Solar Photovoltaic Systems

Presented in Partnership by:

1

Solar Photovoltaic Systems

Developed in Partnership with:

Department of Planning and Development

2

Solar Photovoltaic Systems

3

Solar Photovoltaic Systems

- What is PV?
- Where is it installed?
- Installation requirements

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What is PV?

- **Definition: Solar Photovoltaic System**
- The total components and subsystems that, in combination, convert solar energy into electrical energy suitable for connection to a utilization load

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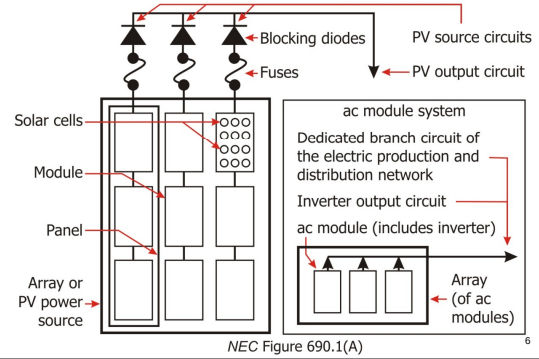
Basic Components of a Solar Photovoltaic System



NEC Figure 690.1(A)

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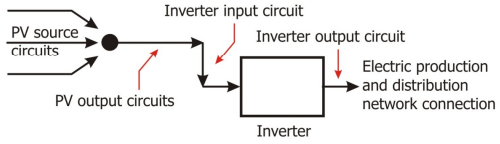
Different Configurations of PV Installations

Interactive System



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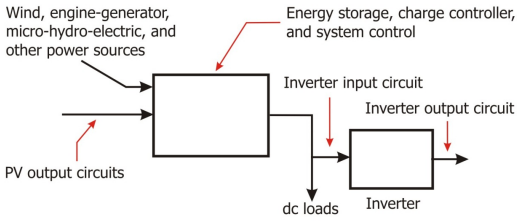
Different Configurations of PV Installations

Hybrid System



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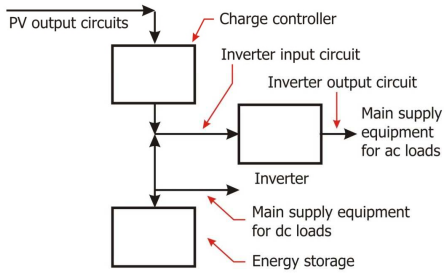
Different Configurations of PV Installations

Stand-Alone System



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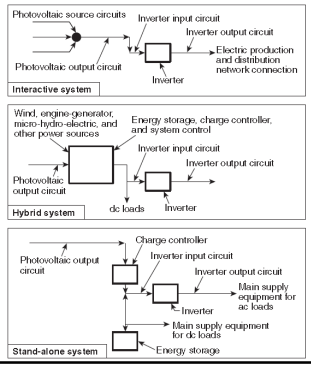
Different Configurations of PV Installations



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Where is PV Installed?

- ***NEC* 690.4(A) Photovoltaic systems**
- Photovoltaic systems shall be permitted to supply a building or other structure in addition to any other electricity supply system(s)

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Residential Rooftops

Photos courtesy of DOE/NREL

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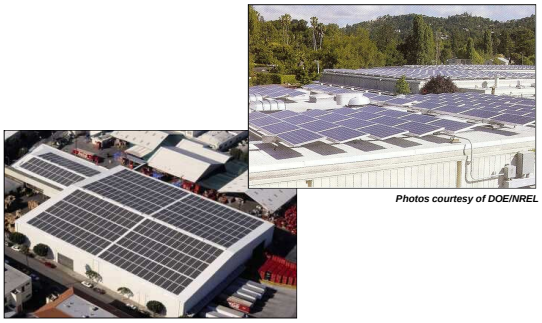
Commercial Rooftops



Photos courtesy of DOE/NREL

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Shade Structures

Photos courtesy of DOE/NREL

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Ground Mounted

Photos courtesy of DOE/NREL

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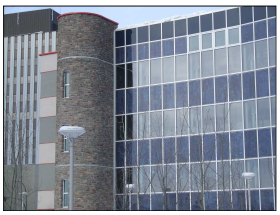
Windows



Photos courtesy of DOE/NREL

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Skylights

Photos courtesy of DOE/NREL

17

Awnings

Photo courtesy of DOE/NREL

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Pole Top Mount

Photos courtesy of DOE/NREL

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Solar Generating Plant

Photo courtesy of DOE/NREL

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PV Installation Concerns

- Utility compatibility and interaction
- Environment
  (e.g. indoor, rainproof, corrosion resistant)
- Maximum number of modules
- Fire exposure ratings
- Location on roof
- Effect on roof covering
- Wind and snow loading

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Items needed to Inspect PV?

- Permits
- Plans
- Wiring
- Attachment
- Equipment

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Plans - Electrical

- **Electrical plan should be submitted that includes the following:**
  - Locations of main service or utility disconnect
  - Total number of modules, number of modules per string and the total number of strings
  - One-line diagram of system
  - Specify grounding/bonding, conductor type and size, conduit type and size and number of conductors in each section of conduit

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Plans - Electrical *(cont.)*

- **Electrical plan should be submitted that includes the following:**
  - Make and model of modules, inverter(s) and/or combiner box if used
  - If batteries are to be installed include them in the diagram and show there locations and venting
  - Equipment cut sheets including inverters, modules, AC and DC disconnects and combiners

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Plans - Electrical *(cont.)*

- **Electrical plan should be submitted that includes the following:**
  - Labeling of equipment as required by Article 690 and Article 705
  - Site diagram showing the arrangement of modules on the roof or ground, north arrow, lot dimensions, and the distance from property lines to adjacent buildings/structures *(existing and proposed)*

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Plans - Structural

- **Structural plan identifying support information for roof mounted systems including the following:**
  - The type of roof covering and the number of roofing layers installed
  - Type of roof framing, size of members and spacing
  - Weight of modules, support locations and method of attachment

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Plans - Structural *(cont.)*

- **Structural plan identifying support information for roof mounted systems including the following:**
  - Framing plan and details for any work necessary to strengthen the existing roof structure
  - Any relevant calculations *(when required)*
  - Location of PV equipment on the building

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Plans - Structural *(cont.)*

- **Structural plan identifying support information for roof mounted systems including the following:**
  - Where an approved racking system is used…
    - provide documentation showing the manufacturer of the rack system
    - maximum allowable weight the system can support
    - attachment method to the roof or ground
    - product evaluation information or structural design for the rack system

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Plans - Code Requirements

- **Site Plan** –
  NEC 80.21 (Annex H), IBC 107.2.5, IRC R106.2
- **One-Line Diagram** –
  NEC 215.5
- **Attachment Details** –
  NEC 110.3(B), IBC 107.2.1, IRC R106.1.2
- **Equipment Specifications** –
  NEC 690.4(D), IRC R905.16.1, IRC R905.16.3, IRC M2302.3, IRC M2302.4, IBC 1505.8, IBC 1507.17.1, IBC 1507.17.3, IBC 1509.7.2, IBC 1509.7.4

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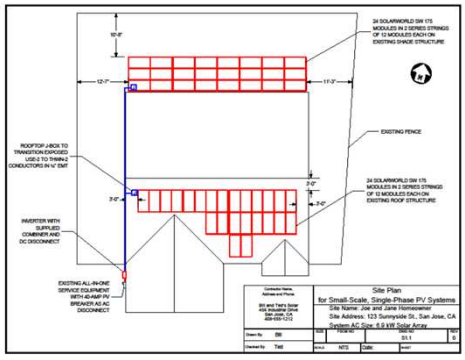
Site Plan



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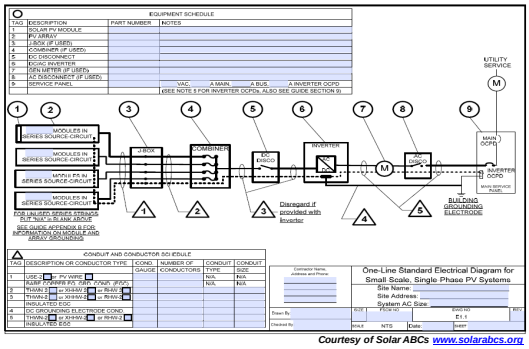
Wiring Diagram



Courtesy of Solar ABCs www.solarabcs.org

Fill in the blanks

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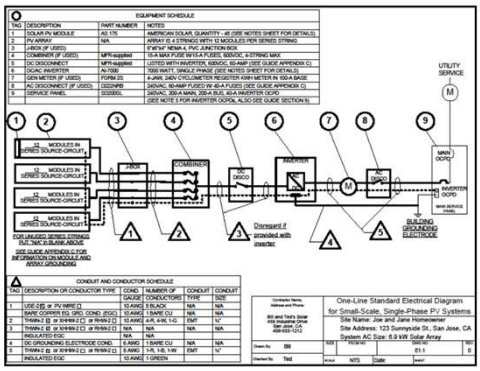

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Attachment

- The International Building Code (IBC) Section 106.3 Load Supports
- Dead loading and wind loading of roof are covered in IBC 1603.1.4, 1603.1.8, 1604.2, 1606,2

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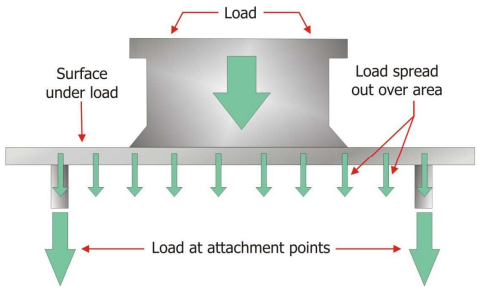
Rooftop Loading



