



Solar Electric Systems and the NEC

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Use Policy

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Solar Electric Systems and the NEC

Course Outline:

- A. Module Types/System Types
- B. NEC Definitions/PV Circuit Requirements
- C. Disconnecting Means/Labeling
- D. Wiring Methods/Grounding
- E. Interconnection Requirements
- F. Common Code Violations



Solar Electric Systems and the NEC

BLOCK A:

PV System Types, Configurations, and Applications

Block A- Executive Summary

•Description

This module will provide an overview of different PV system types, configurations, equipment, and applications.

•Course Outline

- PV Module Types
- PV System Types
 - PV Direct Use Systems
 - Utility Interactive Systems
 - Stand-Alone Systems
 - Bimodal Systems

Photovoltaic Module Types

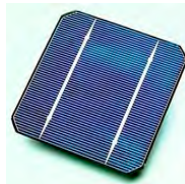
•Module types:

- Mono-crystalline silicon
- Multi-crystalline silicon
- Thin film silicon

Photovoltaic Module Types

•Mono-crystalline Silicon

- Silicon wafers 0.012 inches thick
- Sawn from single crystal ingot
 - 6 inches thick
 - 6 feet long
- 15-18% efficient

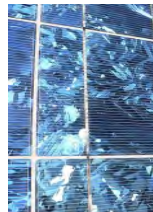


Source: Energypedia. "Solar Cells." http://www.energypedia.info/index.php/Solar_Cells

Photovoltaic Module Types

•Multi-crystalline Silicon

- Made from lower-grade silicon
- Cast in square ingots 12" x 18"
- Sawn from ingots
- Less expensive
- 13-16% efficient



Source: Energypedia. "Solar Cells." http://www.energypedia.info/index.php/Solar_Cells

Photovoltaic Module Types

•Thin film

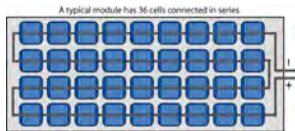
- Thin layer of semiconductor deposited on glass metal, or flexible backing
- Three types
 - Amorphous silicon (a-Si)
 - Cadmium telluride (Cd-Te)
 - Copper-indium (gallium)-diselenide (CIGS)
- Research and development
- Reducing processing costs
- 6-13% efficient



Source: Energypedia. "Solar Cells." http://www.energypedia.info/index.php/Solar_Cells

Photovoltaic Module Cells in Series

- Each cell ≈ 0.5 Volt
- Silver strips running end-to-end are electrical connections combining the individual cells into a series string of cells



Source: PV Education. "Typical Module." pveducation.org.

Photovoltaic Module Ratings

- PV cells and modules produce power (watts) that is relative to the irradiance level and the temperature of the device.

- Irradiance is directly proportional to current
- Temperature affects voltage. As temperature drops, voltage levels rise.

Photovoltaic Module Rating Standard Test Conditions

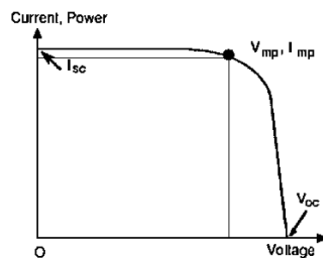
•Standard Test Conditions (STC) established standard set of test conditions to evaluate all PV modules:

- Temperature = 25°C (77°F)
- Irradiance = 1,000 Watts/m²
- Air Mass Coefficient = 1.5

Photovoltaic Module Electrical Characteristics

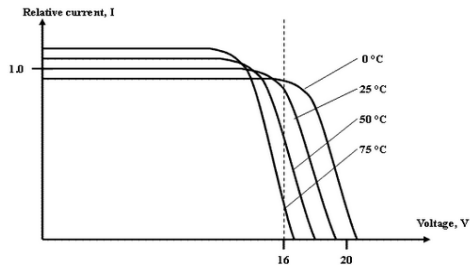
- Short circuit current (highest possible current) I_{SC}
- Open circuit voltage (highest possible voltage) V_{OC}
- Current at maximum power (operating current) I_{MP}
- Voltage at maximum power (operating voltage) V_{MP}

Photovoltaic Module Electrical Characteristics



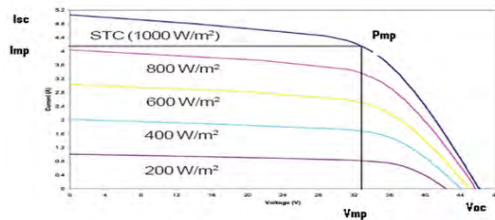
Source: Photovoltaic Panel Simulation User's Guide. "IV Curve."
<http://users.cecs.anu.edu.au/~Andres.Cuevas/Sun/help/Pvguide.html>.

Photovoltaic Module Effect of Temperature



Source: Photovoltaic Panel Simulation User's Guide. "Effect of Temperature."
<http://users.cecs.anu.edu.au/~Andres.Cuevas/Sun/help/Pvguide.html>.

Photovoltaic Module Effect of Irradiance



Photovoltaic Module Marking

- **NEC 690.51**
- Modules shall be marked with identification of terminal/lead polarity, maximum OCPD rating, and:
 1. Open-circuit voltage (V_{OC})
 2. Operating voltage (V_{MP})
 3. Maximum permissible system voltage
 4. Operating current (I_{MP})
 5. Short-circuit current (I_{SC})
 6. Maximum power

Source: NEC 2011.

