-compliant roof or ground mount, submit completed worksheet for roof structure WKS1.*

WKS1

- 1. Roof construction: l **Rafters I Trusses**
- 2. Describe site-built rafter or or site-built truss system.
- a. Rafter Size: ___ x ___ inches
- b. Rafter Spacing: ________ inches
- c. Maximum unsupported span: _____ feet, _____ inches
- d. Are the rafters over-spanned? (see the IRC span tables in **B.2.) I Yes I No**
- e. If *Yes, complete the rest of this section.*

B.2 Span Tables

- A framing plan is required only if the combined weight of the PV array exceeds 5 pounds per square foot (PSF) or the existing rafters are over-spanned. The following span tables from the 2009 International Residential Code (IRC) can be used to determine if the rafters are over-spanned. For installations in jurisdictions using different span tables, follow the local tables.

Span Table R802.5.1(1),

Use this table for rafter spans that have conventional light-weight dead loads and do not have a ceiling attached.

10 PSF Dead Load Roof live load = 20 psf, ceiling not attached to rafters, L/Δ=180							
Rafter Size			2 x 4	2 x 6	2 x 8	2 x 10	2 x 12
Spacing (inches)	Species	Grade	The measurements below are in feet-inches (e.g. 9-10 = 9 feet, 10 inches)				
16	Douglas Fir-larch	#2 or better	9-10	14-4	18-2	22-3	25-9
16	Hem-fir	#2 or better	9-2	14-2	17-11	21-11	25-5
24	Douglas Fir-larch	#2 or better	8-0	11-9	14-10	18-2	21-0
24	Hem-fir	#2 or better	7-11	11-7	14-8	17-10	20-9

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.*

Example 1: Standard String Inverter System

Step 1: Structural Review of PV Array Mounting System

Is the array to be mounted on a defined, permitted roof structure? ☒ **Yes** ☐ **No**
If No due to non-compliant roof or a ground mount, submit completed worksheet for the structure WKS1.

Roof Information:

1. Is the roofing type lightweight (Yes = composition, lightweight masonry, metal, etc...)
Yes— composition
If No, submit completed worksheet for roof structure WKS1 (No = heavy masonry, slate, etc...).
2. If a composition shingle roof, does the roof have a single roof covering? ☒ **Yes** ☐ **No**
If No, submit completed worksheet for roof structure WKS1.
3. Provide method and type of weatherproofing roof penetrations (e.g. flashing, caulk).
flashing____

Mounting System Information:

1. Is the mounting structure an engineered product designed to mount PV modules, with no more than an 18" gap beneath the module frames? ☒ **Yes** ☐ **No** *If No, provide details of structural attachment certified by a design professional.*
2. For manufactured mounting systems, fill out information on the mounting system below:
   a. Mounting System Manufacturer OmniRack Product Name and Model# ModMount 2.0
   b. Total Weight of PV Modules and Rails 1124 lbs
   c. Total Number of Attachment Points 34
   d. Weight per Attachment Point (b ÷ c) 33 lbs (if greater than 45 lbs, see WKS1)
   e. Maximum Spacing Between Attachment Points on a Rail 48 inches (see product manual for maximum spacing allowed based on maximum design wind speed)
   f. Total Surface Area of PV Modules (square feet) 402 ft^2
   g. Distributed Weight of PV System on Roof (b ÷ f) 2.79 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), 705.12(D)).
5. One of the electrical diagrams (E1.1, E1.1a, E1.1b, E1.1c) can be used to accurately represent the PV system.

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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.

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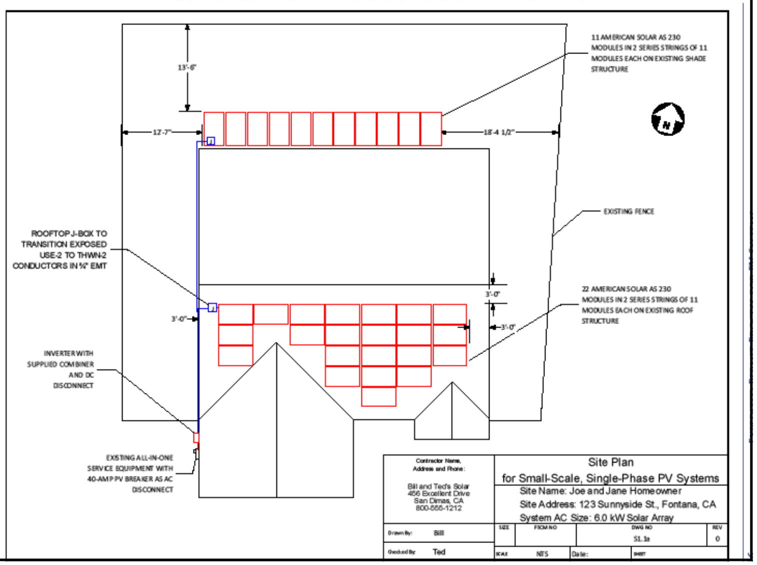
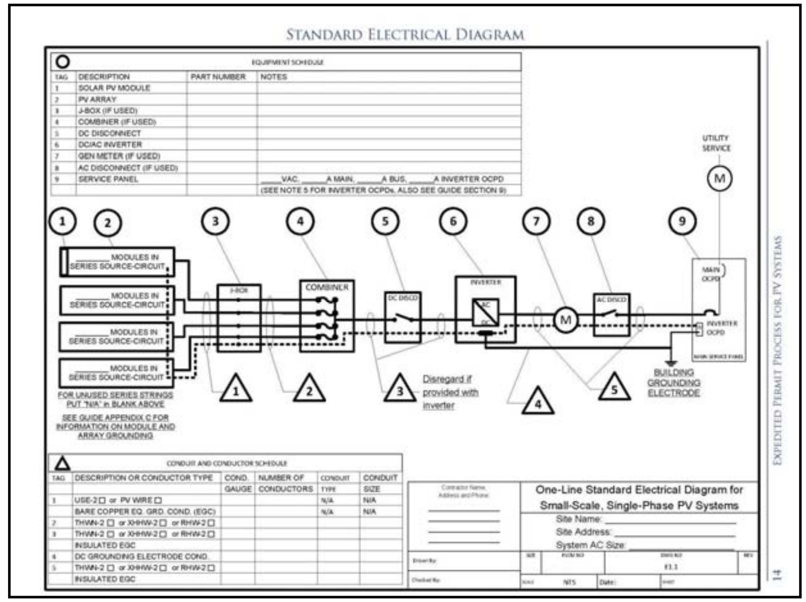
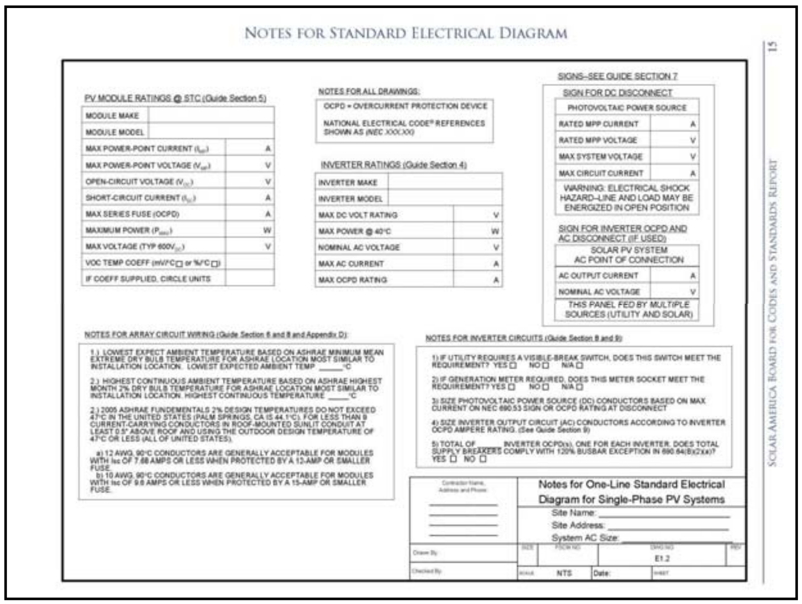
SITE PLAN FOR EXAMPLE 1 - STANDARD STRING INVERTER SYSTEM

