



Solar PV Systems

*Presented by
Fred Mertz, IQ Electrical Training
for the*

*Office of Education and Data Management
Fall 2015 Career Development Series*

Solar Photovoltaic Power

2014 NEC Articles 690 and 705

Your Instructor



Presented by
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City of Bristol CT~ Electrical Inspector
IAEI Master Electrical Inspector
CT and VA Licensed Master Electrician
Licensed Ct. Building Official
NABCEP Entry Level Prepared
IQ Electrical Training- Connecticut
Continuing Education Provider

Objectives

PV Inspections are difficult even for a seasoned Electrical Inspector.

- 1.) To help the Combination Inspector become a better Electrical Inspector.
- 2.) Provide information and explanations in easy to understand terms: using graphics, photos and descriptions to illustrate the major concepts.

9/9/2015

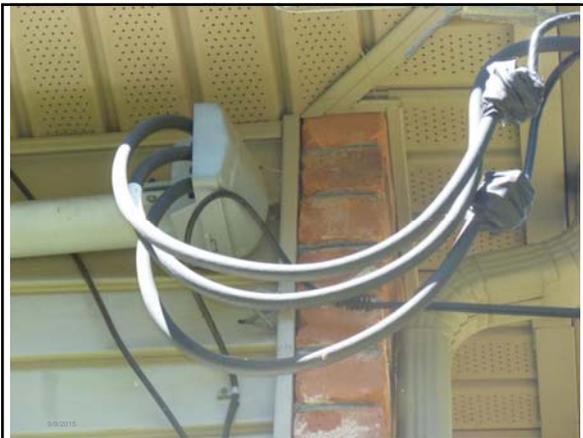
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Definitions

- “Service Point”
- The point of connection between the facilities of the serving utility and the premises wiring.

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Definitions

- **“Service Conductors”**
- **The conductors from the service point to the service disconnecting means.**

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Definitions

- **“Service Equipment”**
- **The necessary equipment, usually consisting of circuit breaker(s) or switch(es) and fuse(s) connected to the load end of the service conductors and intended to constitute the main cutoff of the supply.**

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Definitions

- Service
- The conductors and equipment for delivering electric energy from the serving utility to the wiring system of the premises served. If power is supplied by other than the utility the conductors are considered a feeder.

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Definitions

- “Feeder”
- All circuit conductors between the service equipment, or other power supply source and the final branch-circuit overcurrent device.

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250.6 Objectionable Current

- 250.6(A)-The grounding of electrical systems, circuit conductors, and conductive normally non-current-carrying metal parts of equipment shall be installed and arranged in a manner that will prevent objectionable currents.**

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Definitions

- “Branch Circuit”**
- The circuit conductors between the final overcurrent device protecting the circuit and the outlet(s).**

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Article 690 Definitions

- **DC-to-DC Converter.** A device installed in the PV source circuit or PV output circuit that can provide an output dc voltage and current at a higher or lower value than the input dc voltage and current.

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What does it do??

A photograph of a small, grey, rectangular DC-to-DC converter. It has four cables extending from the bottom: two black cables and two blue cables. The converter is mounted on a surface.

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Most often seen Solaredge



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ARTICLE 690

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Article 690 Definitions

- **Direct-Current Combiner.**
- **A device used in the PV source and PV output circuits to combine two or more dc circuit inputs and provide one dc circuit output.**

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690.12 Rapid Shutdown (NEW)

- 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 5 ft in length inside a building, or more than 10 ft from a PV array.

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690.12 Rapid Shutdown (NEW)

- (2) Controlled conductors shall be limited to not more than 30 volts and 240 volt-amperes within 10 seconds of rapid shutdown initiation.
- (3) Voltage and power shall be measured between any two conductors and between any conductor and ground.

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690.12 Rapid Shutdown (NEW)

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

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690.56 ID of Power Sources

- (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
 - The plaque or directory shall be reflective, with all letters capitalized and having a minimum height of 3/8 in, white on red background.

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690.12 Rapid Shutdown (NEW)

- (5) Equipment that performs the rapid shutdown shall be listed and identified.
- Article 110.3

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III. Disconnecting Means

- 690.13 Building or Other Structure Supplied by a Photovoltaic System.** Means shall be provided to disconnect all ungrounded DC conductors of a PV system from all other conductors in a building or other structure.

