PV SYSTEM CODE COMPLIANCE

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SESSION TOPICS

• NEC Code Basic Principles

• NEC Code Advanced Topics
Photovoltaic System Basics
I-V Curve with Power

- Maximum Power

- Current Versus Voltage

- Maximum Power Point

- Power Versus Voltage

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Current varies with irradiance

![Graph showing current varies with irradiance](image)
Voltage varies with temperature

Irradiance: 1000 W/m²

Temperature Ranges:
- 20°C
- 30°C
- 40°C
- 50°C
- 60°C
NEC Article 690 overview
PV Systems and the NEC

- Article 690 addresses safety standards for the installation of PV systems.
- Many other articles of the NEC may also apply to most PV installations.
NEC Sections Applicable to PV Systems

• Article 110: Requirements for Electrical Installations

• Chapter 2: Wiring and Protection
  Most of the chapter—especially Article 250: Grounding

• Chapter 3: Wiring Methods and Materials
  Most of the chapter—especially Article 300: Wiring Methods
  Article 310: Conductors for General Wiring

• Article 480: Storage Batteries

• Article 690: Solar Photovoltaic Systems
NEC Article 690: Solar Photovoltaic Systems

• I. General (definitions, installation)
• II. Circuit Requirements (sizing, protection)
• III. Disconnect Means (switches, breakers)
• IV. Wiring methods (connectors)
• V. Grounding (array, equipment)
• VI. Markings (ratings, polarity, identification)
• VII. Connection to Other Sources
• VIII. Storage batteries
• IX. Systems over 600 Volts
Key Code References and Summary of 2011 Updates

• Numerous notable updates to the 2011 NEC.
• Routing and identification requirements for conductors.
• Series Arc Fault detectors required above 80 volts.
• 690.64 moved to 705.12(D)
Key Code References and Summary of 2014 Updates

- 690.5 GFP must detect grounded conductor faults.
- 690.7 applies up to 1000V for other than residential rooftop systems.
- Arc-fault protection required for ground-mount.
- 690.12-Rapid Shutdown required.
- 690.15-Combiners require disconnects
- 690.13(B) requires separation of dc and ac conductors in a PV system
- 690.13 through 690.17 completely reorganized and rewritten—better but not great.
Key Code References and Summary of 2014 Updates (cont.)

- 690.31(C)(2) Cable Tray allowed for all PV Wire provided it is supported every 12” & secured-4.5’
- 690.31(D) Multiconductor TC-ER allowed.
- 690.35(D) Metallic-jacketed cable and direct burial cable allowed in ungrounded PV systems
- 705.12(D) Completely overhauled.
- 705.31 Line-side connections require OCPD within 10’ of connection or current limiters
- 705.100 Single-phase inverters allowed on 3-phase systems.
Key Code References and Summary of 2017 Updates

• Reference to new Article 691, Large-Scale PV Supply Stations
• 690.1 Signs to clarify PV System Disconnect location.
• 690.2 New definition for Functional Grounded PV
• 690.4 Multiple PV Systems rather than inverters
• 690.5 Moved to 690.41
• 690.7 Heavily revised and reduced. 3 methods allowed for calculating PV voltage.
• 690.8 Options for calculating current.
• 690.9 OCPD in either + or – of PV array.
Key Code References and Summary of 2017 Updates (cont.)

- 690.10 Section moved to new Article 710.
- 690.11 Ground-mount PV output circuit options not requiring AFP.
- 690.12 Rapid Shutdown—Requirements now inside the array in addition to outside the array.
- 690.13 Rewritten to clarify PV System Disco
- 690.15 Equipment disconnects now specifically allows connectorization of any inverters. All conductors must be disconnected (dc+/-)
- 690.16 through 19 GONE
• 690.31 All PV systems wired same way (USE-2 or PV Wire, one OCPD, disconnect in +&-)
• 690.35 GONE
• 690.41 Clarifies that we install functionally grounded PV systems (solid grounding rare)
• 690.43 Cleaned up and simplified
• 690.47 Completely revamped. Simply requires EGC to be connected to local grounding electrode.
• 690.60 through end is GONE with a few references remaining. Battery section moved to new Article 706.
690.4(H) Multiple Inverters

- Where inverters are remotely located from each other, a permanent plaque or directory, denoting all electric power sources on or in the premises, must be installed at each service equipment location and all interconnected electric power production sources [705.10].

- Ex: A directory isn’t required where all inverters and PV dc disconnecting means are grouped at the service disconnecting means.
Part II. Circuit Requirements
690.7 Maximum System Voltage

•Note: A statistically valid source for lowest-expected ambient temperature is the Extreme Annual Mean Minimum Design Dry Bulb Temperature found in the ASHRAE Handbook — Fundamentals [2011].—available at www.solarabcs.org/permitting
## Correction Factors for Ambient Temperatures Below 25°C (77°F).
(Multiply the rated open circuit voltage by the appropriate correction factor shown below.)