PV Direct Components

•Load

- Load, device, or appliance
- Must be able to accept varying DC voltage and current from the array
 - Ventilation (attic fan)
 - Water pumping
 - Circulation pumps



•Array

- Sized for the load

Source: Sinclair Community College Energy Education Center. "PV Array at the Center for Energy Education Laboratory."

Utility Interactive System

- Most common installation
- No batteries, "stores" energy on the grid as credits
- Disconnects from grid in power outage
- Operates at up to 600 V_{DC} for dwellings

Source: Talbot-Heindl, Chris. "Utility Interactive System." Midwest Renewable Energy Association.

Utility Interactive Components

- Array
- Combiner box
- Inverter
- Disconnects
- Load center
- Utility meter



Source: http://www.ashireporter.org/photos/thumbnails/2009_06/boxes1.jpg

Utility Interactive Components

• Array

- Modules wired in series and/or parallel configurations
- Array voltage matches inverter voltage window
- One- and two-family dwellings = 600 V_{DC} max (690.7C)
- Over 600V must comply with 690 Part IX

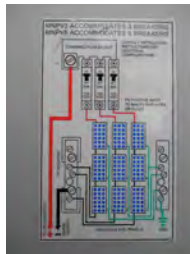


Source: Ammond, Chuck. "Ground mounted array."

Utility Interactive Components

• Combiner Box

- Combines individual series strings (PV Source circuits) into single output circuit. (PV Output Circuit)



Source: Sterling, Clay. "Combiner box lid." Midwest Renewable Energy Association.

Utility Interactive Components

• Combiner Box



Sterling, Clay. "Combiner box." Midwest Renewable Energy Association.
Talbot-Heindl, Chris. "Tracy at the combiner box." Midwest Renewable Energy Association.

Utility Interactive Components

• Inverter



Source: Enphase Energy, "Enphase." www.enphase.com
Sterling, Clay, "Inverter on a PV Training Lab." Midwest Renewable Energy Association.

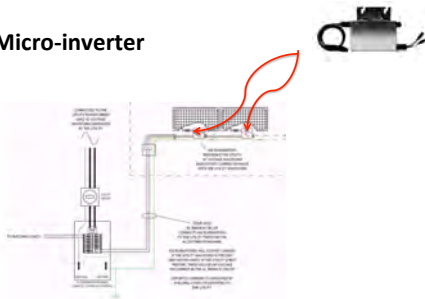
Utility Interactive Components

• Inverter

- Converts high-voltage DC to nominal AC value
- Allows maximum power point tracking of array
- Monitors utility and matches output voltage and frequency to utility power
- Disconnects from utility during utility outage (UL 1741 requirement)
- Sometimes can combine series strings

Utility Interactive Components

• Micro-inverter



Source: Enphase Energy, "Micro-inverter." www.enphase.com

Utility Interactive Components

- **DC Disconnects**
- **AC Disconnects**



Source: Sterling, Clay. "DC Disconnect on a PV Training Lab." Midwest Renewable Energy Association.

Utility Interactive Components

- **Load Center**
- Conventional breaker panel
- Allows load side connection
- Back-fed breaker(s) from inverter(s)
 - Does NOT need fastener required in 408.36(D)
 - Breaker not suitable for backfeed if marked with "line" and "load"



Source: Wilcox Electric, LLC. "Electrical Panel." <http://wilcox-electric.com/residential/residential.html>.

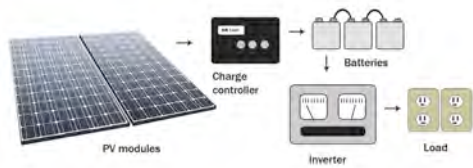
Utility Interactive Components

- **Utility Meter**
- Measures electrical energy in two directions
 - All energy purchased from the utility
 - Excess PV energy not used on site
- May allow for line side connection
- Interconnection contract with the utility required



Source: Schueller, Joe. "Utility meter on a PV Training Lab." Midwest Renewable Energy Association.

Stand-Alone System



Source: Talbot-Heindl, Chris. "Stand-alone system." Midwest Renewable Energy Association.

Stand-Alone Components

- Array
- Disconnects, combiner box
- Charge controller
- Battery bank
- Inverter
- Load center

Stand-Alone Components

- **Array**
 - Modules wired in series and/or parallel configurations
 - Array voltage matches battery bank voltage



Source: Ammond, Chuck. "Ground mounted array."

Stand-Alone Components

•Charge Controller

- Interfaces with array
- Regulates battery charge
- May control some DC loads
- Programmable set points



Source: Talbot-Heindl, Chris. "Charge controller." Midwest Renewable Energy Association.

Stand-Alone Components

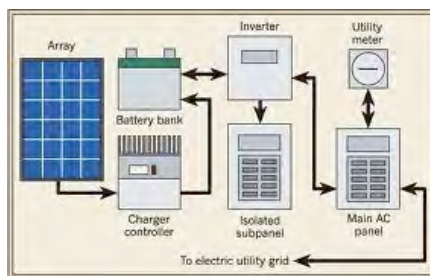
•Battery Bank

- Usually flooded lead acid batteries
 - Ventilation
 - Spill containment
- Often requires back-up
 - Gas generator
 - Wind machine
 - Micro-hydro



Source: Krszjanek, Eric. "Battery bank." Midwest Renewable Energy Association.

Bimodal System



Source: Electrical Contractor Magazine. "Bimodal System."

