



Figure 690–23

(D) Multiple Inverters. Where multiple utility-interactive inverters are located remote from each other, a directory is required at each dc PV system disconnecting means, ac disconnecting means for mini- and micro-inverters, and service disconnecting means showing the location of all dc and ac PV system disconnecting means in the building/structure [705.10].

Ex: A directory isn't required where all PV system disconnecting means are grouped at the service disconnecting means.

2014 CHANGE ANALYSIS: Article 690 might be the most difficult article in the entire *Code* book through which to navigate. For several years, the requirements in this article didn't really change that much, then a huge influx of changes occurred due to the sudden popularity of these systems. When a massive volume of changes occur to one article the end result will almost certainly be confusing, with requirements in sections that don't seem to make much sense. This section is a perfect example of this. Circuit routing and connection requirements were found here in 2011, but are those really "general requirements?" These changes may seem insignificant, but they make this article much easier to use, and therefore were certainly worth making.

One technical change that occurred to this section can be found in 690.4(B), which addressed the listing of PV system equipment. Keeping up with new products and technologies is a very difficult task when updating the *NEC*, so you can expect *Code* changes every time new products come out. The example here is dc combiners and dc-to-dc converters. By adding them to the list of equipment in 690.4(B) they must be listed.

There are several changes in Article 690 that are simple relocations. These certainly make the *NEC* a better document. Examples of this include 690.13 and 690.14 which were condensed into just 690.13 (covering the rules for disconnecting means). Previous editions of the *Code* had 690.13 covering disconnects, then 690.14 covering "additional provisions" for disconnecting means!

690.5 Ground-Fault Protection

Grounded dc PV arrays must be provided with dc ground-fault protection meeting the requirements of 690.5(A) through (C) to reduce fire hazards. [Figure 690–24](#)

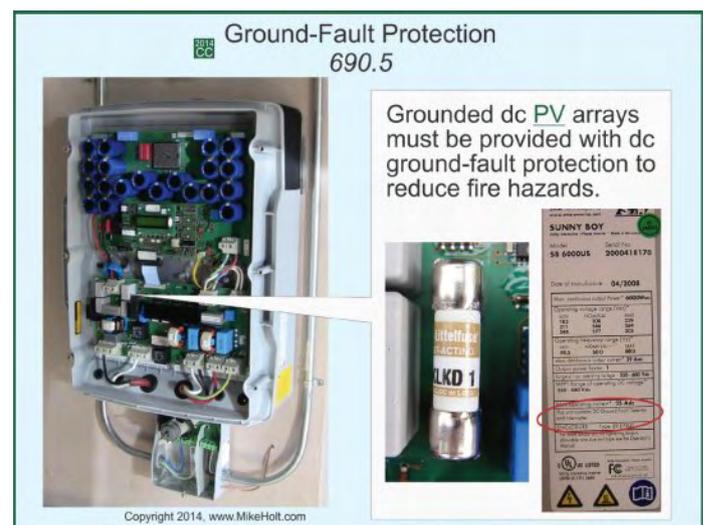


Figure 690–24

Ungrounded dc PV arrays must be provided with dc ground-fault protection in accordance with 690.35(C).

Ex: Ground-fault detection isn't required for ground- or pole-mounted PV arrays with not more than two source circuits isolated from buildings. Figure 690–25

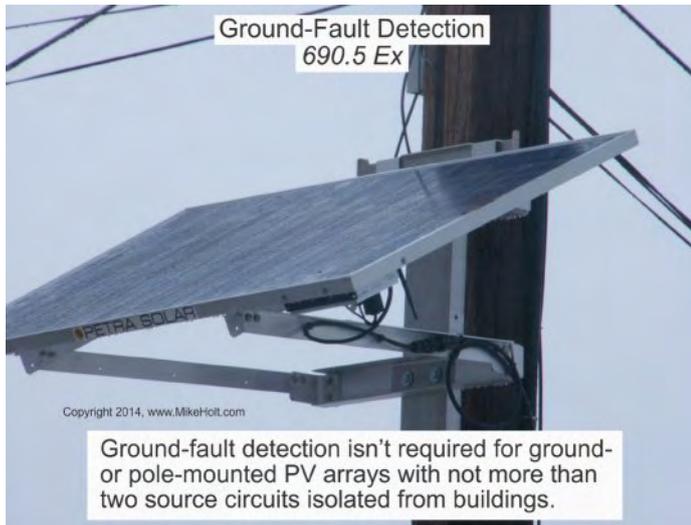


Figure 690–25

(A) Ground-Fault Detection and Interruption (GFDI). The ground fault protection must:

- (1) Be capable of detecting a ground fault in the PV array dc current-carrying conductors and components, including any intentionally grounded conductors,
- (2) Interrupt the flow of fault current,
- (3) Provide an indication of the fault, and,
- (4) Be listed for providing PV ground-fault protection.

(C) Labels and Markings. A warning label that isn't handwritten and is of sufficient durability to withstand the environment involved, must be permanently affixed [110.21(B)] on the utility-interactive inverter at a visible location at PV system batteries stating the following: Figure 690–26

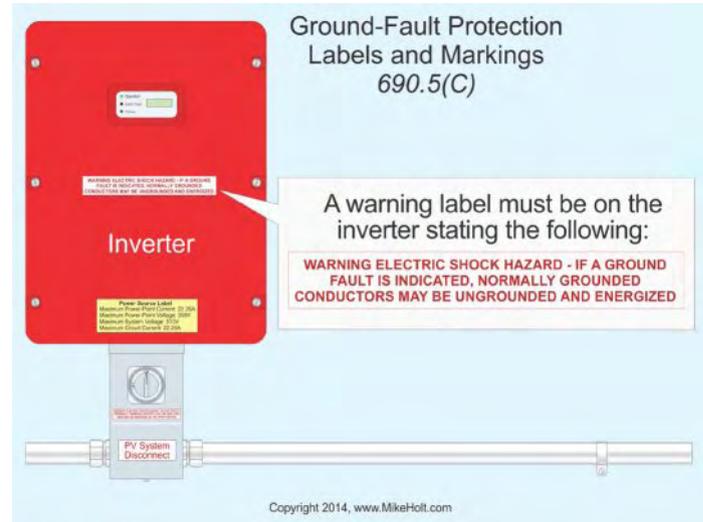


Figure 690–26

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

2014 CHANGE ANALYSIS: Two changes were made in this section, which covers ground-fault detection and interruption, although neither is likely to really affect the installer. New to this edition of the *NEC* is that the grounded conductor must now be provided with ground-fault protection, whereas in 2011 it was permitted but not required. This change will force manufacturers to revise their products. The other change is to 690.5(C), which simply refers the *Code* user back to the general rule of 110.21(B) for the requirements of signs. These requirements include suitability for the environment involved, as well as a prohibition on hand written warnings. This is of little consequence in this context, because this sign is almost always provided by the manufacturer.

