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## Doug Smith, MCP/CBO

- Inspector/Plan Reviewer for over 20 years
- 19 ICC certifications
- Certified ICC Master Code Professional and CBO
- Taught electrical, solar PV, and ESS classes for over 14 years
- Performed well over ten-thousand electrical, solar PV, and ESS plan reviews
- Serve on *NEC* CMP 10 representing IAEI
- Currently serve as a Technical Committee (TC) Member for the following UL standards:
  - UL 61730 (previously 1703) – Flat-Plate PV Modules and Panels
  - UL 1741 - Inverters, Converters, Controllers, and Int. equip…
  - UL 2703 – PV Mounting Systems/Clamps/Gnd. Lugs
  - UL 6703 – Connectors for Use in PV Systems
  - UL 9540 - Energy Storage Systems and Equipment

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## Course Objective/Intent

- The objective of this presentation is to explain the core *NEC*/*IFC* requirements that govern commercial solar photovoltaic (PV) systems. This presentation is based on the **2020/2023 *NEC* and 2021 IBC/*IFC***.
- The intent of this information is to be <u>used as a guide only</u>. This presentation is not intended to indicate any change in any code or local requirements by inference or omission. All diagrams are for <u>illustration purposes only and actual wiring and installation may vary</u>. This presentation is not intended to indicate if one piece or particular brand of equipment is better than another. Also, efficiency and ideal design considerations are not addressed herein. All applicable codes, standards, and manufacturer requirements must always be followed when designing, installing, and inspecting any electrical system, including solar PV and/or battery/energy storage systems.

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## Outline

**<u>Commercial (NON-Residential) Solar PV</u>:**

1. **PV Modules (solar panels)**
2. **Inverters**
3. **DC Combiners and Re-Combiners**
4. **DC Arc Fault Detection**
5. **Rapid Shutdown**
6. **Grounding and Bonding**
7. **Point of Interconnection Requirements**
8. **AC Combiners**
9. **Available Fault Current for AC Equipment**
10. **Ground-Mounted Installations**
11. **Roof Installations**
12. **2021 *IBC* and *IFC* PV Requirements**
13. **General Equipment Requirements**
14. **Large-Scale Solar PV Systems**
15. **Signage**



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# PV Modules (solar panels)



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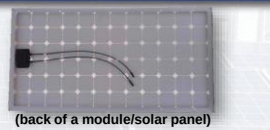
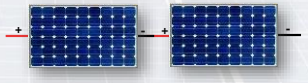
## Concept of Series-Connections

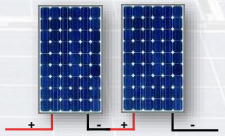
- A circuit with multiple modules that are connected in series is referred to by the *NEC* as a "PV Source Circuit," but is often called a string of modules by the PV industry (PV string circuit).



(back of a module/solar panel)



Or



Series connected modules

Note: these diagrams are very basic in order to explain the concept of solar panels connected in series. Most modern-day systems are required to also include rapid shutdown components (such components are not shown here).



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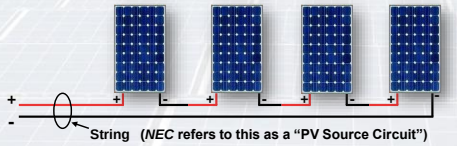
## Series vs. Parallel

**Series connected modules (solar panels):**

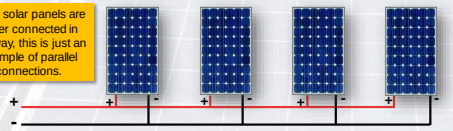
Volts from each module add together but amps stay the same:




**Parallel connected modules:**

Amps from each module add together but voltage stays the same.

Note: solar panels are never connected in this way, this is just an example of parallel connections.



Note: these diagrams are very basic in order to explain the concept of series versus parallel connections. Most modern-day systems are required to also include rapid shutdown components (such components are not shown here).



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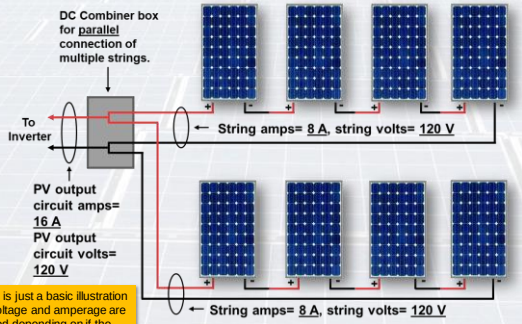
## Example of how series and parallel connections affect a system

If each module (solar panel) produced 8 amps and 30 volts…




Note: this is just a basic illustration of how voltage and amperage are affected depending on if the connection is series or parallel. **Actual wire and overcurrent sizing must comply with *NEC* 690.8 and 690.9**

Note: these diagrams are very basic in order to explain the concept of series versus parallel connections. Most modern-day systems are required to also include rapid shutdown components (such components are not shown here).



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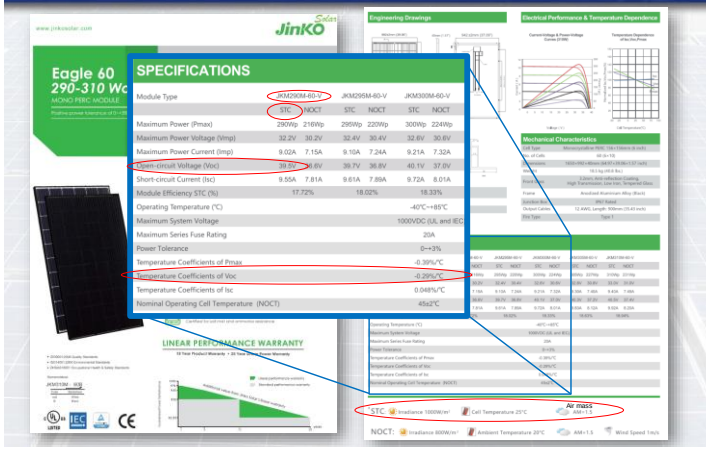
## Jinko® PV Module Specs (example) – Cold Temp dc voltages

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## Cold Temperature DC Voltage

Example

**Maximum dc voltage of a solar PV system on a NON-residential building cannot exceed 1,000V (*NEC* 690.7)**

**Maximum system DC voltage calculation:**

Open Circuit Voltage (Voc) of modules= 39.5V DC (at 25°C or 77°F)

39.5V × **21 modules** on a dc string = **829.5V** (at 77°F)

If we use -28°C for our coldest temperature (which is noted in the ASHRAE Fundamentals Handbook for Bozeman, MT):

The difference in temperature drop from 25°C to -28°C is **53°C**.

Per the module's specs, the voltage of the modules increases by .29% for every 1°C drop in temperature.

Take 53°C × .29 = a voltage increase of 15.37% at -28°C.

829.5V × 1.1537= a cold temperature voltage of **957V**.



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## Cold Temp dc Voltages (continued)

***NEC* 690.7:**

- If solar module temperature coefficients are not available, *NEC* Table 690.7 can be used to determine dc voltages based on cold outdoor temperatures. But doing so will result in higher calculated voltages.
- OR for PV systems 100kW or greater, an engineered design using industry standard methods, can be used for calculating the maximum dc voltages of a system.
  - An example of an industry standard method could be a *Photovoltaic Array Performance Model*, per Sandia National Laboratories software.

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## Inverters



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## Utility Interactive Inverters

- Any PV Inverters (commercial or residential) that are interconnected with the electric utility grid must meet UL 1741 and be listed as "utility interactive" having anti-islanding protection, *NEC* 705.40.




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## Inverters

- For commercial use, inverter's AC output voltage can be 208V, 240V, 277V, or 480V for 1-phase or 3-phase systems (depending on the model).

SMA® Tripower Core™ String Inverter

SolarEdge® SE66.6kUS String Inverter

CPS® 60kW String Inverter



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## String Inverters


String inverters will have one or more dc strings connect to the inverter. Sometimes string inverters also include a dc combiner.



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## Central Inverters

Large inverters, often called "central inverters," will typically include what are often referred to as re-combiners.

Re-combiners combine more than one dc output of other dc combiners.



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## Micro inverters

Micro inverters are installed directly underneath the solar panels and convert dc power to ac power right at the solar panel.

Enphase® IQ8+™ Micro inverter

AP Systems® YC600 Micro inverter



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## DC Combiners and Re-Combiners



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## DC Combiner Box



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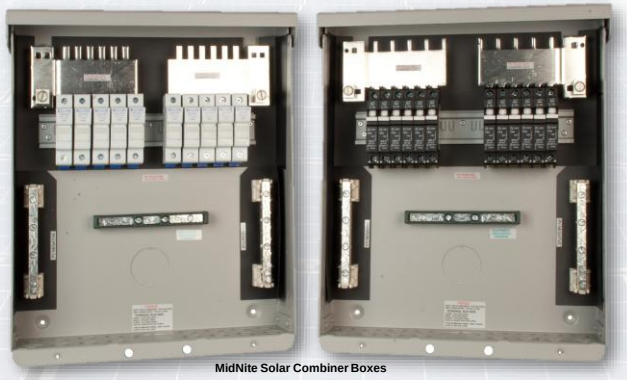
## OCPDs For Each Positive And Negative Conductors is no longer required [See *NEC* 690.9(C)]



MidNite Solar Combiner Boxes



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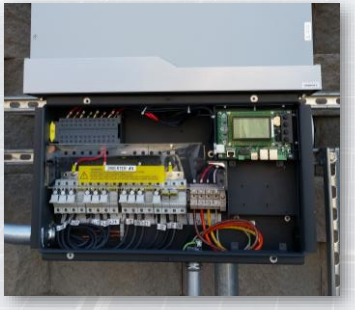
## Some string inverters have dc combiners, and others do not



The above shown string inverters DO have a dc combiner built-in as part of the inverter.



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## Some string inverters have dc combiners, and others do not (continued)

The above shown string inverter does NOT have a dc combiner built-in as part of the inverter.



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## *NEC* – 690.4(B)

**Listing of equipment:**

- DC combiners are included at the list of equipment that are required to be listed for the PV application.




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## Re-Combiners

Positive conductors from combiner boxes each terminate to their own fuse at the re-combiner located within the inverter.

Re-combiner within a central inverter



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## Re-Combiner (another example)

Positive conductors from combiner boxes each terminate to their own fuse at the re-combiner located within the inverter.

Re-combiner within a central inverter

Note: sometimes dc strings are combined together using a cable harness system. See the large-scale PV systems portion of this presentation for more info.



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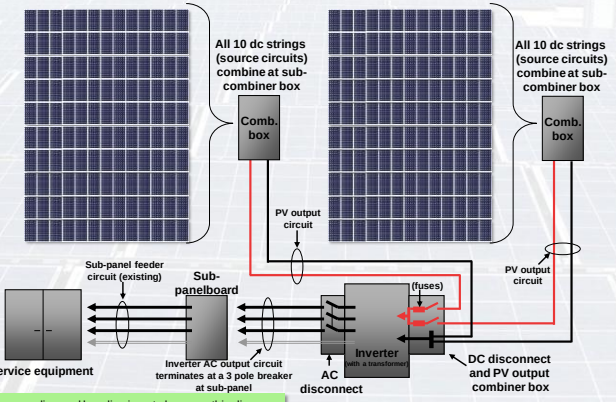
## How to size dc wiring for the "PV output circuit" of a dc combiner




NOTE: grounding and bonding is not shown on this diagram but is required for all solar PV and electrical systems.