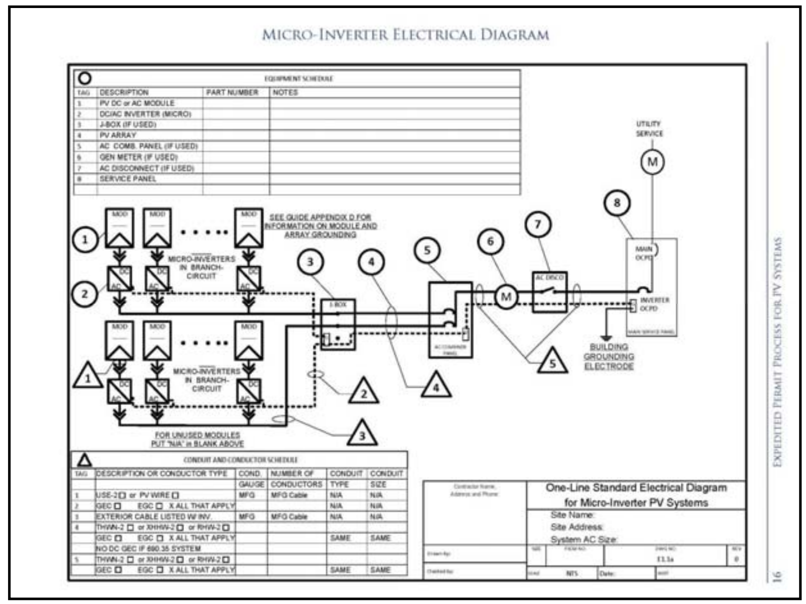


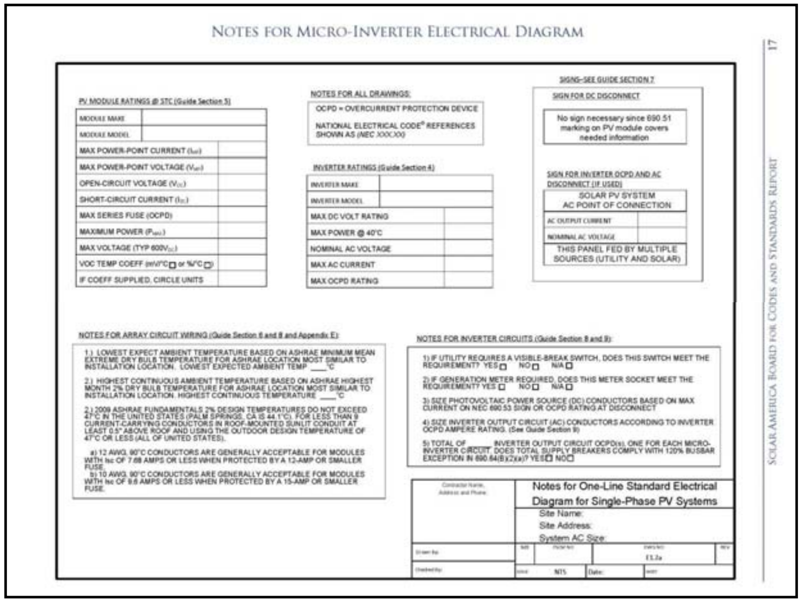
One-line Diagram

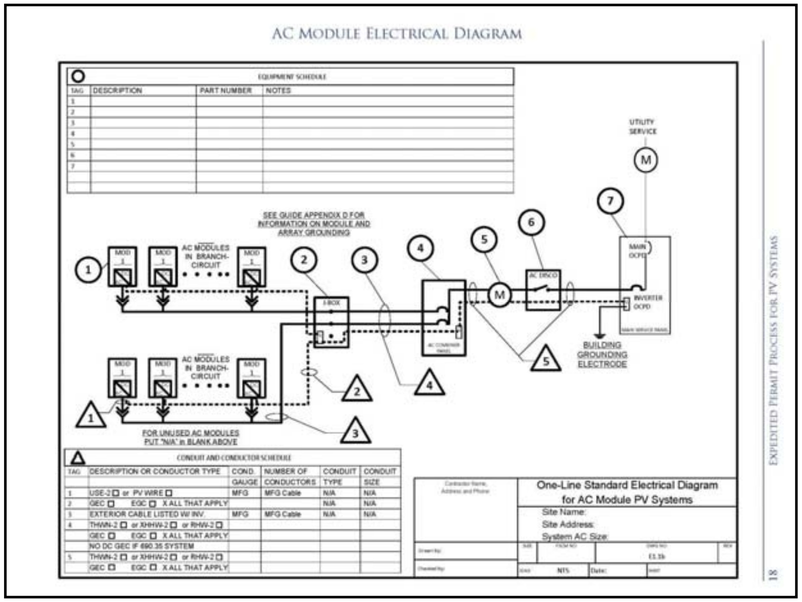
- Should have sufficient detail to call out the electrical components, the wire types and sizes, number of conductors, and conduit type and size where needed.
- Should include information about PV modules and inverter(s).
- Should include information about utility disconnecting means (required by many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

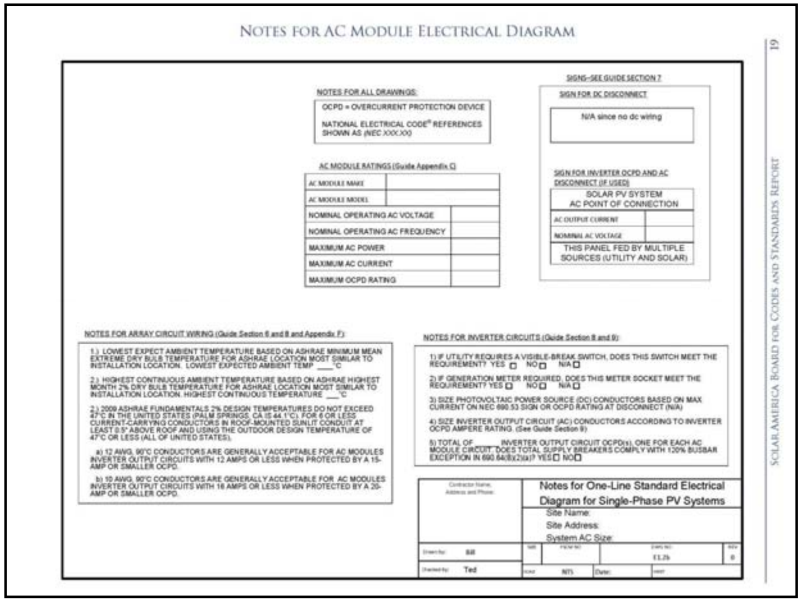


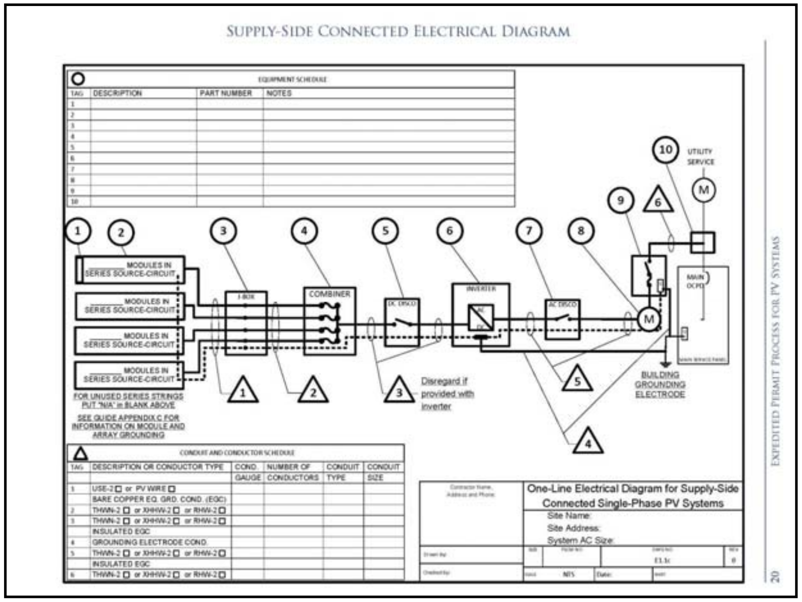





Notes for Micro-Inverter Electrical Diagram


AC Module Electrical Diagram


Notes for AC Module Electrical Diagram


Supply-Side Connected Electrical Diagram

iii) MAXIMUM SYSTEM VOLTAGE [NEC 690.7]

Explanation: Maximum system voltage is calculated by multiplying the value of Voc on the listing label by the appropriate value on Table 690.7 in the NEC, and then multiplying that value by the number of modules in a series string. The table in the NEC is based on crystalline silicon modules and uses lowest expected ambient temperature at a site to derive the correction factor. Some modules do not have the same temperature characteristics as crystalline silicon so the manufacturer's instructions must be consulted to determine the proper way to correct voltage based on lowest expected ambient temperature. As of the 2008 NEC, the manufacturer's temperature correction factor must be used for all modules, regardless of construction, if the information is supplied. All known listed modules currently provide this information.