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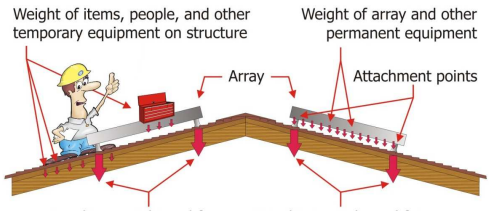
Live Versus Dead Loads



LIVE LOADS **DEAD LOADS**

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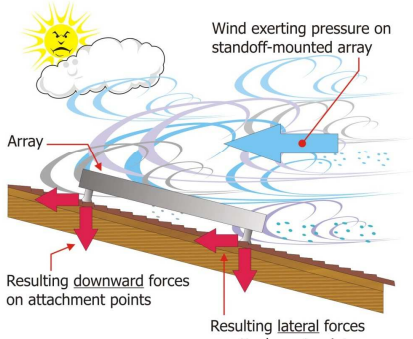
Wind Loading



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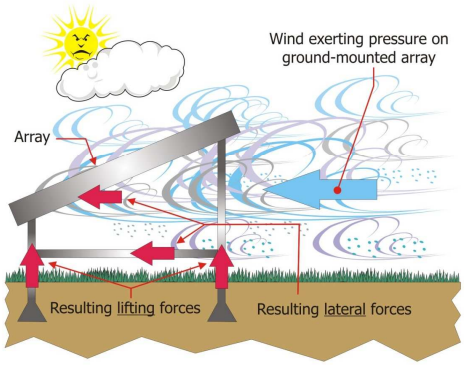
Wind Loading



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Wind & Dead Loading

Photo courtesy of Bill McGovern

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Rooftop Anchorage

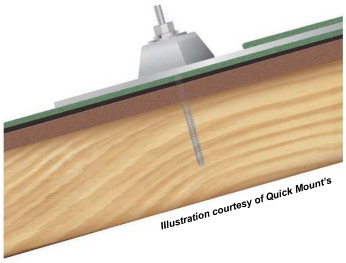

Illustration courtesy of Quick Mount's

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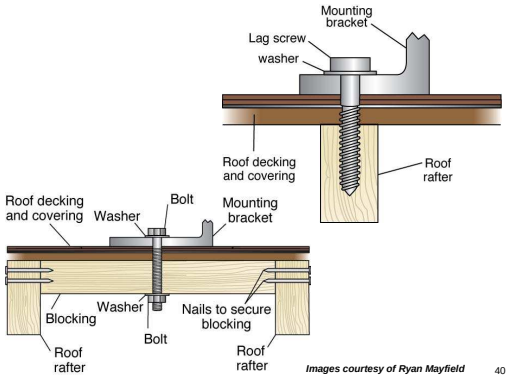
Rooftop Anchorage



Images courtesy of Ryan Mayfield

Module Details

bp solar

SX 3200

200 watt photovoltaic module

High-efficiency photovoltaic module using silicon nitride multicrystalline silicon cells

Performance

Rated power (P_{max})	200W
Power tolerance	±9%
Nominal voltage	16V
Limited Warranty[1]	25 years

Configuration

B — Bronze frame with output cables and polarized Multicontact (MC) connectors

Electrical Characteristics[1]	SX 3200	SX 3195
Maximum power (P_{max})[1]	200W	195W
Voltage at P_{max} (V_{mp})	24.5V	24.4
Current at P_{max} (I_{mp})	8.16A	7.96A
Warranted minimum P_{max}	182.0W	177.5W
Short-circuit current (I_{sc})	8.7A	8.6A
Open-circuit voltage (V_{oc})	30.6V	30.7V
Temperature coefficient of I_{sc}	(0.065 ± 0.015)%/°C	
Temperature coefficient of V_{oc}	-(111 ± 10)mV/°C	
Temperature coefficient of power	-(0.5 ± 0.05)%/°C	
NOCT (Air 20°C; Sun 0.8kW/m²; wind 1m/s)	47 ± 2°C	
Maximum series fuse rating	15A	
Maximum system voltage	600V (U.S. NEC rating)	

PV Module Label

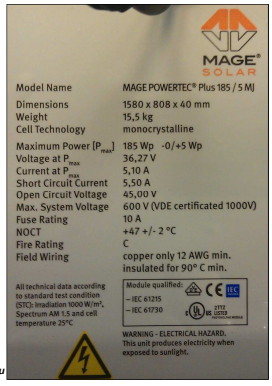


Photo courtesy of Jeff Fecteau

Inverter Details

Specifications

Inverter Technology	Real sine-wave, current source, high frequency PWM
AC Voltage	213-262 (240 V AC)
AC Frequency	59.3 - 60.5 (60 Hz) (50 Hz also available)
DC Input Voltage	250 - 600 V DC
Peak Power Tracking Voltage	234 - 480 V DC
PV Start Voltage	300 V DC
Minimum DC Input Voltage	233 - 256 V DC dependent on available line voltage
Maximum Array Input Power	2600W (240V AC)(DC@STC)
Maximum AC Power Output	2100W (240V AC)
Current THD	< 4%
Power Factor	Unity
Peak Inverter Efficiency	94.8%
CEC Weighted Efficiency	93.0%
Cooling	*Convection cooling (no fan)
Maximum AC Output Current	12A
Maximum DC Input Current	12A

* Optional external fan (Sunny Breeze) available

DC Voltage Ripple	< 5%
Power Consumption	0.25W nighttime < 7W standby
Ambient Temperature Rating	45°C
Enclosure	NEMA 4X (IP65) Stainless Steel
Dimensions	17.10W x 11.60H x 8.40D in 434W x 295H x 214D mm
Weight	71 lb (32 kg)

Compliance	United States
	UL 1741, E210376, UL 1998, IEEE 519, IEEE 929, ANSI C62.41 C1 & C3, FCC part 15 A & B
	International
	DIN EN50082 Part 1, 61000-32, 50081, 50014, 600055 Part 2 55011 Group 1 Class B, 50178, 60146 Part 1-1

SMA America, Inc., 12438-C Loma Rica Dr.
Grass Valley, CA. 95945
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www.sma-america.com

Solar Today...
Energy Tomorrow

Courtesy of SMA

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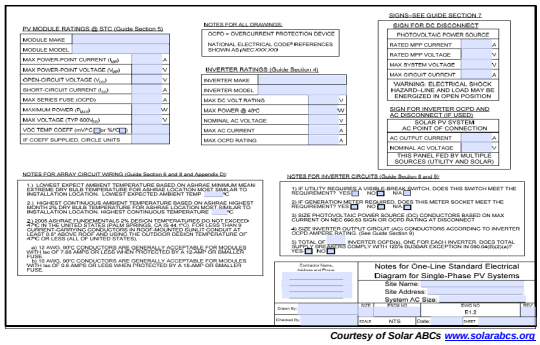
Equipment Details



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Fill in the blanks

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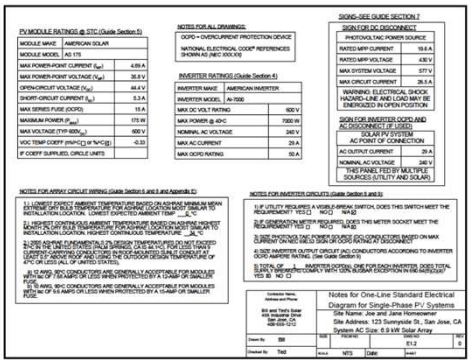

Courtesy of Bill Brooks

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Key Inspection Points

- Number of PV modules and PV model numbers match plans
- Array conductors and components are installed in a neat and workman like manner
- PV array is properly grounded
- Electrical boxes are accessible and connections are suitable for environment
- Array is fastened and sealed according to attachment detail
- Conductors ratings and sizes match plans

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Key Inspection Points *(cont.)*

- Appropriate signs are properly constructed, installed and displayed, including:
  - Sign identifying PV power source system attributes at dc disconnect
  - Sign identifying ac point of connection
  - Sign identifying switch for alternative power system

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Key Inspection Points *(cont.)*

- Equipment ratings are consistent with application and installed signs on the installation, including:
  - Inverter has a rating as high as max voltage on PV Power Source sign
  - DC-side OCPD's are DC rated at least as high as max voltage on sign
  - Switches and OCPDs are installed according to manufacturers specifications

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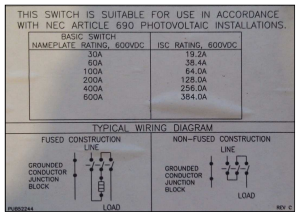
Key Inspection Points *(cont.)*

- Many 600 volt dc switches require passing through the switch poles twice in a specific way



Photos courtesy of Jeff Fecteau

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Key Inspection Points *(cont.)*

- Equipment ratings are consistent with application and installed signs on the installation, including:
  - Inverter is rated for the site ac voltage supplied and shown on the ac point of connection sign
  - OCPD connected to the ac output of the inverter is rated at least 125% of maximum current on sign, and is no larger than the maximum OCPD on the inverter listing label
  - Sum of the main OCPD and the inverter OCPD is rated for not more than 120% of the busbar rating

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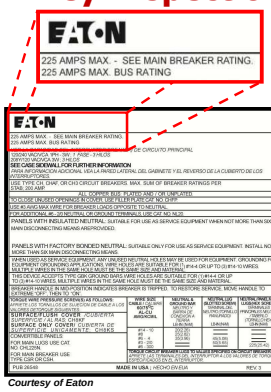
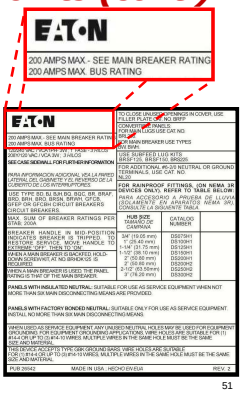
Key Inspection Points *(cont.)*





Courtesy of Eaton

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NEC Article 690
Solar Photovoltaic (PV) Systems

- Part I General
- Part II Circuit Requirements
- Part III Disconnecting Means
- Part IV Wiring Methods
- Part V Grounding
- Part VI Marking
- Part VII Connection to Other Sources
- Part VIII Storage Batteries
- Part IX Systems Over 600 Volts

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NEC Article 705
Interconnected Electric Power Production Sources

- Part I General
- Part II Utility-Interactive Inverters
- Part III Generators

(see Article 705 slides later in presentation)

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Article 690 - Part I General

Photos courtesy of DOE/NREL

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NEC Article 690 - Definitions

- **Definitions:**
  - Array
  - Building Integrated Photovoltaics
  - Interactive System
  - Inverter
  - Inverter Output Circuit
  - Module
  - Panel
  - Photovoltaic Output Circuit
  - Photovoltaic Source Circuit
  - Stand-Alone System

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NEC Article 690 - Definitions

Array. A mechanically integrated assembly of modules or panels with a support structure and foundation, tracker, and other components, as required, to form a direct-current power-producing unit.