<table>
<thead>
<tr>
<th>Ambient Temperature (°C)</th>
<th>Factor</th>
<th>Ambient Temperature (°F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 to 20</td>
<td>1.02</td>
<td>76 to 68</td>
</tr>
<tr>
<td>19 to 15</td>
<td>1.04</td>
<td>67 to 59</td>
</tr>
<tr>
<td>14 to 10</td>
<td>1.06</td>
<td>58 to 50</td>
</tr>
<tr>
<td>9 to 5</td>
<td>1.08</td>
<td>49 to 41</td>
</tr>
<tr>
<td>4 to 0</td>
<td>1.10</td>
<td>40 to 32</td>
</tr>
<tr>
<td>−1 to −5</td>
<td>1.12</td>
<td>31 to 23</td>
</tr>
<tr>
<td>−6 to −10</td>
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<td>22 to 14</td>
</tr>
<tr>
<td>−11 to −15</td>
<td>1.16</td>
<td>13 to 5</td>
</tr>
<tr>
<td>−16 to −20</td>
<td>1.18</td>
<td>4 to −4</td>
</tr>
<tr>
<td>−21 to −25</td>
<td>1.20</td>
<td>−5 to −13</td>
</tr>
<tr>
<td>−26 to −30</td>
<td>1.21</td>
<td>−14 to −22</td>
</tr>
<tr>
<td>−31 to −35</td>
<td>1.23</td>
<td>−23 to −31</td>
</tr>
<tr>
<td>−36 to −40</td>
<td>1.25</td>
<td>−32 to −40</td>
</tr>
</tbody>
</table>
• $V_{\text{max}} = \text{Module Voc} \times \text{Table}$
  $690.7 \text{ C.F.} \times \# \text{ Modules per String}$

• $P_{\text{V max}} = 37 \text{ Voc} \times 1.14 \times 14$

• $P_{\text{V max}} = 591 \text{ Voc}$
• \( V_{\text{max}} = \text{Rated Voc} \times \{1+[(\text{Min. Temp.}^\circ C - 25^\circ C) \times \text{Coeff}\%/^\circ C]\} \times \# \text{ Modules} \)

• \( V_{\text{max}} = 37V \times \{1+[( -7^\circ C - 25^\circ C) \times -0.32\%/^\circ C]\} \times 14 \)

• \( V_{\text{max}} = 37V \times \{1+[( -32^\circ C) \times -0.32\%/^\circ C]\} \times 14 \)

• \( V_{\text{max}} = 37V \times \{1 + 10.24\%\} \times 14 \)

• \( V_{\text{max}} = 37V \times \{1.1024\} \times 14 \)

• \( V_{\text{max}} = 40.79V \times 14 \)

• \( V_{\text{max}} = 571 \text{ Voc} \)
• $V_{\text{max}} = \{V_{\text{oC}} + [(\text{Min. Temp.} \, ^{\circ}\text{C} - 25^{\circ}\text{C}) \times \text{Module Coeff V/}^{\circ}\text{C}]\} \times \text{Modules in String}$

• $V_{\text{max}} = \{37V + [(-7^{\circ}\text{C} - 25^{\circ}\text{C}) \times -0.126V/^{\circ}\text{C}]\} \times 14$
  $V_{\text{max}} = \{37V + [-32^{\circ}\text{C} \times -0.126V/^{\circ}\text{C}]\} \times 14$

• $V_{\text{max}} = \{37V + 4.0V\} \times 14$
  $V_{\text{max}} = \{41V\} \times 14$
  $V_{\text{max}} = 574V$
2014 NEC Revisions:
690.7—Maximum Voltage
Article 690.7 Applies up to 1000V for “other installations”

- “(C) Photovoltaic Source and Output Circuits. In one and two-family dwellings, PV source circuits and PV output circuits that do not include lampholders, fixtures, or receptacles shall be permitted to have a maximum PV system voltage up to 600 volts. Other installations with a maximum PV system voltage over 1000 volts shall comply with Article 690, Part IX.”
Related Part IX. Systems over 1000 Volts

• “690.80 General. Solar PV systems with a maximum system voltage over 1000 volts dc shall comply with Article 490 and other requirements applicable to installations rated over 1000 volts.”

• This basically says 1000V or less is governed by Article 690.
Implications of new 690.7—
it’s a big deal.

• Changing “600V” to “1000V” means that we stay in article 690 instead of being subjected to article 490 requirements.

• Products listed for PV systems up to 1000V can be installed on non-one- and two-family dwellings.
690.8(B) Overcurrent Protection

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

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

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

- For an ungrounded system [690.35], both the plus and minus conductors must have overcurrent protection.
- For grounded systems, only the ungrounded conductor requires overcurrent protection [240.15].
240.6 Standard Ampere Ratings.

(A) Fuses and Fixed-Trip Circuit Breakers. The standard ampere ratings for fuses and inverse time circuit breakers shall be considered 15, 20, 25, 30, 35, 40, 45, 50, 60, 70, 80, 90, 100, 110, 125, 150, 175, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 1000, 1200, 1600, 2000, 2500, 3000, 4000, 5000, and 6000 amperes. Additional standard ampere ratings for fuses shall be 1, 3, 6, 10, and 601. The use of fuses and inverse time circuit breakers with nonstandard ampere ratings shall be permitted.
Part III. Disconnecting Means
2014 NEC Revisions:
690.15(C)—DC Combiner Disconnects
(C) Direct-Current Combiner Disconnects.

- “The dc output of dc combiners mounted on roofs of dwellings or other buildings shall have a load break disconnecting means located in the combiner or within 1.8 m (6 ft) of the combiner. The disconnecting means shall be permitted to be remotely controlled but shall be manually operable locally when control power is not available.”
690.15(C)—DC Combiner Disconnects
Compliance Options

1. string combiner with contactor
   (mounted within 10 feet of the array if rooftop)

2. string combiner with motorized disconnect
   (mounted within 10 feet of the array if rooftop)

3. String combiner box with nearby switch (6’)
   (likely only used for ground mount systems that do not require rapid shutdown)
III. Disconnecting Means [2014 NEC] Article 690.15(A)

- Moved from 690.14(D) to 690.15(A) Utility-Interactive Inverters Mounted in Not-Readily Accessible Locations. Utility-interactive inverters shall be permitted to be mounted on roofs or other exterior areas that are not readily accessible. These installations shall comply with (1) through (4):