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III. Disconnecting Means

- 690.13(A) Location.**
- The PV disconnecting means shall be installed at a readily accessible location either on the outside of a building or structure or inside nearest the point of entrance of the system conductors.**

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III. Disconnecting Means

- **Exception: Installations that comply with 690.31(G) shall be permitted to have the disconnecting means located remote from the point of entry of the system conductors.**

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690.31(G) Class Discussion

- **690.31(G) DC Photovoltaic Source and DC Output Circuits on or Inside a Building.**
- **Where DC PV source or DC PV output circuits from a PV systems are run inside a building or structure, they shall be contained in metal raceways,**

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Section Continued

Type MC cable that complies with 250.118(10), or metal enclosures from the point of penetration of the surface of the building or structure to the first readily accessible disconnecting means.

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Back to Disconnecting means

- The disconnecting means shall comply with 690.13(B) and (C) and 690.15(A) and (B). The wiring methods shall comply with the additional installation requirements in 690.31(G)(1)through(4)

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690.13 (B)

- (B) Marking.
- Each PV system disconnecting means shall be permanently marked to identify it as a PV system disconnect.

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690.13(C)

- (C) Suitable for Use.
- Each PV system disconnecting means shall not be required to be suitable as service equipment.

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Notes on 690.13

- The wording of this section can lead to some confusion. As the industry grows up and the various disconnects in a PV system are clearly named things will become clearer.

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690.13 (A)

- (A)The PV system disconnecting means shall not be installed in bathrooms.

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690.13(D)

- (D) Maximum Number of Disconnects.
- The PV system disconnecting means shall consist of not more than six switches or six circuit breakers mounted in a single enclosure or in a group of separate enclosures.

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690.15
Disconnection of
Photovoltaic Equipment

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690.15 (A) and (B)

- (A) **Utility-Interactive Inverters Mounted in Not Readily Accessible Locations.**
- (B) **Equipment. Equipment such as PV source circuit isolating switches, overcurrent devices, dc-to-dc converters, and blocking diodes shall be permitted on the PV side of the PV disconnecting means. (NOTES)**

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690.15(C)

- (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 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.**

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Soladeck box with DIN rail



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690.17(E)

- **690.17(E) Interrupting Rating.** The building or structure disconnecting means shall have an interrupting rating sufficient for the maximum circuit voltage and current that is available at the line terminals of the equipment. Where all terminals of the disconnecting means may be energized in the open position, a warning sign shall be mounted on or adjacent to the disconnecting means. The sign shall be clearly legible and have the following words or equivalent:

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690.17(E)

- **WARNING :**
 - **ELECTRIC SHOCK HAZARD DO NOT TOUCH TERMINALS. TERMINALS ON BOTH THE LINE AND LOAD SIDES MAYBE ENERGIZED IN THE OPEN POSITION.**
- **The warning sign(s) or label(s) shall comply with 110.21(B)**

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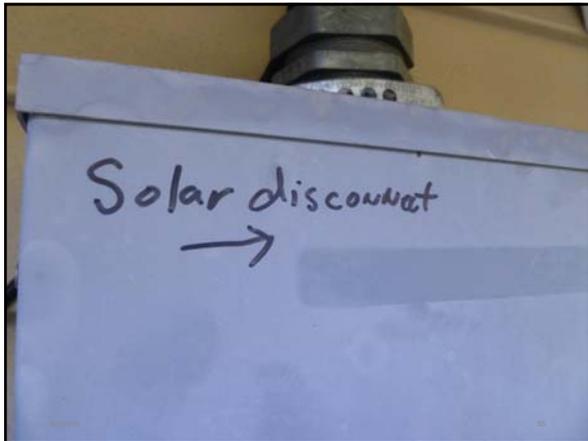




What about Sharpie

- **Sharpie Extreme permanent markers have high-contrast ink that resists fading when exposed to harsh UV rays, rain, and snow. Sharpie Extreme delivers bold color and can be used on most surfaces, including plastic, glass and wood.**

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680.35(F)

- 690.35(F) Marking. The PV power source shall be labeled with the following warning at each junction box, combiner box, disconnect, and device where energized, ungrounded circuits may be exposed during service:
- **WARNING: ELECTRIC SHOCK HAZARD. THE DC CONDUCTORS OF THIS PHOTOVOLTAIC SYSTEM ARE UNGROUNDED AND MAY BE ENERGIZED.**
- The warning sign(s) or label(s) shall comply with 110.21(B).