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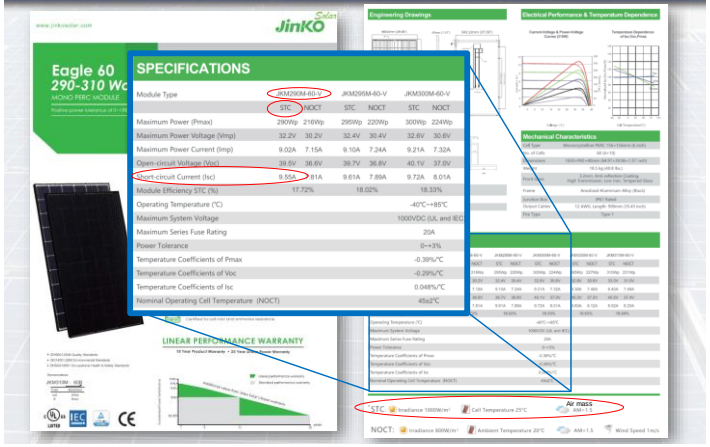
## Jinko® PV Module Specs (example) – Conductor (wire) Sizing

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## Example – Conductor And OCPD Sizing

| | 1. Max current *NEC* 690.8(A)(1)(a) | 2. Breaker or fuse size *NEC* 690.8(B) & 690.9(B) |
|---|---|---|
| String circuit (Source Circuit) | (string Isc x 125%) **9.55** x 1.25= **11.9** A → | (string max current x 125% again) **11.9** x 1.25= **14.9** A |
| PV output Circuit (circuit between combiner box and inverter) | (all combined strings max current from above line) **11.9** x #of strings= **119** A → | (Total combined strings max current x 125%) **119** x 1.25= **148.8** A |
| Inverter AC Output Circuit | (inverter max output) ____amps → | (inverter max output x 125%) ___x 1.25= _____A |

Use the max amps in this column when starting the adjustment of wires for temp. and conduit fill. Take the larger of either the final adjusted ampacity from this column or the final amps in column 2 to size the conductors , *NEC* 690.8(B)(2).

If no deration or adjustment of wires is needed then use this column to size wires . Use this column to size the breaker or fuses (use next size up breaker or fuse if between ratings).



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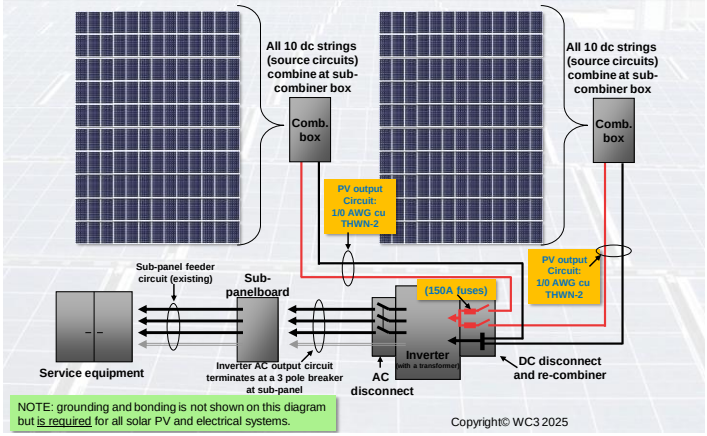
## How to Size dc Wiring & OCPDS (continued)



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## DC Conductor and OCPD Sizing (continued)

| | 1. Max current NEC 690.8(A)(1)(a) | 2. Breaker or fuse size NEC 690.8(B) & 690.9(B) |
|---|---|---|
| String circuit (Source Circuit) | (string Isc x 125%) 9.55 x 1.25= 11.9 A | (string max current x 125% again) 11.9 x 1.25= 14.9 A |
| PV output Circuit (circuit between combiner box and inverter) | (all combined strings max current from above line) 11.9 x #of strings= 119 A | (Total combined strings max current x 125%) 119 x 1.25= 148.8 A |
| Inverter AC Output Circuit | (inverter max output) ____amps | (inverter max output x 125%) ____ x 1.25= ____A |

Per *NEC* 690.8(B)(1) exception, and 690.9(B)(2), the second 125% factor does not need to be applied when the conductors connect to an assembly together (with its overcurrent protection devices) is listed for continuous operation at 100% of its rating.



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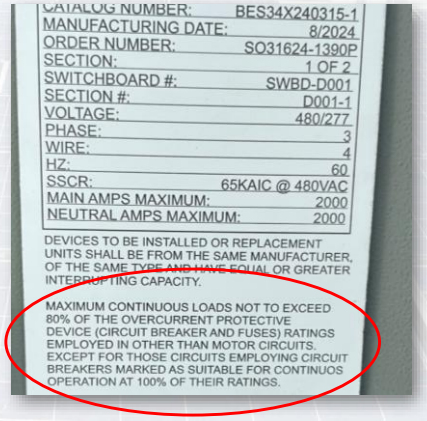
- In this example, the switchboard label is indicating that the continuous loads cannot exceed 80% of the rating of the OCPD, therefore the exception of 690.9(B)(1) **cannot be used**.



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## Option for Simulated Maximum Current of the System

***NEC* 690.8(A)(1)(a)(2):**

- For PV systems 100kW or greater, an engineered design using industry standard simulated methods, can be used for calculating the maximum dc ***current*** of a system instead of increasing the short circuit rating of the modules by 125%.
  - An example of an industry standard method could be a *Photovoltaic Array Performance Model*, per Sandia National Laboratories software.

**The 3-hour maximum simulated current cannot be less than 70% of the short circuit current (Isc) multiplied by 125%.**

| | 1. Max current NEC 690.8(A)(1)(a) | 2. Breaker or fuse size NEC 690.8(B) & 690.9(B) |
|---|---|---|
| String circuit (Source Circuit) | (string Isc x 125%) 9.55 x 1.25= 11.9 A | (string max current x 125% again) 11.9 x 1.25= 14.9 A |
| PV output Circuit (circuit between combiner box and inverter) | (all combined strings max current from above line) 11.9 x #of strings= 119 A | (Total combined strings max current x 125%) 119 x 1.25= 148.8 A |
| Inverter AC Output Circuit | (inverter max output) ____amps | (inverter max output x 125%) ____ x 1.25= ____A |



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# DC Arc-Fault Detection



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## Arc-Fault Protection (AFPD)

- Section **690.11 of the *NEC*** requires that a PV system with DC circuits that operate at 80 volts or greater, shall be protected by a listed PV DC arc-fault circuit interrupter or have listed system components that provide equivalent protection.
- This section does not apply to micro inverter or ac module systems that are currently on the market.

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## *NEC* 690.11 – DC Arc-Fault Protection

**Exceptions:**

- DC conductors that are part of MC cable, in metal raceways, enclosed metal cable trays, or buried underground do not require DC arc-fault protection as long as the circuit conductors are also installed per one of the following:
  - NOT installed on or in a building
  - Or are located in or on a detached building that is dedicated for the PV system equipment.

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## Arc-Fault Protection Continued…

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## Arc-Fault Protection Continued…

37

## Arc-Fault Protection Continued…

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## Rapid Shutdown



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## Rapid Shutdown

**690.12(B) Controlled Limits:**

- The use of the term **array boundary** in this section is defined as **(1 ft) from the array in all directions (and 3' into the attic)**. Controlled conductors outside the array boundary shall comply with *NEC* 690.12(B)(1) and inside the array boundary shall comply with 690.12(B)(2).



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## Rapid Shutdown

- **(B)(1) <u>Outside</u> the Array Boundary.** For any controlled conductors that are located outside the boundary are limited to not more than **30 volts within 30 seconds** of rapid shutdown initiation.



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## Rapid Shutdown

**690.12(B)(2) <u>Inside</u> the Array Boundary:**

- The PV system is required to comply with *one* of the following:
  - (1) The system be listed as a "<u>PV hazard control system</u>" (PVHCS per **UL 3741**) installed per manufacturer's instructions and listing of the system, shall be installed in accordance with the instructions included with the listing or field labeling of the system. Also, when the system requires initiation to a controlled state, the rapid shutdown initiation device required in 690.12(C) is required for the initiation.
  - (2) The system be provided with "shock hazard control" for firefighters to reduce the voltage of the system's controlled conductors to not more than **80 volts within 30 seconds** of rapid shutdown initiation.

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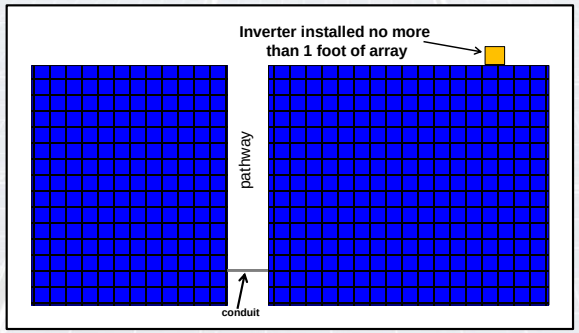
## UL 3741

**There are currently on the market PV systems available which are listed UL 3741 as a PV Hazard Control System. Such systems often require the inverter to be installed within 1 foot of the solar array. ALWAYS follow the manufacturer's installation instructions!!**



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## UL 3741 continued…

**UL 3741 listed systems installed per the manufacturer's instructions, and per the listing of the equipment, are considered as meeting the rapid shutdown requirements of 690.12.**



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## Carports/Shade Structures

**Per the 2023 *NEC,* Section 690.12, non-enclosed detached structures do NOT require rapid shutdown functionality.**



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## Rapid Shutdown Initiation Device

***NEC* 690.12(C) Initiation Device:**

- For **NON** one-family and two-family dwellings, the initiation device is **NOT REQUIRED** to be at a readily accessible location on the outside of the building.
- The rapid shutdown initiation device(s) shall consist of at least one of the following:
  - (1) Service disconnecting means.
  - (2) PV system disconnecting means.
  - (3) Readily accessible switch that plainly indicates whether it is in the "off" or "on" position.

There are not allowed more than six switches or six sets of circuits breakers (or a combination of breakers with switches) for multiple PV systems that are installed with rapid shutdown functions on a single service.

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## Rapid Shutdown Initiation Device

The type of rapid shutdown initiation device used will depend on the type of rapid shutdown components of the system.



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## Rapid Shutdown Signage

- **690.12(D) [previously 690.56(C)] Buildings with Rapid Shutdown.** Buildings with PV systems shall have permanent labels as described in 690.12(D)



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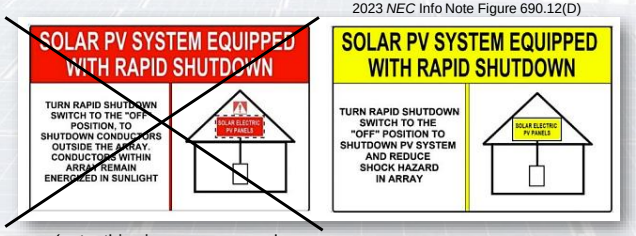
## Rapid Shutdown Signage

2020 *NEC* Info Note Figure 690.56(C), and
2023 *NEC* Info Note Figure 690.12(D)




(note: this sign was removed from the 2020 *NEC*)

See also 1205.4 in the 2021 *IFC* for similar requirements.

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## Rapid Shutdown Signage For Buildings with More Than One Rapid Shutdown Type

***NEC* 690.12(D)(1) [previously 690.56(C)(1)] Buildings with More Than One Rapid Shutdown Type:**

- When a building has multiple PV systems with more than one type of rapid shutdown, **or** a PV system with a rapid shutdown type and a PV system with no rapid shutdown, then a detailed diagram of the roof shall be provided to show each separate PV system, and the diagram must include a dotted line around areas that remain energized after rapid shutdown is initiated.

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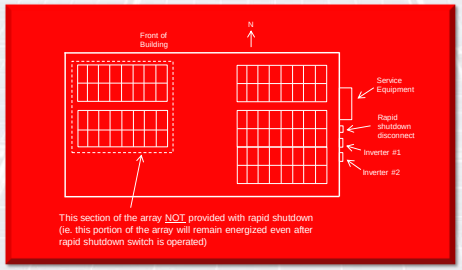
## Rapid Shutdown Signage For Buildings with More Than One Rapid Shutdown Type

**Example of a plaque showing which portion(s) of the PV system are equipped with rapid shutdown and which are not:**



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## Rapid Shutdown Switch Signage

- ***NEC* 690.12(D)(2) [previously 690.56(C)(2)] Rapid Shutdown Switch.** There must be provided a sign on or within 3 feet of the rapid shutdown switch and such sign must include the following wording: **"RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM"**
- The label is required to have all letters be capitalized having a minimum height of 3⁄8 inches with white words on red background.