Bimodal Components

- Array
- Charge controller
- Battery bank
- Inverter with transfer switch
- Load center
- Utility meter
- Isolated subpanel (Critical Loads)

Works Cited

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- Helios Solar Works. "Spec Sheet for 6T Series."
- <http://www.heliossolarworks.com/Portals/132436/images/graphic-specsheet-9T6series.png>
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- Krszjanek, Eric. Midwest Renewable Energy Association.
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- Wilcox Electric, LLC. "Electrical Panel." <http://wilcox-electric.com/residential/residential.html>.



Solar Electric Systems and the NEC

Block B:
NEC Definitions, Overcurrent
Protection, and General Installation
Requirements

Block B- Executive Summary

•Description

–This module will discuss the scope of and definitions used in Article 690, as well as PV circuit characteristics, general installation requirements, and overcurrent protection for PV systems.

•Course Outline

- Definitions
- Installation Requirements
- Ground fault protection
- AC modules
- Maximum voltage
- Circuit sizing and current
- Overcurrent protection

Article 690 Definitions

•Module

- A complete, environmentally protected unit consisting of solar cells, optics and other components, exclusive of tracker, designated to generate DC power when exposed to sunlight



Source: NEC 2011; solarconduit.com

Article 690 Definitions

•Array

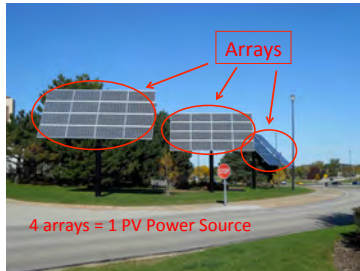
- A mechanically integrated [assembly of modules](#) or panels [with a support structure and foundation](#), tracker, and other components, as required, [to form a DC power producing unit](#)

•Photovoltaic Power Source

- An array or aggregate of arrays that generates DC power at system voltage and current

Source: NEC 2011.

Article 690 Definitions



Source: Sterling, Clay. "Ground Mount." Midwest Renewable Energy Association.

Article 690 Definitions

•PV Source Circuit

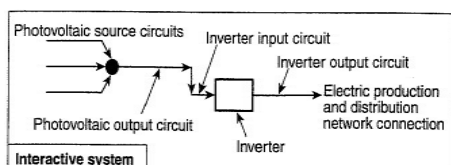
- Circuits between modules and **from modules to the common connection point** of the DC system (combiner box)

•PV Output Circuit

- Circuit **conductors between the PV source circuit(s) and the inverter** or DC utilization equipment

Source: NEC 2011.

Article 690 Definitions



Source: NEC 2011, Figure 690.1(B)

Article 690 Definitions

- **Bipolar PV Array**
 - 2 outputs of opposite polarity going to a common point/center tap
- **Building Integrated PV**
 - Integrated into surface of building (roofing, windows)
- **Electrical Production and Distribution Network**
 - The grid; independent of the PV system
- **Hybrid System**
 - Multiple power sources (PV, wind, hydro, generators)

Source: NEC 2011.

690.3

•Other Articles that may apply:

- Chapters 1-4, as they apply to all electrical installations
- Article 705 – Interconnected Electric Power Production Sources
- Articles 500 & 501 (Hazardous Locations) may apply if lead acid batteries are used in the PV system
- Article 480 – Storage Batteries

Source: NEC 2011.

690.4

•690.4(B)

- PV circuits shall not be in the same raceway/box as non-PV conductors, unless separated by a partition
- PV conductors shall be identified and grouped (color/tape/tags)
 1. PV source circuits
 2. PV output and inverter circuits
 3. Conductors of multiple systems
 4. Grouping – For more than one PV system in a raceway/box with a removable cover, group AC and DC conductors shall be grouped separately at intervals not to exceed 6'

Source: NEC 2011.

690.4

•690.4(C)

- Removal of any module shall not interrupt a grounded conductor to other PV source circuits

•690.4(D)

- All equipment shall be listed and identified for the application

•690.4(E)

- PV equipment and systems shall be installed only by qualified persons

Source: NEC 2011.

690.4

•690.4(F)

- PV source and output circuit conductors inside a building shall be routed along structural members where they can be seen
- Where embedded in roofing materials not covered by modules, PV circuit locations shall be clearly marked

Source: NEC 2011.

690.4

•690.4(H)

- Multiple inverters shall be permitted in the same building
- Where located remotely from each other, a directory shall be installed at each DC and AC disconnecting means, and at the main service disconnecting means - showing location of all PV disconnecting means in the building

•Exception: Not required where all inverters and DC disconnecting means are grouped at main service disconnecting means

Source: NEC 2011.

690.4(H) – Multiple Inverters



Source: Schmid, Kris. Legacy Solar.

690.5

•690.5

- Grounded PV systems shall be provided with DC ground-fault protection to reduce fire hazards. Ungrounded systems shall comply with 690.35.
 - Not required for ground- or pole-mounted systems with not more than 2 paralleled source circuits
 - Not required at **other than** dwelling units if each grounding conductor is sized in accordance with 690.45

Source: NEC 2011.

690.5



Source: International Association of Electrical Inspectors (iaei.org)

690.5

- A. Ground fault device or system shall be capable of detecting a ground-fault, interrupting fault current, and indicating fault
- B. Faulted circuits shall be isolated
- C. A warning label is required on the inverter or near the ground-fault indicator:

WARNING
ELECTRIC SHOCK HAZARD
IF A GROUND FAULT IS INDICATED,
NORMALLY GROUNDED CONDUCTORS
MAY BE UNGROUNDED AND ENERGIZED

Source: NEC 2011.