From the example in Appendix A:

Module V_{OC} = 37.0 Volts

Rating temperature = 25°C

Number of Modules in Series = 11

Lowest expected ambient temperature (ASHRAE) = 1°C (Ontario, California)

Maximum System Voltage = V_{MAX} = V_{OC} x # of Modules in Series x Temperature Correction Factor

Method 1— Module Manufacturer's Temperature Correction Factor—Percentage Method

Temperature Coefficient for V_{OC} = αV_{OC} = -0.37%/C = -0.0037/C

Temperature Correction Factor = 1 + α VOC (%) x (TempLOW - TempRATING)

= 1 + (-0.0037/C) x (-1°C - 25°C)

= 1 + 0.0962 = 1.0962

V_{MAX} = 37V x 11 x 1.0962 = 446 Volts < 500Volts (compliant for a 500V_{MAX} inverter)

Method 2— Module Manufacturer's Temperature Correction Factor—Voltage Method

Temperature Coefficient for V_{OC} = αV_{OC} = 137mV/C = 0.137 V/C

Temperature Correction Factor = 1 + [αVOC (V) x (TempLOW - TempRATED) ÷ VOC]

= 1 + [0.137 V/C x (-1°C - 25°C) ÷ 37V]

= 1 + [5.206V ÷ 37V] = 1.0963

V_{MAX} = 37V x 11 x 1.0963 = 446 Volts < 500Volts (compliant for a 500V_{MAX} inverter)

Method 3—Table 690.7 Temperature Correction Factor

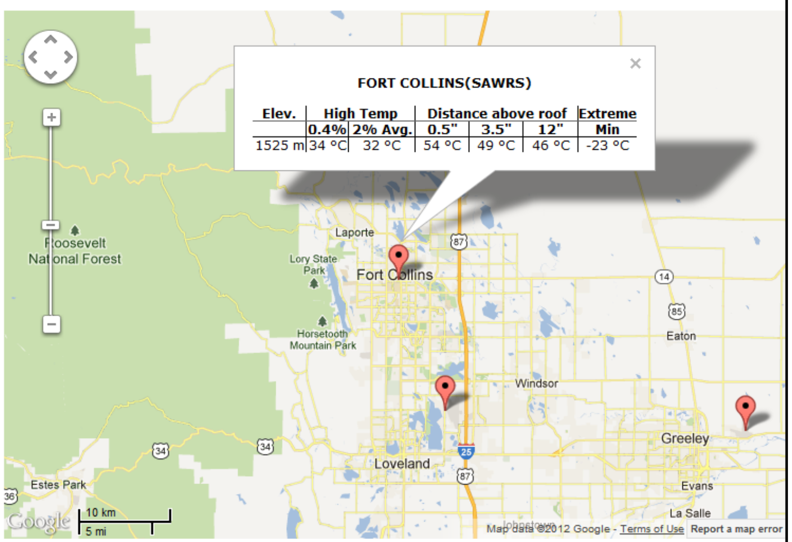
From row for ambient temperature = -1°C to -5°C 1.12

V_{MAX} = 37V x 11 x 1.12 = 456 Volts < 500Volts (compliant for a 500V_{MAX} inverter)

ASHRAE Temperature Data

CA	SAN LUIS CO RGNL	66	32	28	50	45	42	-2
CA	SANDBERG	1379	35	32	54	49	46	-5
CA	SANTA BARBARA MUNICIPAL AP	6	29	26	48	43	40	-1
CA	SANTA MARIA PUBLIC ARPT	73	29	25	47	42	39	-3
CA	SANTA ROSA (AWOS)	45	38	34	56	51	48	-3
CA	STOCKTON METROPOLITAN ARPT	8	41	38	60	55	52	-3
CA	TRAVIS AFB/FAIRFLD	18	40	36	58	53	50	-3
CA	TRUCKEE-TAHOE	1798	34	30	52	47	44	N/A
CA	TUSTIN MCAF	17	34	31	53	48	45	2
CA	UKIAH MUNICIPAL AP	191	41	37	59	54	51	-3
CA	VISALIA MUNI (AWOS)	89	39	37	59	54	51	-3
CO	AKRON WASHINGTON CO AP	1409	38	34	56	51	48	-23
CO	ALAMOSA SAN LUIS VALLEY RGNL	2299	32	29	51	46	43	-30
CO	ASPEN PITKIN CO SAR	2444	32	28	50	45	42	-24
CO	BUCKLEY ANGB/DENVER	1726	36	33	55	50	47	-22
CO	COLORADO SPRINGS MUNI AP	1881	35	32	54	49	46	-23
CO	CORTEZ/MONTEZUMA CO	1803	37	34	56	51	48	-19
CO	CRAIG-MOFFAT	1915	35	31	53	48	45	-31
CO	DENVER INTL AP	1655	37	34	56	51	48	-23
CO	DENVER STAPLETON INTL ARPT	1611	36	34	56	51	48	-25
CO	DENVER/CENTENNIAL	1793	36	33	55	50	47	-23
CO	DURANGO/LA PLATA CO	2038	34	32	54	49	46	-21
CO	EAGLE COUNTY AP	1992	33	30	52	47	44	-28
CO	FORT COLLINS (AWOS)	1529	38	34	56	51	48	-23
CO	FORT COLLINS(SAWRS)	1525	34	32	54	49	46	-23
CO	GRAND JUNCTION WALKER FIELD	1475	39	36	58	53	50	-17
CO	GREELEY/WELD (AWOS)	1420	38	35	57	52	49	-27

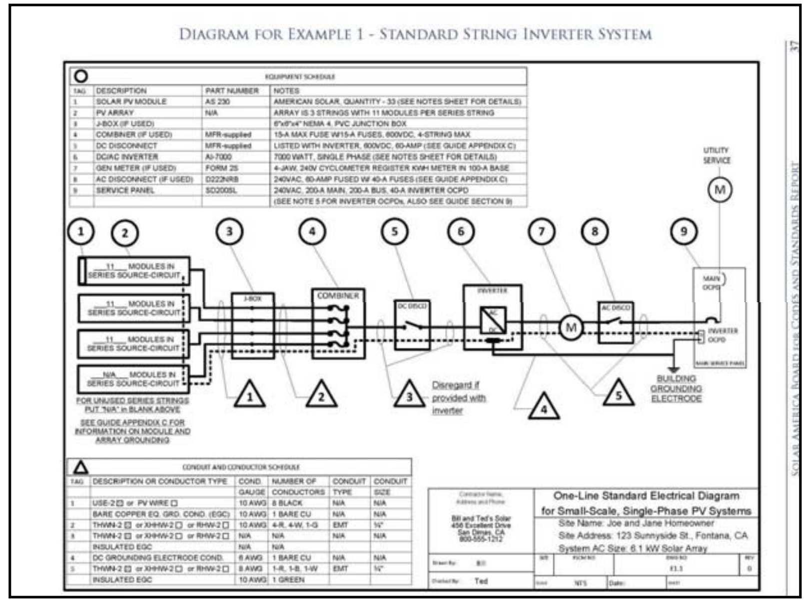
Search near (City, State): Fort Collins, CO Submit