  1. A dc PV disconnecting means shall be mounted within sight of or in each inverter.
  2. An ac disconnecting means shall be mounted within sight of or in each inverter.
  3. The ac output conductors from the inverter and an additional ac disconnecting means for the inverter shall comply with 690.13(A).
  4. A plaque shall be installed in accordance with 705.10.
690.15 Disconnection of Photovoltaic Equipment

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

• If the equipment is energized from more than one source, the disconnecting means for all sources must be grouped and identified.
690.16(B) Fuse Servicing

- The disconnect must be within sight of or integral with the fuse holder, be externally operable, and plainly indicating whether in the open or closed position.
- Where the disconnecting is located more than 6 ft from the fuse, a directory showing the location of the fuse disconnect must be installed at the fuse location.
(B) Identification and Grouping.

- “PV source circuits and PV output circuits shall not be contained in the same raceway, cable tray, cable, outlet box, junction box, or similar fitting as conductors, feeders, branch circuits of other non-PV systems, or inverter output circuits, unless the conductors of the different systems are separated by a partition.”
690.31(B) change implications

- No longer allowed to run dc and ac from the inverter in the same gutter. Gutter would require a partition or ac raceway would have to continue through the gutter so that separation is maintained.
690.31(C)(2) **Cable Tray.**

- “PV source circuits and PV output circuits using single-conductor cable listed and labeled as photovoltaic (PV) wire of all sizes, with or without a cable tray marking/rating, shall be permitted in cable trays installed in outdoor locations, provided that the cables are supported at intervals not to exceed 300 mm (12 in.) and secured at intervals not to exceed 1.4 m (4.5 ft).”
690.31(C)(2) Cable Tray Application

• 2014 NEC now makes it clear that products specifically designed for cable support can be used for cable support (no size limitations when using PV Wire)

• Support rungs must be no further apart than 12” and cables must be secured (cable ties) at intervals 4.5’ or less.
690.31(D) Multiconductor Cable.

- “Multiconductor cable Type TC-ER or Type USE-2 shall be permitted in outdoor locations in PV inverter output circuits where used with utility-interactive inverters mounted in locations that are not readily accessible. The cable shall be secured at intervals not exceeding 1.8 m (6 ft). Equipment grounding for the utilization equipment shall be provided by an equipment grounding conductor within the cable.”
690.33 Connectors
Article 690.33 [2008 NEC]
Connectors

- New language in 690.33(E)
- (E) Interruption of Circuit. Connectors shall be either (1) or (2):
  - (1) Be rated for interrupting current without hazard to the operator.
  - (2) Be a type that requires the use of a tool to open and marked “Do Not Disconnect Under Load” or “Not for Current Interrupting.”
Article 690.35 Ungrounded Photovoltaic Power Systems

- Ungrounded systems have not been prohibited, but the 2005 NEC was the first code cycle where the requirements are specifically called out.
- Included is an exception in 690.41 for consistency.
Article 690.35 Ungrounded Photovoltaic Power Systems

• “Photovoltaic power systems shall be permitted to operate with ungrounded photovoltaic source and output circuits where the system complies with 690.35(A) through 690.35(G).

(A) Disconnects. All photovoltaic source and output circuit conductors shall have disconnects complying with 690, Part III.

(B) Overcurrent Protection. All photovoltaic source and output circuit conductors shall have overcurrent protection complying with 690.9.

(C) Ground-Fault Protection. All photovoltaic source and output circuits shall be provided with a ground-fault protection device or system that complies with (1) through (3):

• (1) Detects a ground fault.
• (2) Indicates that a ground fault has occurred
• (3) Automatically disconnects all conductors or causes the inverter or charge controller connected to the faulted circuit to automatically cease supplying power to output circuits.
(D) The photovoltaic source and output conductors shall consist of the following:

1. Nonmetallic jacketed multiconductor cables
2. Conductors installed in raceways, or
3. Conductors listed and identified as Photovoltaic (PV) Wire installed as exposed, single conductors.

(E) The photovoltaic power system direct-current circuits shall be permitted to be used with ungrounded battery systems complying with 690.71(G).

(F) The photovoltaic power source shall be labeled with the following warning at each junction box, combiner box, disconnect, and device where the ungrounded circuits may be exposed during service:

WARNING
ELECTRIC SHOCK HAZARD
THE DC CIRCUIT CONDUCTORS OF THIS PHOTOVOLTAIC POWER SYSTEM ARE UNGROUNDED AND MAY BE ENERGIZED WITH RESPECT TO GROUND DUE TO LEAKAGE PATHS AND/OR GROUND FAULTS.

(G) The inverters or charge controllers used in systems with ungrounded photovoltaic source and output circuits shall be listed for the purpose.
2014 NEC Revisions:
690.35—Ungrounded PV Power Systems
One significant addition to 690.35

• “(D) Conductors. The PV source conductors shall consist of the following:

  • (1) Metallic or nonmetallic jacketed multiconductor cables
  • (2) Conductors installed in raceways
  • (3) Conductors listed and identified as PV wire installed as exposed, single conductors, or
  • (4) Conductors that are direct-buried and identified for direct-burial use”
Part V. Grounding
690.41 System Grounding

- All systems above 50 Volts must be grounded or follow 690.35.
- Bi-polar systems must have a center-tap ground.
690.42 Point of System Grounding Connection

• System grounding point at the ground-fault detection device.
“Devices listed and identified for grounding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to grounded mounting structures. Devices identified and listed for bonding the metallic frames of PV modules shall be permitted to bond the exposed metallic frames of PV modules to the metallic frames of adjacent PV modules.”
Early Improvements for Grounding