690.7

•Maximum Voltage

A. Maximum PV system voltage shall be calculated as the **sum of the rated open-circuit voltage (V_{OC}) of the series connected PV modules, corrected for the lowest expected ambient temperature**. This voltage is used to determine voltage rating of cables, disconnects, OCPD, and other equipment. If an open-circuit voltage temperature coefficient is supplied by the PV manufacturer, that number shall be used instead of the value found in **Table 690.7**.

Source: NEC 2011.

Table 690.7 Temperature Correction

Ambient Temperature (F)	Voltage Correction Factor
76-68	1.02
67-59	1.04
58-50	1.06
49-41	1.08
40-32	1.1
31-23	1.12
22-14	1.14
13-5	1.16
4 to -4	1.18
-5 to -13	1.2
-14 to -22	1.21
-23 to -31	1.23
-32 to -40	1.25

Source: NEC 2011.

690.7

•690.7(C)

- Maximum PV system voltage = 600V (dwelling units)

•690.7(D)

- Live parts of PV source and output circuits over 150 volts to ground shall not be accessible to other than qualified persons while energized (dwelling units)

Source: NEC 2011.

690.8

•690.8(A)(1)&(2) – PV Source and Output Circuits:

- Maximum current = sum of parallel module rated short-circuit currents (I_{SC}) $\times 1.25$

•690.8(B)(1)(a) – Ampacity and OCPD Ratings:

- Value from 690.8(A) $\times 1.25$
- Considered *continuous* current
- Informational Note: When applied, the resulting multiplication factor is **1.56** ($1.25 \times 1.25 = 1.56$)

Source: NEC 2011.

690.8

• 690.8(A)(3) – Inverter Output Circuit Current

- Maximum current = inverter continuous output current rating (provided by manufacturer)

• 690.8(B)(1)(c) – Correction Factors

- Where temperature exceeds 104F, use manufacturer's correction factors

• 690.8(B)(1)(d) - OCPD

- Overcurrent device ratings follow **240.4(B),(C)&(D)**

Source: NEC 2011

690.9

•690.9(A)

- PV source circuits, output circuits, inverter output circuits, and storage battery circuits shall be protected per Article 240
- Circuits connected to more than one source shall have OCPD to provide protection from all sources

•Exception: OCPD not required for PV modules/source circuits if:

- There are no external sources such as parallel-connected circuits, batteries, or backfeed from inverters
- I_{sc} from all sources does not exceed conductor ampacity or OCPD rating on module nameplate

Source: NEC 2011.

690.9

•690.9(C) - PV Source Circuits:

- Permitted to be protected by branch-circuit or supplementary-type devices
- Shall be accessible, but not required to be readily accessible
- Standard values = 1-15 amps in one amp intervals; sizes over 15A based on standard sizes in 240.6(A)

Source: NEC 2011.

690.9 – Supplemental Overcurrent Protection

- Combiner box – Not required to be readily accessible



Source: Kris Schmid, Legacy Solar

690.9

•690.9(D)

- Fuses and circuit breakers shall be listed for use in **DC** circuits and have appropriate voltage, current, and interrupt ratings

•690.9(E)

- A single OCPD shall be permitted to protect modules and interconnecting conductors in PV source circuits

Source: NEC 2011.

690.9(D) – DC Fuses



Source: Cooper Industries. cooperindustries.com.

690.11

- PV systems with DC source circuits, DC output circuits, on or penetrating a building, operating at 80 volts or greater shall be protected by a listed arc-fault circuit interrupter.

- Shall disable or disconnect inverter, charge controller, or system components
- Requires manual restart
- Requires visual indication of a fault

Source: NEC 2011.

Works Cited

- NEC 2011.
- Sterling, Clay. "Ground Mount." Midwest Renewable Energy Association.
- Schmid, Kris. "Combiner Box" and "Multiple Inverters." Legacy Solar.
- "PV module." www.solarconduit.com
- International Association of Electrical Inspectors. "Ground Fault Protection." www.iaei.org
- "DC Fuses." Cooper Industries. www.cooperindustries.com



Solar Electric Systems and the NEC

Block C:
Disconnecting Means and Labeling

Block C- Executive Summary

- Description
This module will discuss the scope of Article 690 and requirements for disconnecting means and marking/labeling PV systems.
- Course Outline
 - Disconnecting Means
 - Fuses
 - Marking

690.13

- Means shall be provided to disconnect current-carrying DC conductors of a PV system from all other conductors in a building
- Switches or circuit breakers shall not be installed in grounded conductors

Exceptions:

- Part of ground-fault protection system
- Used only for maintenance, accessible only to qualified persons, and rated for maximum DC voltage and current that could be present during any operation

Source: NEC 2011.

690.14

- A. Disconnecting means shall not be required to be listed as service equipment and shall comply with 690.17:

- Manually operable
- Readily accessible
- Externally operable
- Plainly indicates open or closed
- Sufficient interrupting rating
- Warning sign if terminals may be energized in open position

- B. Source circuit isolating switches, OCPD, and blocking diodes shall be permitted on PV side of the disconnecting means

Source: NEC 2011.