690.6 Alternating-Current Modules

(A) PV Source Circuits. Article 690 requirements pertaining to dc PV circuits don't apply to ac PV modules since ac PV modules don't have a dc source or output circuit. [Figure 690–27](#)

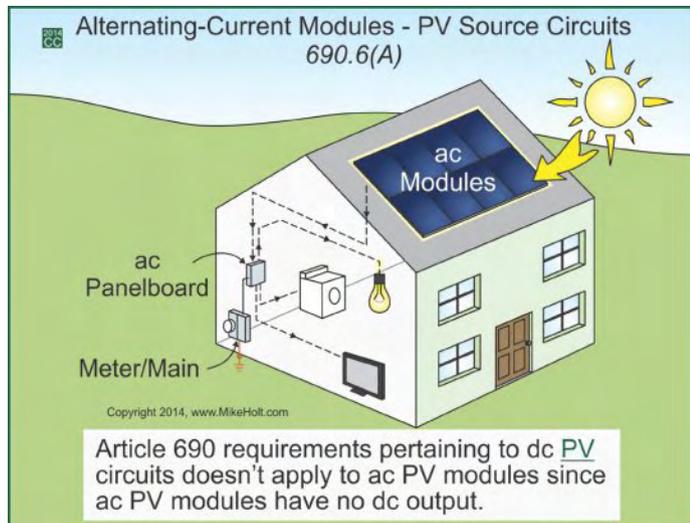


Figure 690–27

(B) Inverter Output Circuit. The output circuit conductors of an ac module are considered an “Inverter Output Circuit” as defined in 690.2. [Figure 690–28](#)

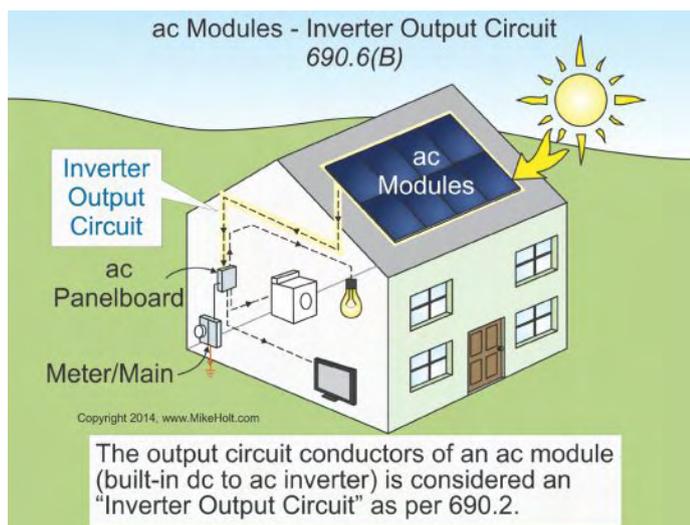


Figure 690–28

Part II. Circuit Requirements

690.7 Maximum Voltage

(A) Maximum PV System Voltage. For dc circuits, the maximum PV system voltage for that circuit is equal to the rated open-circuit voltage (Voc) of the series-connected PV modules, as corrected for the lowest expected ambient temperature. This voltage is used to determine the voltage rating of conductors and equipment for the dc circuits. [Figure 690–29](#)

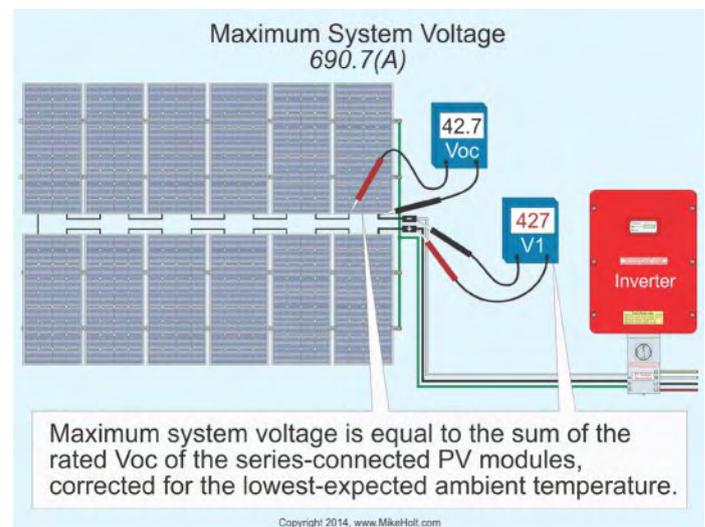


Figure 690–29

Author's Comment:

- Open circuit voltage (Voc) is the voltage when there's no load on the system.

When open-circuit voltage temperature coefficients are supplied by the manufacturer as part of the installation instructions for listed PV modules, they must be used to calculate the maximum PV system voltage instead of using Table 690.7, as required by 110.3(B).

Note: One source for lowest-expected ambient temperature is the Extreme Annual Mean Minimum Design Dry Bulb Temperature found in the *ASHRAE Handbook—Fundamentals*. See www.solarabcs.org/permitting/map.

Author's Comment:

- PV module voltage has an inverse relationship with temperature, which means that at lower temperatures, the PV modules' voltage increases; at higher temperatures, the PV modules' voltage decreases from the manufacturers nameplate Voc values.