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690.41 System Grounding

- 690.41 System Grounding. Photovoltaic systems shall comply with one of the following:
- (1) Ungrounded systems shall comply with 690.35.

A-Disconnects B-Overcurrent Protection
C-Ground Fault Protection D-Conductors
E-Battery systems F-Marking
G-Equipment shall be listed

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690.41 System Grounding

- 690.41(2) Grounded two-wire systems shall have one conductor grounded or be impedance grounded, and the system shall comply with 690.5.
- 690.5-Ground Fault Protection

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Grounded DC System



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690.47(C)(1)-(2)-(3) Grounding Electrode Sytem

- (1) Separate Direct-Current Grounding Electrode System Bonded to the Alternating-Current Grounding Electrode System.**
- (2) Common Direct-Current and Alternating-Current Grounding Electrode.**
- (3) Combined Direct-Current Grounding Electrode Conductor and Alternating-Current Equipment Grounding Conductor.**

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690.47(D)

- (D) Additional Auxiliary Electrodes for Array Grounding.**
- A grounding electrode shall be installed in accordance with 250.52 and 250.54 at the location of all ground- and pole-mounted PV arrays and as close as practicable to the location of roof-mounted PV arrays.**
- 250.166**
- Exception No. 2: An additional array grounding electrode(s) shall not be required if located within 6 ft of the premises wiring electrode.**

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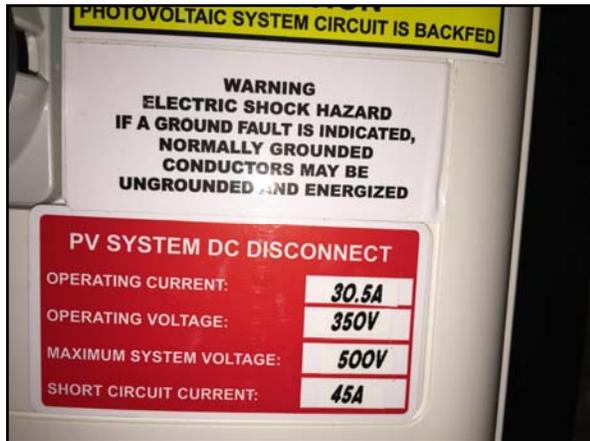
690.53 More Labels

•690.53 Direct-Current Photovoltaic Power Source. A permanent label for the direct-current PV power source indicating the information specified in (1) through (5) shall be provided by the installer at the PV disconnecting means:

- (1) Rated maximum power-point current.
- (2) Rated maximum power-point voltage.
- (3) Maximum system voltage.
- (4) Maximum circuit current. Where the PV power source has multiple outputs, 690.53(1) and (4) shall be specified for each output.

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690.54

•690.54 Interactive System Point of Interconnection.

•All interactive system(s) points of interconnection with other sources shall be marked at an accessible location at the disconnecting means as a power source and with the rated ac output current and the nominal operating ac voltage.

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690.56 -- ID of Power Sources

- 690.56(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.

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690.56(C) New for 2014

- (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
- The plaque or directory shall be reflective, with all letters capitalized and having a minimum height of 3/8 in. in white on a red background.

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VII. Connection to Other Sources

- 690.60 Identified Interactive Equipment. Only inverters and ac modules listed and identified as interactive shall be permitted in interactive systems**

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690.61

- 690.61 Loss of Interactive System Power.**
- An inverter in an interactive PV system shall automatically de-energize its output to the utility upon loss of voltage in that system and shall remain in that state until the utility has been restored.**

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690.61

- A normally interactive PV system shall be permitted to operate as a stand-alone system to supply loads that have been disconnected from the utility.**

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Typical Indoor Installation



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690.64--Point of Connection

690.64 Point of Connection.

Point of connection shall be in accordance with 705.12.