Photos courtesy of DOE/NREL

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NEC Article 690 - Definitions

Building Integrated Photovoltaics. Photovoltaic cells, devices, modules, or modular materials that are integrated into the outer surface or structure of a building and serve as the outer protective surface of that building.

Photos courtesy of DOE/NREL

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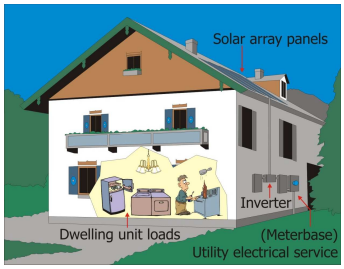
NEC Article 690 - Definitions

Interactive System. A solar photovoltaic system that operates in parallel with and may deliver power to an electrical production and distribution network. For the purpose of this definition, an energy storage subsystem of a solar photovoltaic system, such as a battery, is not another electrical production source.



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NEC Article 690 - Definitions

Inverter. Equipment that is used to change voltage level or waveform, or both, of electrical energy.

Commonly, an inverter [also known as a power conditioning unit (PCU) or power conversion system (PCS)] is a device that changes dc input to an ac output.

Inverters may also function as battery chargers that use alternating current from another source and convert it into direct current for charging batteries.

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NEC Article 690 - Definitions

Inverter. Equipment that is used to change voltage level or waveform, or both, of electrical energy.

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NEC Article 690 - Definitions

Module. A complete, environmentally protected unit consisting of solar cells, optics, and other components, exclusive of tracker, designed to generate dc power when exposed to sunlight.

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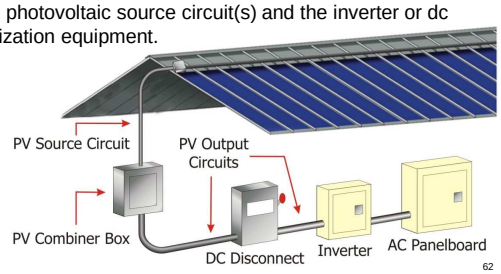
NEC Article 690 - Definitions

Photovoltaic Source Circuit. Circuits between modules and from modules to the common connection point(s) of the dc system.

Photovoltaic Output Circuit. Circuit conductors between the photovoltaic source circuit(s) and the inverter or dc utilization equipment.



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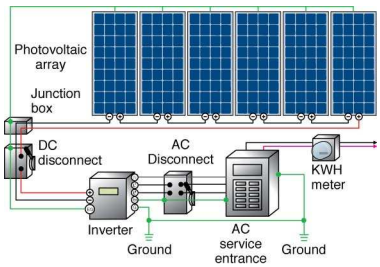
690.3 Other Articles

- Where the PV system is operated in parallel with a primary source(s) of electricity, the applicable requirements in Article 705 shall apply



**Article 705 Interconnected Electric Power Production Sources*

Image courtesy of Ryan Mayfield

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690.4(A) Photovoltaic Systems

- PV system(s) shall be permitted to supply a building or other structure in addition to any other electricity supply system(s)

Photo courtesy of DOE/NREL

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690.4(B) Identification & Grouping

- PV circuits (dc/ac) shall not be contained in the same raceway, cable tray, cable, outlet box, junction box, or similar fitting as conductors, feeders, or branch circuits of other non-PV systems, unless the conductors of the different systems are separated by a partition

Photo courtesy of Jeff Fecteau

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690.4(B) Identification & Grouping

Photo courtesy of Bill McGovern

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690.4(B) Identification & Grouping

(1) PV Source Circuits. …shall be identified at all points of termination, connection, and splices

(2) PV Output and Inverter Circuits. …shall be identified at all points of termination, connection, and splices

(3) Conductors of Multiple Systems. …of more than one PV system occupy the same … the conductors of each system shall be identified at all termination, connection, and splice points

(4) Grouping. …of more than one PV system occupy the same junction box or raceway with a removable cover(s), the ac and dc conductors of each system shall be grouped separately by wire ties or similar means at least once, and then shall be grouped at intervals not to exceed 1.8 m (6 ft)

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690.4(D) Equipment

- Inverters, PV modules, combiners, charge controllers and … shall be identified and listed for the application

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690.4(E) Wiring & Connections

- "Qualified persons" are required to perform the described work on photovoltaic (PV) systems

- **Qualified Person**. One who has skills and knowledge related to the construction and operation of the electrical equipment and installations and has received safety training to recognize and avoid the hazards involved

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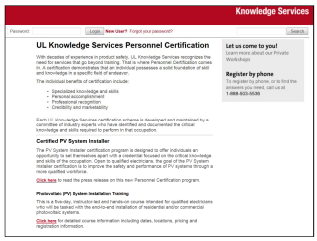
NABCEP Recognized PV Training Programs

- UL Knowledge Services
  http://lms.ulknowledgeservices.com/certification



*North American Board of Certified Energy Practitioners (**NABCEP**)*

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Basic PV Standards

- **UL 1699B** – Photovoltaic DC Arc-Fault Circuit Protection
- **UL 1703** - Flat Plate Photovoltaic Modules and Panels
- **UL 1741** - Inverters, Converters, Controllers, and Interconnection System Equipment For Use With Distributed Energy Resources
- **UL 2703** - Rack Mounting Systems and Clamping Devices for Flat-Plate Photovoltaic Modules and Panels
- **ICC ES AC 365** - Building Integrated Photovoltaic Systems

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UL Product Categories

DIUR - Circuit Breakers, Molded Case and Circuit-breaker Enclosures for Use in Photovoltaic Systems

IZMR - Fuseholders, Photovoltaic

JFGA - Fuses for Photovoltaic System

JDDZ - Cartridge Fuses, Nonrenewable

(Intended for AC circuits only, unless also marked with DC voltage rating)

QIGU - Photovoltaic Modules & Panels

QIKA - Photovoltaic Solar Trackers

QIKH - Photovoltaic Inverters

QIBP - Photovoltaic Charge Controllers

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UL Product Categories

QIIO - Distributed Generation Power Systems Accessory Equipment

QIJL - Distributed Resource Power Systems

QIMS - Photovoltaic Mounting Systems, Mounting Devices, Clamping Devices and Ground Lugs

(Both mounting systems and clamping devices may be for bonding and/or mechanical loading)

QHYZ - AC Modules

QHZK - Building-integrated Photovoltaic Modules & Panels

QHZS - Distributed Generation Wiring Systems and Harnesses

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UL Product Categories

QHZQ - Building-integrated Photovoltaic Mounting Systems

QIIA - Photovoltaic Modules and Panels with System Voltage Ratings above 600 V

WJBE - Switches, Molded Case, for Use in Photovoltaic Systems

WHXX - Switches, Dead-front for Use in Photovoltaic Systems

WIBC - Switches, Enclosed for Use in Photovoltaic Systems

ZKLA - Photovoltaic Wire

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690.4(F) Circuit Routing

- New requirements were added for visibility and roof marking of certain PV circuits
- Firefighting community has expressed concern about the safety of ventilating roofs where PV circuits are present
- Routing PV circuits along the building structural members will lower probability that the structural members will be compromised by the firefighting process during a fire
- When PV module system circuits are integrated into the roof, PV associated circuits are to be clearly marked on the surface of the roof as a visual aid for firefighters and other maintenance personnel

76

690.4(H) Multiple Inverters

- PV systems permitted to have multiple utility-interactive inverters installed in or on a single building or structure

Photo courtesy of DOE/NREL

77

690.4(H) Multiple Inverters

- Where the inverters are remotely located from each other, a directory in accordance with 705.10 shall be installed at each dc PV system disconnecting means, at each ac disconnecting means, and at the main service disconnecting means showing the location of all ac and dc PV system disconnecting means in the building

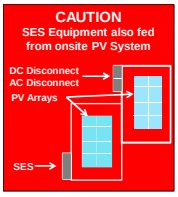

Photo courtesy of DOE/NREL

78

690.5 Ground-Fault Protection

- Grounded DC PV arrays shall be provided with dc ground-fault protection per 690.5(A) through (C) to reduce fire hazard

Not for personnel protection!