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

Figure 2. Insert a bolt in the aluminum rail or through the clearance hole in the stainless steel flat washer. Place the stainless steel flat washer on the bolt, oriented so the dimples will contact the aluminum rail. Place the lug portion on the bolt and stainless steel flat washer. Install stainless steel flat washer, lock washer and nut. Tighten the nut until the dimples are completely embedded into the rail and lug. The embedded dimples make a gas-tight mechanical connection and ensure good electrical connection between the aluminum rail and the lug through the WEEB.
Metallic mounting racks must be identified as an equipment grounding conductor or have bonding jumpers/devices connected between the separate metallic racks and be connected to an equipment grounding conductor.
690.45 Size of Equipment Grounding Conductors [2008 NEC]

- “(A) General. Equipment grounding conductors in photovoltaic source and photovoltaic output circuits shall be sized in accordance with Table 250.122.”
Table 250.122 Minimum Size Equipment Grounding Conductors for Grounding Raceway and Equipment

<table>
<thead>
<tr>
<th>Rating or Setting of Automatic Overcurrent Device in Circuit Ahead of Equipment, Conduit, etc., Not Exceeding (Amperes)</th>
<th>Size (AWG or kcmil)</th>
<th>Aluminum or Copper-Clad Aluminum*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Copper</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>14</td>
<td>12</td>
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<td>20</td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td>60</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>100</td>
<td>8</td>
<td>6</td>
</tr>
<tr>
<td>200</td>
<td>6</td>
<td>4</td>
</tr>
<tr>
<td>300</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>400</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>500</td>
<td>2</td>
<td>1/0</td>
</tr>
<tr>
<td>600</td>
<td>1</td>
<td>2/0</td>
</tr>
</tbody>
</table>
(1) Separate dc Grounding Electrode System Bonded to the ac Grounding Electrode System.

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

- A dc grounding electrode conductor of the size specified by 250.166 shall be run from the marked dc grounding point to the ac grounding electrode. Where an ac grounding electrode is not accessible, the dc grounding electrode conductor shall be connected to the ac grounding electrode conductor.
(3) Combined DC Grounding Electrode Conductor and AC Equipment Grounding Conductor.

- An unspliced, or irreversibly spliced, combined grounding conductor shall be run from the marked dc grounding point to the grounding busbar in the associated ac equipment. This combined conductor shall be the larger of the sizes specified by 250.122 or 250.166
2014 NEC Revisions:
Part V—Grounding
690.46 Array Equipment Grounding Conductors.
(new paragraph)

- “Where installed in raceways, equipment grounding conductors and grounding electrode conductors not larger than 6 AWG shall be permitted to be solid.”
690.47 Grounding Electrode System. (B) Direct-Current Systems.

- New Paragraph
- “An ac equipment grounding system shall be permitted to be used for equipment grounding of inverters and other equipment and for the ground-fault detection reference for ungrounded PV systems.”

- New sentence
- “For ungrounded systems, this conductor shall be sized in accordance with 250.122 and shall not be required to be larger than the largest ungrounded phase conductor.”
2014 NEC Revisions:
690.47(D)—Additional Auxiliary Electrodes for Array Grounding.
(Night of the Dead Part III)
Exception 2 is still available

- “An additional array grounding electrode(s) shall not be required if located within 1.8 m (6 ft) of the premises wiring electrode.”

- Open to interpretation. Proper interpretation of this exception is that any PV system mounted on a building with a grounding electrode puts the array within 6’ of the electrode and meets the exception. No other interpretation makes sense.
Part VI. Marking
690.53 Marking: DC PV Power Source [2008 NEC]

- **(1) Rated maximum power-point current**
  \[ \text{Imp} \times \text{number of series strings} \]

- **(2) Rated maximum power-point voltage**
  \[ \text{Vmp} \times \text{number of modules in series} \]

- **(3) Maximum system voltage**
  FPN to (3): See 690.7(A) for maximum photovoltaic system voltage.

- **(4) Short-circuit current**
  FPN to (4): See 690.8(A) for calculation of maximum circuit current.

- **(5) Maximum rated output current of the charge controller (if installed)**
690.56 Identification of Power Sources
690.56(A) Facilities with Stand-Alone Systems

- Building/structure with a stand-alone PV system must have a permanent plaque at a readily visible exterior location indicating the location of the stand-alone disconnecting means and that the structure contains a stand-alone system.
Part VII. Other Sources
Article 705—Interconnected Electric Power Production Sources
705.12 Point of Connection
705.12(D) Point of Connection Load Side

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

“(1) Dedicated Overcurrent and Disconnect. Each source interconnection shall be made at a dedicated circuit breaker or fusible disconnecting means.”
705.12(D) Point of Connection
Load Side

“(2) Bus or Conductor Rating. The sum of the ampere ratings of overcurrent devices in circuits supplying power to a busbar or conductor shall not exceed 120 percent of the rating of the busbar or conductor.”
705.12(D) Point of Connection
Load Side

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

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

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

• (6) Fastening. Listed plug-in-type circuit breakers backfed from utility-interactive inverters shall be permitted to omit the additional fastener normally required by 408.36(D) for such applications.
705.12(D)(7) Inverter Output Connection

• When the sum of the OCPDs supplying power to a panelboard exceeds the bus bar rating as permitted in 705.12(D)(2), a dedicated ac inverter circuit breaker must be located at the opposite end from the input feeder supply conductors.
2014 NEC Revisions: 705.12(D)—Load Side Connections
705.12(D) Got overhauled—Load-Side Connections Continue to Confuse Contractors and AHJs

- **Busbars and Conductors** are lumped together when they needed to be separated. New 705.12(D) creates three categories: 1. Feeders, 2. Taps, and 3. Busbars. Each have different rules since they have different characteristics.
• “(1) Dedicated Overcurrent and Disconnect. The source interconnection of one or more inverters installed in one system shall be made at a dedicated circuit breaker or fusible disconnecting means.”