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Definitions Article 705

- “Point of Common Coupling”
- The point at which the power production and distribution network and the customer interface occurs in an interactive system. Typically this is the load side of the power network meter.

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705.12 Point of Connection.

- The output of an interconnected electric power source shall be connected as specified in 705.12(A), (B), (C), or (D).

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- For our purposes 705.12(B) and (C) do not apply however 705.12(A) includes changes for 2014 and 705.12(D) is significantly changed.

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705.12(A) AKA: Line Side Tap

- 705.12(A) Supply Side.
- An electric power production source shall be permitted to be connected to the supply side of the service disconnecting means as permitted in 230.82(6).

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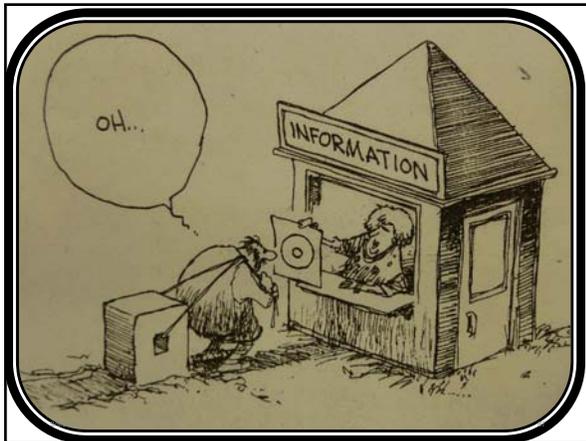
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TAP CONDUCTORS ????????

- Article 240 Definition
- Tap Conductors. As used in this article, a tap conductor is defined as a conductor, other than a service conductor, that has overcurrent protection ahead of its point of supply that exceeds the value permitted for similar conductors that are protected as described elsewhere in 240.4.

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230.82

- **Equipment Connected to the Supply Side of the Service Disconnect.**
- **Only the following equipment shall be permitted to be connected to the supply side of the service disconnecting means.**

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230.82(6)

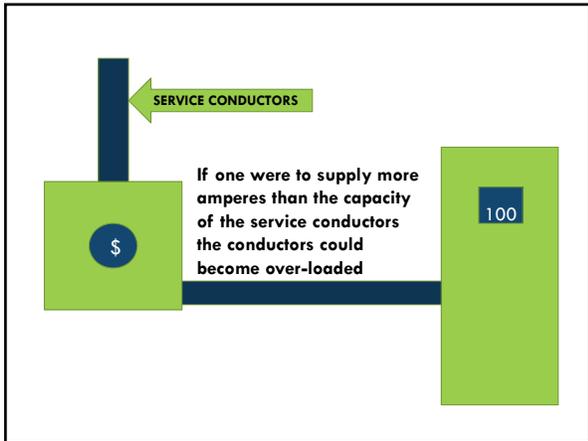
- **230.82(6)**
- **Solar photovoltaic systems, fuel cell systems, or interconnected electric power production sources.**

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705.12(A) Continued

- **The sum of the ratings of all the overcurrent devices connected to power production sources shall not exceed the rating of the service.**

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Trade Practice???

- In most trades the way things are done has been fine tuned over many years. PV is new enough that standard procedures are still being developed.

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Commentary (not code)

Beyond 705.12(A), the NEC does not provide rules for the methods required to make supply-side connections.

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Commentary (not code)

- PV installers have had to improvise and work with their inspectors to install systems that everyone thinks are safe.

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Commentary (not code)

- In most cases, this has resulted in treating supply-side connections as services and following the direction of Article 230

9/9/2015 95

Commentary (not code)

- This approach is not completely accurate because of the differences between utility services and PV.