690.14

- C. Means shall be provided to disconnect all building conductors from PV system conductors

1. Readily accessible, outside the building or inside nearest point of entrance, and not in bathrooms
2. Permanently marked
3. Suitable for prevailing conditions
4. No more than 6 switches/circuit breakers...
5. Grouped with other system disconnects
 - Disconnecting means not required at PV module/array location

Source: NEC 2011.

690.14 – DC Disconnecting Means



Source: Schmid, Kris. Legacy Solar.

690.14

D. Utility-interactive inverters permitted on roofs or other exterior areas that aren't readily accessible, provided:

1. DC disconnecting means mounted within sight of inverter
2. AC disconnecting means mounted within sight of inverter
3. Inverter output (AC) conductors and disconnecting means shall comply with 690.14(C) (prior slide)
4. Plaque shall be installed in accordance with 705.10 (at service location, noting all power sources on premises)

Source: NEC 2011.

690.15

•Means shall be provided to disconnect equipment (inverters, batteries, charge controllers, etc.) from all ungrounded conductors of all sources

- If equipment is energized from more than one source, disconnects shall be grouped and identified
- A single disconnecting means is permitted for combined AC output of multiple inverters

Source: NEC 2011.

690.16

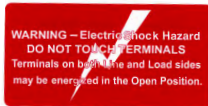
- A. If a fuse is energized from both directions, it must have a disconnecting means that disconnect it from all sources of supply and independently of fuses in other PV source circuits
- B. Disconnecting means required where fuses must be serviced that can't be isolated from energized sources
- Within sight of, and accessible to, fuse location or integral with the fuse holder
 - If disconnect is more than 6 feet away, a directory is required at the OCPD location showing where each disconnect is located

Source: NEC 2011.

690.17

•The disconnecting means shall be manually operable switches or circuit breakers:

- Readily accessible
- Externally operable
- Plainly indicate open or closed
- Sufficient interrupting rating
- Warning sign if terminals may be energized in open position



Source: NEC 2011.

690.17

Source: civicsolar.com

690.18

•Installation and Service of an Array

•An array (or portion of) can be disabled for servicing or installation by open-circuiting, short-circuiting, or using an opaque covering

•Remember – PV modules produce electricity when exposed to sunlight!

•Most modules have touch-safe connectors

Source: NEC 2011.

690.51

•PV modules shall be marked with identification of terminal/lead polarity, maximum OCPD rating and:

1. Open-circuit voltage (V_{OC})
2. Operating voltage (V_{MP})
3. Maximum permissible system voltage
4. Operating current (I_{MP})
5. Short-circuit current (I_{SC})
6. Maximum power

Source: NEC 2011.

690.51



Source: Home Power Magazine and nmsu.edu

690.53

•A permanent label for the DC power source shall be located at the PV disconnecting means, indicating:

1. Rated maximum power-point current
2. Rated maximum power-point voltage
3. Maximum system voltage
4. Short-circuit current
5. Maximum rated output current of the charge controller (if installed)

Source: NEC 2011.

690.54**•690.54**

- All points of interconnection shall be marked at an accessible location at the disconnecting means with rated AC voltage and current

•690.55

- PV systems with energy storage shall be marked with maximum operating voltage, including equalization voltage and polarity of grounded conductor

Source: NEC 2011.

690.56

- A. Stand-alone PV systems shall have a permanent plaque or directory installed on the exterior of the building at a readily visible location, that indicates the location of the disconnecting means
- B. Facilities with utility services and PV systems shall have a permanent plaque or directory providing the location of the service disconnect and the PV system disconnect (if not located in the same location)

Source: NEC 2011.

690.56 – Identification of Power Sources

SOLAR DC & AC DISCONNECTS LOCATED IN 3 PLACES:

1. ELECTRICAL ROOM AC PANEL B
NO. 22, 24, 26 3x208VAC.
2. OUTSIDE ON THE ROOF AC.
3. DC DISCONNECTS ON THE
INVERTER: PV POWERED 30KVA.

Source: specialtysolarsupply.com

Works Cited

- NEC 2011. National Fire Protection Agency.
- Schmid, Kris. "Disconnecting Means." Legacy Solar.
- "Warning Sign." www.civicsolar.com
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Solar Electric Systems and the NEC

Block D:
Wiring Methods and Grounding

Block D- Executive Summary

•Description

This module will discuss wiring methods and grounding requirements in Article 690.

•Course Outline

- Wiring Methods
- Grounding
- Grounding Electrode System
- Ungrounded PV Systems

690.31

A. Where PV source and output circuits **greater than 30 volts** are installed in readily accessible locations, circuit conductors **shall be installed in a raceway**

B. **USE-2 and PV wire** are permitted for module interconnections within the array for PV source circuits in exposed outdoor locations

Source: NEC 2011.

690.31

C. Flexible cords and cables for connecting moving parts (trackers) shall be:

- Identified as hard service cord or portable power cable
- Suitable for extra hard usage
- Listed for outdoor use
- Water resistant
- Sunlight resistant

For temperatures exceeding 86°F, use correction factors in **Table 690.31(C)**

Source: NEC 2011.

690.31(C) - Flexible Cords and Cables



Adjustable and Tracking Arrays may require flexible wiring methods.

Source: Kris Schmid. Legacy Solar.