**Sign located next to the rapid shutdown disconnect**



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# Grounding and Bonding



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## Grounding and Bonding of Equipment

**Equipment to be grounded:**

- ***NEC* 690.43:** The metal parts of all modules, support rails, elect. boxes, and other equipment associated with the PV system must be bonded together and connected to an equipment grounding conductor.
- **690.43(A):** Devices and systems used for mounting PV modules that are also used for bonding module frames shall be listed, labeled, and identified for bonding PV modules. Devices that mount adjacent PV modules shall be permitted to bond adjacent PV modules.



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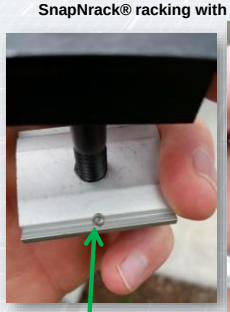
## Racking With Integrated Bonding

SnapNrack® racking with integrated bonding



Bonding ring digs into rails

T-clamp pin digs into the PV modules (panels)

Unirack® racking with integrated bonding



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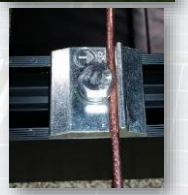
## Racking With Integrated Bonding



SnapNrack® racking with integrated bonding

- Racking systems should be listed per UL 2703.
- Parts designed for bonding should be tested per UL 467.



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## Bonding to Support Rails

WEEBL 6.7 assembly

(Wiley Electric/Burndy)


Metal parts of the PV system are required to be bonded to the equipment grounding conductor. *NEC* 690.43.



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WEEBL lay-in lug assembly



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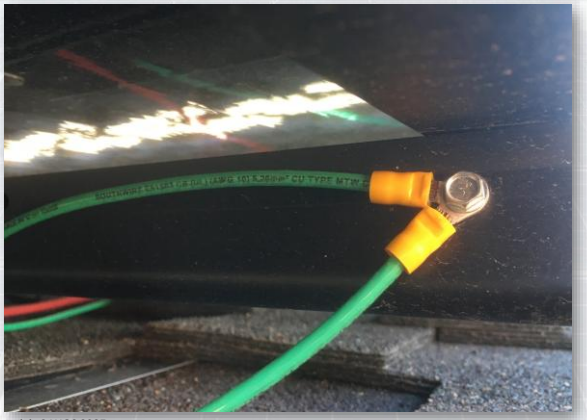
## Violations!!!





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## Bonding of Support Rails

Missing stainless steel washer between rail and lay-in lug.

Stainless steel washer installed when connecting lay-in lug to galvanized metal surfaces.




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**Grounding lugs outdoors must be outdoor rated! Typically, they will be listed for direct burial. This one does not have DB marking on it.**



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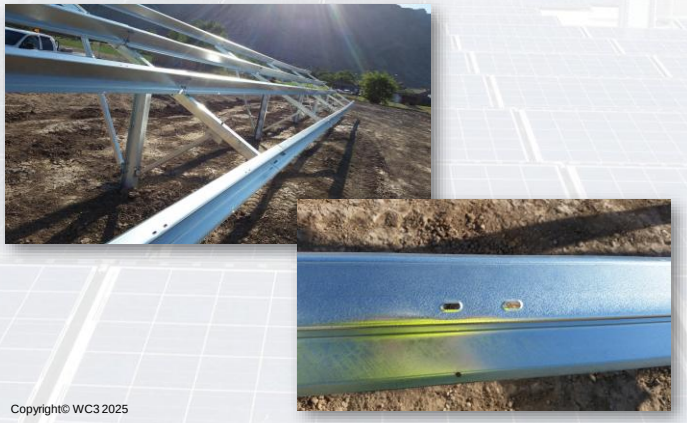
## Ground-Mounted System Racking With Integrated Bonding





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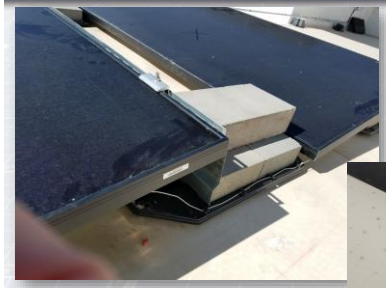
## Bonding at Array



Devices or equipment that bond solar modules (panels) together must be listed for the application. *NEC* 690.43(A).



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Devices used for bonding solar modules together or to support rails must be listed and tested for the application. *NEC* 690.43(A).



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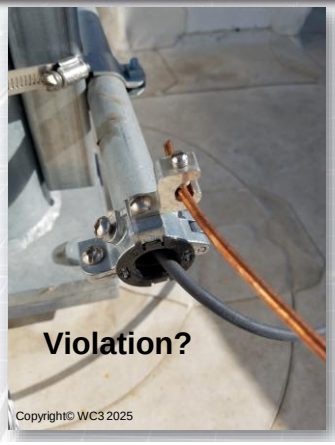
## Bonding at Conduit




Verify that any bond bushings and ground lugs used outdoors are listed for wet locations (they will often also be listed for direct burial). *NEC* 110.3(B).

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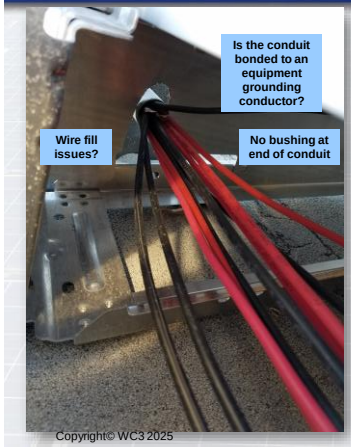
## Installation Errors

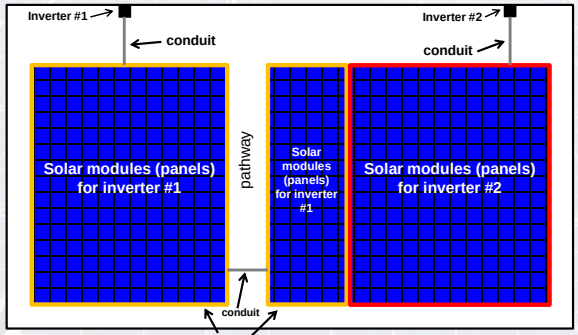




66

## Required Equipment Grounding Conductor Must Extend to Inverter

The equipment grounding conductor(s) which connect to racking and solar modules (and other metal parts) must extend to the inverter served!




67


68

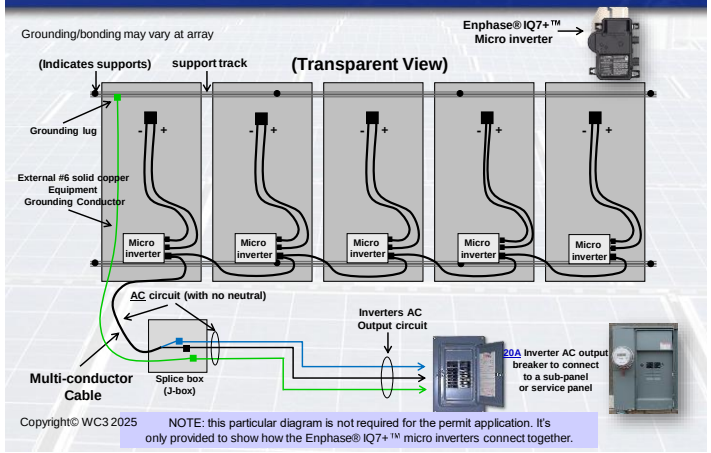
## Grounding and Bonding

**2020 *NEC* 690.47(A) - Grounding Electrode System:**

- A building or structure that supports a PV system must have a grounding electrode system (per Part III of *NEC* Article 250).
- For connection of the PV system to the grounding electrode system, either of the applicable following methods must be used:
  - PV systems that are NOT solidly grounded (such as functionally grounded systems) the equipment grounding conductor (EGC) of inverter's ac output circuit is permitted to be the only connection to ground for the PV system when such equipment ground wire is connected to a distribution system that is already connected to a grounding electrode system.
  - The second option applies to solidly grounded PV systems [see 690.41(A)(5)]. These systems are very rare.

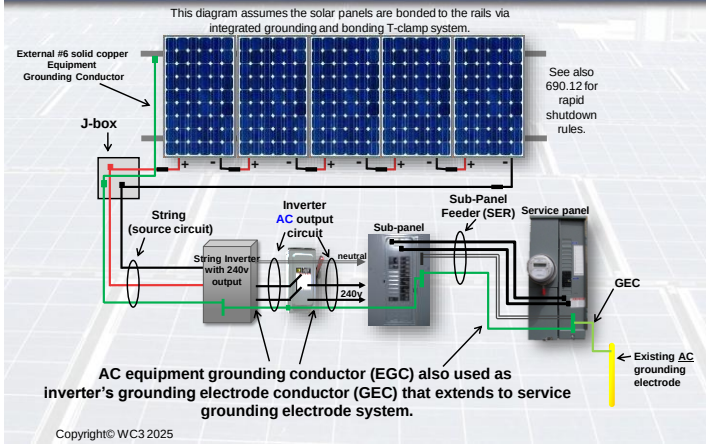
69

## Enphase® IQ7+™ Micro Inverter System



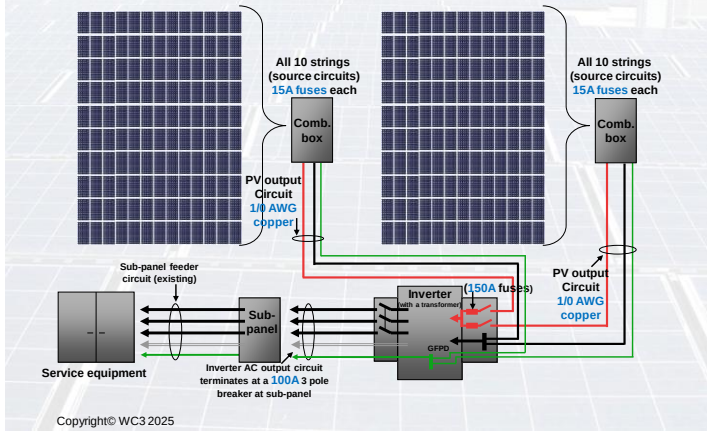

70

## Same wire used as both the EGC and grounding electrode conductor for the inverter - 690.47(A)(1)



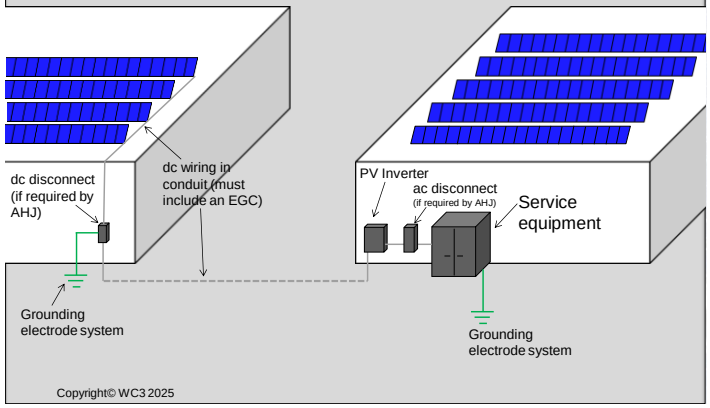

71

## Example System – Grounding



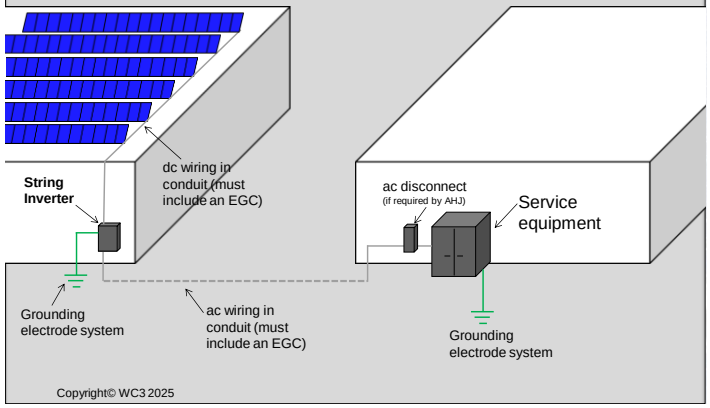

72

## Solar PV on Multiple Blds (example)




73

## Solar PV on Multiple Buildings (another example)




74

## Electrodes for Ground-Mounted Arrays???


75

## Point of Interconnection Requirements (Article 705)



76

## Splices and Taps

**230.46 – Splices and Taps**

- Any pressure connectors and devices for splicing or taps onto service conductors must be marked "suitable for use on the line side of the service equipment," or equivalent wording. Per UL, the use of **'SR' or 'SVC'** is also allowed.