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Commentary (not code)

- **The lack of direct guidance pertaining to the methods required to make supply-side connections leads to multiple interpretations by installers and inspectors.**

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Supply Side Interconnections

- **We have to have a name for the wires that are used to connect the PV system to the premises service conductors. For the sake of this discussion we will call these wires:**
- **CONDUCTORS CONNECTED TO THE SUPPLY SIDE OF THE SERVICE DISCONNECTING MEANS**

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2014 NEC-----705.31 (NEW)

- **705.31-Overcurrent Protection for electric power production source conductors, connected to the supply side of the service disconnecting means in accordance with 705.12(A), shall be located within 10 feet of where the electric power production source conductors are connected to the service.**

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2014 NEC-----705.31

•This new section limits the length of unprotected conductors in supply side interconnections to 10 feet due to safety concerns. Substantiation provided by Code Making Panel #4 states:

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2014 NEC-705.31-CMP No. 4

•“Often, when connections are made to, or ahead of, existing service entrance equipment, space limitations do not allow for a disconnecting means with OC protection to be adjacent to the service entrance equipment and still have proper working clearances.”

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2014 NEC-705.31-CMP No. 4

“Consequently, many of the required disconnects with OC protection are being installed remote from the service entrance equipment.”

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2014 NEC-705.31-CMP No. 4

- The CMP concludes, “A fault on these conductors will likely result in violent, explosive conductor vaporization and potential equipment damage or complete burn down”
- The unanimous decision to limit the unprotected conductor length to 10 ft. mitigates this safety hazard.

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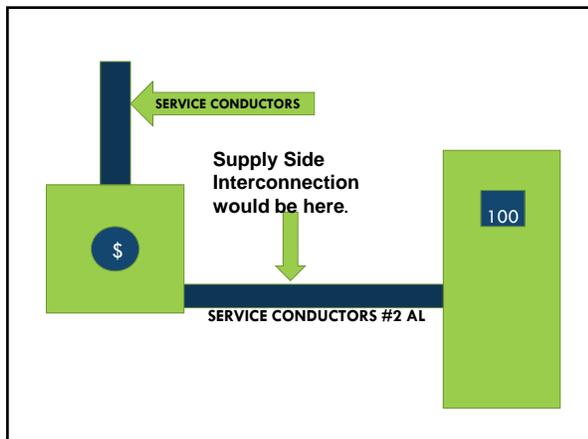
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Fault Current

- The reason for the limitation is the current available on the service conductors.
- 448 Marcia Dr. Bristol
- 25 KVA transformer -----8680 fault Current Amperes
- 845 Brook St. Rocky Hill
- 300 KVA Transformer-----56,000 fault Current Amperes

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What a supply side interconnection might look like



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Supply Side Interconnection



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Supply Side Interconnection



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Another Supply Side Connection



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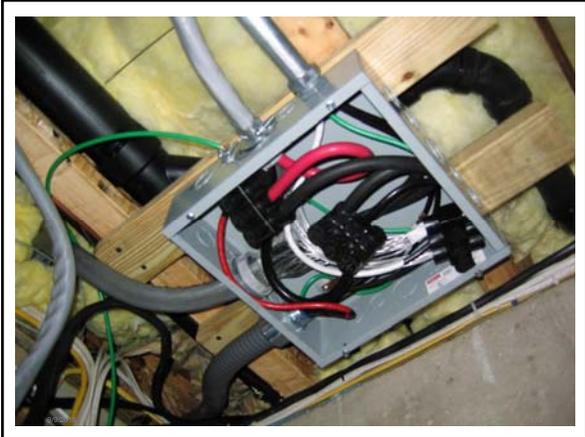
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Supply Side Interconnection



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Another supply side interconnect



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Insulation Piercing Connector



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312.8

- 312.8-Switch and Overcurrent Device enclosures with splices, taps, and feed through conductors.**

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230.7

- **Conductors other than service conductors shall not be installed in the same service raceway or service cable.**
- **Service conductors are not provided with OC protection where they receive their supply**

230.7

- **The amount of current that would be imposed on feeders or branch circuits should they be in the same raceway and a fault occur would be much higher than the ampacity of the feeder or branch circuit conductors.**

**•IF THEY ARE NOT
SERVICE CONDUTORS
CAN THIS BE TRUE?**

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**230.7-Other Conductors in
Raceway or Cable**



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Article 705.12(D)

Utility Interactive Inverters

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705.4

- 705.4 Equipment Approval.
- All equipment shall be approved for the intended use. Utility-interactive inverters for interconnection systems shall be listed and identified for interconnection service.