Table 690.31(C) Correction Factors

Ambient Temperature	60C Insulation	75C Insulation	90C Insulation	105C Insulation
86	1	1	1	1
87-95	0.91	0.94	0.96	0.97
96-104	0.82	0.88	0.91	0.93
105-113	0.71	0.82	0.87	0.89
114-122	0.58	0.75	0.82	0.86
123-131	0.41	0.67	0.76	0.82
132-140		0.58	0.71	0.77
141-158		0.33	0.58	0.68
159-176			0.41	0.58

Source: NEC 2011.

690.31

D. 16 and 18 AWG single-conductor cables listed for outdoor use that are sunlight and moisture resistant are permitted for module interconnections where they meet ampacity requirements of 690.8 ($\times 1.56$) and shall be derated according to section 310.15

Source: NEC 2011.

690.31

- E. DC PV source and output circuits **inside a building** shall be contained in **metal raceways**, type **MC cable** that complies with 250.118(10), or **metal enclosures**, from point of penetration to disconnection means



Source: NEC 2011; Kris Schmid.

690.31(E)

1. Shall not be installed within **10"** of roof decking or sheathing, and shall run perpendicular to roof penetration point to supports at least **10"** below roof decking (for firefighting)
2. Guard strips shall protect flexible conduit/cable when run across ceiling or floor joists, and shall closely follow building surface
3. **"PHOTOVOLTAIC POWER SOURCE"** shall be permanently marked on exposed raceways, enclosures, conduit bodies, and box covers
4. PV labels shall appear on every section of raceway separated by enclosures, walls, partitions, ceilings, or floors – spaced not more than **10'** apart

Source: NEC 2011.

690.32

- 690.32** - Fittings and connectors shall be permitted to be concealed at the time of installation (if listed)
- 690.33** - Connectors shall be:
 - A. Polarized and noninterchangeable with other receptacles
 - B. Guarded against inadvertent contact with live parts
 - C. Of the latching or locking type, and where over 30V, shall require a tool for opening
 - D. Of the first-make, last-break grounding type
 - E. Rated to interrupt current without hazard to the operator **OR** be a type that requires a tool to open and marked **"DO NOT DISCONNECT UNDER LOAD"** (or similar)

Source: NEC 2011.

690.33

Source: civicsolar.com;
phaesun.com

690.34

- Junction, pull, and outlet boxes located behind modules shall be installed so that the wiring can be rendered accessible directly, or by removing a panel that's secured by removable fasteners and connected with flexible wiring

Source: NEC 2011.

690.41

- **690.41** – One conductor of a two-wire PV system over 50 volts shall be solidly grounded
 - Exception: Ungrounded systems
- **690.42** – DC grounding connection shall be made at any point on the PV output circuit
 - Exception: Systems with ground-fault protection
 - Informational Note: The closer the grounding point to the PV source, the better the lightning protection

Source: NEC 2011.

690.43

- A. All non-current carrying exposed metal parts of module frames, electrical equipment, and enclosures shall be grounded in accordance with 250.134 or 250.136(A)
- B. Equipment grounding conductor between the array and other equipment is required and shall comply with 250.111
- C. Exposed metal surfaces can be bonded to mounting structures using devices listed and identified for the purpose
- D. Devices for mounting PV modules that are also used to provide grounding shall be listed and identified as such
- E. Devices identified for bonding module frames are permitted to bond adjacent modules
- F. Equipment grounding conductors must be routed with other PV conductors after leaving the array

Source: NEC 2011.

690.43



Source: Kris Schmid. Legacy Solar

690.43



Lay-in Lugs

WEEB Clamp

Source: elecdirect.com; cooperindustries.com

Article 690

•690.45 - Sized according to (A) or (B):

A. Table 250.122, no smaller than 14 AWG

B. Where no ground-fault is provided (other than dwellings), EGC shall be sized to carry not less than twice the temperature and conduit-fill corrected conductor ampacity

•690.46

- EGCs smaller than 6 AWG shall be protected from physical damage (250.120(C))

Source: NEC 2011.

690.47(B)

- GES for a grounded DC system shall comply with 250.166 for grounded systems
 - Not smaller than the largest conductor
 - Not smaller than 8 AWG copper
- GEC shall be installed in accordance with 250.64
- Common DC GEC permitted for multiple inverters
 - Sized per 250.166
 - Listed connector or welding required; no splices or joints

Source: NEC 2011.

690.48

•690.48 – Where removal of equipment disconnects the bonding connection between the GEC and exposed conducting surfaces in PV source or output circuit equipment, a bonding jumper shall be installed

•690.49 – Where removal of equipment disconnects the bonding connection between the GEC and PV circuit grounded conductor, a bonding jumper shall be installed

•690.50 – Bonding jumpers shall be sized per 250.120(C)

Source: NEC 2011.

Works Cited

- NEC 2011.
- Schmid, Kris. "Flexible Cords and Cables," "Equipment Grounding," "Wiring Methods." Legacy Solar.
- "Connectors." www.civicsolar.com and www.phaesun.com
- "Lay-in Lugs." www.elecdirect.com
- "WEEB Clamp." www.cooperindustries.com



Solar Electric Systems and the NEC

Block E:
Interconnection

Block E- Executive Summary

- Description
This module will discuss the requirements for interconnecting a PV system with a customer's electrical service, per NEC Articles 690 and 705.
- Course Outline
 - Connection to Other Sources (690 Part VII)
 - Article 705

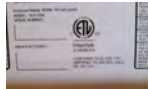
Article 690 Part VII Connection to Other Sources

- 690.57** - A load disconnect that has multiple sources of power shall disconnect all sources when in the off position
- 690.60** - Inverters shall be listed and identified as interactive
- 690.61** – Inverter shall automatically de-energize its output to the grid upon loss of (grid) voltage and shall remain off until voltage has been restored

Source: NEC 2011.