(That would be GFCI protection)

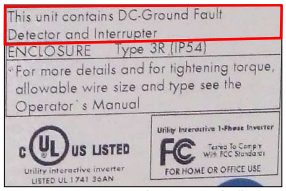

Photo courtesy of Jeff Fecteau

79

Ground-Fault Protection

80

690.5(A) Ground-Fault Detection and Interruption

- Permits automatic opening of the grounded conductor of the faulted circuit
- If the grounded conductor is opened, all conductors of the faulted circuit shall be automatically and simultaneously opened
- Manual operation of the PV dc disconnect shall not activate the GFP or result in the grounded conductors becoming ungrounded

81

UL 1741 Overcurrent Protection

- 31.1 Inverters or charge controllers with direct photovoltaic inputs from a grounded photovoltaic array or arrays shall be provided with a ground-fault detector/interrupter (GFDI)
  - *Exception No. 1: ac modules are not required to be provided with a GFDI*
  - *Exception No. 2: Inverters or charge controllers without GFDI devices may be used when the unit includes the following markings*

82

690.5(C) Labels and Markings

- 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

83

690.6 Alternating-Current (ac) Modules

- **690.2 Definitions**
  - **Alternating-Current (ac) Module (Alternating-Current Photovoltaic Module).** A complete, environmentally protected unit consisting of solar cells, optics, inverter, and other components, exclusive of tracker, designed to generate ac power when exposed to sunlight.
- An ac PV module consists of a single integrated mechanical unit
- Because there is no accessible, field-installed dc wiring in this single unit, the dc PV source-circuit requirements in the *NEC* are not applicable to the dc wiring in an ac PV module

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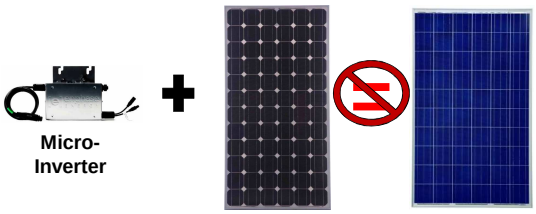
690.6 Alternating-Current (ac) Modules



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690.6 Alternating-Current (ac) Modules

Photo courtesy of Bill McGovern

86

Article 690
Part II Circuit Requirements

Photo courtesy of Jeff Fecteau

87

690.7 Maximum Voltage

- One- and Two-Family dwellings maximum is 600 volts
- Other occupancies is unlimited

Photos courtesy of DOE/NREL

88

690.7 Maximum Voltage

- 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
- These temperature coefficients provide a more accurate maximum system voltage and are required to be used instead of applying Table 690.7
- The *NEC* does not require temperature coefficient information to be included in the installation instructions

89

Table 690.7 Voltage Correction Factors for Crystalline and Multicrystalline Silicon Modules *(in part)*

Correction Factors for Ambient Temperatures Below 25° C (77F) (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

90

690.8(A) Circuit Sizing

- DC: The maximum current shall be the sum of parallel module rated short-circuit currents multiplied by 125%

5.5 X 1.25 = **6.875 A** maximum current

Maximum Power [P_{max}]	185 Wp -0/+5 Wp
Voltage at P_{max}	36,27 V
Current at P_{max}	5,10 A
Short Circuit Current	5,50 A
Open Circuit Voltage	45,00 V
Max. System Voltage	600 V (VDE certificated 1000V)
Fuse Rating	10 A
NOCT	+47 +/- 2 °C
Fire Rating	C
Field Wiring	copper only 12 AWG min. insulated for 90° C min.

Photo courtesy of Jeff Fecteau

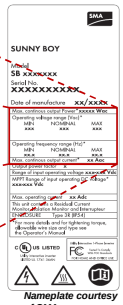
Reason: *PV output circuits can deliver output currents higher than the rated short-circuit currents for more than 3 hours near solar noon*

91

690.8(A)(3) Circuit Sizing

- AC: The maximum current shall be the inverter continuous output current rating

Max. continuous output Power* **xxxxx Wac**
Operating voltage range (Vac)* MIN **XXX** NOMINAL **XXX** MAX **XXX**
Operating frequency range (Hz)* MIN **XX.X** NOMINAL **XX.X** MAX **XX.X**
Max. continuous output current* **xx Aac**



Nameplate courtesy of SMA

92

690.8(B)(1) Ampacity

- The circuit conductors and overcurrent devices shall be sized to carry not less than 125 percent of the maximum currents as calculated in 690.8(A)

690.8(A) Maximum Circuit Current

SSC 5.50 x 125 % = 6.875 Amps

Maximum Power [P_{max}]	185 Wp -0/+5 Wp
Voltage at P_{max}	36,27 V
Current at P_{max}	5,10 A
Short Circuit Current	5,50 A
Open Circuit Voltage	45,00 V
Max. System Voltage	600 V (VDE certificated 1000V)
Fuse Rating	10 A
NOCT	+47 +/- 2 °C
Fire Rating	C
Field Wiring	copper only 12 AWG min. insulated for 90° C min.

Photo courtesy of Jeff Fecteau

690.8(B)(1) Conductor & OCPD Size

6.875 Amps x 125% = **8.59 Amps**

93

690.8 Circuit Sizing and Current

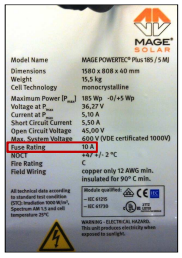
(D) Where a single overcurrent device is used to protect a set of two or more parallel-connected module circuits, the ampacity of each of the module interconnection conductors shall not be less than the sum of the rating of the single fuse plus 125 percent of the short-circuit current from the other parallel-connected modules

Photo courtesy of Jeff Fecteau

94

690.9 OCPD for PV Array

- When modules are shaded, back feeding is possible from other parallel strings
  - Result - overheating of modules and wiring
  - Key - proper rated fuse, not exceeding modules' max. fuse rating



Photos courtesy of DOE/NREL and Jeff Fecteau

95

Combiner Box

Photos courtesy of DOE/NREL and Jeff Fecteau

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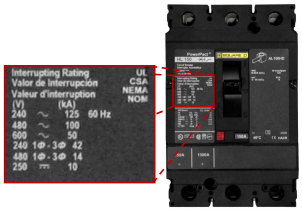
690.9(D) Direct-Current Rating

- Overcurrent devices, either fuses or circuit breakers, used in any DC portion of a PV power system shall be listed for use in DC circuits



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690.9(D) Direct-Current Rating

- DC fault currents are considerably harder to interrupt than AC fault currents
- Overcurrent devices marked or listed only for AC use should not be used in DC circuits
- Automotive and marine-type fuses, although used in DC systems, are not suitable for use in premise wiring of residential or commercial electrical power systems

98

UL Category JDDZ

- These fuses are intended for use on **AC circuits only**, unless also marked with a DC voltage rating
- These fuses are suitable for branch circuit, feeder and service overcurrent protection in accordance with the *NEC*

99

690.10 Stand-Alone Systems

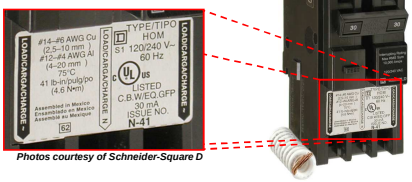
- **690.10(E) Back-fed Circuit Breakers.** Plug-in type back-fed circuit breakers connected to a stand-alone inverter output in either stand-alone or utility-interactive systems shall be secured in accordance with 408.36(D)


Photos courtesy of Jeff Simpson

100

Back-fed Circuit Breakers

- **690.10(E) Back-fed Circuit Breakers.** Circuit breakers that are marked "line" and "load" shall not be backfed
- **UL 489.** Line and load markings on a circuit breaker are intended to limit connections thereto as marked
- Load markings on a circuit breaker are intended to limit connections



Photos courtesy of Schneider-Square D

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690.11 Arc-Fault Circuit Protection (Direct Current)

- AFCI protection (dc) shall be provided for PV systems with dc source circuits, dc output circuits, or both, on or penetrating a building operating at a PV system maximum system voltage of 80 volts or greater
- System shall detect and interrupt arcing faults in the dc PV source and output circuits
- System shall disable or disconnect inverters or charge controllers connected to the fault circuit or system components within the arcing circuit
- Disabled or disconnected equipment shall be manually restarted
- System to have an annunciator that provides a visual indication that the AFCI has operated
- Indication shall not reset automatically

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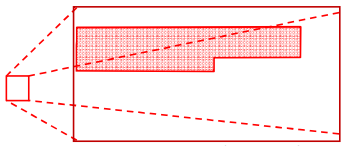

Photos courtesy of SMA

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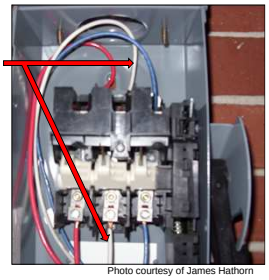

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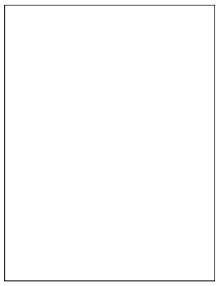

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- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

1. …shall be installed in a readily accessible location … outside of a building or structure or inside nearest the point of entrance…not to be installed in bathrooms

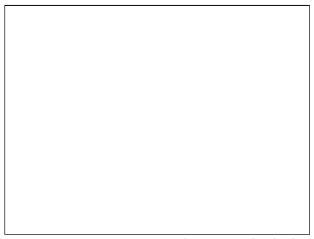

Photo courtesy of Mark Ode

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- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

2. Each PV system disconnecting means shall be permanently marked to identify it as a PV system disconnecting means

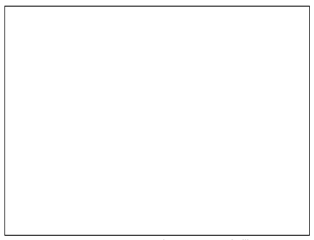

Photo courtesy of Bill McGovern

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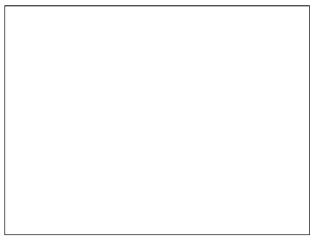
- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

3. Each PV system disconnecting means shall be suitable for the prevailing conditions



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- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

4. PV disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure, in a group of separate enclosures, or in or on a switchboard

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- Means shall be provided to disconnect all conductors in a building or other structure from the PV system conductors