77

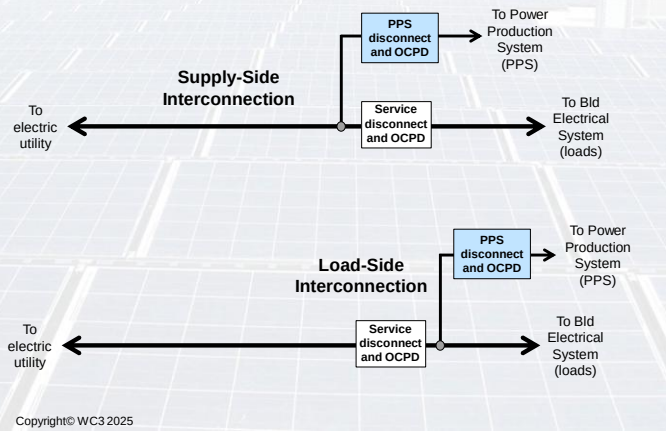
## Multiple Sources of Power

**705.10 – Identification of Power Sources:**

- A permanent plaque, label, or directory is required to be installed at each service equipment location (or other approved readily visible location). Such must denote the location of each power source disconnecting means for the building or structure and be grouped with any other plaques or directories.
- New for 2023 *NEC*, the plaque, label, or directory must also include the emergency phone number of any off-site companies/entities that service the power source system(s).
- Such plaque, label, or directory must be marked with the words "CAUTION: MULTIPLE SOURCES OF POWER."

78

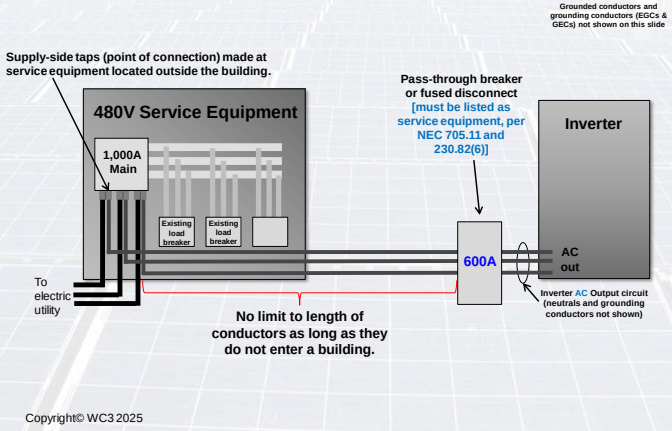
## Supply (line) Connections Vs Load Connections






79

## Supply (line) side connection – Made Outside of a Building






80

## Modifications of Equipment?

Cannot drill or modify electrical equipment unless permitted per the manufacturer's instructions, or the modification must be field evaluated for the application (and be field labeled). *NEC* 110.3(B) and 705.11(D) [2020 NEC].



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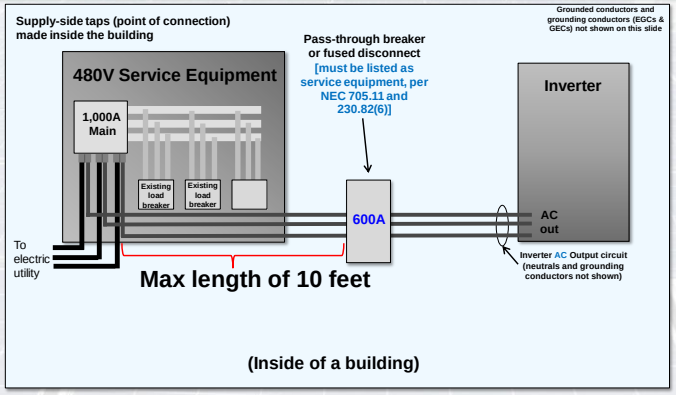
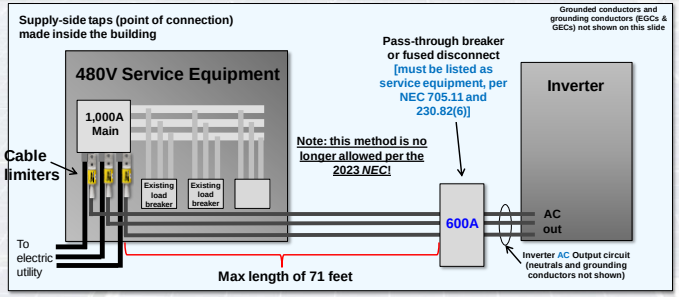
## Supply (line) side connection – Made Inside of a Building






82

## Supply (line) side connection (2020 *NEC*) – Made Inside of a Building




For non-dwellings, the overcurrent protection device can be located within 71 feet (maximum conductor length) as long as cable limiters are provided for each ungrounded conductor. The cable limiters would need to be within 16.5 feet of the point of connection (maximum conductor length).



83

## Supply (line) side connection continued…

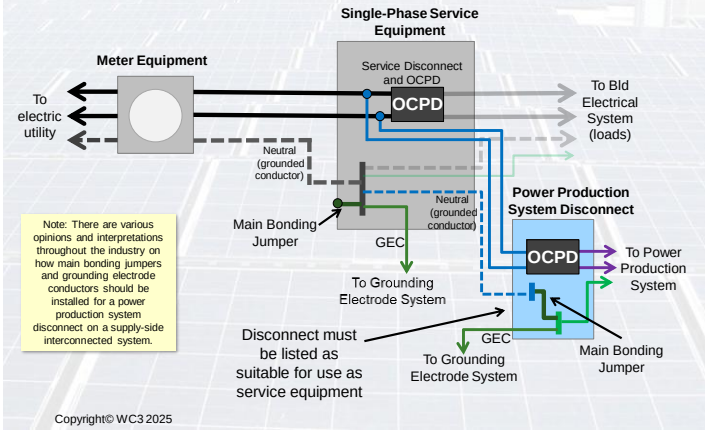

Examples of cable limiters

Cooper Bussman cable limiter

Ferraz Shawmut cable limiters

84

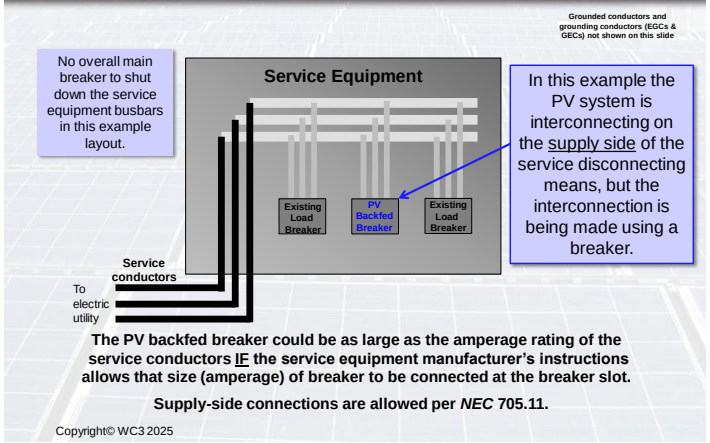
## Section 250.25 of the 2020 & 2023 *NEC* (example)






85

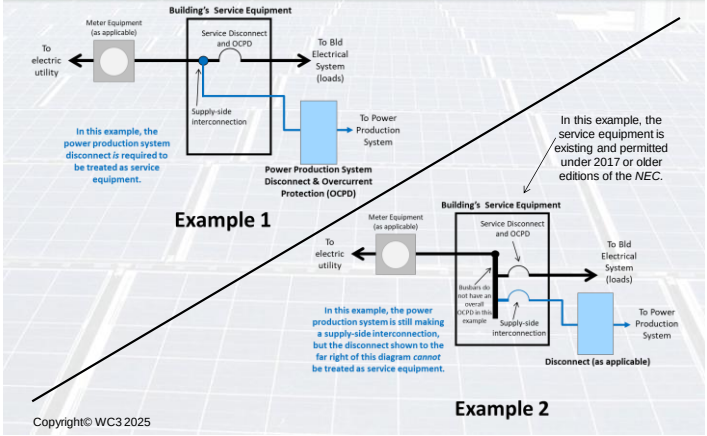
## What About Supply (line) Interconnections Made with a Breaker?






86

## Supply (Line) side connection continued…






87

## Load Side Connections – 705.12

- Load side connections occur after (downstream of) the main electrical service disconnect(s).
- The requirements of *NEC* 705.12 in the 2023 *NEC* are similar to those shown in 705.12 of the 2020 *NEC*, with a few minor changes.
- **For the purposes of this presentation, the *NEC* sections referenced on the following slides are per 2020 *NEC* unless otherwise noted on the slide.**

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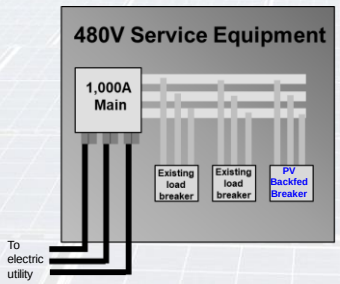
## *Load-Side* Interconnection Example

Grounded conductors and grounding conductors (EGCs & GECs) not shown on this slide




In this example the PV system is interconnecting on the LOAD side of the 1,000A service disconnecting means, and therefore the requirements of *NEC* 705.12 apply.

**Load-side connections need to comply with the requirements of *NEC* 705.12(B).**



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## 705.12(B) - Bus or Conductor Ampacity Rating

**Bus or Conductor Calculations:**

- 125% of the inverter(s) AC (or "power source") output current is to be used when determining the ampacity calculations of 705.12(B)(1) through (B)(3).

| Technical data | Sunny Tripower CORE1 (US) |
|---|---|
| **Input (DC)** | |
| Max. array power | 75000 Wp STC |
| DC voltage [max] | 1000 V |
| Rated MPP voltage range | 500 V ... 800 V |
| MPPT operating voltage range | 150 V ... 1000 V |
| Min. DC voltage / start voltage | 150 V / 188 V |
| Number of independent MPP trackers / strings per MPP input | 6 / 2 |
| Max. operating input current / per MPP tracker | 120 A / 20 A |
| Max. short circuit current per MPPT / string input | 30 A / 30 A |
| **Output (AC)** | |
| AC nominal power | 50000 W |
| Max. AC apparent power | 53000 VA |
| Output phases / line connections | 3 / 3-(N)-PE |
| Nominal AC voltage | 480 V / 277 V WYE |
| AC voltage range | 244 V ... 305 V |
| Rated AC grid frequency | 60 Hz |
| AC grid frequency / range | 50 Hz, 60 Hz / -5Hz ... +5Hz |
| Max. output current | 64 A |
| Power factor at rated power / adjustable displacement | 1 / 0.0 leading ... 0.0 lagging |
| Harmonics THD | <3% |

**Example:**
**64 amps × 1.25 = 80 amps**

SMA® CORE1 Inverter specs

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## 705.12(B)(1) – Feeders

**Feeders**

- When an inverter ("power source") connection is made to a feeder, the feeder is required to have an ampacity not less than 125% of the output current (amps) of the inverter(s).
- Per 705.12(B)(1), when the inverter ("power source") AC output connection is made to a feeder at a location **other than** the opposite end of the feeder from the primary source overcurrent device, the portion of feeder on the load side of the inverter ("power source") output connection must be protected by *NEC* 705.12(B)(1)(**a**) or (B)(1)(**b**).