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705.6

- 705.6 System Installation.
- Installation of one or more electrical power production sources operating in parallel with a primary source(s) of electricity shall be installed only by qualified persons.

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705.12(D) The Basic Rule

- 705.12(D)---Utility-Interactive Inverters.
- The output of a utility interactive inverter shall be permitted to be connected to the load side of the service disconnecting means of the other source(s) at any distribution equipment on the premises.

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2014 NEC 705.12(D)

- Where distribution equipment is fed simultaneously by a primary source and one or more utility interactive inverters and where this distribution equipment is capable of supplying multiple branch circuits or feeders, or both, the interconnecting provisions for the utility interactive inverter(s) shall comply with 705.12(D)(1)through (D)(6).

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2014 NEC 705.12(D)(1)

- 705.12(D)(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.
- -----KEY WORD—DEDICATED-----

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2014 NEC 705.12(D)(2)

- 705.12(D)(2)
- Bus or Conductor Ampere Rating. 125% of the inverter output circuit current shall be used in ampacity calculations for the following:
- Key Word-----125% of inverter output

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NAMEPLATE



2011 705.12(D) read like this:

- The sum of the ampere ratings of overcurrent devices in circuits supplying power to a busbar or conductor shall not exceed 120% of the rating of the busbar or conductor.

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2014 NEC 705.12(D)(2)(1)

- 705.12(D)(2)(1)--Feeder.

•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:

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Definitions

- “Feeder”
- All circuit conductors between the service equipment, or other power supply source and the final branch-circuit overcurrent device.

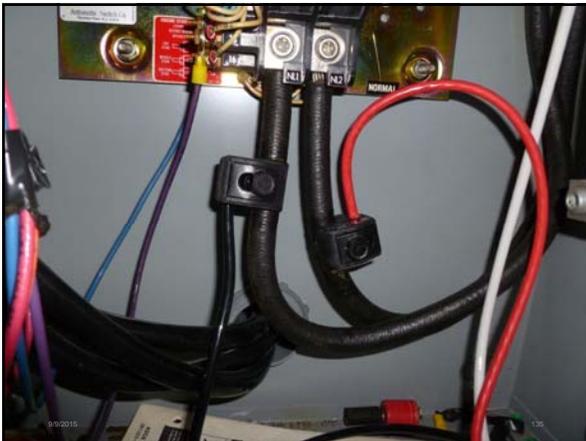
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2014 NEC 705.12(D)(2)(1)(a)

- (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.

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Primary OC Device 200A



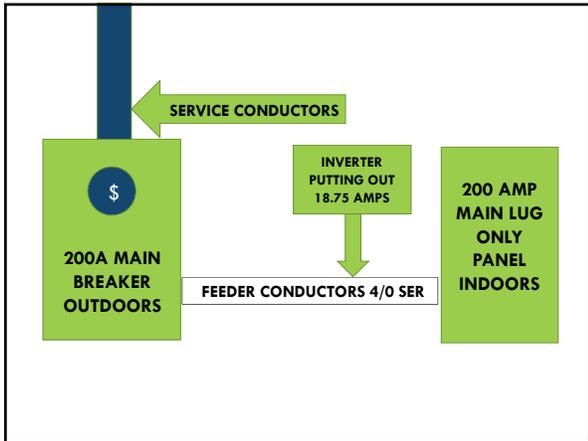
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Calculation

- Primary OC device=200A
- Inverter Output=15A
- $200 + (15 \times 1.25)$
- $200 + 18.75 = 218.75$ min. ampacity of feeder conductor.

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705.12(D)(2)(b)

- 705.12(D)(2)(b)
- An overcurrent device on the load side of the inverter connection shall be rated not greater than the ampacity of the feeder.

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CL&P I&R Book

- Section 10 Page 58 (in bold letters)
- Under no circumstances shall the generator be interconnected inside the meter socket.

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705.12(D)(2)(2)

- 705.12(D)(2)(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).