5. PV disconnecting means shall be grouped with other disconnecting means for the system… shall not be required at the PV module or array location

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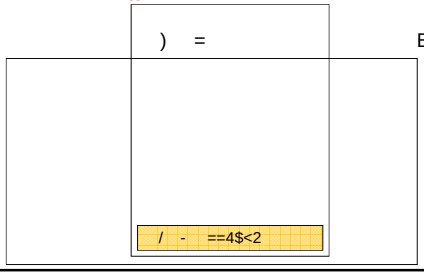

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(1) A direct-current PV disconnecting means shall be mounted within sight of or in the inverter

(2) An alternating-current disconnecting means shall be mounted within sight of or in the inverter

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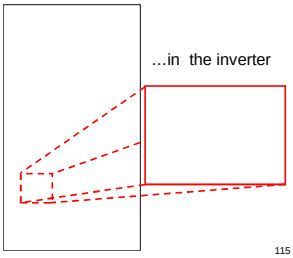
(1) A direct-current PV disconnecting means shall be mounted within sight of or in the inverter

(2) An alternating-current disconnecting means shall be mounted within sight of or in the inverter



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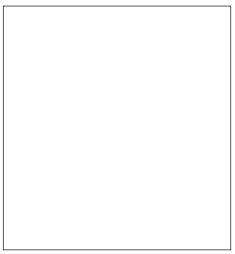

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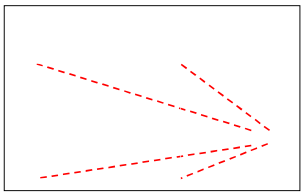
(permanent plaque or directory denoting all electric power sources…)



Photos courtesy of Jeff Fecteau

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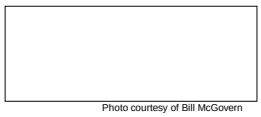

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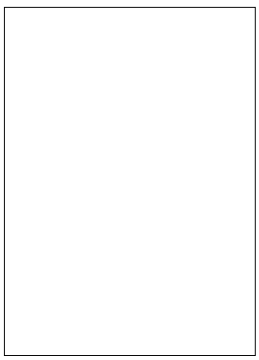

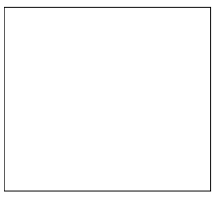

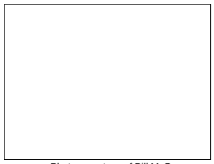

Photos courtesy of Bill McGovern

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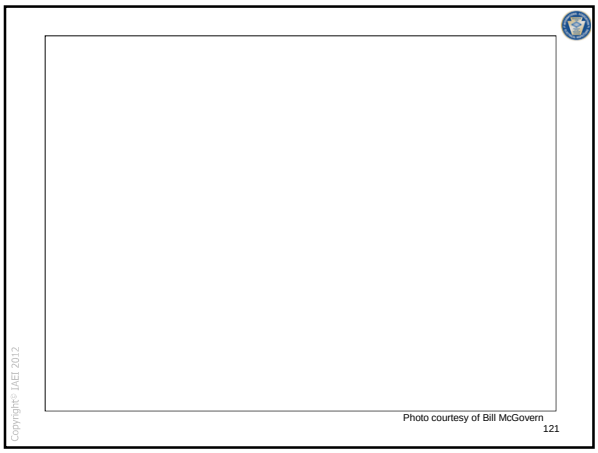

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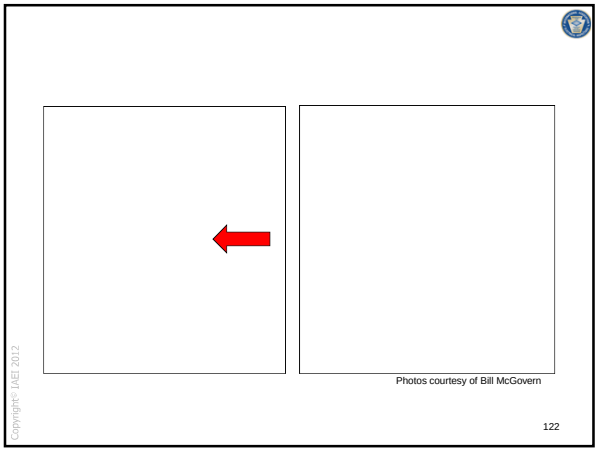

Photos courtesy of Bill McGovern

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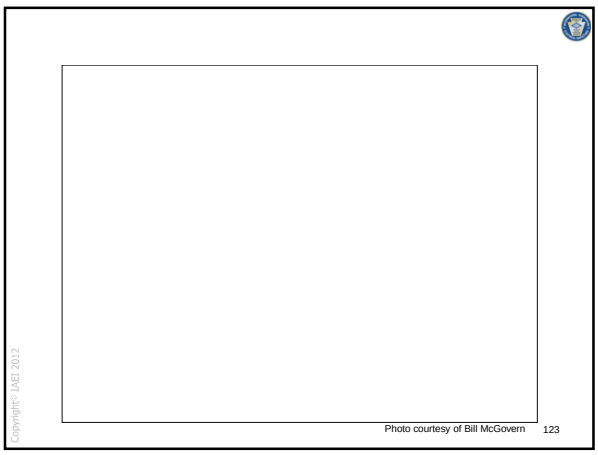

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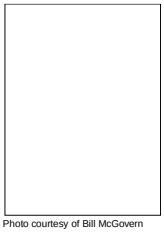
WARNING

ELECTRIC SHOCK HAZARD

DO NOT TOUCH TERMINALS

TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION



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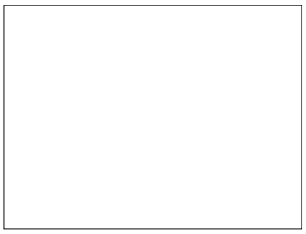

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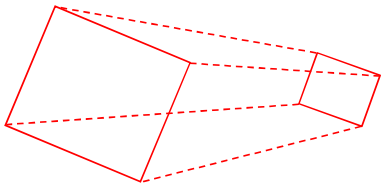

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Photo courtesy of Bill McGovern

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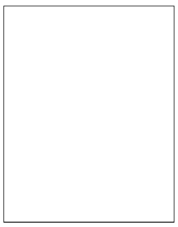

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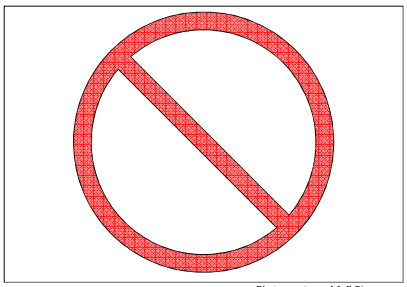

Photo courtesy of Jeff Simpson

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Minimum 25 cm (10 in.) below roof decking

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Min. 25 cm (10 in.)

Photos courtesy of Bill McGovern

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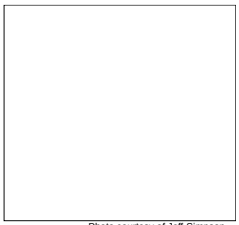

Photo courtesy of Jeff Simpson

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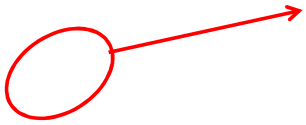

Photo courtesy of T&B

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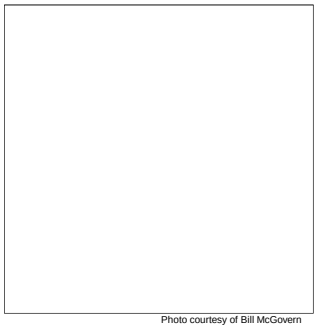

Photo courtesy of Bill McGovern

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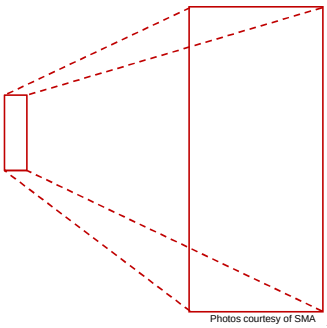

Photos courtesy of SMA

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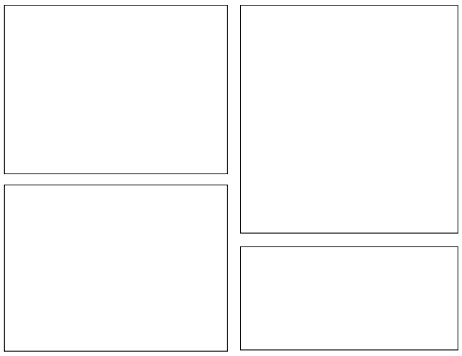

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  - Exception: Systems with a 690.5 GFP device shall be permitted to have the required grounded conductor-to-ground bond made at the GFP device
  - This bond, where internal to the GFP equipment, shall not be duplicated with an external connection
- Note: Locating the grounding connection point as close as practicable to the PV source better protects the system from voltage surges due to lightning

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Photo courtesy of Bill McGovern

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Photos courtesy of Bill McGovern

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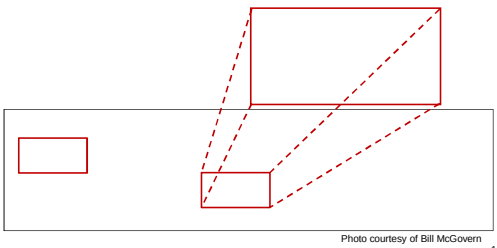

Photo courtesy of Bill McGovern

156

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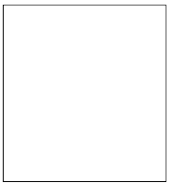