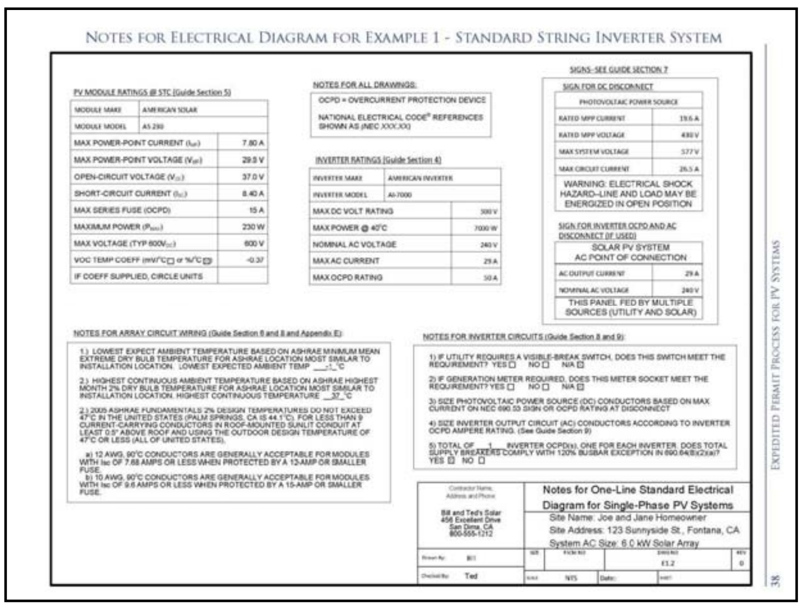


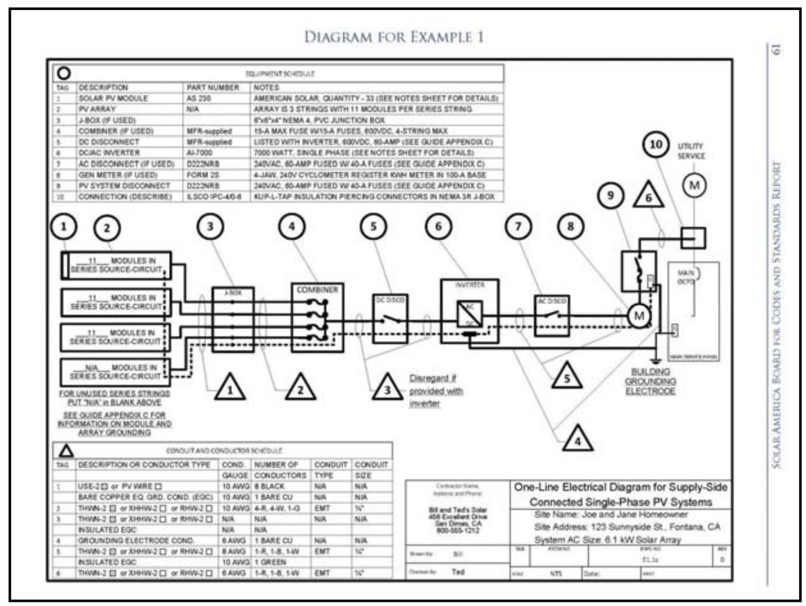
Conductor Sizing Chart for Hottest U.S. Climate						
For Sunlit Raceway 0.5"-3.5" from Roof and Max 2% Design Temp - 47°C						
80% Duty Fuses		100% Duty Fuses		Minimum Conductor Size in Raceway		
Fuse Size	Max Rated ISC	Fuse Size	Max Rated ISC	Based on # of Cond. in Raceway (AWG)		
Amps	Amps	Amps	Amps	8 conductors	4-6 cond.	2 cond.
10	6.4	10	8	14	14	14
12	7.68	12	9.6	12	14	14
15	9.6	15	12	10	10	14
20	12.8	20	16	10	10	12
25	16	25	20	8	8	10
30	19.2	30	24	6	8	8
35	22.4	35	28	6	68	
40	25.6	40	32	4	4	6
45	28.8	45	36	3	4	6
50	32	50	40	2	3	4
60	38.4	60	48	2	3	4
70	44.8	70	56	1	2	3
80	51.2	80	64	2/O	1/O	2
90	57.6	90	72	3/O	2/O	1
100	64	100	80	3/O	2/O	1/O
110	70.4	110	88	4/O	3/O	2/O
125	80	125	100	250MCM	4/O	2/O
150	96	150	120	300MCM	250MCM	3/O
175	112	175	140	400MCM	350MCM	4/O
200	128	200	160	2-3/O	400MCM	300MCM
225	144	225	180	2-4/O	500MCM	350MCM
250	160	250	200	2-250MCM	2-4/O	500MCM
300	192	300	240	2-300MCM	2-250MCM	600MCM
350	224	350	280	2-400MCM	2-350MCM	700MCM
400	256	400	320	2-500MCM	2-400MCM	1000MCM

TABLE OF NEC 690.64(B) AC INTERCONNECTION OPTIONS

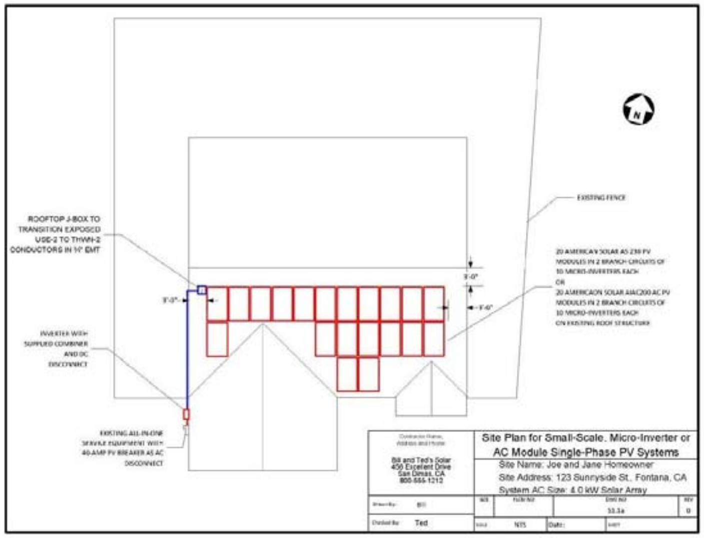
Maximum Inverter Current	Required Inverter OCPD Size	Minimum Conductor Size in Conduit	Minimum Busbar/Main Breaker Combinations (Busbar Amps/Main Amps)
64 Amps	80 Amps	4 AWG	400/400; 200/150
56 Amps	70 Amps	4 AWG	225/200; 250/225
48 Amps	60 Amps	6 AWG	300/300; 200/175
40 Amps	50 Amps	8 AWG	125/100; 150/125
36 Amps	45 Amps	8 AWG	225/225
32 Amps	40 Amps	8 AWG	200/200
24 Amps	30 Amps	10 AWG	150/150
16 Amps	20 Amps	12 AWG	100/100; 70/60
12 Amps	15 Amps	14 AWG	80/80



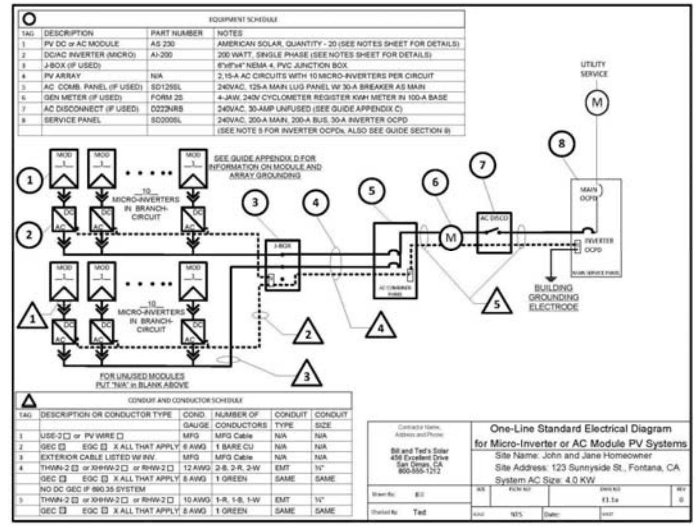




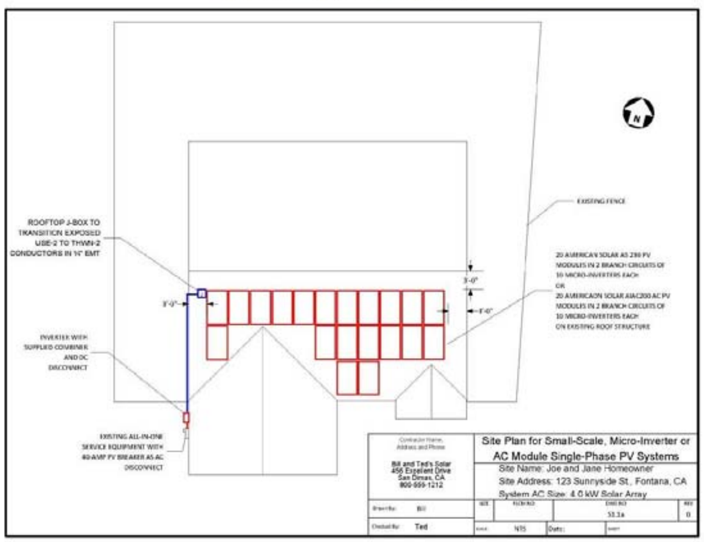
Site Plan for Example 2 - Micro-Inverter



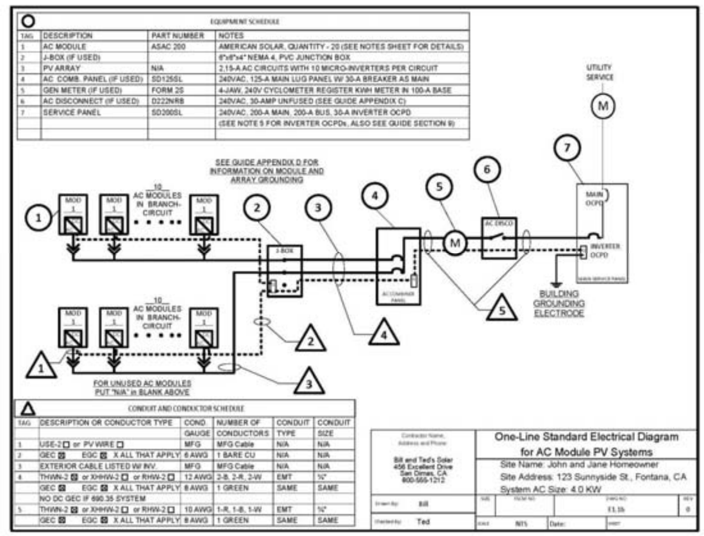
Electrical Diagram for Example 2 - Micro-Inverter