Article 705

- 705.4** – Inverters shall be listed and identified for interconnection ([UL 1741](#))
- 705.10** – Permanent plaque or directory required at service, denoting all power sources on premises



Source: NEC 2011; ulstandardsinfo.net; wind-sun.com; symmetryco.com

705.12

A. Supply (line) side of service disconnecting means



Source: NEC 2011; Home Power Magazine.

705.12

D. Load side of service disconnecting means, provided:

1. Interconnection made at dedicated circuit breaker or fusible disconnecting means in load center
2. Sum of overcurrent devices (panel main and PV breaker) doesn't exceed 120% of the busbar rating
3. Interconnection point on line side of ground-fault protection
4. Equipment with interconnected OCPD shall be marked
5. Circuit breakers shall be suitable for backfeed (no "line/load")
6. Backfed circuit breakers don't require fastener like in 408.36(D)
7. Backfed circuit breakers shall be installed at opposite end of main in load center

Source: NEC 2011.

705.12(D)(7)

•Permanent warning label shall be applied to distribution equipment:

WARNING
INVERTER OUTPUT
CONNECTION
DO NOT RELOCATE THIS
OVERCURRENT DEVICE

Source: NEC 2011.

Article 705

- **705.14** – Inverter output shall be compatible voltage, wave shape, and frequency of the grid
- **705.20** – Means shall be provided to disconnect PV circuit conductors from all other conductors
- **705.21** – Means shall be provided to disconnect inverter from ungrounded conductors of all supply sources

Source: NEC 2011.

705.22

•Manual or power operable switch(es) or circuit breakers:

1. Readily accessible
2. Externally operable
3. Plainly indicate open or closed
4. Sufficient ratings for load and fault current, with markings to indicate **all** terminals may be energized (from both directions)
5. Simultaneously disconnects all ungrounded conductors
6. Capable of being locked in the open position

Source: NEC 2011.

Article 705

•**705.30** – Conductors shall be protected in accordance with Article 240 (and 690)

•**705.32** – Inverter output shall be connected to **line** side of ground-fault protection

•**705.40** – Inverter shall **automatically disconnect** from the primary source **upon loss of grid power**, and shall not be reconnected until power is restored

•**705.42** – All phases shall be automatically disconnected upon loss of grid power in three-phase circuits

Source: NEC 2011.

Article 705

•**705.60(B)** – Inverter currents considered **continuous**; sized for 125% of maximum currents

•**705.70** – Inverters permitted to be mounted on roofs or other exterior areas that aren't readily accessible:

1. DC disconnecting means within sight of inverter
2. AC disconnecting means within sight of inverter
3. AC disconnecting means complies with 705.22 (manually operable, readily accessible, externally operable...)
4. Plaque installed to denote all power sources

Source: NEC 2011.

Additional AC Disconnecting Means MAY be Required



Source: Kris Schmid. Legacy Solar.

Works Cited

- NEC 2011. National Fire Protection Agency.
- Schmid, Kris. "AC Disconnecting Means." Legacy Solar.
- "UL." www.ulstandardsinfo.net/ul.com
- "UL 1741." www.wind-sun.com and www.symmetryco.com
- Home Power Magazine. "Supply Side Connection." www.homepower.com



Solar Electric Systems and the NEC

Block F:
Common Code Violations

Block F- Executive Summary

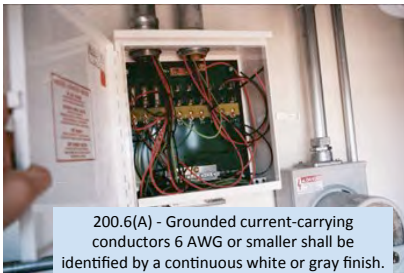
•Description

This module will discuss common code violations that an electrician or electrical inspector might encounter when installing or inspecting PV systems.

•Course Outline

- Listing requirements
- Equipment suitable for application
- Conductors and wire management
- Grounding
- Labeling

Conductor Color Coding



Source: John Wiles, Southwest Technology Development Institute and NEC 2011.

Mechanical Execution of Work



Source: John Wiles, Southwest Technology Development Institute and NEC 2011.

Equipment Not Installed to Listing Specifications



Source: Neil Matthes, Duck Creek Electric.

Listing: Disconnects

SQUARE D Alternate Photovoltaic System Wiring, Evaluated and Self-Certified by Schneider Electric (Not UL Listed)

Current Ratings

Switch Nameplate 600 V	Switch dc Rating per Pole ¹	Photovoltaic Maximum Circuit Current ²	Photovoltaic Short-Circuit Current (I_{sc})
30 A	20 A	16 A dc per pole	12.8 A (20/1.56)
60 A	60 A	48 A dc per pole	38 A (60/1.56)
100 A	100 A	80 A dc per pole	64 A (100/1.56)

¹ The switch per pole rating must be at least the photovoltaic maximum circuit current multiplied by 125%.

² From NEC 2008 and NFPA 70, Article 690.8: the photovoltaic maximum circuit current is I_{sc} multiplied by 125%.