Photos courtesy of Bill McGovern

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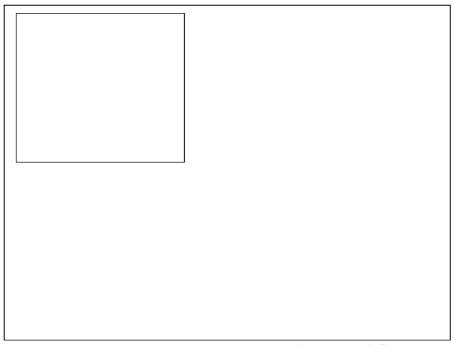

Photo courtesy of Bill McGovern

158

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- PV mounting systems, mounting devices, clamping devices and ground lugs are intended for use with specific PV modules and panels, specified module frames, mounting structures as identified in the individual certifications
- Mounting systems and clamping devices may be investigated for mechanical mounting alone, or mechanical mounting and ground bonding as identified in the individual certifications
- Ground lugs may be investigated for use with specific PV modules, specific PV module frames, or specific mounting-system rails

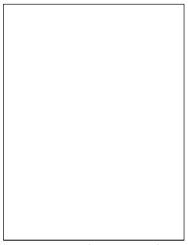

Photo courtesy of S-5

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Photo courtesy Bill Brooks

Photo courtesy Rhonda Parkhurst

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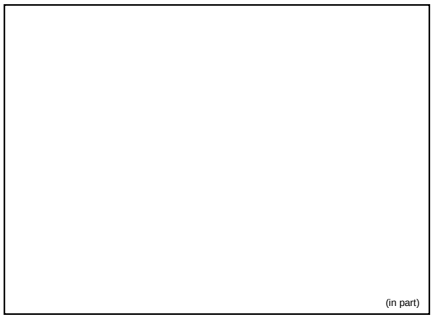

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Photos courtesy of Bill McGovern

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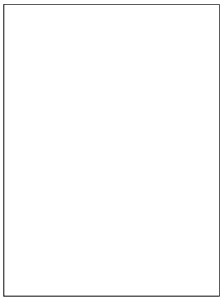

Photo courtesy of Rhonda Parkhurst

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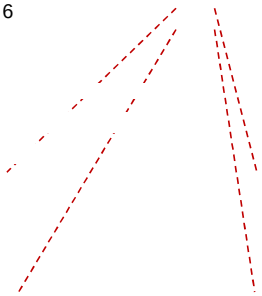

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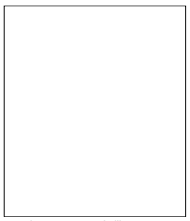

Photos courtesy of Bill McGovern

168

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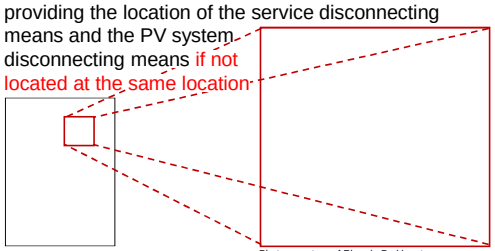
- (B) Facilities with Utility Services and PV Systems . Buildings or structures with both utility service and a PV system shall have a permanent plaque or directory providing the location of the service disconnecting means and the PV system disconnecting means if not located at the same location



Photos courtesy of Rhonda Parkhurst

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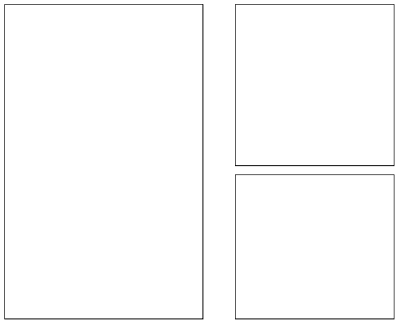

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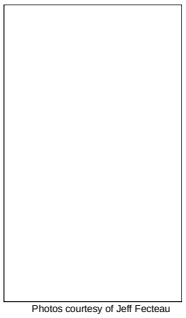

Photos courtesy of Jeff Fecteau

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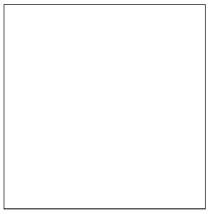
- (3) The interconnection point shall be on the line side GFP
- (4) Equipment containing overcurrent devices in circuits supplying power to a busbar or conductor supplied from multiple sources shall be marked to indicate the presence of all sources



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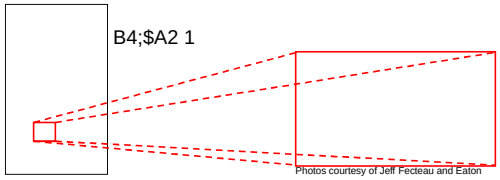

Photos courtesy of Jeff Fecteau and Eaton

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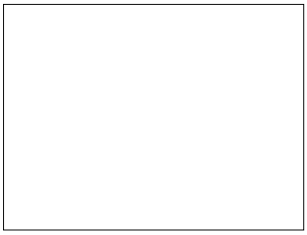

Photos courtesy of Bill McGovern

178

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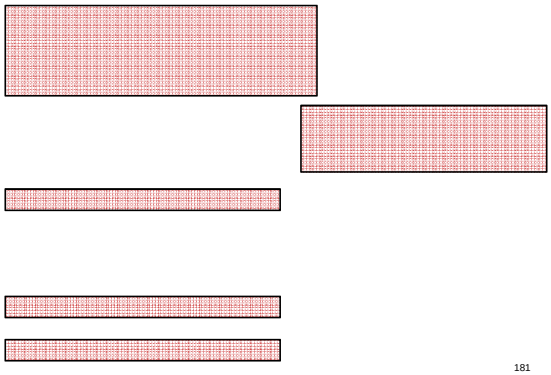
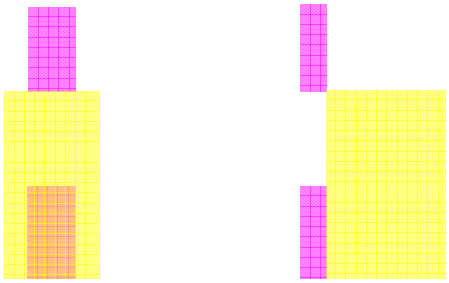
NEC 90.3 Code Arrangement



181

110.26(A) Working Space



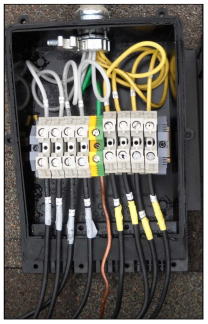
182

Table 110.26(A)(1) Working Space

183

200.6(A)(6) Means of Identifying Grounded Conductors

- A single-conductor, sunlight-resistant, outdoor-rated cable used as a grounded conductor in photovoltaic power systems, as permitted by 690.31, in sizes 6 AWG and smaller shall be identified at the time of installation by distinctive white marking at all terminations



Photos courtesy of Bill McGovern

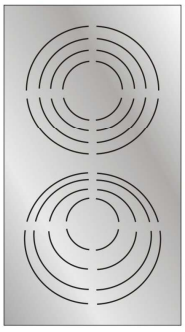
184

250.97 Bonding for Over 250 Volts

- For circuits of over 250 volts to ground, where oversized concentric, or eccentric knockouts are encountered "Listed Fittings" are required to provide a reliable bonding connection
- Bonding jumpers shall be used around impaired connections, such as reducing washers or oversized, concentric, or eccentric knockouts at service equipment regardless of the voltage *[see 250.92(B)]*

185

Concentric and Eccentric Knockouts



Concentric knockouts

May be necessary to bond around concentric knockouts to ensure current-carrying capacity

Bonding jumpers required around impaired connections such as reducing washers, concentric or eccentric knockouts

Eccentric knockouts

Eccentric rings present the same obstacle to carrying fault current as concentric knockouts

186

250.97 Bonding for Over 250 Volts

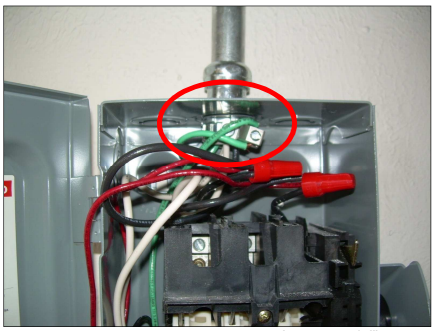


Photo courtesy of Bill McGovern

187

250.97 Bonding for Over 250 Volts

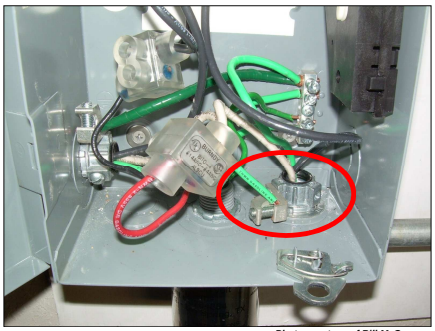


Photo courtesy of Bill McGovern

188

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

Photos courtesy of Bill Brooks

189

Other Code Requirements for PV Systems

190

2012 IFC - PV Systems

- **601.2 Permits**
  Permits shall be obtained for refrigeration systems, battery systems and PV power systems as set forth in Sections 105.6 and 105.7
- **605.11 Solar Photovoltaic Power Systems**
  PV power systems shall be installed in accordance with Sections 605.11.1 through 605.11.4, the International Building Code and the *NEC*
  - ***Exception:*** *Detached, nonhabitable Group U structures including, but not limited to, parking shade structures, carports, solar trellises and similar structures shall not be subject to the requirements of this section*

191

2012 IFC - PV Systems

- **605.11.1 Marking**
  - Marking is required on interior and exterior DC conduit, enclosures, raceways, cable assemblies, junction boxes, combiner boxes and disconnects
- **605.11.1.1 Materials**
  - The materials used for marking shall be reflective, weather resistant and suitable for the environment
  - Marking as required in Sections 605.11.1.2 through 605.11.1.4 shall have all letters capitalized with a minimum height of 10 mm (⅜ in.) white on red background