Site Plan for Example 3 - AC Module



Electrical Diagram for Example 3 - AC Module



Field Inspection

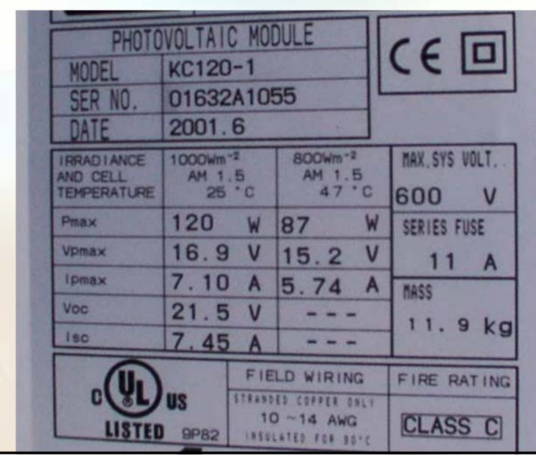
Section 1. Field Inspection Checklist for Array:

- 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



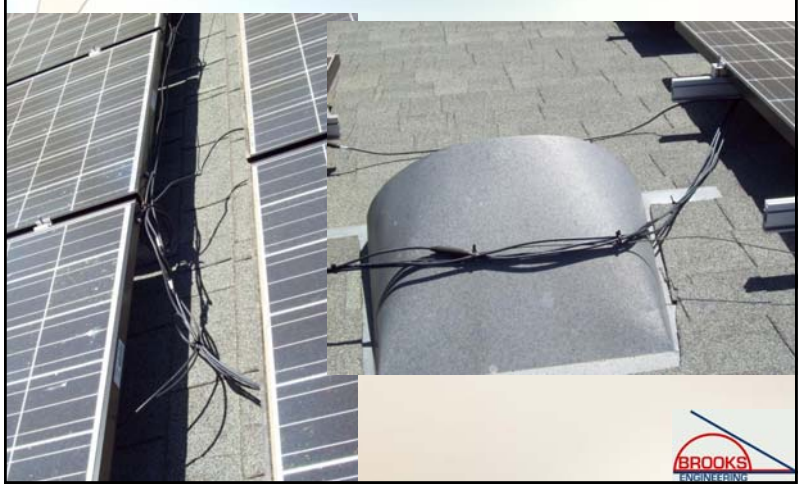
Common Installation Mistakes with Array Modules and Configurations

- 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—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

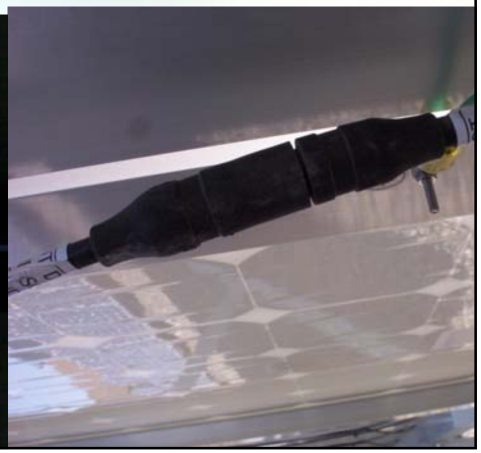
Common Installation Mistakes with Wire Management—cont.

- 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 count the bad ideas

Wire Management —wire bending radius

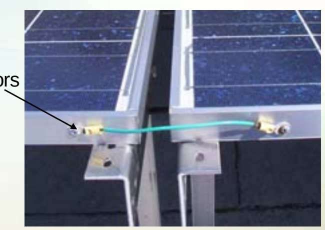
Wire Management—plug engagement



Wire Management—Follow structural members & What the…?

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.



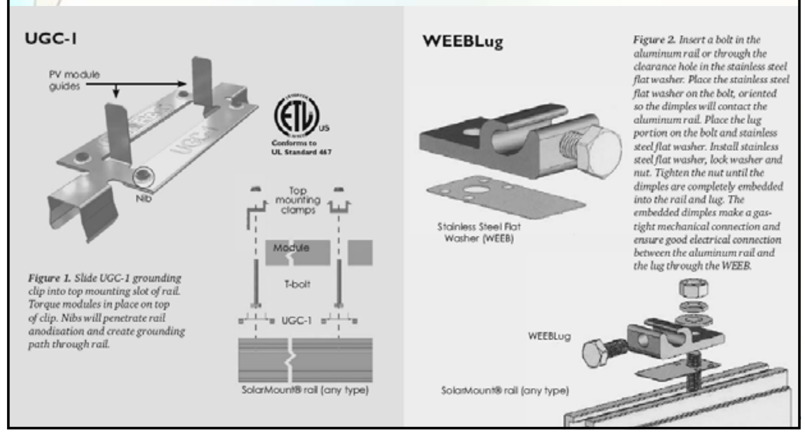
Module bonding and grounding methods

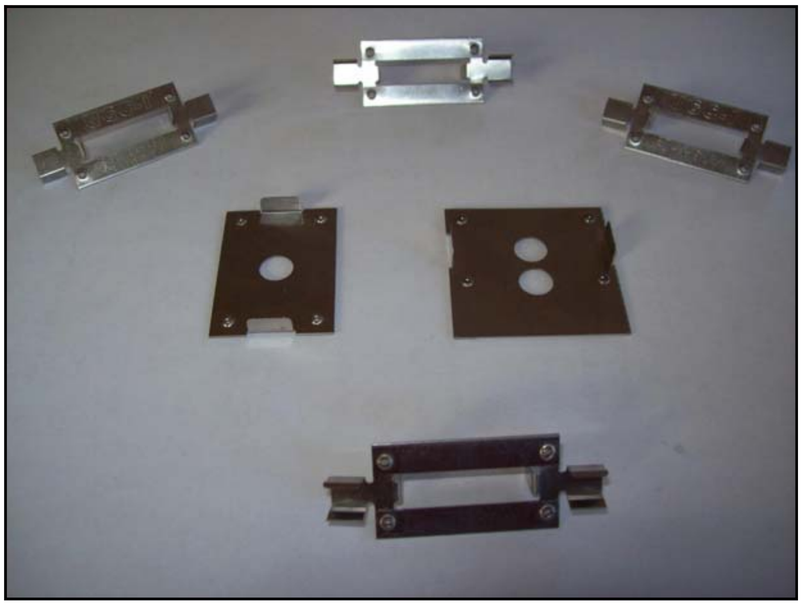
- 1. Some modules are designed to be grounded using a stainless-steel thread-forming screw threaded into the module frame holding the EGC at a grounding symbol. An isolating washer, such as a stainless cup washer is often used to isolate the copper conductor from the aluminum frame to prevent galvanic 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

Notice slight gap caused by properly installed clip.

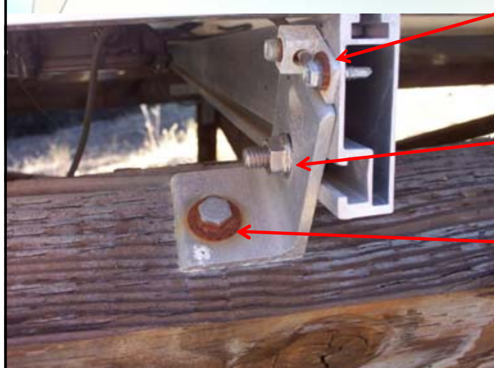
Common Installation Mistakes with Module and Array Grounding

- 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.

Nice Lugs! (poor fasteners)

Improper Cad Tek screw used to hold lug

Grounding Hardware and Components



Indoor lug and Tek screw

Stainless hardware looks like new

Galvanized washer showing galvanic corrosion with aluminum contact

Improper Connections

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

Dry wirenut and not in a j-box

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

Ratings and locations of Combiner Boxes

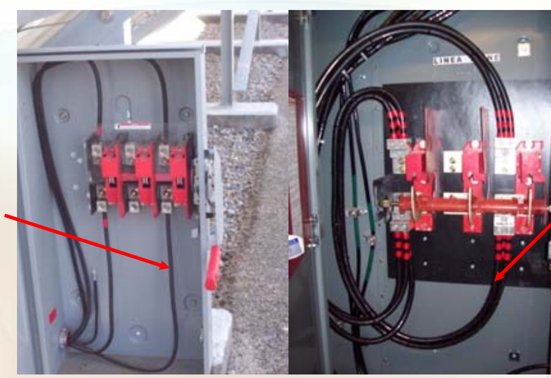
NEMA 4 Combiner Box with disconnect built-in. Designed for horizontal or vertical mounting

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

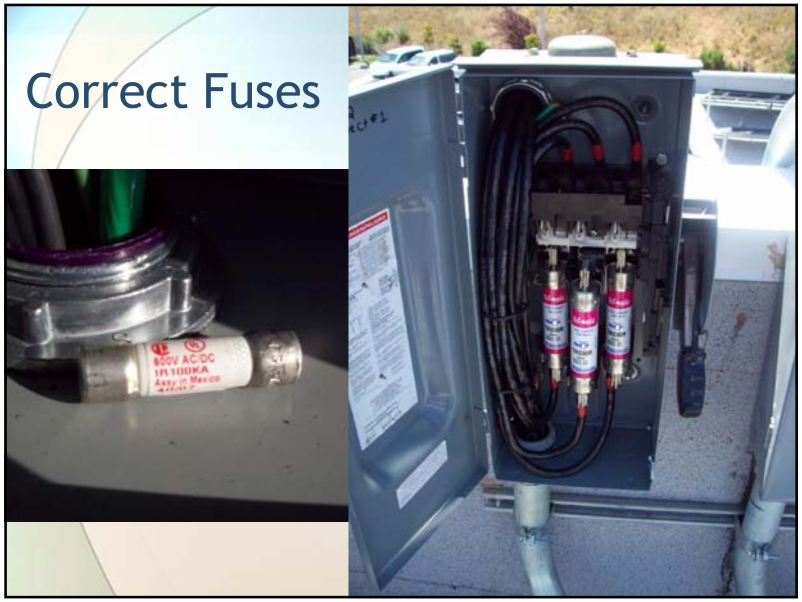
- 1. Installing disconnects rated for vertical installation in a non-vertical application.
- 2. Installing improperly rated fuses in source combiners and fused disconnects.
- 3. Covering boxes or conduit bodies making them nearly inaccessible for service.
- 4. Not following manufacturer's directions 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.