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240.21 Tap Rules

- (1) Taps Not over 3 m (10 ft) Long.
- If the length of the tap conductors does not exceed 3 m (10 ft) and the tap conductors comply with all of the following
- (1) The ampacity of the tap conductors is

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240.21

- A-- Not less than the combined calculated loads on the circuits supplied by the tap conductors, and

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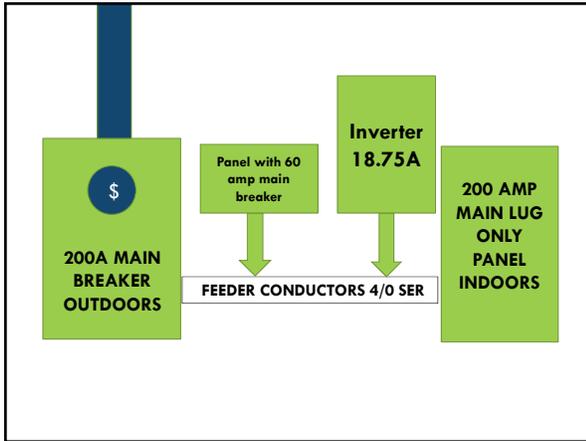
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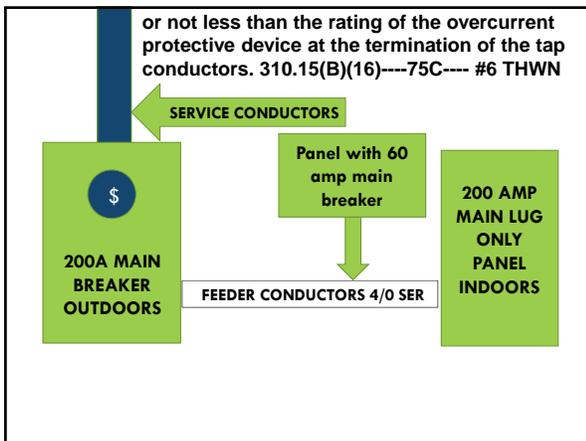
240.21 Tap Rules

- B-- Not less than the rating of the equipment containing an overcurrent device(s) supplied by the tap conductors or not less than the rating of the overcurrent protective device at the termination of the tap conductors.

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705.12(D)(3)

- **705.12(D)(3)-Busbars**
- **One of the methods that follows shall be used to determine the ratings of busbars in panel boards.**

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705.12(D)(2)(3)(a)

- **705.12(D)(2)(3)(a)**
- **The sum of 125% 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. AKA the 100% Rule.**

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Informational Note to
705.12(D)(3)(a)

- **This general rule assumes no limitation in the number of the loads or sources applied to busbars or their locations.**