Photos Courtesy of RLP & Associates

192

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- **605.11.1.2 Marking Content**
  The marking shall contain the words "WARNING: PHOTOVOLTAIC POWER SOURCE"
- **605.11.1.3 Main Service Disconnect**
  The marking shall be placed adjacent to the main service disconnect in a location clearly visible from the location where the disconnect is operated

193

2012 IFC - PV Systems

- **605.11.1.4 Location of Marking**
  Marking shall be placed on interior and exterior DC conduit, raceways, enclosures and cable assemblies every 3.0 m (10 ft), within 300 mm (1 ft) of turns or bends and within 30 mm (1 ft) above and below penetrations of roof/ceiling assemblies, walls or barriers

194

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- **605.11.2 Locations of DC Conductors**
  - Conduit, wiring systems, and raceways for PV circuits shall be located as close as possible to the ridge or hip or valley and from the hip or valley as directly as possible to an outside wall to reduce trip hazards and maximize ventilation opportunities
  - Conduit runs between sub arrays and to DC combiner boxes shall be installed in a manner that minimizes the total amount of conduit on the roof by taking the shortest path from the array to the DC combiner box

195

2012 IFC - PV Systems

- **605.11.2 Locations of DC Conductors *(cont.)***
  - The DC combiner boxes shall be located such that conduit runs are minimized in the pathways between arrays
  - DC wiring shall be installed in metallic conduit or raceways when located within enclosed spaces in a building
  - Conduit shall run along the bottom of load bearing members

196

2012 IFC - PV Systems

- **605.11.3 Access and Pathways**

  Roof access, pathways, and spacing requirements shall be provided in accordance with Sections 605.11.3.1 through 605.11.3.3.3
  - ***Exception No. 1.*** *Residential structures shall be designed so that each photovoltaic array is no greater than 45 m (150 ft) by 45 m (150 ft) in either axis*
  - ***Exception No. 2.*** *Panels/modules shall be permitted to be located up to the roof ridge where an alternative ventilation method approved by the fire chief has been provided or where the fire chief has determined vertical ventilation techniques will not be employed*

Photo courtesy of DOE/NREL

197

2012 IFC - PV Systems

- **605.11.3.1 Roof Access Points**

  Roof access points shall be located in areas that do not require the placement of ground ladders over openings such as windows or doors, and located at strong points of building construction in locations where the access point does not conflict with overhead obstructions such as tree limbs, wires, or signs

Photo courtesy of DOE/NREL

198

2012 IFC - PV Systems

- **605.11.3.2 Residential Systems for One- and Two-Family Dwellings**
  Access to residential systems for one- and two-family dwellings shall be provided in accordance with Sections 605.11.3.2.1 through 605.11.3.2.4

Photo courtesy of DOE/NREL

199

2012 IFC - PV Systems

- **605.11.3.2.1 Residential Buildings with Hip Roof Layouts**
  - PV panels/modules installed on residential buildings with hip roof layouts shall be located in a manner that provides a 900 mm (3 ft) wide clear access pathway from the eave to the ridge on each roof slope where PV panels/modules are located
  - The access pathway shall be located at a structurally strong location on the building capable of supporting the live load of fire fighters accessing the roof
  - *Exception: These requirements shall not apply to roofs with slopes of two units vertical in 12 units horizontal (2:12) or less*

200

2012 IFC - PV Systems

- Hip roofs need one a 900 mm (3 ft) wide clear access pathway from the eave to the ridge on each roof slope where PV panels/modules are located

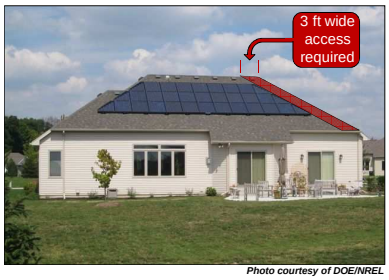

Photo courtesy of DOE/NREL

201

2012 IFC - PV Systems

- **605.11.3.2.2 Residential Buildings with a Single Ridge**
  - PV panels/modules installed on residential buildings with a single ridge shall be located in a manner that provides two, 900 mm (3 ft) wide access pathways from the eave to the ridge on each roof slope where PV panels/modules are located
  - *Exception: This requirement shall not apply to roofs with slopes of two units vertical in 12 units horizontal (2:12) or less*

202

2012 IFC - PV Systems

- Ridge roofs need two, 900 mm (3 ft) wide access pathways from the eave to the ridge

Photo courtesy of DOE/NREL

203

2012 IFC - PV Systems

- **605.11.3.2.3 Residential Buildings with Roof Hips and Valleys**
  - PV panels/modules installed on residential buildings with roof hips and valleys shall be located no closer than 450 mm (18 in.) to a hip or a valley where panels/modules are to be placed on both sides of a hip or valley
  - Where panels are to be located on only one side of a hip or valley that is of equal length, the panels shall be permitted to be placed directly adjacent to the hip or valley
  - ***Exception:*** *These requirements shall not apply to roofs with slopes of two units vertical in 12 units horizontal (2:12) or less*

204

2012 IFC - PV Systems

- Residential buildings with PV panels placed on both sides of a hip or valley, they shall not be located closer than 450 mm (18 in.) to a hip or a valley

Photo courtesy of DOE/NREL

205

2012 IFC - PV Systems

- Roofs with hips and valleys, with PV panels only one side of a hip or valley that is of equal length, the panels shall be permitted to be placed directly adjacent to the hip or valley

Photo courtesy of DOE/NREL

206

2012 IFC - PV Systems

- **605.11.3.2.4 Residential Building Smoke Ventilation**
  PV panels installed on residential buildings shall be located no higher than 900 mm (3 ft) below the ridge in order to allow for fire department smoke ventilation operations

Photo courtesy of DOE/NREL

207

2012 IFC - PV Systems

- **605.11.3.3 Other Than Residential Buildings**
  Access to systems for occupancies other than one- and two-family dwellings shall be provided in accordance with Sections 605.11.3.3.1 through 605.11.3.3.3
  - ***Exception:*** *Where it is determined by the fire code official that the roof configuration is similar to that of a one- or two-family dwelling, the residential access and ventilation requirements in Sections 605.11.3.2.1 through 605.11.3.2.4 shall be permitted to be used*

208

2012 IFC - PV Systems

- **605.11.3.3.1 Access**
  There shall be a minimum 1.8 m (6 ft) wide clear perimeter around the edges of the roof
  - ***Exception:*** *Where either axis of the building is 75 m (250 ft) or less, there shall be a minimum 1.2 m (4 ft) wide clear perimeter around the edges of the roof*

Photo courtesy of DOE/NREL

209

2012 IFC - PV Systems

- **605.11.3.3.2 Pathways**
  - The PV installation shall be designed to provide designated pathways
  - The pathways shall meet the following requirements:
    1. The pathway shall be over areas capable of supporting the live load of fire fighters accessing the roof
    2. The centerline axis pathways shall be provided in both axes of the roof

       Centerline axis pathways shall run where the roof structure is capable of supporting the live load of fire fighters accessing the roof

210

2012 IFC - PV Systems

- **605.11.3.3.2 Pathways *(cont.)***
  - The PV installation shall be designed to provide designated pathways
  - The pathways shall meet the following requirements:
    3. Shall be a straight line not less than 1.2 m (4 ft) clear to skylights or ventilation hatches
    4. Shall be a straight line not less than 1.2 m (4 ft) clear to roof standpipes
    5. Shall provide not less than 1.2 m (4 ft) clear around roof access hatch with at least one not less than 1.2 m (4 ft) clear pathway to parapet or roof edge

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Photo courtesy of DOE/NREL

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- **605.11.3.3.3 Smoke Ventilation**
  The PV installation shall be designed to meet the following requirements:
  - 1. Arrays shall be no greater than *45 m (150 ft) by 45 m (150 ft)* in distance in either axis in order to create opportunities for fire department smoke ventilation operations

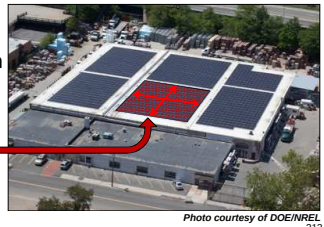

Photo courtesy of DOE/NREL

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- **605.11.3.3.3 Smoke Ventilation**
  The PV installation shall be designed to meet the following requirements:
  - 2. Smoke ventilation options between array sections shall be one of the following:
  - 2.1. A pathway 2.5 m (8 ft) or greater in width
  - 2.2. A 1.2 m (4 ft) or greater in width pathway and bordering roof skylights or smoke and heat vents
  - 2.3. A 1.2 m (4 ft) or greater in width pathway and bordering 1.2 m (4 ft) by 2.5 m (8 ft) "venting cutouts" every 6.0 m (20 ft) on alternating sides of the pathway

Photo courtesy of DOE/NREL

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- **605.11.4 Ground-Mounted PV Arrays**
  - Ground-mounted PV arrays shall comply with Sections 605.11 through 605.11.2 and this section
  - Setback requirements shall not apply to ground-mounted, free-standing PV arrays
  - A clear, brush-free area of 3.0 m (10 ft) shall be required for ground-mounted PV arrays

Photos courtesy of DOE/NREL

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- **R905.16 & 1507.17 Photovoltaic Modules/Shingles**
  The installation of PV modules/shingles shall comply with the provisions of this section
- **R905.16.1 & 1507.17.1 Material Standards**
  Photovoltaic modules/shingles shall be listed and labeled in accordance with UL 1703

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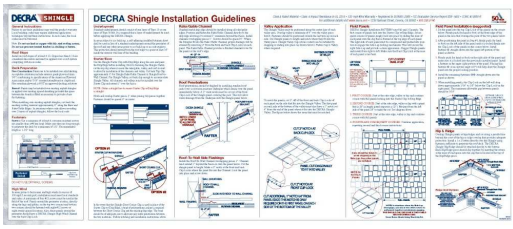
R905.16.2 & 1507.17.2 Attachment.
PV modules/shingles **shall be attached** in accordance with the manufacturer's installation instructions.