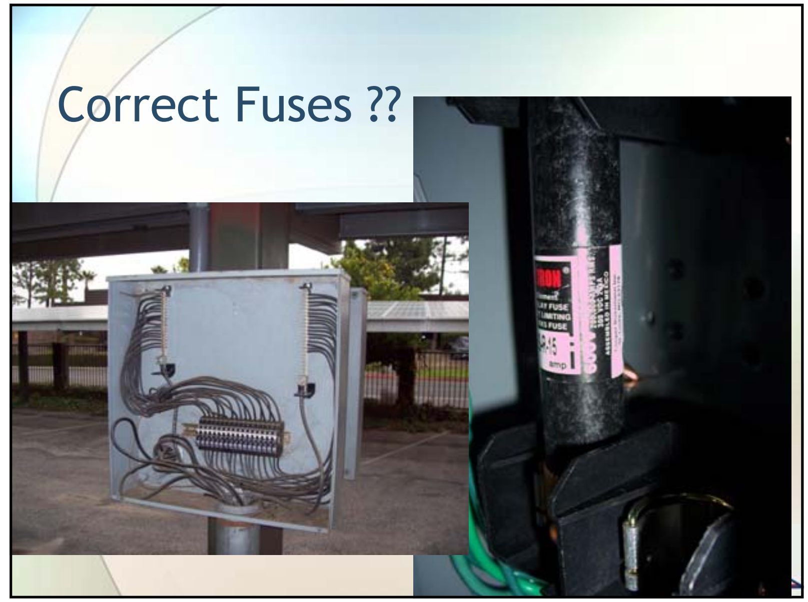
Many disconnects like these require the ungrounded conductor to be broken twice in series to get the 600Vdc rating

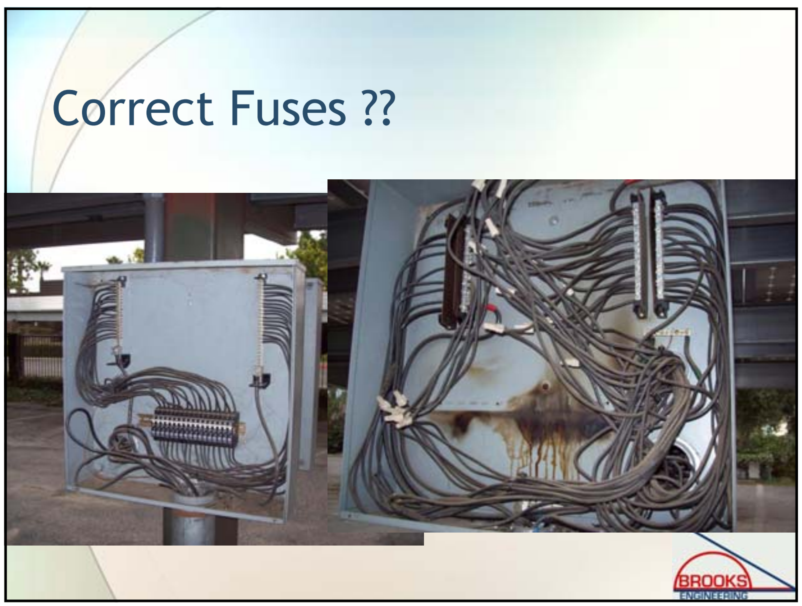
Incorrect Breaking of grounded conductor

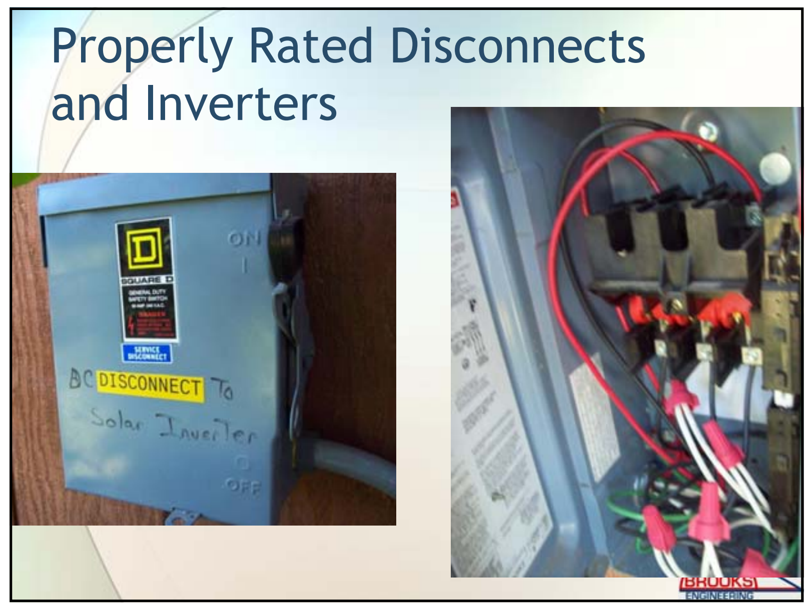


Correct


Correct Fuses
600V AC/DC
IR 100KA


Correct Fuses ??

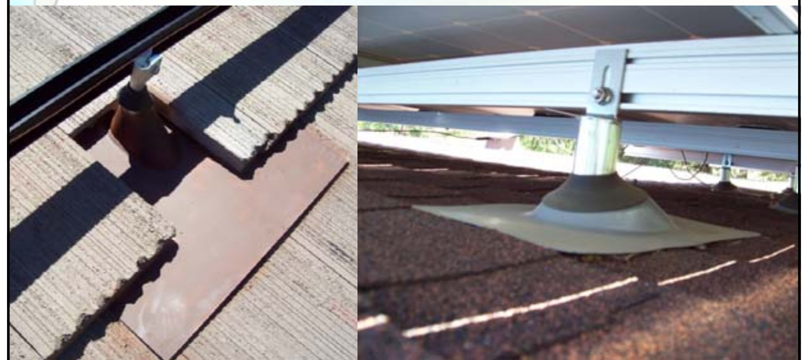

Correct Fuses ??
BROOKS


Properly Rated Disconnects and Inverters
SQUARE D
DC DISCONNECT To
Solar Inverter
ON
OFF

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

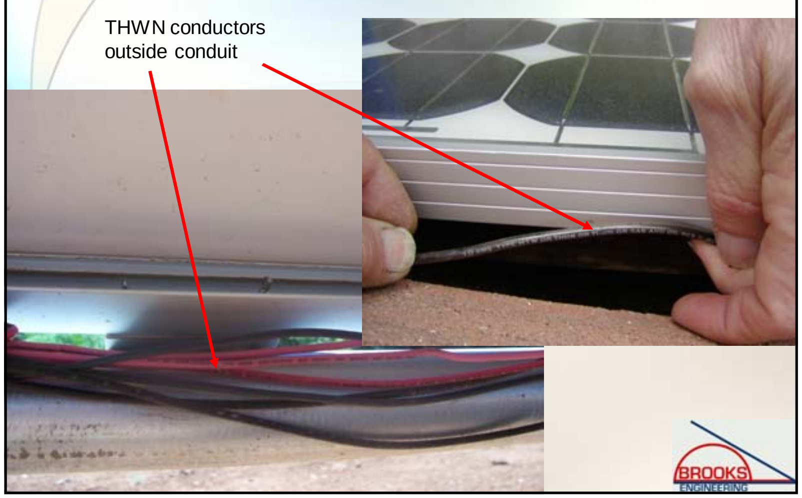
- Exposed Array Conductors—The only single-conductor cables allowed in 690.31(B) are USE-2 and PV Wire (Cable).
- Conductors in raceways on rooftops—Table 310.15(B)(2)(a) adds an additional 14°C-30°C to the ambient temperature. These high temperatures nearly always limit ampacity below the terminal temperature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