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## 705.12(B)(1) (Feeders) continued…

- If the PV connection to a feeder is not at the opposite end of the feeder from the feeder's main breaker (primary overcurrent protection device), the feeder's ampacity on the load side of the PV connection must be as per *NEC* 705.12(B)(1)(**a**) or (B)(1)(**b**):
  - a) The feeder ampacity must not be less than the sum of the primary source OCPD and 125% of the inverter(s) (power source) output current.

    OR
  - b) An overcurrent device on the load side of the inverter (power source) AC output connection must be rated not greater than the ampacity of the feeder.



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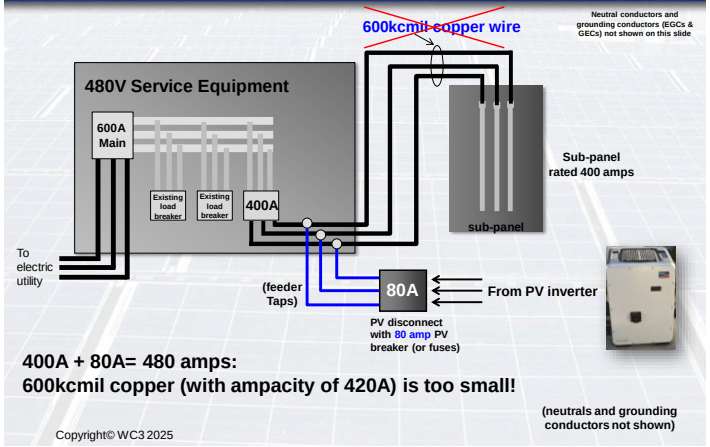
## Feeders – Example For Option "a" [*NEC* 705.12(B)(1)(a)]

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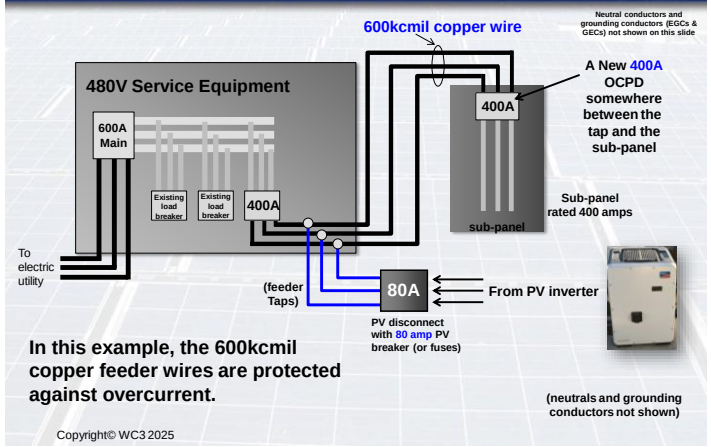
## Feeders – Example For Option "b" [*NEC* 705.12(B)(1)(b)]




94

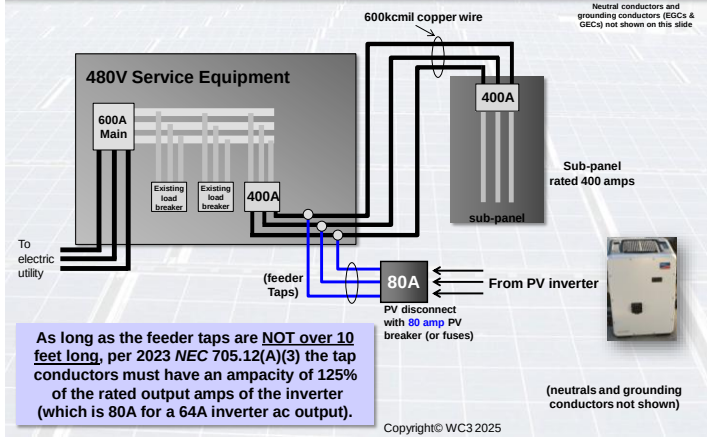
## *NEC* 705.12(A)(3) [2023 *NEC*] – Taps

**Feeder Taps:**

- Where inverter (power source) AC output circuits tap feeder conductors, the **taps** are to be sized based on 125% of the inverter (power source) output circuit current.
- If either *NEC* 240.21(B)(2) or (B)(4) will be used (for taps OVER 10 feet and up to 25 feet long), then the ampacity of the taps cannot be less than 1/3 of the sum of the rating of the OCPD that is protecting the feeder conductors plus the rating of the power source OCPD.

95

## *NEC* 705.12(A)(3) – Taps continued...




96

## *NEC* 705.12(B)(3) – Busbars

**Busbars**

- *NEC* 705.12(B)(3)(1) through (B)(3)(6) must be used for determining the minimum ratings of busbars, unless the distribution equipment has specific listing and instructions for combining multiple sources.



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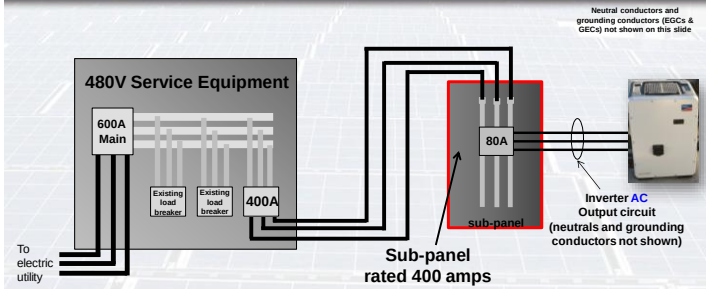
## Busbars – Example For Method "1" [*NEC* 705.12(B)(3)(1)]




**400A + 80A = 480A**
**The sub-panel's busbar rating is exceeded! Violation!**



98

## Method "2" [*NEC* 705.12(B)(3)(2)]

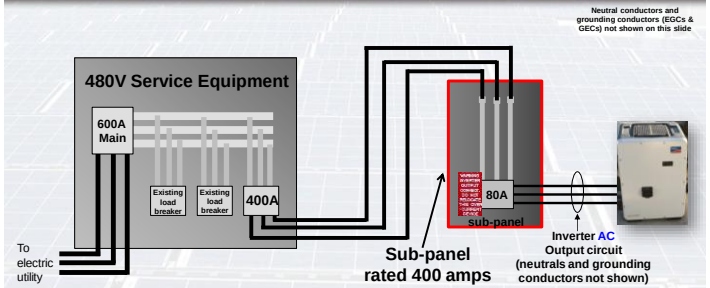
2) Where two sources, one a utility (primary power source) and the other an inverter (or other power source), are located at opposite ends of a busbar that also has other loads, the sum of the rating of the OCPD protecting the busbar and the inverter(s) (power source) current rating × 125% cannot exceed 120% of the rating of the busbar.

- The busbars must already be sized for the connected loads as per Article 220 in the *NEC*.
- A sign must be provided next to the backfed PV breaker stating: "WARNING: POWER SOURCE OUTPUT - DO NOT RELOCATE THIS OVERCURRENT DEVICE"



99

## Example for method "2" [*NEC* 705.12(B)(3)(2)]

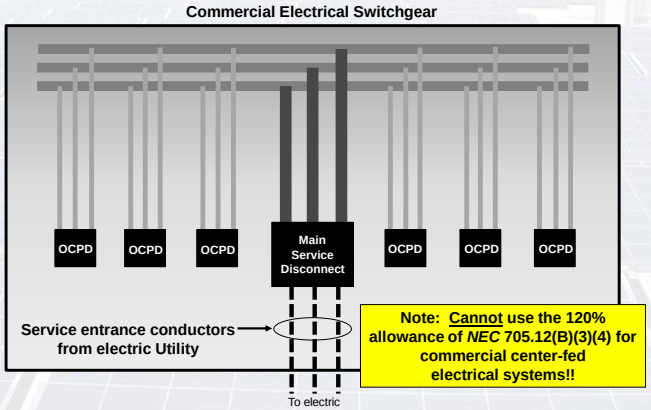



**400A + 80A = 480A**
**400A rated sub-panel × 120% = up to 480 amps allowed**



100

## Center-Fed Equipment cannot use the 120% allowance [see *NEC* 705.12(B)(3)(4)]





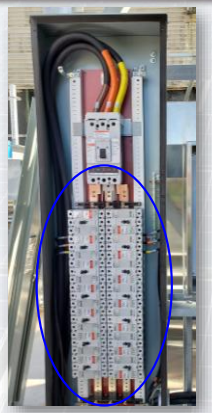

101

## Method "3" [*NEC* 705.12(B)(3)(3)]

3) The sum of the ampere ratings of all breakers (OCPDs) on panelboards, including load and supply breakers (but NOT counting the main breaker protecting the panel), must not exceed the rating of the panelboard's busbars.
   - The rating of the main breaker protecting the panelboard must not exceed the rating of the busbars.
   - Permanent warning label must be applied to the panel (distribution equipment) with the words: "WARNING: EQUIPMENT FED BY MULTIPLE SOURCES. TOTAL RATINGS OF ALL OVERCURRENT DEVICES, EXCLUDING MAIN SUPPLY OVERCURRENT DEVICE, SHALL NOT EXCEED THE AMPACITY OF BUSBAR."

102

## Example for method "3" [*NEC* 705.12(B)(3)(3)]



400A rated panel

**For option #3, The combined ratings of all breakers shown in this panelboard must not exceed the rating of the panelboard's busbars.**

**The main breaker is NOT counted when adding up the breakers.**

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

Required Sign



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## Method "5" [*NEC* 705.12(B)(3)(5)]

6) Connections made to switchgear, switchboards, and panelboards that are in configurations differing from *NEC* 705.12(B)(3)(1) through (B)(3)(4) are permitted as long as designed under engineering supervision that includes available fault-current and busbar load calculations.