• The additional words were to clarify that more than one inverter can be connected to a dedicated breaker. “Dedicated” in this context means only generation—no loads.
Bus or Conductor Ampere Rating.

• “One hundred twenty-five percent of the inverter output circuit current shall be used in ampacity calculations for the following:”

• 1. Feeders; 2. Taps; and, 3. Busbars
(1) **Feeders.**

- “Where the inverter output connection is made to a feeder at a location other than the opposite end of the feeder from the primary source overcurrent device, that portion of the feeder on the load side of the inverter output connection shall be protected by one of the following:”
First—Understand Opposite End

- Feeder conductor does not require upsizing (no 120% rule) when PV at opposite end from feeder breaker.
(1) Feeders; (a) and (b)

- “(a) The feeder ampacity shall be not less than the sum of the primary source overcurrent device and 125 percent of the inverter output circuit current.

- (b) An overcurrent device on the load side of the inverter connection shall be rated not greater than the ampacity of the feeder.”
Summary of (a) and (b)

- If not at opposite end, currents add for remainder of circuit, wherever the PV is connected.

FEEDER SIZE INCREASED TO 400-AMPS
Load Side Connections: (b) OCPD on load side of PV connection.
(2) Taps.

“In systems where inverter output connections are made at feeders, any taps shall be sized based on the sum of 125 percent of the inverter(s) output circuit current and the rating of the overcurrent device protecting the feeder conductors as calculated in 240.21(B).”
Taps with PV

• Taps are sized based on size of the feeder breaker and the length of the tap.

• To simplify the calculation with a PV inverter installed on the feeder, 125% of the PV inverter current is added to the feeder breaker size. This is highly conservative, but simple.
Load Side Connections: Scenario 1

Scenario 1:

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

9° Tap—Minimum conductor size based on 240.21(b)(2) = 1/10 of 200A + 200A = 40A
Actual size is 100A due to panel size

Main Breakers necessary in panelboards to protect buswork
Load Side Connections: Scenario 2

Scenario 2:

- Largest allowable PV system on load side at the opposite end of the primary supply OCPD
- 200-amp feeder
- 24’, 100-amp tap to 100-amp subpanel must be sized for 133A to meet tap rule.
- Large PV at opposite end of feeder—requires 200-amp connection—size governed by inverter output
- OKAY—Overcurrent protection covers all cases of overcurrent (tap prohibition not required)
Load Side Connections: Scenario 2-OKAY

24" Tap—Minimum conductor size based on 2402.1(B)(3) = 1/3 of 200A +200A = 133A
Actual size is 133A due to tap rule

Main Breakers necessary in panelboards to protect buswork
Load Side Connections: Scenario 3

Scenario 3:

- Largest allowable PV system on load side.
- 200-amp feeder
- Large PV requires 200-amp connection—size governed by inverter output
- NOT OKAY since 200-amp feeder and panelboard bus could be overloaded
Load Side Connections: Scenario 3-
NOT OKAY

PV (160A continuous)

Main Distribution Panel

1000 A BUS

200 A BUS

MLO

Load

Load

Load

Subpanel

200 A BUS
(3) **Busbars.**

- “One of the methods that follows shall be used to determine the ratings of busbars in panelboards.

  (a) The sum of 125 percent of the inverter(s) output circuit current and the rating of the overcurrent device protecting the busbar shall not exceed the ampacity of the busbar.”
(a) Informational note

- “This general rule assumes no limitation in the number of the loads or sources applied to busbars or their locations.”
- Sum of the supply breakers, utility, PV, or whatever, are less than or equal to busbar rating.
- No limitation on number or size of load breakers since supply breakers protect the bus.
(3) Busbars. (b) 2011 120% rule

- (b) restates the 2011 NEC 120% busbar rule (only applies to busbars, not conductors).
- Better wording and 125% of inverter current used rather than OCPD rating.
705.12(D)(2)(3)(b) 120% of Busbar Rule
1000 A (bus) x 1.2 = 1200 A
1200 A – 1000 A (main) = 200 A (max)

Minimum Overcurrent Device
Inverter Max Current = 157.5 A
Min OCPD = 157.5 A x 1.25 = 197 A (200 A)
(c) Sum of branch breakers used to protect busbar

- “(c) The sum of the ampere ratings of all overcurrent devices on panelboards, both load and supply devices, excluding the rating of the overcurrent device protecting the busbar, shall not exceed the ampacity of the busbar.

- The rating of the overcurrent device protecting the busbar shall not exceed the rating of the busbar.”
(C) Warning label required

- "WARNING: THIS EQUIPMENT FED BY MULTIPLE SOURCES. TOTAL RATING OF ALL OVERCURRENT DEVICES, EXCLUDING MAIN SUPPLY OVERCURRENT DEVICE, SHALL NOT EXCEED AMPACITY OF BUSBAR.