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- **R905.16.3 & 1507.17.3 Wind Resistance**
  - PV modules/shingles shall be tested in accordance with procedures and acceptance criteria in ASTM D 3161.
  - PV modules/shingles shall comply with the classification requirements of Table R905.2.4.1(2) & Table 1507.2.7.1(2) for the appropriate maximum basic wind speed.
  - PV modules/shingle packaging shall bear a label to indicate compliance with the procedures in ASTM D 3161 and the required classification from Table R905.2.4.1(2) & Table 1507.2.7.1(2).

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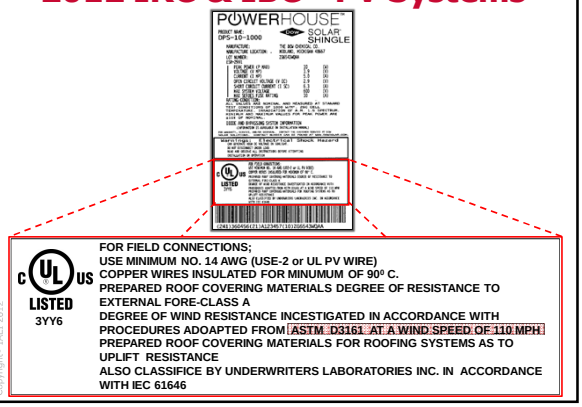

2012 IRC - PV Systems

- **M2302.2.1 Roof-Mounted Panels and Modules**
  - Where PV panels and modules are installed on roofs, the roof shall be constructed to support the loads imposed by such modules
  - Roof-mounted PV panels and modules that serve as roof covering shall conform to the requirements for roof coverings in Chapter 9
  - Where mounted on or above the roof coverings, the PV panels and modules and supporting structure shall be constructed of noncombustible materials or fire-retardant-treated wood equivalent to that required for the roof construction

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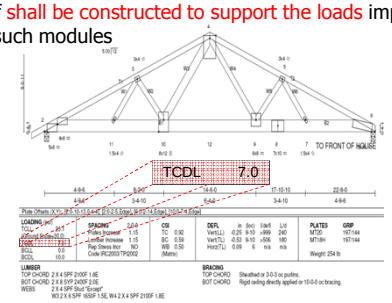
2012 IRC - PV Systems

- **M2302.2.1 Roof-Mounted Panels and Modules**
  Where PV panels and modules are installed on roofs, the roof shall be constructed to support the loads imposed by such modules



* *Top chord dead load is 7 psf for this engineered truss*

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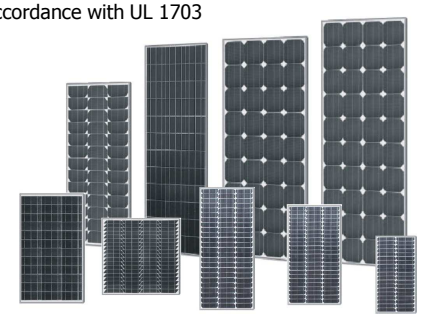
- **M2302.3 Photovoltaic Panels and Modules**
  Photovoltaic panels and modules shall be listed and labeled in accordance with UL 1703



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- **M2302.4 Inverters**
  - Inverters shall be listed and labeled in accordance with UL 1741
  - Systems connected to the utility grid shall use inverters listed for utility interaction

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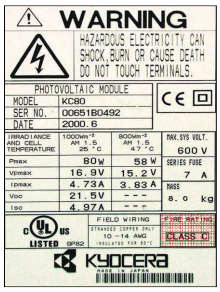
- **1505.8 Photovoltaic Systems**
  Rooftop installed photovoltaic systems that are adhered or attached to the roof covering or PV modules/shingles installed as roof coverings shall be labeled to identify their fire classification in accordance with the testing required in Section 1505.1



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- **1509.7 Photovoltaic Systems**
  Rooftop mounted PV systems shall be designed in accordance with this section
- **1509.7.1 Wind Resistance**
  Rooftop mounted PV systems shall be designed for wind loads for component and cladding in accordance with Chapter 16 using an effective wind area based on the dimensions of a single unit frame

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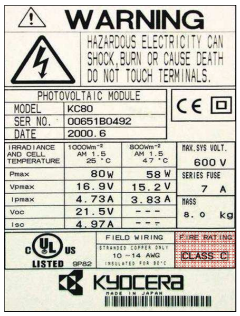
- **1509.7.2 Fire Classification**
  Rooftop mounted PV systems shall have the same fire classification as the roof assembly required by Section 1505



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- **1509.7.3 Installation**
  Rooftop mounted PV systems shall be installed in accordance with the manufacturer's installation instructions
- **1509.7.4 Photovoltaic Panels and Modules**
  PV panels and modules mounted on top of a roof shall be listed and labeled in accordance with UL 1703 and shall be installed in accordance with the manufacturer's installation instructions

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- **1511.1 Solar photovoltaic Panels/Modules**
  Solar PV panels/modules installed upon a roof or as an integral part of a roof assembly shall comply with the requirements of this code and the International Fire Code
- **1511.1.1 Structural Fire Resistance**
  The structural frame and roof construction supporting the load imposed upon the roof by the PV panels/ modules shall comply with the requirements of Table 601

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TABLE 601 FIRE-RESISTANCE RATING REQUIREMENTS FOR BUILDING ELEMENTS (HOURS)

BUILDING ELEMENT	TYPE I		TYPE II		TYPE III		TYPE IV	TYPE V	
	A	B	A[e]	B	A[e]	B	HT	A[e]	B
Primary structural frame[g] (see Section 202)	3[a]	2[a]	1	0	1	0	HT	1	0
Bearing walls									
Exterior[f, g]	3	2	1	0	2	2	2	1	0
Interior	3[a]	2[a]	1	0	1	0	1/HT	1	0
Nonbearing walls and partitions Exterior	See Table 602								
Nonbearing walls and partitions Interior[e]	0	0	0	0	0	0	See Section 602.4.6	0	0
Floor construction and associated secondary member (see Section 202)	2	2	1	0	1	0	HT	1	0
Roof construction and associated secondary members (see Section 202)	1 1/2[b]	1[b, c]	1[b, c]	0[c]	1[b, c]	0	HT	1[b, c]	0

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- **610.1 Renewable Energy Systems Requirements**
  - Buildings that consume energy shall comply with this section
  - Each building … shall be equipped with one or more renewable energy systems in accordance with this section
  - Renewable energy systems shall comply with the requirements of Section 610.2 for solar photovoltaic systems, Section 610.3 for wind systems, or Section 610.4 for solar water heating systems, and Section 610.5 for performance monitoring and metering of these systems as approved by the Code Official
  - These systems shall be commissioned in accordance with the requirements of Section 611

2012 IGCC - PV Systems

- **610.1.1 Building Performance-Based Compliance** Buildings and surrounding property or building sites where there are multiple buildings on the building site…
  - that are designed and constructed in accordance with Section 601.3.1, Performance-Based Compliance…
  - shall be equipped with one or more renewable energy systems that have the capacity to provide not less than 2 percent of the total calculated annual energy use of the building, or collective buildings on the site

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- **610.1.2 Building Prescriptive Compliance**
  Buildings that are designed and constructed in accordance with Section 601.3.2, Prescriptive Compliance…
  - shall be equipped with one or more renewable energy systems having the capacity to provide not less than 2 percent of the total estimated annual energy use of the building or collective buildings on the building site…
  - with onsite renewable energy demonstrating that onsite renewable energy production has a rating of not less than 1.75 Btu/h (0.5 W) or not less than 0.50 watts per sq. ft. of conditioned floor area…
  - and using any single or combination of renewable energy generation systems meeting the requirements of Sections 610.2, 610.3, or 610.4

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- **610.2 Solar Photovoltaic systems**
  PV systems shall be sized to provide not less than 2 percent of the total estimated annual electric energy consumption of the building, or collective buildings on the building site in accordance with Section 610.1.1 or 610.1.2
- **610.2.1 Limitation**
  PV systems shall not be used to comply with Section 610.1 where building sites have total global insolation levels lower than 2.00 kWh/m2/day as determined in accordance with NREL SERI TR-642-761

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- **610.2.2 Requirements**
  The installation, inspection, maintenance, repair and replacement of PV systems and system components shall comply with the manufacturer's instructions, Section 610.2.2.1, the International Fire Code, the International Building Code and NFPA 70 *(NEC)*
- **610.2.2.1 Performance Verification**
  - PV systems shall be tested on installation to verify that the installed performance meets the design specifications
  - A report of the tested performance shall be provided to the building owner

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- **C402.2.1.1 Roof Solar Reflectance and Thermal Emittance**
  Low-sloped roofs, with a slope less than 2 units vertical in 12 horizontal, directly above cooled conditioned spaces in Climate Zones 1, 2, and 3 shall comply with one or more of the options in Table C402.2.1.1
  - ***Exceptions:*** *The following roofs and portions of roofs are exempt from the requirements in Table C402.2.1.1:*
    1. *Portions of roofs that include or are covered by:*
       - *1.1. Photovoltaic systems or components*
       - *1.2. Solar air or water heating systems or components*
       - *1.3. Roof gardens or landscaped roofs*
       - *1.4. Above-roof decks or walkways*
       - *1.5. Skylights*
       - *1.6. HVAC systems, components, and other opaque objects mounted above the roof*

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Solar Photovoltaic Systems

Thanks for Participating

Any Questions?

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