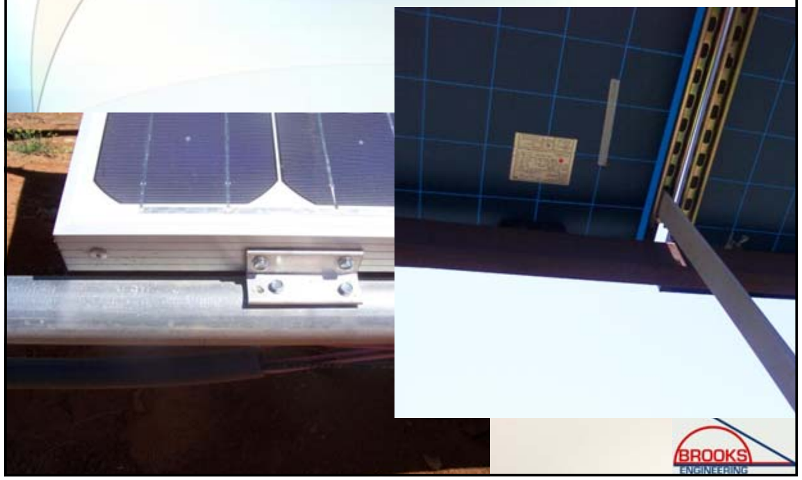
Improperly Rated Conductors



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



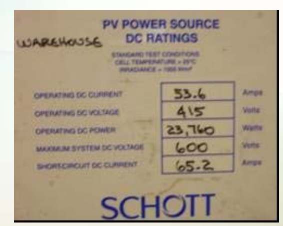
Readily accessible or not?

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

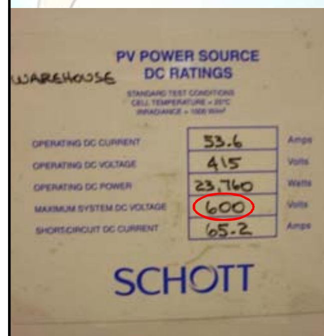
- Sign construction
- Photovoltaic Power Source
- AC point of connection
- alternative power system

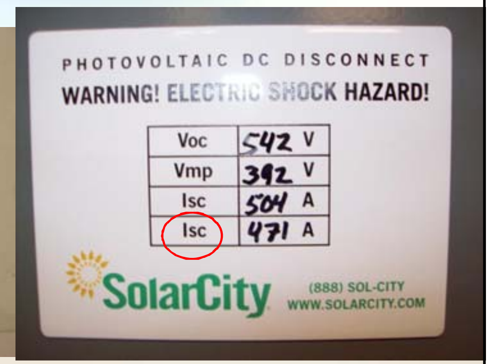


Sign Construction

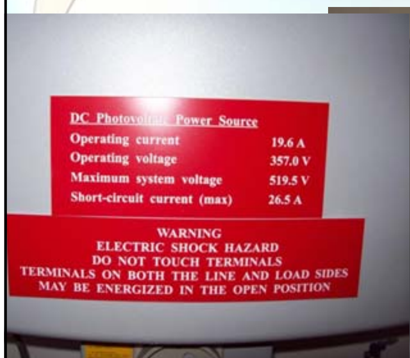
- The NEC is not extremely specific about what signs should be made of.
- NEC 110.21 states, “The marking shall be of sufficient durability to withstand the environment involved.”
- Electrical industry standards for outdoor signs is that signs should be metal or plastic with engraved or machine printed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



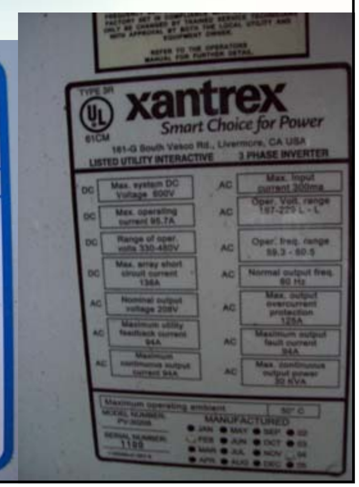
Signs and Labels

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

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 – IBC, IRC, ASCE 7, IFC
- 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

690.3 Other Articles

- The requirements of Chapters 1 thru 4 apply to PV installations, except as modified by Article 690.

NEC Sections Commonly 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 overview

Key Code References and Summary of 2011 Updates

- Numerous updates to the 2011 NEC for Article 690. Most are editorial in nature.
- Routing and identification requirements for conductors.
- Series Arc Fault detectors required above 80 volts.
- 690.64 moved to 705.12(D)

Part II. Circuit Requirements

104

690.7 Maximum System Voltage

- Note: A statistically valid source for lowest-expected ambient temperature is the Extreme Annual Mean Minimum Design Dry Bulb Temperature found in the ASHRAE Handbook — Fundamentals [2011].—available at www.solarabcs.org/permitting

BROOKS ENGINEERING 105

Correction Factors for Ambient Temperatures Below 25°C (77°F). (Multiply the rated open circuit voltage by the appropriate correction factor shown below.)

Ambient Temperature (°C)	Factor	Ambient Temperature (°F)
24 to 20	1.02	76 to 68
19 to 15	1.04	67 to 59
14 to 10	1.06	58 to 50
9 to 5	1.08	49 to 41
4 to 0	1.10	40 to 32
−1 to −5	1.12	31 to 23
−6 to −10	1.14	22 to 14
−11 to −15	1.16	13 to 5
−16 to −20	1.18	4 to −4
−21 to −25	1.20	−5 to −13
−26 to −30	1.21	−14 to −22
−31 to −35	1.23	−23 to −31
−36 to −40	1.25	−32 to −40

- Vmax = Module Voc x Table 690.7 C.F. x # Modules per String
- PV Vmax = 37 Voc x 1.14 x 14
- PV Vmax = 591 Voc

BROOKS ENGINEERING 107

- *Vmax = Rated Voc × {1+[(Min. Temp.ºC - 25ºC)×Coeff%/ºC]}× # Modules*
- Vmax =37Vx{1+[(-7ºC-25ºC)x-.32%/ºC]}x14
- Vmax =37Vx{1+[(-32ºC) x -0.32%/ºC]} x 14
- Vmax = 37V x {1 + 10.24%} x 14
- Vmax = 37 V x {1.1024} x 14
- Vmax = 40.79V x 14
- Vmax = 571 Voc

BROOKS ENGINEERING 108

690.8 Circuit Sizing and Protection

109

690.8(B) Overcurrent Protection

- PV circuit overcurrent, *when required*, must be sized to carry not less than 125 percent of 690.8(A) calculated current.

110

690.8 Circuit Sizing and Protection

- (B)(2)(a) Circuit conductors must be sized to carry 125% of the maximum current as calculated in 690.8(A) without conductor adjustment and correction factors of 310.15.

111

690.8 Circuit Sizing and Protection

- (B)(2)(b) Circuit conductors must be sized to carry 100% the maximum current as calculated in 690.8(A) after the application of conductor adjustment and correction of 310.15.

112

690.11 Arc-Fault Circuit Protection

- Photovoltaic dc circuit conductors operating at 80V or greater on buildings must be protected by a series dc arc-fault circuit interrupter.

113

Part III. Disconnecting Means

114

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.

690.15 Disconnection of Photovoltaic Equipment

- A disconnecting means is required for inverters, batteries, and charge controllers from all ungrounded conductors of all sources.

116

690.16(B) Fuse Servicing

- The disconnect must be within sight of or integral with the fuse holder, be externally operable, and plainly indicating whether in the open or closed position.

117

690.17 Switch or Circuit Breaker

- Must have warning sign when line and load can be energized in open position.
- Exception allows connectors to be used as disconnecting means provided they meet the requirements of 690.33. (this completes micro-inverter as a viable option)

118

Part IV. Wiring Methods

119

690.31(E)(1) Beneath Roofs

- PV system conductors are not permitted to be located within 10 in. of roof decking, except below PV equipment.

120

690.31(E)(1) Beneath Roofs

- Note: The 10 in. from the roof decking is to prevent contact to energized conductors from saws used by firefighters for roof ventilation.

BROOKS ENGINEERING 121

690.31(E)(2) Flexible Wiring

- FMC smaller than ¾ or Type MC cable smaller than 1 in. run across ceilings or floor joists must be protected by guard strips as high as the wiring method.

BROOKS ENGINEERING 122

690.31(E)(2) Flexible Wiring

- Where run exposed, other than within 6 ft of their connection to equipment, wiring methods must closely follow the building surface or be protected from physical damage by an approved means.

BROOKS ENGINEERING 123

690.31(E)(4) Marking/Labeling

- The markings must be visible after installation and on every section of the wiring system separated by enclosures, walls, partitions, ceilings, or floors.

BROOKS ENGINEERING 124

690.31(E)(4) Marking/Labeling

- Spacing between labels or markings, or between a label and a marking, must not be more than 10 ft and labels must be suitable for the environment where they are installed.

BROOKS ENGINEERING 125

690.33 Connectors

BROOKS ENGINEERING 126

Article 690.33 [2008 NEC] Connectors

- New language in 690.33(E)
- **“(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.” ”

BROOKS ENGINEERING

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.