PV System Voltage Based on Manufacturer Temperature Coefficient %/°C

Example: Using the manufacturer's temperature coefficient of $-0.36\%/^{\circ}\text{C}$, what's the maximum PV source circuit voltage for twelve modules each rated Voc 38.30, at a temperature of -7°C ? **Figure 690-30**

$$\text{PV Voc} = \text{Rated Voc} \times \{1 + [(\text{Temp. } ^{\circ}\text{C} - 25^{\circ}\text{C}) \times \text{Module Coefficient } \%/^{\circ}\text{C}]\} \times \# \text{ Modules per Series String}$$

Module Voc = $38.30 \text{ Voc} \times \{1 + [(-7^{\circ}\text{C} - 25^{\circ}\text{C}) \times -0.36\%/^{\circ}\text{C}]\}$
 Module Voc = $38.30 \text{ Voc} \times \{1 + [-32^{\circ}\text{C} \times -0.36\%/^{\circ}\text{C}]\}$
 Module Voc = $38.30 \text{ Voc} \times \{1 + 11.52\%\}$
 Module Voc = $38.30 \text{ Voc} \times 1.1152$
 Module Voc = 42.71V
 PV Voltage = 42.71×12
 PV Voltage = 513V

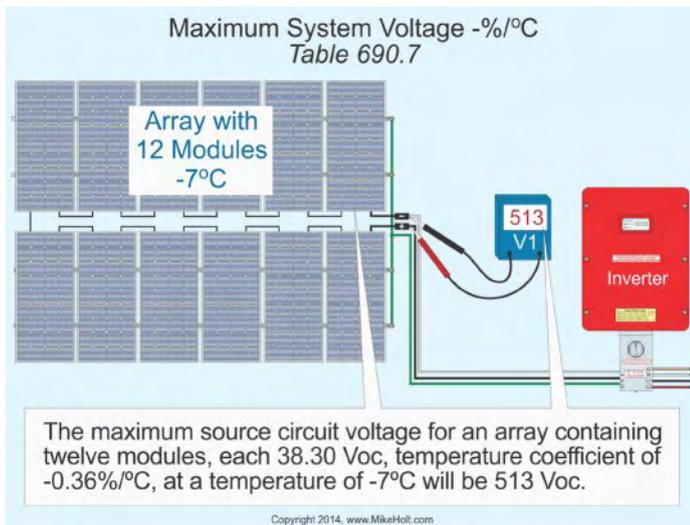


Figure 690-30

PV System Voltage Based on Manufacturer Temperature Coefficient V/°C

Example: Using the manufacturer's temperature coefficient of $-0.137\text{V}/^{\circ}\text{C}$, what's the maximum PV source circuit voltage for twenty-three modules each rated Voc 38.30, at a temperature of -7°C ? **Figure 690-31**

$$\text{PV Voc (V/}^{\circ}\text{C)} = \{\text{Rated Voc} + [(\text{Temp. } ^{\circ}\text{C} - 25^{\circ}\text{C}) \times \text{Module Coefficient V/}^{\circ}\text{C}]\} \times \# \text{ Modules per Series String}$$

Module Voc = $\{38.30\text{V} + [(-7^{\circ}\text{C} - 25^{\circ}\text{C}) \times -0.137\text{V}/^{\circ}\text{C}]\}$
 Module Voc = $\{38.30\text{V} + [-32^{\circ}\text{C} \times -0.137\text{V}/^{\circ}\text{C}]\}$
 Module Voc = $(38.30\text{V} + 4.384\text{V})$
 Module Voc = 42.68V
 PV Voc = $42.68\text{V} \times 12$
 PV Voc = 512V

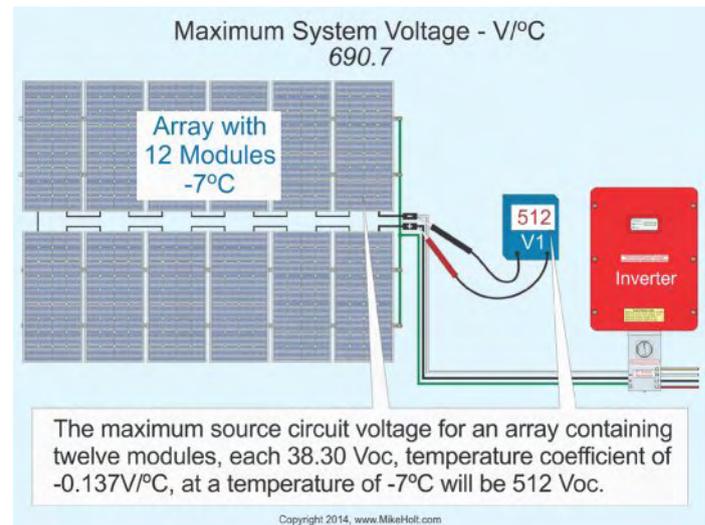


Figure 690-31

Only for crystalline and multicrystalline silicon modules, and only where temperature coefficients aren't provided by the manufacturer, the rated open-circuit voltage must be multiplied by the correction factor provided in Table 690.7.

Table 690.7 Voltage Correction Factors

Lowest-Expected Ambient Temperature		Temperature Correction Factor
°C	°F	
4 to 0	40 to 32	1.10
-5 to -1	31 to 23	1.12
-10 to -6	22 to 14	1.14
-15 to -11	13 to 5	1.16
-20 to -16	-4 to 4	1.18
-25 to -21	-13 to -5	1.20
-30 to -26	-22 to -14	1.21
-35 to -31	-31 to -23	1.23
-40 to -36	-40 to -32	1.25



CAUTION: Illumination at dawn, dusk, heavy overcast, and even on rainy days is sufficient to produce dangerous voltage. Figure 690–32