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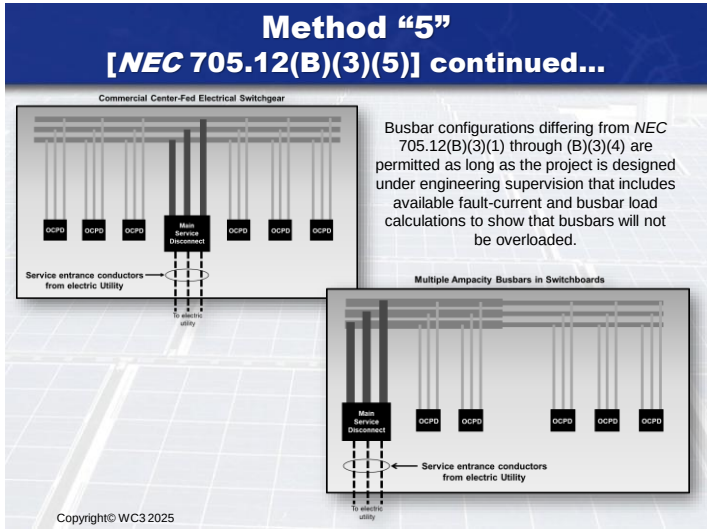


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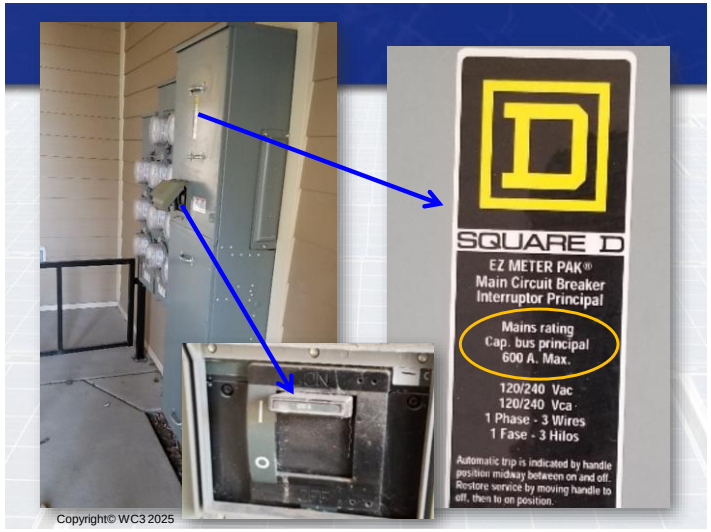
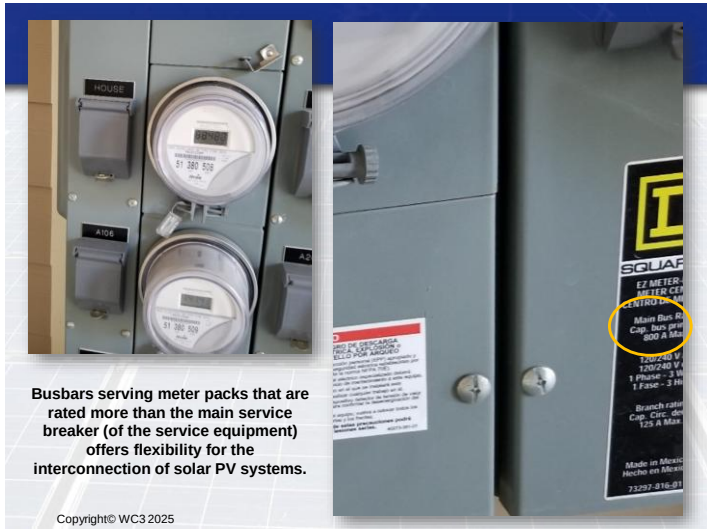



107

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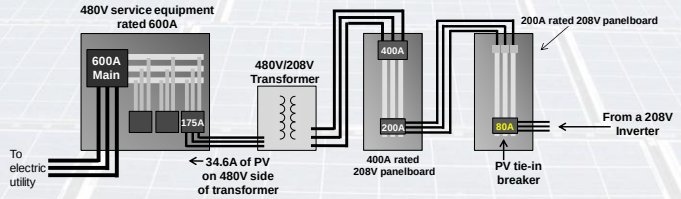
## Back-fed Equipment

Neutral conductors and grounding conductors (EGCs & GECs) not shown on this slide

A PV system effects all equipment and conductors that are backfed by the PV system all the way back to the service equipment. *NEC* 705.12(B) applies to all equipment and conductors being backfed on the load side of main service disconnect.




Note: To determine what 80A on the 208V side of above transformer looks like on the 480V side of the transformer, simply take the 208V and divide by 480V = ratio of .433 x 80A = 34.6A



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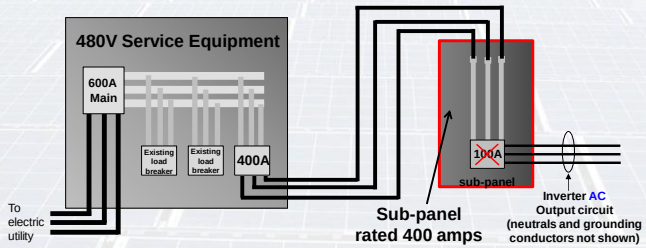
## Example System #1 – Point Of Interconnection

Neutral conductors and grounding conductors (EGCs & GECs) not shown on this slide




The sum of the breaker feeding the sub-panel plus the solar PV (400A main breaker plus the 100A solar) cannot exceed 120% of the rating of the sub-panel.

400 amp rated panel x 1.2= 480amps

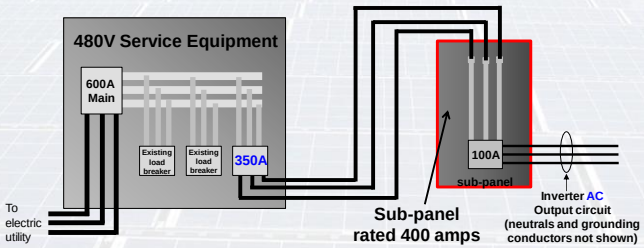
Only a 80A PV backfed breaker can be added to the sub-panel at end of bus bars.



110

## Example System #1 – Point Of Interconnection Continued…

Neutral conductors and grounding conductors (EGCs & GECs) not shown on this slide




If the main breaker for the sub-panel is reduced to 350 amps:

350A+100A= 450A < 480A

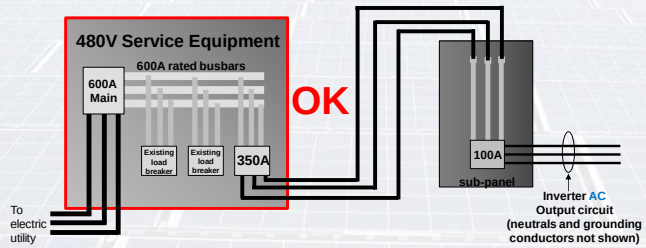
Ok to add new 100 amp PV backfed breaker ONLY if new 350A breaker feeding the panel is sized for all loads connected to the sub-panel per *NEC* 220.



111

## Example System #1 – Back-Fed Service Equipment

Neutral conductors and grounding conductors (EGCs & GECs) not shown on this slide




The sum of the main breaker plus the solar feeding the service equipment bus bars cannot exceed 120% of the rating of the bus bars if backfed breaker is located at end of bus bars.

600 amp rated bus bars x 1.2 = 720amps

600A main + 100A PV breaker = 700A feed the bus bars. 700A < 720A.



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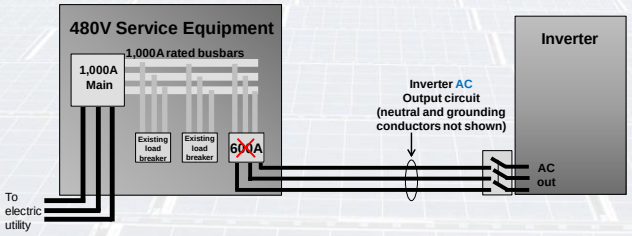
## Example System #2 – Point Of Interconnection




The sum of the breakers feeding the service equipment bus bars cannot exceed 120% of the rating of the bus bars if backfed breaker is located at end of bus bars.

1,000 amp rated bus bars x 1.2= 1,200amps

1,000A main + 600A PV breaker= 1,600A feed the bus bars. 1,600A > 1,200A.



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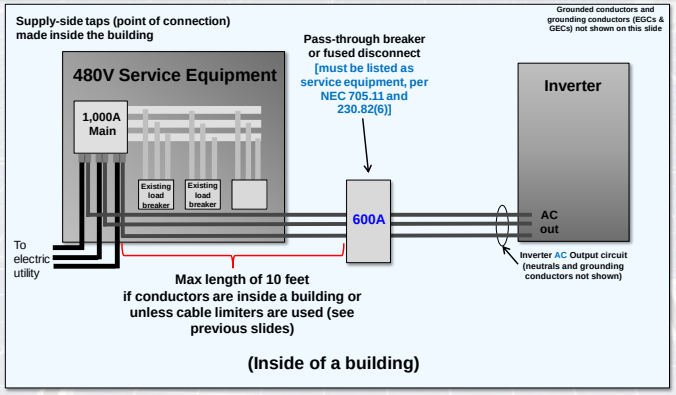
## Example System #2 – Point Of Interconnection



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## Photo of a Switchboard



115

## Photo of a Switchboard



116

## Photo of a Switchboard



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## Panelboard (example)



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## AC Combiner Panel (if needed)



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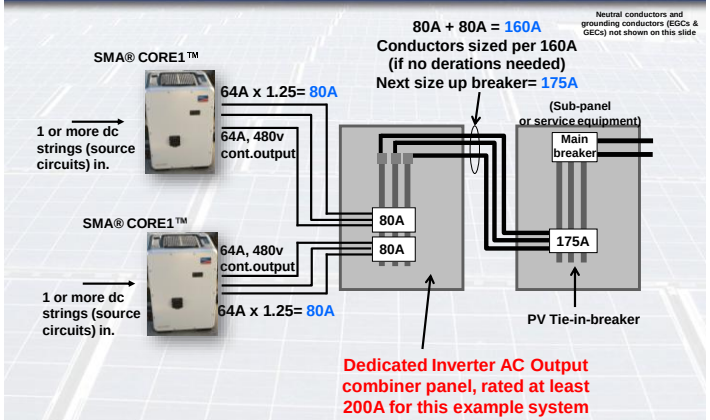
## AC Combiner Panels

- Panelboards (or switchboards) which are dedicated for the connection of PV inverter breakers do not need to follow the requirements of *NEC* 705.12(B) as long as there are no loads in such panelboard/switchboards.



120

## Combining Multiple Inverter AC Output Circuits (alternate example)



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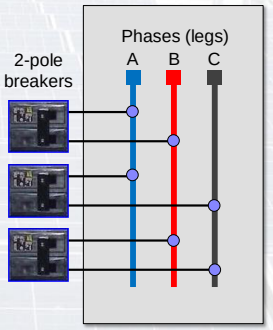
## 1-Phase Inverters Connected to 3-Phase Panelboards

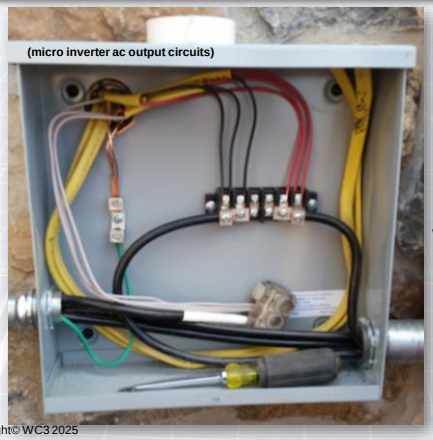
- ***NEC* 705.45(A):** The ac output of single-phase inverters can be connected to three-phase panelboards as long as interconnections are balanced across all three phases in such a manner to limit voltage imbalances to 3% or less.






122

## Installation Errors




**Many violations!!**



123

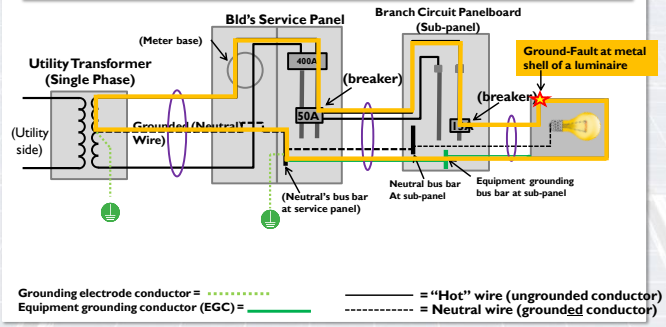
## Available Fault Current (for AC equipment)



124

# Fault Current

The amount of fault current that could flow on a faulted circuit depends on a variety of items such as: size of utility transformer, length of wire, size and type of wire or conductors, and impedance of the total circuit.