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200 amp main,200 bus-EASY

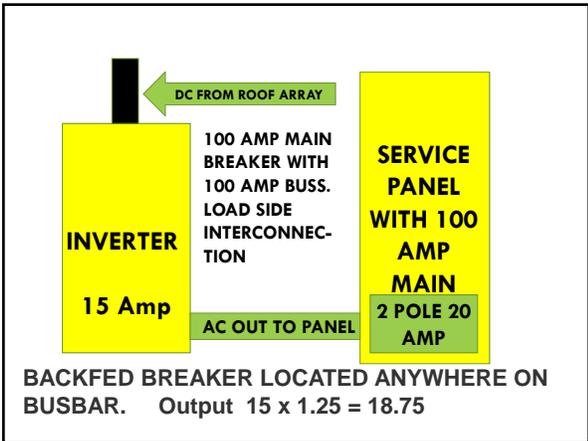


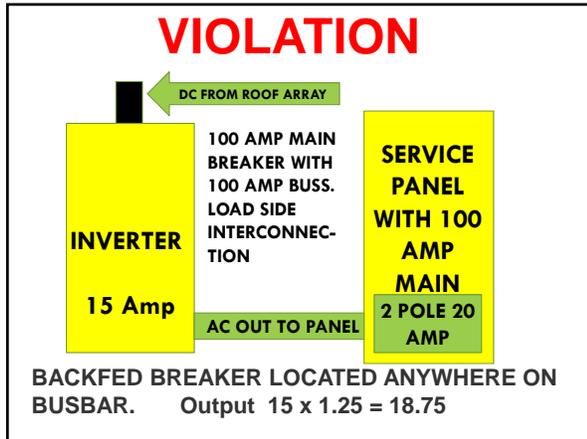
Now--Inverter Output Current 15A



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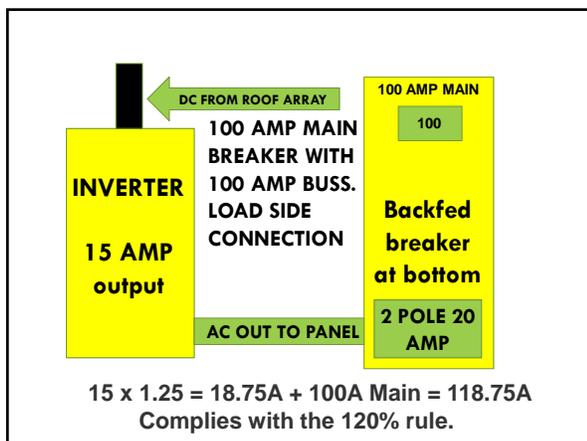




2014 NEC 705.12(D)(2)(3)(b)

- (b) Where two sources, one a utility and the other an inverter are located at opposite ends of a busbar that contains loads, the sum of 125% of the inverter(s) output circuit current and the rating of the main OC device protecting the busbar shall not exceed 120% of the ampacity of the busbar.

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2014 NEC States 705.12

- (b)(continued) The busbar shall be sized for the loads connected in accordance with Article 220. A permanent warning label shall be applied to the panel adjacent to the backfed breaker which reads the following wording or equivalent.

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**WARNING:
INVERTER OUTPUT CONNECTION.
DO NOT RELOCATE THIS
OVERCURRENT DEVICE.**

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LOAD SIDE INTERCONNECTION



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Violation of Section 705.12(D)(3)(b)—Label does not include wording prohibiting relocation.

PHOTOVOLTAGE
BACKFEED



705.16

- 705.16-Interrupting and Short-Circuit Current Rating.
- Consideration should be given to the contribution of fault currents from all interconnected power sources for the interrupting and short-circuit current ratings of equipment on interactive systems.

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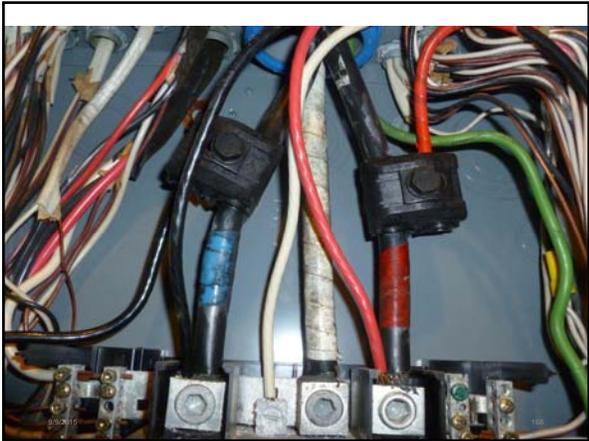






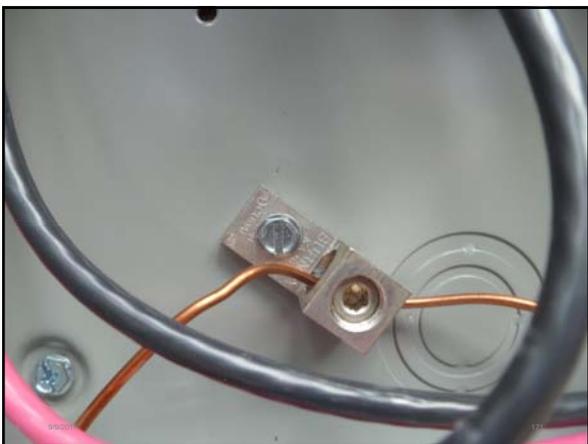












Notes: from Enphase

- If using a generator ensure that the Enphase Microinverters are shut-off when the generator is running. The best method is to use a voltage controlled relay that is activated by the generator panel. Use a transfer switch to ensure that the generator is always isolated from the Enphase Microinverters

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Solar PV Systems

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Thank you !

Frederick Mertz
City of Bristol, CT
Electrical Inspector

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