Source: <http://static.schneider-electric.us/docs/Electrical%20Distribution/Safety%20Switches/3100CT0901.pdf>

Listing: Fuses

1000 VDC • 1-30 Amperes



Specifications

Voltage Rating	1000 VDC
Amperage Rating	1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, 30
Max. Interrupting Rating	20 kA, Time Constant less than 2 ms
Min. Interrupting Rating	1.35A Current Rating
Material	Body: Melamine Case: Copper Alloy
Operating Temperature	See Operating Curve (Page 2)
Approvals	UL 2579 Listed (File E309112) IEC 60068-8 (1-25 A) VDE Certified (No. 42030088)
Environmental	RoHS Compliant
Country of Origin	Mexico

Source: www.littelfuse.com


Suitable for the Application

- Must be suitable for the environment
 - Outdoors
 - Wet locations
 - UV resistant



Source: heyco.com

Suitable for the Application




NEMA 3R Rating may not apply when mounted in other than vertical position.

Source: Ryan Mayfield, "Common Code Violations," Solarpro.

Suitable for the Application

- Listing must be suitable for the environment
 - Rooftops
 - Table 310.15(B)(3)(c) - Temperature adjustments for circular Raceways exposed to sunlight on or above rooftops
 - ASHRAE temperatures for rooftops
 - Conduit temperature limits
 - Conductor temperature limits
 - Expansion joints



Source: Copper Development Association (copper.org) and NEC 2011.

PV Combiner Boxes



690.4 (D) requires equipment used in PV Systems to be identified and listed for the application

Source: rstcenterprises.com/soladeck and NEC 2011.

Dissimilar Metals



Source: John Wiles, 2008.

Readily Accessible Conductors



Source: Neil Matthes, Duck Creek Electric.

Wire Management



Source: www.mtnhighinspections.com/off_grid_photovoltaic_systems.html

Wire Management



Source: Ryan Mayfield. "Common Code Violations." Solarpro.

Wire Management



Source: Solar Novus Today, June 2012.

Flexible Cords and Cables



Source: mvpowersystems.org

Flexible Cords and Cables

- 690.31(C) - Required where used to connect moving parts (of a tracker system)
 - “Hard service” or “portable power cable”
 - Suitable for extra-hard service
 - Listed for outdoor use
 - Water resistant
 - Sunlight resistant
- Does this apply to module wiring if it must be lifted to service a combiner box below?

Source: NEC 2011.

Grounding Conductor Serves as *Both* EGC and GEC

- **2008 NEC** allows installer to use the same grounding conductor for both the equipment grounding conductor (EGC) and the grounding electrode conductor (GEC)
 - If sized to meet the larger of the two size requirements
 - If it is a continuous conductor or irreversibly spliced to meet GEC requirement
- **2011 NEC** code change prohibits the use of equipment grounding (EGC) conductor as grounding electrode conductor (GEC) because they serve different purposes (**250.121**)
 - EGC is meant to provide low impedance ground fault path to the source to operate OCPD
 - GEC is meant to direct lightning induced energy to earth

Source: NEC 2011.

Labeling at Disconnects



Source: Florence: Delmar Cengage Learning, 2010.

Labeling at Disconnects



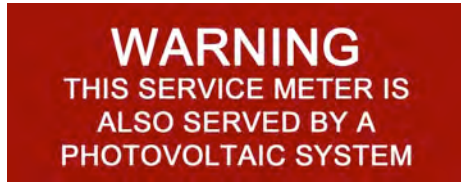
Source: Florence: Delmar Cengage Learning, 2010.

Labeling at Load Center



Source: Florence: Delmar Cengage Learning, 2010.

Labeling at Meter



Source: Florence: Delmar Cengage Learning, 2010.

Labeling of Raceways

- Required on all exposed raceways, enclosures, conduit bodies and box covers
- Marking shall appear on every section of raceway separated by enclosures walls, partitions, ceilings or floors
- Spaced not more than 10 feet apart

PHOTOVOLTAIC POWER SOURCE

Source: NEC 2011.

Label Requirements

•Format

- Red background
- White lettering
- Minimum 3/8" letter height
- All capital letters *
- Arial or similar font, non-bold*

•Materials

- Reflective*
- Weather resistant material
- Suitable for environment (durable adhesive materials may meet this requirement)

•* Blue indicates IFC requirements

Source: CalFire PV Installation Guidelines. "Solar Photovoltaic Guideline."
<http://osfm.fire.ca.gov/pdf/reports/solarphotovoltaicguideline.pdf>.

Resources



<http://irecusa.org/wp-content/uploads/2010/07/PV-Field-Inspection-Guide-June-2010-F-1.pdf>



<http://www.solarabcs.org/about/publications/reports/expedited-permit/pdfs/Expermitprocess.pdf>

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- "Fuses." www.littlefuse.com
- "Outdoor applications." www.heycoco.com
- Mayfield, Ryan. "Common Code Violations." Solarpro. Dec/Jan 2010.
- "Rooftop Temperatures." Copper Development Association. www.copper.org.
- "Combiner boxes." www.rstcenterprises.com/soladeck
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- "Flexible cords and cables." www.mvpoweresystems.org
- Labels: Florence. Delmar Cengage Learning. 2010.
- "Disconnect." www.civicsolar.com
- CalFire PV Installation Guidelines. "Solar Photovoltaic Guideline." <http://oefm.fire.ca.gov/pdf/reports/solarphotovoltaicguideline.pdf>