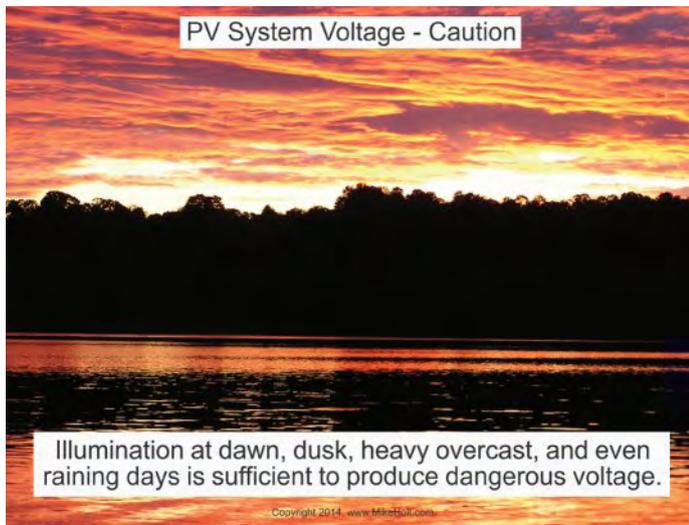


Figure 690–32

PV System Voltage Based on Table 690.7 Temperature Correction

Example: Using Table 690.7, what's the maximum PV source circuit voltage for twelve modules each rated V_{oc} 38.30, at a temperature of -7°C ? Figure 690–33

String V_{oc} Table 690.7 = Module V_{oc} × Table 690.7 Correction Factor × # Modules per Series String

$$\text{Module } V_{oc} = 38.30 \text{ Voc} \times 1.14$$

$$\text{Module } V_{oc} = 43.66\text{V}$$

$$\text{PV } V_{oc} = 43.66\text{V} \times 12 \text{ modules}$$

$$\text{PV } V_{oc} = 524\text{V}$$

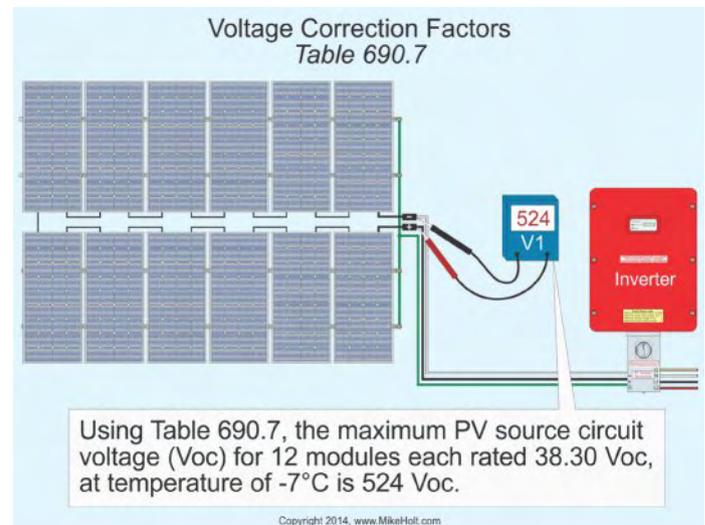


Figure 690–33

(C) Maximum PV System Voltage One- and Two-Family Dwellings. For one- and two-family dwellings, the maximum PV system dc voltage is limited to 600V, which is equal to the standard voltage insulation of electrical conductors. Figure 690–34

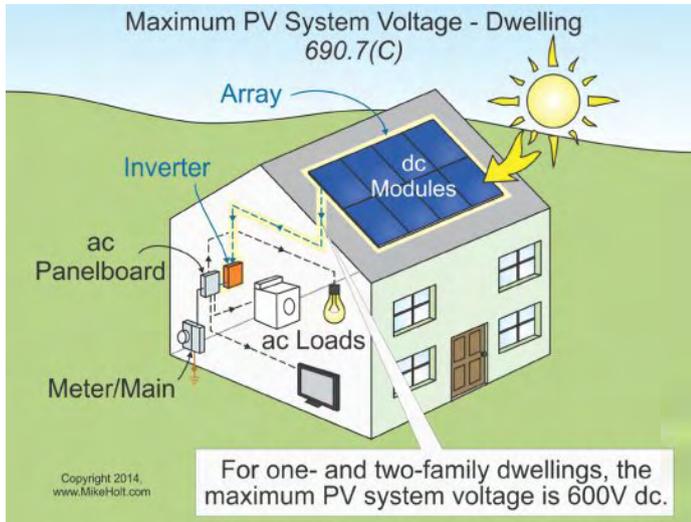


Figure 690–34

Author's Comment:

- The maximum PV system dc voltage for other than one- and two-family dwelling units is permitted to be up to 1,000V, but the working space, the voltage rating of conductor insulation, and equipment (such as disconnects and fuses), must be based on the maximum PV dc system voltage of 1,000V.

2014 CHANGE ANALYSIS: *Code* users that are experienced in Article 690 will notice that the voltages discussed in this article have been changed from 600V to 1,000V. These changes were made as a result of a task group for the 2014 *NEC* that wanted to make changes that would result in the *Code* corresponding more closely with the IEC (International Electrotechnical Commission) standard that's used in some other countries. By changing the voltage threshold in the *NEC*, it allows products that are manufactured for IEC compliance to be used in *NEC* installations, with no real safety concerns being added. It's interesting to note that the original proposal to this section wanted to allow for 1,000V installations at dwelling units, but that portion of the proposal was rejected. It will be interesting to see if this changes in future editions of the *Code*, as many people are already a bit put off by having 600V systems at dwelling units!

(E) Bipolar Circuits. For a 2-wire circuit connected to bipolar systems, the maximum system voltage of the circuit is the highest voltage between the conductors of the 2-wire circuit if all of the following conditions apply:

- (1) One conductor of the 2-wire circuit is solidly grounded.
- (2) Each 2-wire circuit is connected to a separate subarray.
- (3) Bipolar equipment must have a permanently affixed label that isn't handwritten and is of sufficient durability to withstand the environment involved [110.21(B)] with the following wording:

WARNING—BIPOLAR PV ARRAY. DISCONNECTION OF NEUTRAL OR GROUNDED CONDUCTORS MAY RESULT IN OVERVOLTAGE ON ARRAY OR INVERTER.