- The warning sign(s) or label (s) shall comply with 110.21(B)."
705.12(D)(2)(3)(c)

Sum of Breakers Equal Busbar Rule
200 A (bus) = 30A+30A+30A+40A+40A (either load or supply)

WARNING
THIS EQUIPMENT FED BY MULTIPLE SOURCES
TOTAL RATING OF ALL OVERCURRENT DEVICES,
EXCLUDING MAIN SUPPLY, SHALL NOT EXCEED
AMPACITY OF BUSBAR
(d) multi-ampacity or center-fed panelboards

• “(d) Connections shall be permitted on multiple-ampacity busbars or center-fed panelboards where designed under engineering supervision that includes fault studies and busbar load calculations.”
Example of multi-ampacity buswork approved

SERVICE #1-1

3000A FRAME w/ 2500A Plug

- Refrigeration RC-1 125A
- Panel MCC-C 400A
- Panel 1HD 200A
- Panel 1HA 200A

2500-Amp Section Bus
(typical 2 plcs)

Maximum sum of load breakers
2000 amps per branch

3000-Amp Main Bus

- Panel MCCA 300A

2000A TIE BREAKER

- Panel 1HE 200A
- Panel 1HF 200A
- Panel 1HJ 200A

Normally Open Tie Breaker;
Only closed temporarily when one of service breakers are opened to perform work on utility service conductors

SERVICE #1-2

3000A FRAME w/ 2000A Plug

- Panel EHA 225A
- Refrigeration RC-2 250A
- Refrigeration RC-3 250A
- Refrigeration RC-5 250A

3000-Amp Main Bus

- Panel SDP 1-2 1000A

2000-Amp Section Bus
(typical 2 plcs)

Maximum sum of load breakers
2000 amps per branch

- PV Inverter 800A
- Panel MCCB 800A
- Panel 1HB 400A
- Panel 1HH 400A
- Panel 1HA 200A

- Refrigeration RC-1 250A
- Refrigeration RC-3 250A
705.12(D)(3) removed.
Redundant with 705.32.

- “705.32 Ground-Fault Protection. Where ground-fault protection is used, the output of an interactive system shall be connected to the supply side of the ground-fault protection.

- Exception: Connection shall be permitted to be made to the load side of ground-fault protection, provided that there is ground-fault protection for equipment from all ground-fault current sources.”
705.12(D) (4) Suitable for Backfeed.

• “Circuit breakers, if backfed, shall be suitable for such operation.
  
  Informational Note: Fused disconnects, unless otherwise marked, are suitable for backfeeding.”

• Information about breakers was removed since some breakers with “line” and “load” are suitable for backfeed.
New (6) Wire Harness and Exposed Cable Arc-Fault Protection.

- “A utility-interactive inverter(s) that has a wire harness or cable output circuit rated 240 V, 30 amperes, or less, that is not installed within an enclosed raceway, shall be provided with listed ac AFCI protection.”
- Microinverters with wire harnesses require AFCI breaker protection.
- Since no products exist that can provide this function, NEC 90.4 applies (not required to be installed). Proposal to remove this requirement was accepted.
705.31 Location of Overcurrent Protection.

- New section requires OCPD to be within 10’ of connection to service conductors unless current limiters are installed.
705.100 Unbalanced Interconnections. (A) Single Phase

- Previous version (1996-2011 NEC) has been used by utility companies and AHJs to justify not allowing single phase inverters on 3-phase systems.
- Fundamental misunderstanding by utilities and AHJs of how PV inverters work and contribute to voltage imbalance.
(A) Single Phase—New Language

• “(A) Single Phase. Single-phase inverters for hybrid systems and ac modules in interactive hybrid systems shall be connected to three-phase power systems in order to limit unbalanced voltages to not more than 3 percent.

Informational Note: For utility-interactive single-phase inverters, unbalanced voltages can be minimized by the same methods that are used for single-phase loads on a three-phase power system. See ANSI/C84.1-2011, Electric Power Systems and Equipment — Voltage Ratings (60 Hertz).”
The American National Standard for Electric Power Systems and Equipment ANSI C84.1 recommends that “electric supply systems should be designed and operated to limit the maximum voltage unbalance to 3 percent when measured at the electric-utility revenue meter under no-load conditions.”
Voltage Unbalance Formula:

Percent Voltage Unbalance = \(100 \times \frac{\text{Maximum Voltage Deviation}}{\text{Average Voltage}}\)

Example:
Assume the following phase-phase voltages were measured:
A-B = 479V
B-C = 472 V
C-A = 450 V

Average Voltage = \(\frac{479 V + 472 V + 450 V}{3} = 467 V\)

Maximum Voltage Deviation from Average = 467 V - 450 V = 17 V

Voltage Unbalance = \(100 \times \frac{17 V}{467 V} = 3.6\%\)
COURSE AGENDA

• INTRODUCTION OF TOPICS—WORKING WITH FIRE DEPARTMENTS AND BUILDING DEPARTMENTS
• RAPID SHUTDOWN [690.12, 2014 NEC]
• GROUND-FAULT DETECTION [690.5]
• ARC-FAULT DETECTION [690.11]
• WIRING METHODS [690.31]
• 2012 INTERNATIONAL FIRE CODE (AND NFPA1)
WORKING WITH FIRE DEPARTMENTS AND BUILDING DEPARTMENTS

• Most fire departments have little knowledge of PV systems, but that is changing.

• Always approach an Authority Having Jurisdiction (AHJ) as an ambassador of solar energy.