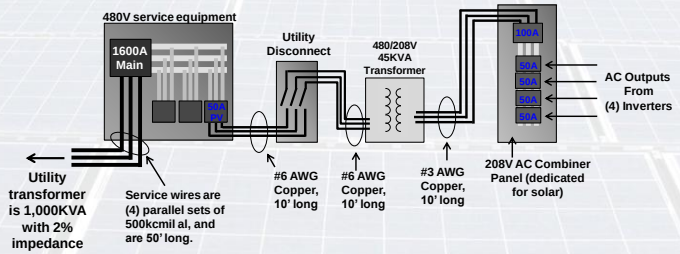



125

# Available Fault Current

**(See example calculation handout)**

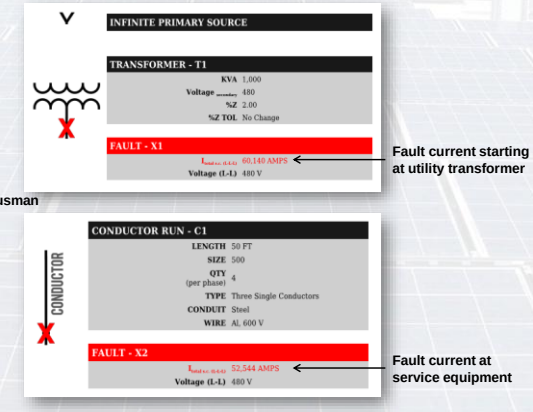
All ac equipment must have a fault current rating not less than the calculated available fault current that could be provided to the equipment!






126

# Example Fault Current Calculation



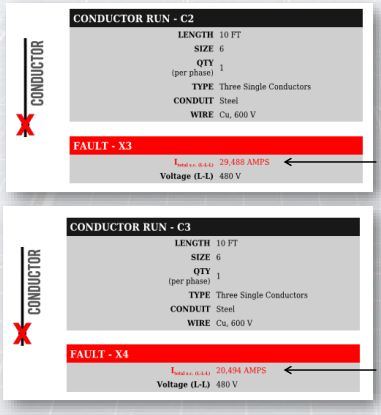

*Calculation using the free Eaton/Cooperbusman fault current calculator

Fault current starting at utility transformer

Fault current at service equipment

127

# Example Fault Current Calculation (continued)




*Calculation using the free Cooperbusman fault current calculator

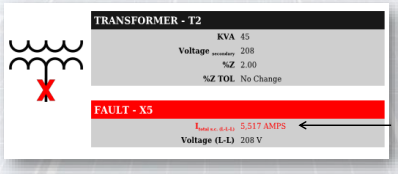
Fault current at the AC disconnect

Fault current at primary side of the 45KVA trans.

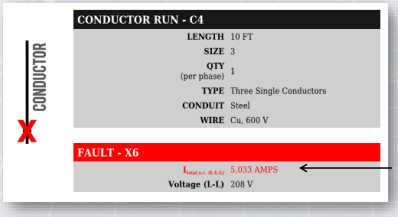
128

## Example Fault Current Calculation (continued)

*Calculation using the free Cooperbusman fault current calculator




Fault current at the secondary side of the 45KVA transformer

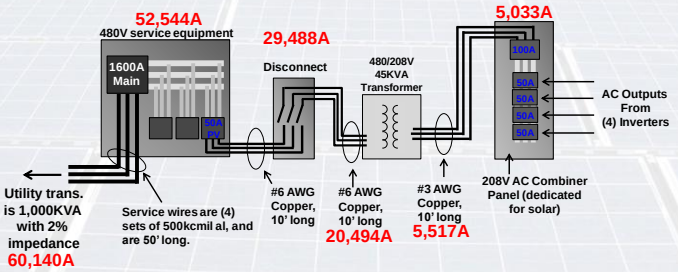



Fault current at AC combiner panel

129

## Available Fault Current
**(See example calculation handout)**

All AC equipment must have a fault current rating not less than the calculated available fault current that could be provided to the equipment!






130

## Ground-Mount Installations



131

## Wire Protection
**(where DC conductors are readily accessible)**

***NEC* 690.31(A):**

- Where PV source and output circuits operating at voltages greater than 30 volts are installed in readily accessible locations, circuit conductors shall be **guarded or installed in Type MC cable or in raceway**.

**"Guarded circuit conductors?**



132


133

## Fence around solar array


134


135

## Ground-Mounted Arrays

- Detailed manufacturer info and engineering must be submitted to show that any pole or ground-mounted structures will be able to handle the local wind and snow loads.

136

# Roof Installations



137

## PV Modules On Commercial Roofs



138

## Ballasted Roof Mounted Systems

Ballasted systems typically are only allowed to have a tilt of 0 to 25˚

Photo courtesy of Unirac Incorporated



139

## Ballasted Roof Mounted Systems

- Engineering should be obtained to justify that the existing roof can handle the weight of the PV system with ballast blocks installed.
- A detailed layout must also be obtained from the racking manufacturer to show the exact layout of the array, show how many ballast blocks are required per racking tray, and to show that the system can handle local wind and seismic loads.



140

In order to reduce weight of a ballasted system, some systems utilize roof anchors periodically throughout the array.

The roof anchor system must be installed per the racking manufacturer's requirements.



141

## Structural Integrity



Make sure the roof structure is adequate to support the PV system. This is especially important for ballasted PV racking systems.

142

## Roof Flashings Required

Properly flashed supports



143

## Wire Management

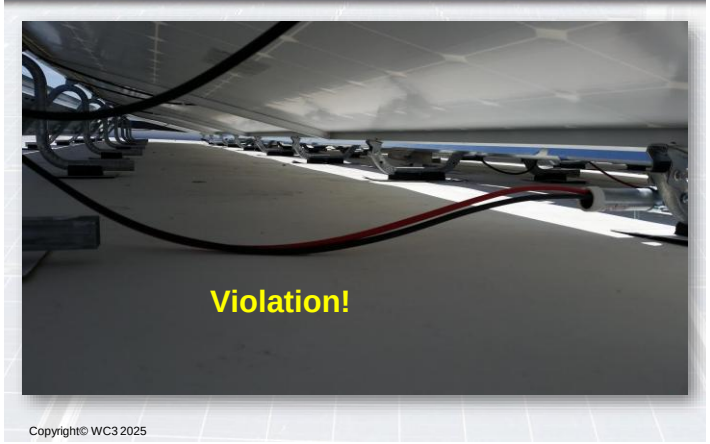


144

## Wire Management


145

## Wire Management




146

## Wire Management

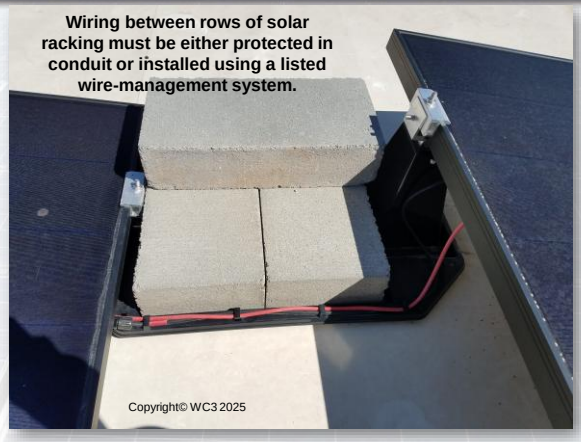

147

## Wire Management


148

## Wire Management

Wiring between rows of solar racking must be either protected in conduit or installed using a listed wire-management system.





149




150

## Wire Management

Inverters mounted on the roof should be mounted as close as possible to the solar modules (panels) to minimize exposure of wiring to physical damage.

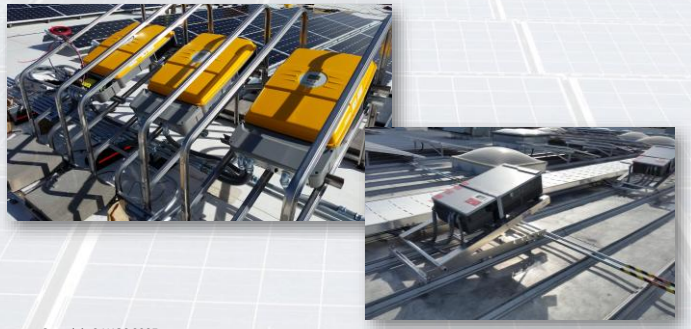
Otherwise, a listed wire management system may be needed for the wiring extending from the array to the inverter.



151

## Inverters on Roof

Roof-mounted string inverters and combiner panels are often required to be installed at a 45° or more angle and usually cannot be installed horizontal (see installation instructions).





152

## Equipment Mounted to Parapets



153

## Junction Boxes

Violations! Box not properly supported and no flashing for roof penetration.

Still needs flashing for roof penetration.



154

## 2021 *IBC* and *IFC* PV Requirements



155

## 2021 *International Building Code* (*IBC*) Requirements

- PV modules installed on the roof must be labeled to identify their fire classification, *IBC* 1505.9.
- The listed fire class must meet *IBC* table 1505.1 based on the type of construction of the building, *IBC* 1505.9.




156

## 2021 *IBC* Requirements Continued…

- ***IBC* 1507.16.6:** PV shingles or Building Integrated PV (BIPV) must be listed per UL 7103, or both UL 61730-1 and UL 61730-2.



157

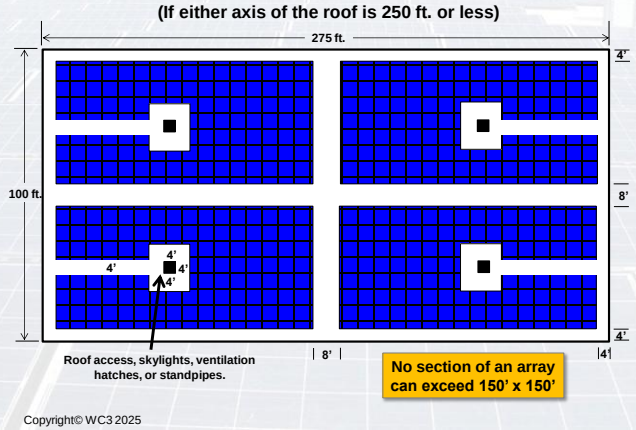
## Building Integrated PV (BIPV)

(Photo courtesy of Canadian Solar)

Uni-Solar (United Solar) modules on Coke bld.

158

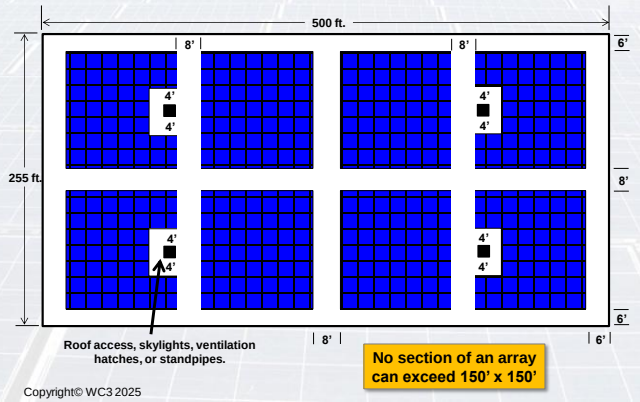
## 2021 *IFC* Required Pathways On Non-Residential Roofs (1205.3.1-1205.3.3)






159

## 2021 *IFC* Required Pathways On Non-Residential Roofs (1205.3.1-1205.3.3)






160

Violation!

There's not a 3' or 4' clear pathway around the perimeter of the roof (next to the solar panels).



161

## Example of Roof Access Pathway


Install by Hunt Electric



162

## General Equipment Requirements



163

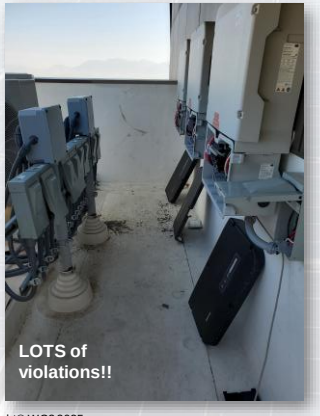
## Clear Working Space?

Clear working space is required per *NEC* 110.26.