BROOKS ENGINEERING

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.

Part V. Grounding

131

690.41 System Grounding

- All systems above 50 Volts must be grounded or follow 690.35.
- Bi-polar systems must have a center-tap ground.

132

690.42 Point of System Grounding Connection

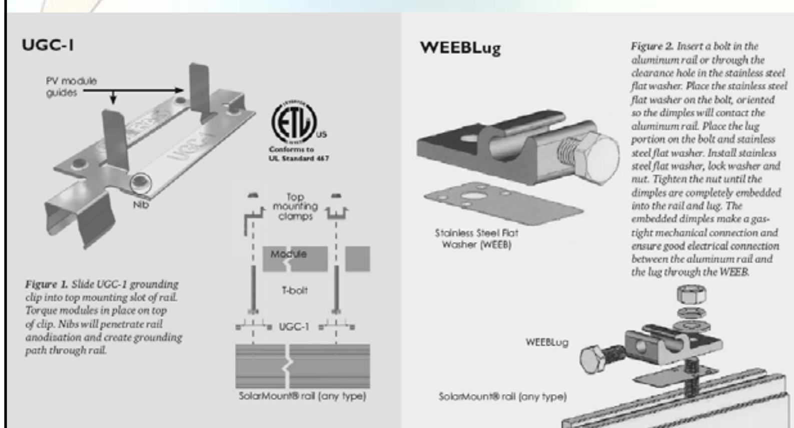
- System grounding point at the ground-fault detection device.

133

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



690.43(C) Structure as Equipment Grounding Conductor

- Metallic mounting racks must be identified as an equipment grounding conductor or have bonding jumpers/devices connected between the separate metallic racks and be connected to an equipment grounding conductor.

136

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."

Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)	Size (AWG or kcmil) Copper	Size (AWG or kcmil) Aluminum or Copper-Clad Aluminum*
15	14	12
20	12	10
60	10	8
100	8	6
200	6	4
300	4	2
400	3	1
500	2	1/0
600	1	2/0

690.47(C) Grounding Electrode System (2011)

(1) Separate dc Grounding Electrode System Bonded to the ac Grounding Electrode System.

- A separate dc grounding electrode shall be bonded directly to the ac grounding electrode system. Bonding jumper(s) between the ac and dc systems shall be based on the larger grounding electrode conductor.

139

690.47(C) Grounding Electrode System (2011)

(2) Common dc and ac Grounding Electrode.

- A dc grounding electrode conductor of the size specified by 250.166 shall be run from the marked dc grounding point to the ac grounding electrode. Where an ac grounding electrode is not accessible, the dc grounding electrode conductor shall be connected to the ac grounding electrode conductor

140

690.47(C) Grounding Electrode System (2011)

(3) Combined DC Grounding Electrode Conductor and AC Equipment Grounding Conductor.

- An unspliced, or irreversibly spliced, combined grounding conductor shall be run from the marked dc grounding point to the grounding busbar in the associated ac equipment. This combined conductor shall be the larger of the sizes specified by 250.122 or 250.166

141

Part VI. Marking

142

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)

Part VII. Other Sources

144

Article 705—Interconnected Electric Power Production Sources

145

705.12 Point of Connection

146

705.12(D) Point of Connection Load Side

- Where this distribution equipment is capable of supplying multiple branch circuits or feeders or both, the interconnecting provisions for the utility-interactive inverter(s) must comply with (D)(1) through (D)(7).

147

705.12(D) Point of Connection Load Side

"(1) Dedicated Overcurrent and Disconnect. Each source interconnection shall be made at a dedicated circuit breaker or fusible disconnecting means."

705.12(D) Point of Connection Load Side

"(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."

705.12(D) Point of Connection Load Side

(3) Ground-Fault Protection. The interconnection point shall be on the line side of all ground-fault protection equipment." Exception-listed for backfeed

(4) Marking. Equipment containing circuits supplying power to a busbar or conductor shall be marked to indicate the presence of all sources.

705.12(D) Point of Connection Load Side

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

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

705.12(D)(7) Inverter Output Connection

- When the sum of the OCPDs supplying power to a panelboard exceeds the bus bar rating as permitted in 705.12(D)(2), a dedicated ac inverter circuit breaker must be located at the opposite end from the input feeder supply conductors.

152

705.12(D)
2014 NEC Revisions

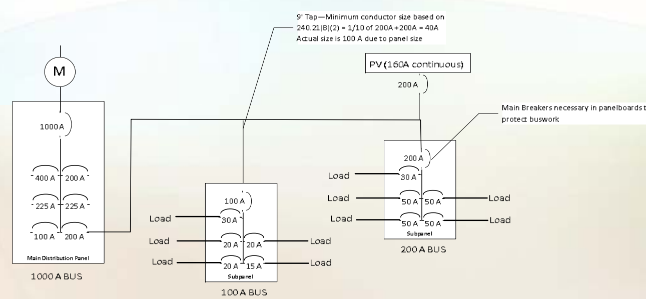
705.12(D) Got overhauled—Load-Side Connections Continue to Confuse Contractors and AHJs

- Busbars and Conductors are lumped together when they needed to be separated. New 705.12(D) creates three categories: 1. Feeders, 2. Taps, and 3. Busbars. Each have different rules since they have different characteristics.

Load Side Connections: Scenario 1

Scenario 1:
- Largest allowable PV system on load side at the opposite end of the primary supply OCPD
- 200-amp feeder
- 9', 100-amp tap to 100-amp subpanel
- Large PV at opposite end of feeder—requires 200-amp connection—size governed by inverter output
- OKAY—Overcurrent protection covers all cases of overcurrent (tap prohibition not required)

Load Side Connections: Scenario 1-OKAY

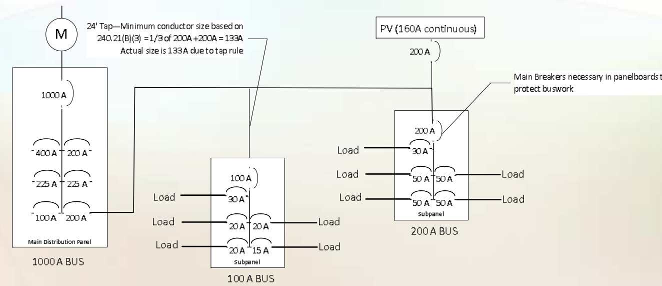


Load Side Connections: Scenario 2

Scenario 2:

- Largest allowable PV system on load side at the opposite end of the primary supply OCPD
- 200-amp feeder
- 24’, 100-amp tap to 100-amp subpanel must be sized for 133A to meet tap rule.
- Large PV at opposite end of feeder—requires 200-amp connection—size governed by inverter output
- OKAY—Overcurrent protection covers all cases of overcurrent (tap prohibition not required)

Load Side Connections: Scenario 2-OKAY

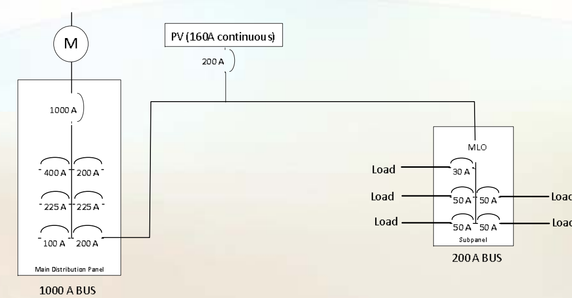


Load Side Connections: Scenario 3

Scenario 3:

- Largest allowable PV system on load side.
- 200-amp feeder
- Large PV requires 200-amp connection—size governed by inverter output
- NOT OKAY since 200-amp feeder and panelboard bus could be overloaded

Load Side Connections: Scenario 3-NOT OKAY

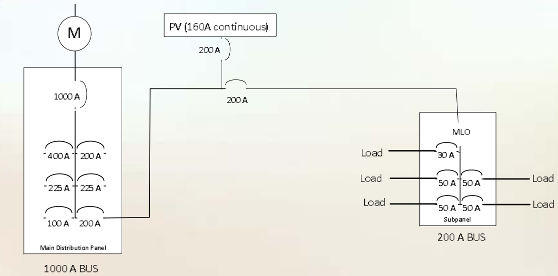


Load Side Connections: Scenario 4

Scenario 4:

- Largest allowable PV system on load side.
- 200-amp feeder
- Large PV requires 200-amp connection—size governed by inverter output
- OKAY—Load-side section of feeder protected with OCPD

Load Side Connections: Scenario 4-OKAY



Load Side Connections: Scenario 5

Scenario 5:

- Largest allowable PV system on load side.
- 200-amp feeder on supply side of U-I inverter, and 400-amp feeder and panelboard on load side
- Large PV requires 200-amp connection—size governed by inverter output
- OKAY—Load-side section of feeder sufficient for both currents

Load Side Connections: Scenario 5-OKAY