• The contractor must be knowledgeable of the electrical, building, and fire codes that govern PV systems. In other words, you must be educated so that you can educate AHJs. Far more installation problems have occurred from lack of education, by all parties, than any intention to dodge code requirements.
Rapid Shutdown of PV Systems

Firefighter Safety in the 2014 National Electrical Code

As PV systems become increasingly safer, NFPA has targeted firefighter safety in its 2014 NEC for PV systems. In addition to several requirements included in the 2011 NEC for firefighter safety — (690.4(F), which provided specific PV conductor installation requirements; 690.11, which provides a requirement for dc arc-fault protection; and 690.31(F), which provides further installation and marking requirements for PV conductors in a building) — NFPA established a task group in Code-Making Panel 4 (C4MP-4) to address potential proposals for the 2014 NEC. The primary outcome of the firefighter safety task group was the development of a new code section 690.12, entitled "Rapid Shutdown of PV Systems on Buildings." The focus of this new section is to allow first responders to quickly and easily control the PV system circuits leaving an array in a PV system. Although the most predominant issue of concern was "cooking systems," the requirement would also extend to ground-mounted systems if the conductors enter a building for more than 5 feet. Multiple methods to achieve rapid shutdown were discussed at length during the proposal and comment periods, resulting in the language that is currently in the 2014 NEC.

As with any new code language, it is helpful to understand what the committee was attempting to accomplish with the language so that those involved in either the installation of PV systems or the electrical code enforcement for the installation can appropriately understand and apply the electrical code requirements to the unique system installation. This article is intended to explain the language of the new section 690.12 and provide context and examples of how to understand and enforce the requirements. Those examples that are portrayed in this article are not intended to be an exhaustive treatment of how to comply with 690.12, but rather are intended to show there are numerous ways, with existing PV products, to meet the requirements of 690.12, and improve safety for emergency responders.

Background

Emergency responders are becoming more aware of the presence of PV systems as well as some of their inherent safety hazards. This awareness is particularly true in areas of the country where PV systems are common such as California, New Jersey, Hawaii, Massachusetts, just to name a few. One of the first questions a firefighter or other emergency responder asks is, "How do I shut the system down so I won't get shocked?" This simple question may have a complicated answer for many PV systems. Thinking that a PV system is similar to utility electrical services, many fire departments have required a rooftop disconnecting means so that firefighters can turn off a PV system switch during rooftop operations believing that once they open the disconnect their concerns are alleviated.
690.12 Rapid Shutdown of PV Systems on Buildings.

- “PV system circuits installed on or in buildings shall include a rapid shutdown function that controls specific conductors in accordance with 690.12(1) through (5) as follows.

1) Requirements for controlled conductors shall apply only to PV system conductors of more than 1.5 m (5 ft) in length inside a building, or more than 3 m (10 ft) from a PV array.

2) Controlled conductors shall be limited to not more than 30 volts and 240 volt-amperes within 10 seconds of rapid shutdown initiation.
For AEE Internal Use Only.
690.12 Rapid Shutdown of PV Systems on Buildings. (cont.)

(3) Voltage and power shall be measured between any two conductors and between any conductor and ground.

(4) The rapid shutdown initiation methods shall be labeled in accordance with 690.56(B).

(5) Equipment that performs the rapid shutdown shall be listed and identified.”

• No standard yet for specialized equipment to meet the requirement.
690.12 Rapid Shutdown Compliance Options

1. Dc string contactor combiners or dc string combiners with motorized switch mounted within 10 feet of the array paired with central inverter that has a dc contactor between the array and internal capacitors.

2. String inverter or dc optimizer inverter located on roof within 10 feet of the array.

3. Use micro-inverters

4. Use dc optimizers at modules or combiner level paired with central inverter that has a dc contactor between the array and internal capacitors.
690.56 (C) Facilities with Rapid Shutdown.

• “Buildings or structures with both utility service and a PV system, complying with 690.12, shall have a permanent plaque or directory including the following wording:

  PHOTOVOLTAIC SYSTEM EQUIPPED WITH RAPID SHUTDOWN”
Other Related Code Provisions that Protect Firefighters:
690.5—Ground-Fault Protection
690.5(A) Ground-Fault Detection and Interruption.

- “The ground fault protection device or system shall:
  
  (1) Be capable of detecting a ground fault in the PV array dc current-carrying conductors and components, including any intentionally grounded conductors,
  
  (2) Interrupt the flow of fault current
  
  (3) Provide an indication of the fault, and
  
  (4) Be listed for providing PV ground-fault protection”
690.5 Ground-Fault Protection Compliance Options

1. Non-isolated inverters (AKA transformerless) that have ungrounded arrays when not running [690.35]
2. Ungrounded micro-inverters
3. Central inverters with high resolution ground-fault detectors (Bender residual current monitors)
4. Combiner boxes with high resolution ground-fault detection on both positive and negative conductors
Field Guide for Testing Existing Photovoltaic Systems for Ground Faults and Installing Equipment to Mitigate Fire Hazards

November 2012 — October 2013

William Brooks
Brooks Engineering
Key Points

- Existing PV system owners need to consider retrofits to reduce fire risk.
- Many current designs still have the ability to start fires.
- Properly applying the NEC will lead to selecting products that will not allow ground fault and arc faults to start fires.
Background on Previous Work and Ongoing Project

• **Known fire hazards exist with PV systems**
  - Ground faults in older systems (no blind spot necessary)
  - Ground fault blind spot fires
  - Arcing fires (connection, connector, or conductor failures)

• **SolarABCs research project outlines ground fault blind spot concerns.**
  [http://solarabcs.org/about/publications/reports/blindspot/index.html](http://solarabcs.org/about/publications/reports/blindspot/index.html)

• **The National Renewable Energy Laboratory (NREL) is continuing work in this area. Field Guide for retrofitting existing PV systems is first project under this contract.**

• **The Field Guide has recently been published.**
Purpose of the Field Guide

- Provide practical guidance to field technicians on how best to perform testing on PV systems with known and unknown ground faults.
- Discuss need for residual current monitors on grounded PV systems to improve ground fault detection to a safe level.
- Discuss equipment and methods of installation for residual current monitors that can be retrofitted to any grounded PV system.
- Discuss need for arc fault detection equipment to complete the safety hardware necessary to cover remaining known fire hazards.
2014 NEC Revisions: 690.11—Arc-Fault Protection
690.11 Arc-Fault Circuit Protection (Direct Current).