164

## Violations!




**Clear working space is required per *NEC* 110.26.**



165

## Disconnects From All Sources

***NEC* 690.15(C) requires disconnects for inverters from all sources of power.**

**The required disconnect(s) must be within sight and within 10' of the equipment unless the disconnecting means is lockable or located behind a cover that can be locked.**



166

## Some Inverters Have Both a DC and an AC disconnect Provided



167

## Fuses at DC Combiners


**Verify that all fuses at a DC combiner are listed for PV use (see *NEC* 690.9(B)) and are rated for the maximum voltage of the system (*NEC* 110.3(B))**



168

## Equipment at the array

**Equipment must be protected from damage. *NEC* 110.27(B)**



169

**Careful consideration should be given to wire bending space!**



170

## Large-Scale Solar PV Systems



171

## Large Solar PV Systems

- Systems that are at least 5,000kw (5MW), and are not under exclusive control of the utility, are permitted to comply with *NEC* Article 691.
  - Article 691 offers a lot of flexibility to engineered designed systems.
  - Article 691 supersedes Article 690 if conflicting requirements apply.
- Smaller systems (smaller than 5MW) are required to comply with Article 690.



172

## Proper support of wiring, even at ground-mount arrays, is important!

Violations!!



173


174

## Wire Management is VERY Important!

Much better!



175

## Wire Management




176

## Wire Support System



177

## Wire Harness System

Many modern large-scale solar PV systems utilize listed wire harness systems for combining dc strings together.

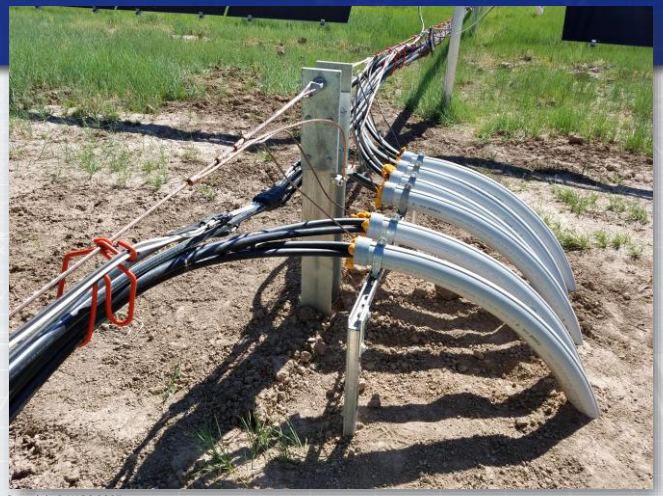


178

Wire harness system.



179





180

## DC Disconnects (typically load-break rated)



181




182

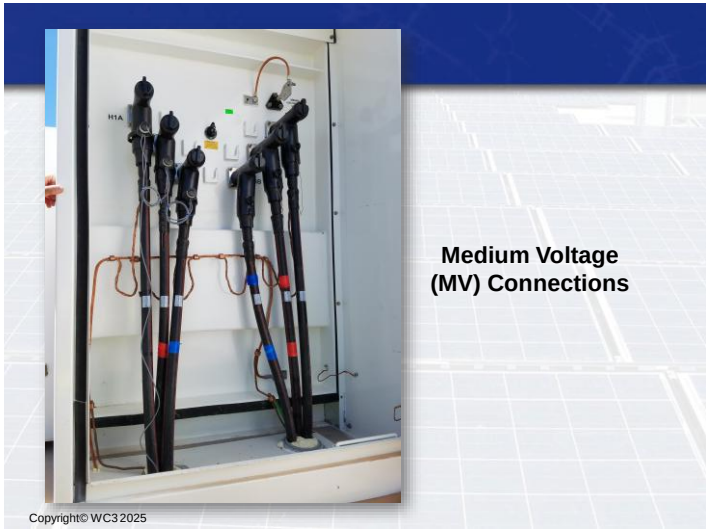
DC re-combiner at central inverter.




183



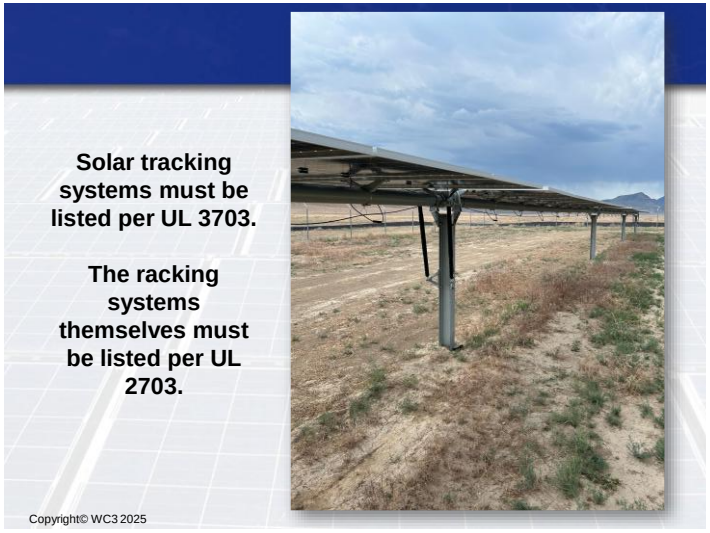

184




185


186


187




188

## Ground-Mounted System Racking With Integrated Bonding



189

## Signage


190

## Signage, Per *NEC* 110.21(B)


- Signs must be durable and be able to handle the environment they are installed in.
- Signage cannot be hand-written.
- The markings must adequately warn of the hazard using effective words and/or symbols.



191

## Signage at Service Equipment

**A sign is required at the service equipment to include the words "CAUTION: MULTIPLE SOURCES OF POWER." *NEC* 705.10.**

CAUTION: MULTIPLE SOURCES OF POWER
(and phone number of off-site entities servicing the system)

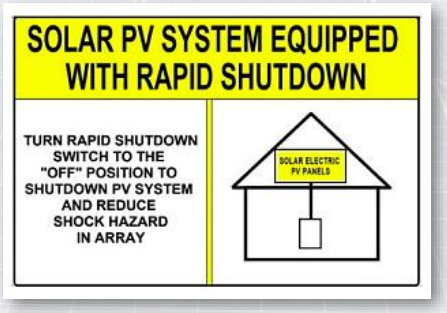
**The sign must also note the location of all power production disconnecting means for the premises. *NEC* 705.10.**



192

## Rapid Shutdown Signage

**Rapid shutdown sign required per *NEC* 690.12(D) [previously 690.56(C)].**






193

## Rapid Shutdown Signage

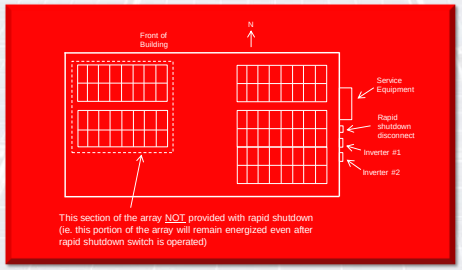
**690.12(D)(1) [previously 690.56(C)(1)] Buildings with More Than One Rapid Shutdown Type:**

- For buildings that have PV systems with **both** rapid shutdown types **or** a PV system with a rapid shutdown type and a PV system with no rapid shutdown, a detailed plan view diagram of the roof shall be provided showing each different PV system and a dotted line around areas that remain energized after the rapid shutdown switch is operated.

194

## Rapid Shutdown Signage For Buildings with More Than One Rapid Shutdown Type

**Example of a plaque showing which portion(s) of the PV system are equipped with rapid shutdown and which are not:**






195

## Rapid Shutdown Signage

- **690.12(D)(2) [previously 690.56(C)(2)] Rapid Shutdown Switch.** A rapid shutdown switch shall have a label located on or no more than (3 ft) from the switch that includes the following wording: **"RAPID SHUTDOWN SWITCH FOR SOLAR PV SYSTEM"**
- The label shall have all letters capitalized and having a minimum height of 9.5 mm (3⁄8 in.), in white on red background.


**Sign located next to the rapid shutdown disconnect**



196

## Sign at Point of Interconnection


**Per the 2020 and older editions of the *NEC*, a sign is required at the point of interconnection noting the rated AC output current (amps) and AC voltage of the inverter(s). *NEC* 690.54.**



197

## Signage at PV Backfed Breakers


**If the 120% rule of *NEC* 705.12(B)(3)(2) is utilized and the breaker is located at the end of the panel, a sign is required saying not to relocate such breaker.**



198

## Sign at String Inverters

**A sign is required at a string inverter, or distribution equipment associated with the PV system, giving the maximum DC voltage of the PV system. *NEC* 690.7(D) [previously 690.53].**

**Maximum DC Voltage = 600V**



199

## Wiring Methods

**690.31(D)(2) – Markings/Labels:**

- There must be provided labels on the exterior of all exposed raceways, enclosures, boxes, and conduit bodies. The wording of the labels must state either of the following: "PHOTOVOLTAIC POWER SOURCE" or "SOLAR PV DC CIRCUIT."

PHOTOVOLTAIC POWER SOURCE

**Or**

SOLAR PV DC CIRCUIT



200

## External Identification Of DC Wiring



201

## Warning Signage

***NEC* 690.13(B):**

- A sign is required at any disconnect or electrical box where both sides of terminals can be energized in the open position and must state:

WARNING ELECTRIC SHOCK HAZARD
TERMINALS ON THE LINE AND LOAD SIDES
MAY BE ENERGIZED IN THE OPEN POSITION.



202

## AC disconnects

**Here is an example of an AC disconnect switch (used for a PV system) that would require the following sign:**

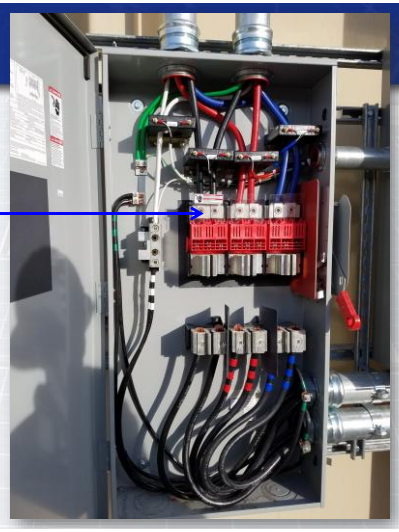
WARNING ELECTRIC SHOCK HAZARD
TERMINALS ON THE LINE AND LOAD
SIDES MAY BE ENERGIZED IN THE
OPEN POSITION.

**NOTE: It's STRONGLY recommended that only AC disconnects with dead-fronts be used for a PV system or provide a lock for the disconnect (if the disconnect is readily accessible to unqualified persons)!**



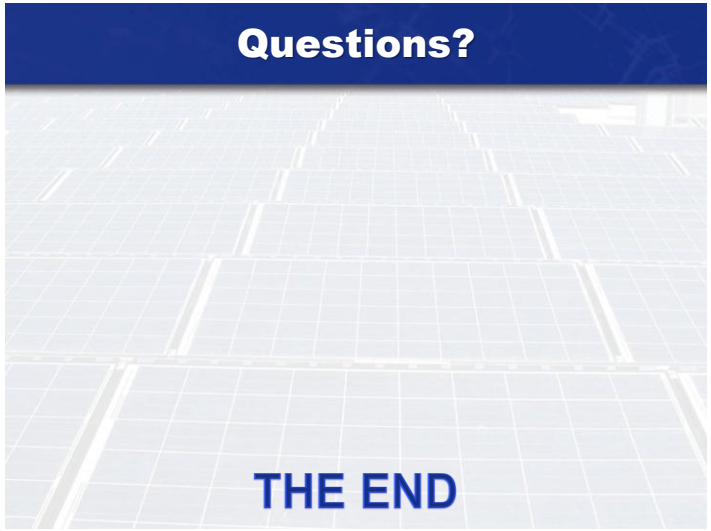
203

**This disconnect includes dead-fronts to protect line terminals.**





204




205