690.8 Circuit Current and Circuit Sizing

Scan this QR code for a video of this *Code* rule. See page xiii for information on how to use the QR codes.

(A) Calculating Maximum Circuit Current.

(1) Maximum PV Source Circuit Current. The maximum PV source circuit current is calculated by multiplying the module nameplate short-circuit current rating (I_{sc}) by 125 percent.

Figure 690–35

Maximum PV Source Circuit Current (I_{sc})
690.8(A)(1)

ELECTRICAL CHARACTERISTICS	
Maximum Power (P_{max})*	250 W
Tolerance of P_{max}	+5%/-0%
PTC Rating	223.6 W
Type of Cell	Polycrystalline silicon
Cell Configuration	60 in series
Open Circuit Voltage (V_{oc})	38.3 V
Maximum Power Voltage (V_{mp})	29.8 V
Short Circuit Current (I_{sc})	8.90 A
Maximum Power Current (I_{mp})	8.40 A
Module Efficiency (%)	15.3%
Maximum System (DC) Voltage	600 V (UL)/1000V (IEC)
Series Fuse Rating	15 A
NOCT	47.5°C
Temperature Coefficient (P_{max})	-0.485%/°C
Temperature Coefficient (V_{oc})	-0.36%/°C
Temperature Coefficient (I_{sc})	0.053%/°C

*Illumination of 1 kW/m² (1 sun) at spectral distribution of AM 1.5 (ASTM E892 global spectral irradiance) at a cell temperature of 25°C.

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Maximum PV source circuit current is calculated by multiplying the module nameplate I_{sc} by 125 percent.

Figure 690–35

Author's Comment:

- The 125% current multiplier is due to the module's ability to produce more current than its rated value based on the intensity of the sunlight, which can be affected by altitude, reflection due to snow or other buildings, or even the dryness of the air.
- The PV source circuit consists of the circuit conductors between the PV modules and the terminals of the dc combiner or inverter dc input terminals if no dc combiner is used [690.2].

Maximum PV Source Circuit Current

Example: What's the maximum PV source circuit current for 12 series connected dc modules having a nameplate I_{sc} of 8.90A? Figure 690-36

$$\text{Maximum PV Source Circuit Current} = \text{Module } I_{sc} \times 1.25$$

$$\begin{aligned} \text{Maximum PV Source Circuit Current} &= 8.90A \times 1.25 \\ \text{Maximum PV Source Circuit Current} &= 11.13A \end{aligned}$$

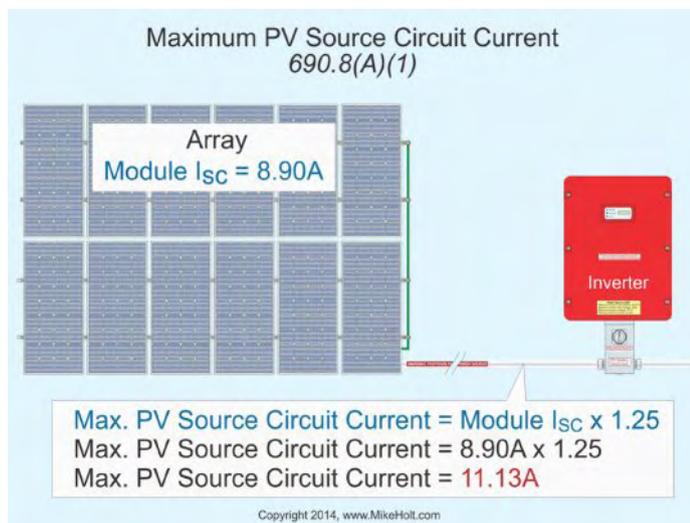


Figure 690-36

(2) Maximum PV Output Circuit Current. The maximum PV output circuit current is equal to the sum of parallel PV maximum source circuit currents as calculated in 690.8(A)(1).

Author's Comment:

- The PV output circuit consists of circuit conductors between the PV source circuit (dc combiner) and the dc input terminals of the inverter or dc disconnect.

Maximum PV Output Circuit Current

Example: What's the maximum PV output circuit current for two PV source circuits (strings), each containing 12 dc modules having a nameplate I_{sc} of 8.90A? Figure 690-37

$$\text{Maximum PV Output Circuit Current} = (\text{Module } I_{sc} \times 1.25)^* \times \text{Number of Strings}$$

$$\begin{aligned} \text{Maximum PV Output Circuit Current} &= (8.90A \times 1.25)^* \times 2 \\ \text{Maximum PV Output Circuit Current} &= 11.13A \times 2 \\ \text{Maximum PV Output Circuit Current} &= 22.26A \\ &^*690.8(A)(1) \end{aligned}$$

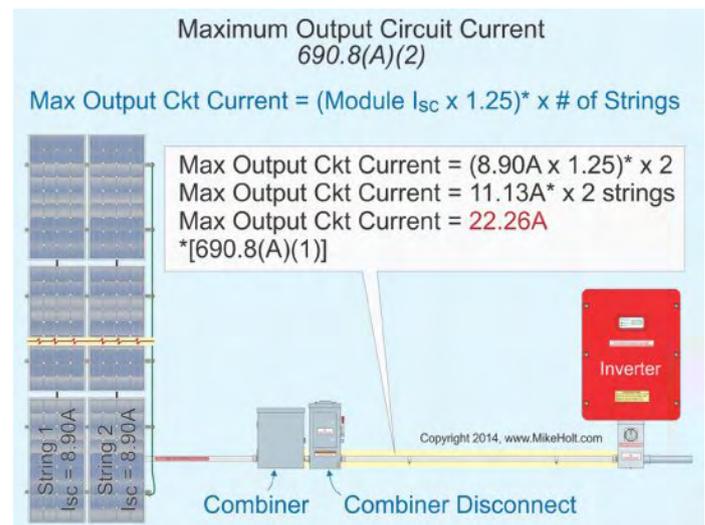


Figure 690-37

(3) Maximum Inverter Output Circuit Current. The maximum inverter output current is equal to the continuous output current marked on the inverter nameplate or installation manual. [Figure 690–38](#)