- “Photovoltaic systems with dc source circuits, dc output circuits, or both, operating at a PV system maximum system voltage of 80 volts or greater, shall be protected by a listed (dc) arc-fault circuit interrupter, PV type, or other system components listed to provide equivalent protection.”
690.11 Arc-Fault Protection Compliance Options

1. String inverters with arc-fault protection built in
2. Micro-inverters (under 80 Volts)
3. Dc optimizers (under 80 Volts)
4. Central inverters with string combiner boxes with arc-fault detection built in
5. Central inverters with PV output circuit combiner box with arc-fault detection built in
Part IV. Wiring Methods
NEC 690.31
PV system conductors are not permitted to be located within 10 in. of roof decking, except below PV equipment.

Note: The 10 in. from the roof decking is to prevent contact to energized conductors from saws used by firefighters for roof ventilation.
690.31(E)(2) Flexible Wiring

- FMC smaller than $\frac{3}{4}$ or Type MC cable smaller than 1 in. run across ceilings or floor joists must be protected by guard strips as high as the wiring method.

- Where run exposed, other than within 6 ft of their connection to equipment, wiring methods must closely follow the building surface or be protected from physical damage by an approved means.
690.31(E)(4)  
Marking/Labeling

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

- Spacing between labels or markings, or between a label and a marking, must not be more than 10 ft and labels must be suitable for the environment where they are installed.
2012 IFC and 2011 NEC Have Parallel Requirements

- **2012 IFC Requires**
  - Sign at main service disconnect
  - Conduit markings
  - Conduit location
  - Access pathways and ventilation opportunities

- **2011 NEC Requires**
  - Sign at main service disconnect
  - Conduit markings
  - Conduit location

- **2015 IFC removes electrical details**
2.0 ACCESS, PATHWAYS AND SMOKE VENTILATION (IFC 605.11.3)

- Section 2.0 relates to fire departments that engage in vertical ventilation operations.
- Some departments are beginning to limit vertical ventilation for lightweight construction.
- Other buildings already have automatic roof vents making roof access unnecessary.
- Metal and concrete decked buildings are rarely trenched, so access to vents and skylights is all that may be necessary.
Purpose of Section 2.0

Access and spacing requirements should be observed in order to:

• *Ensure access to the roof*
• *Provide pathways to specific areas of the roof*
• *Provide for smoke ventilation opportunities*
• *Provide emergency egress from the roof*
Exceptions to Section 2.0

Local jurisdictions may create exceptions to this requirement where access, pathway or ventilation requirements are reduced due to:

- Proximity and type of adjacent exposures
- Alternative access opportunities (as from adjoining roofs)
- Ground level access to the roof area in question
Exceptions to Section 2.0 (cont.)

- Adequate ventilation opportunities beneath solar array (as with significantly elevated or widely-spaced arrays)
- Adequate ventilation opportunities afforded by module set back from other rooftop equipment (shading or structural constraints may leave significant areas open for ventilation near HVAC equipment, for example.)
- Automatic ventilation device.
- New technology, methods, or other innovations that ensure adequate fire department access, pathways and ventilation opportunities.
Roof Ventilation—Residential Roof Layouts Ventilation (IFC 605.11.3.2.4)

- 3’ space along ridge of roof
  Ridge setback based on enough room to make 2’ wide ventilation cut.
  ASCE 7, Minimum Design Loads for Buildings, requires this setback in high wind locations (e.g. eastern seaboard)

- No rooftop disconnect requirement. (see appendix)

- Each roof face treated independently.

- PV array and wiring is off limits to fire fighters.
Roof Access—Residential Hip Roof Layouts
(IFC 605.11.3.2.1)

- Single hip needs one 3’ pathway on array faces.
- Pathway should be along a structurally strong location such as a load bearing wall.
- IFC adds a statement that ladder locations cannot be in front of windows or doors and cannot conflict with tree limbs, wires, or signs. (this is a problem)
Roof Access—Residential with Single Ridge
(IFC 605.11.3.2.2)

- Single ridge needs two 3’ pathways on array faces along edge of load bearing exterior wall.
Full Gable
Roof Access—Residential Hips and Valleys
(IFC 605.11.3.2.3)

• 1.5’ space on either side of a hip or valley.
• PV array can go to the center of the hip or valley if the hip or valley is of equal length on adjacent faces and no modules are on the adjacent face.
Cross Gable with Valley
Access—Commercial (IFC 605.11.3.3.1)

- Commercial flat roof with no roof dimension more than 250 feet—4’ space around perimeter wall.
- Commercial flat roof with a roof dimension more than 250 feet—6’ space around perimeter wall.
- No rooftop disconnect requirement for fire fighters. (Rapid Shutdown in 2014 NEC is different)
Pathways and Ventilation—Commercial (IFC 605.11.3.3.2 & 605.11.3.3.3)

- Minimum 4’ pathway on center access of building in both directions. A 4’ access to skylights, roof hatches, and fire standpipes shall be provided to the perimeter wall.
- Commercial rooftop arrays shall be no greater than 150 by 150 feet in distance in either axis.
- Array off limits to fire fighters.
Commercial < 250’
Commercial > 250’
Commercial > 250’
Vent openings every 20’
THANK YOU!