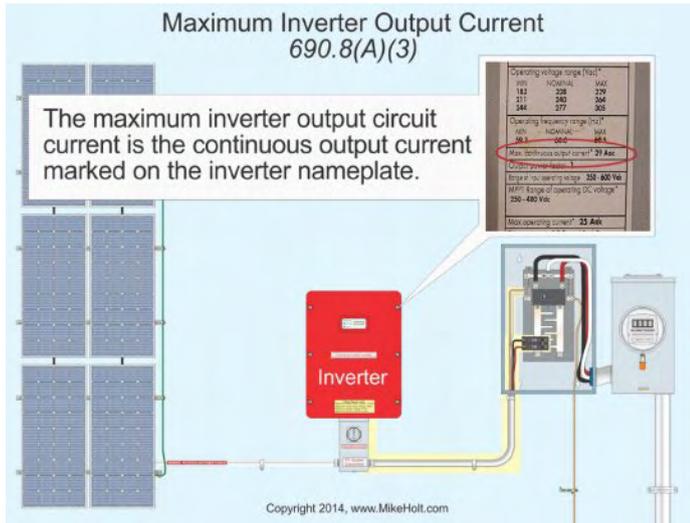


Figure 690–38

Author's Comment:

- The inverter output circuit consists of the circuit conductors from the inverter output terminals or ac modules [690.6(B)] to ac premises wiring.
- The instruction manual should be used because the inverter output current can change based on the input voltage. Regardless of the modules, conductors and overcurrent devices are based on the output current, whether there's one module or one million modules.

(5) DC-to-DC Converter Output Current. The maximum output current for a dc-to-dc converter is the converter continuous output current rating. [Figure 690–39](#)

(B) Conductor Ampacity Sizing. PV circuit conductors must be sized to the larger of 690.8(B)(1) or 690.8(B)(2).

(1) Before Ampacity Correction or Adjustment. PV circuit conductors must have an ampacity of not less than 125 percent of 690.8(A) current before the application of conductor



Figure 690–39

ampacity correction [310.15(B)(2)(a) and 310.15(B)(3)(c)] and adjustment [310.15(B)(3)(a)]. [Figure 690–40](#)

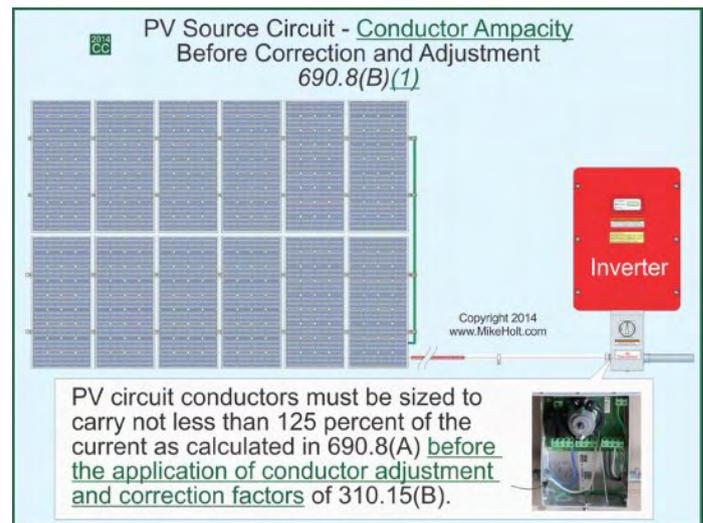


Figure 690–40

Author's Comment:

- Conductors terminating on terminals rated 75°C are sized in accordance with the ampacities listed in the 75°C temperature column of Table 310.15(B)(16) [110.14(C)(1)(a)(3)], if the conductor insulation temperature rating is 75°C or 90°C.

PV Source Circuit Ampacity before Correction and Adjustment

Example: What's the minimum PV source circuit conductor ampacity before the application of conductor correction or adjustment for the PV source circuit (string) conductors having a short-circuit current rating of 8.90A; assuming all terminals are rated 75°C? Figure 690–41

$$\text{Conductor Ampacity} = (\text{Module } I_{sc} \times 1.25)^* \times 1.25$$

$$\text{Conductor Ampacity} = (8.90A \times 1.25)^* \times 1.25$$

$$\text{Conductor Ampacity} = (11.13A)^* \times 1.25$$

$$\text{Conductor Ampacity} = 13.91A$$

$$\text{Conductor Ampacity} = 14 \text{ AWG rated } 20A \text{ at } 75^\circ\text{C}$$

[Table 310.15(B)(16)]

*690.8(A)(1)

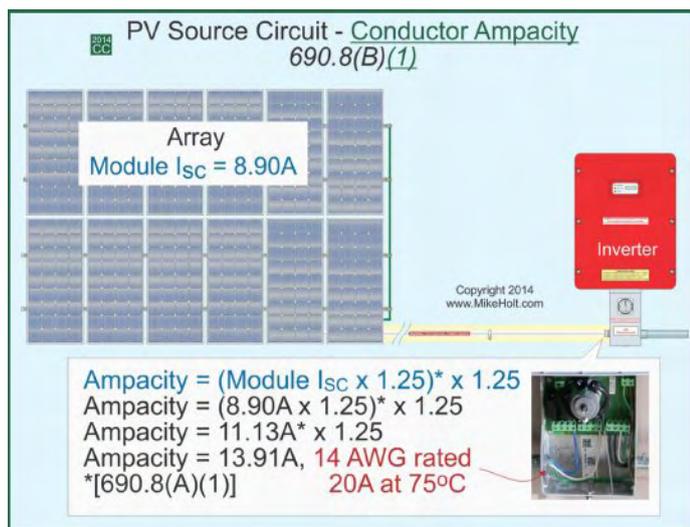


Figure 690–41

PV Output Circuit Ampacity before Correction and Adjustment

Example: What's the minimum PV output circuit conductor ampacity, before the application of conductor correction or adjustment, supplied by two PV source circuits, each having a short-circuit current rating of 8.90A; if all terminals are rated 75°C? Figure 690–42

$$\text{Conductor Ampacity} = (\text{Module } I_{sc} \times 1.25 \times \text{Number of Source Circuits})^* \times 1.25$$

$$\text{Conductor Ampacity} = (8.90A \times 1.25 \times 2 \text{ strings})^* \times 1.25$$

$$\text{Conductor Ampacity} = 22.26A^* \times 1.25$$

$$\text{Conductor Ampacity} = 27.83A$$

$$\text{Conductor Ampacity} = 10 \text{ AWG rated } 35A \text{ at } 75^\circ\text{C}$$

[Table 310.15(B)(16)]

*690.8(A)(2)

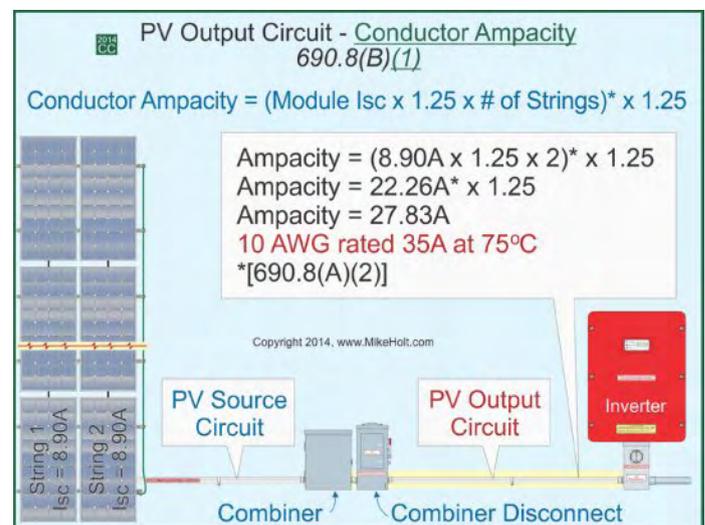


Figure 690–42

Inverter Output Circuit Ampacity before Correction and Adjustment

Example: What's the minimum inverter ac output circuit conductor ampacity, before the application of conductor correction or adjustment factors, if the maximum continuous nameplate ac rating of the inverter is 24A; if all terminals are rated 75°C? Figure 690-43

$$\text{Conductor Ampacity} = \text{Inverter Nameplate Rating}^* \times 1.25$$

$$\text{Conductor Ampacity} = 24A^* \times 1.25$$

$$\text{Conductor Ampacity} = 30A$$

Conductor Ampacity = 10 AWG rated 35A at 75°C
[310.15(B)(16)]

*690.8(A)(3)

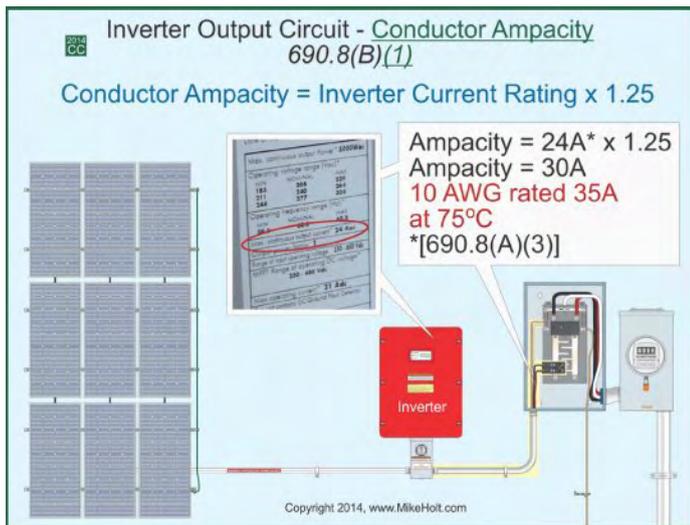


Figure 690-43

(2) After Ampacity Correction or Adjustment. Circuit conductors must have an ampacity to carry 100% of 690.8(A) current after the application of conductor ampacity correction [310.15(B)(2)(a) and 310.15(B)(3)(c)] and adjustment [310.15(B)(3)(a)]. Figure 690-44

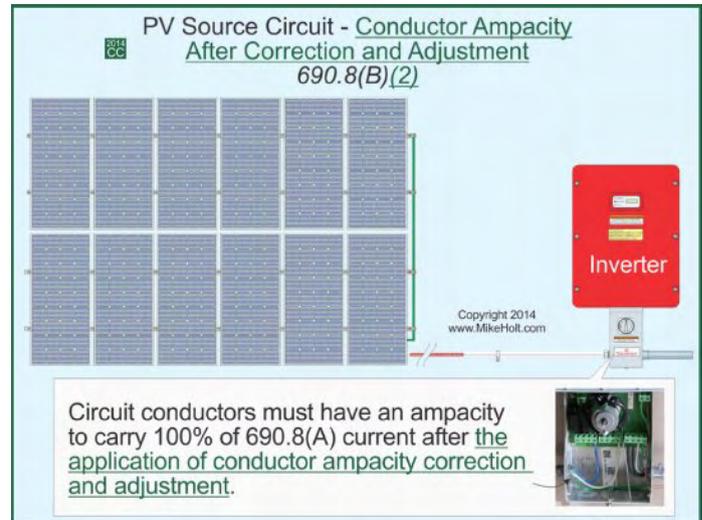


Figure 690-44

Author's Comment:

- When performing conductor ampacity correction and adjustment calculations, use the conductor ampacity listed in the 90°C column of Table 310.15(B)(16) for RHH/RHW-2/USE-2 [310.15(B)] and PV wire at 90°C [110.14(C)(1)(b)(2)]. Figure 690-45

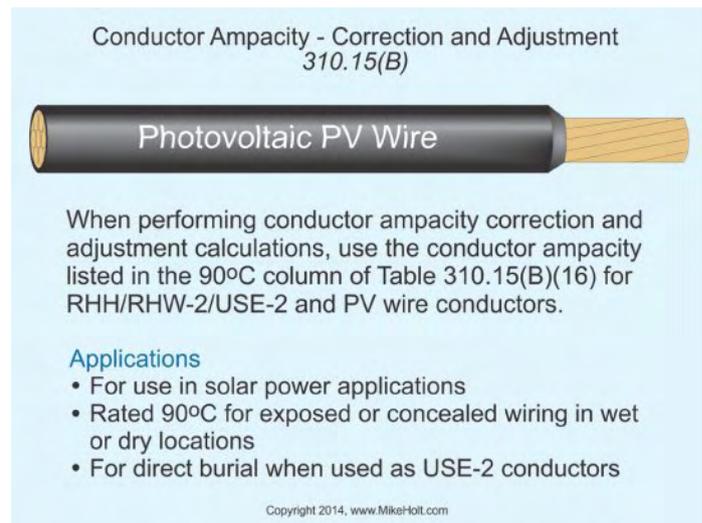


Figure 690-45

PV Source Circuit Ampacity after Correction and Adjustment

Example: What's the conductor ampacity after temperature correction for two current-carrying size 14 RHH/RHW-2/USE-2 or PV wires rated 90°C in a raceway or cable on the roof, where the ambient temperature is 90°F with 60°F added in accordance with Table 310.15(B)(3)(c), supplying modules having a nameplate I_{sc} rating of 8.90A? Figure 690-46

Conductor Ampacity = Table 310.15(B)(16) Ampacity at 90°C Column x Temperature Correction

Temperature Correction = 0.58, Table 310.15(B)(2)(a) based on 150°F (ambient plus 60°F roof temperature adder)

Conductor Ampacity = $25A \times 0.58$

Conductor Ampacity = 14.50A, which has sufficient ampacity after correction and adjustment to supply the PV source circuit current of 11.13A ($8.90A \times 1.25$) [690.8(A)(1)].

PV Source Circuit after Correction and Adjustment

Example: What's the conductor ampacity after temperature correction and adjustment for four current-carrying size 14 RHH/RHW-2/USE-2 or PV wires rated 90°C in a raceway or cable on the roof, where the ambient temperature is 90°F with 60°F added in accordance with Table 310.15(B)(3)(c), supplying modules having a nameplate I_{sc} rating of 8.90A for each circuit? Figure 690-47

Conductor Ampacity = Table 310.15(B)(16) Ampacity at 90°C Column x Temperature Correction x Adjustment

Temperature Correction = 0.58, Table 310.15(B)(2)(a) based on 150°F (ambient plus 60°F roof temperature adder)

Adjustment = 0.80, Table 310.15(B)(3)(a), based on four current-carrying conductors in a raceway or cable

Conductor Ampacity = $25A \times 0.58 \times 0.80$

Conductor Ampacity = 11.60A, which has sufficient ampacity after correction and adjustment to supply the PV source circuit current of 11.13A [$8.90A \times 1.25$, 690.8(A)(1)].

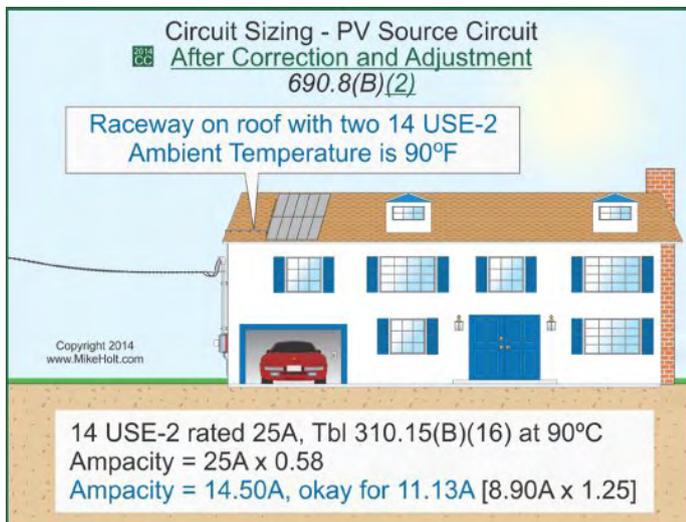


Figure 690-46

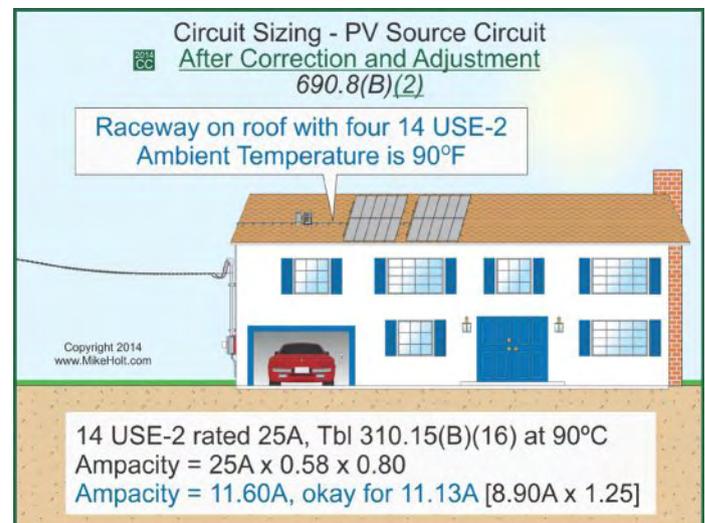


Figure 690-47

Inverter ac Output Circuit after Correction and Adjustment

Example: What's the conductor ampacity after temperature correction for two current-carrying size 10 RHH/RHW-2/USE-2 or PV wires rated 90°C installed at a location where the ambient temperature is 90°F, supplying a 24A inverter output circuit? [Figure 690-48](#)

Conductor Ampacity = Table 310.15(B)(16) Ampacity at 90°C Column x Temperature Correction

Temperature Correction = 0.96, Table 310.15(B)(2)(a) based on 90°F ambient temperature

Conductor Ampacity = 40A x 0.96 [Table 310.15(B)(2)(a)]

Conductor Ampacity = 38.40A, which has sufficient ampacity after correction to supply the inverter ac output circuit current of 24A [690.8(A)(3)].

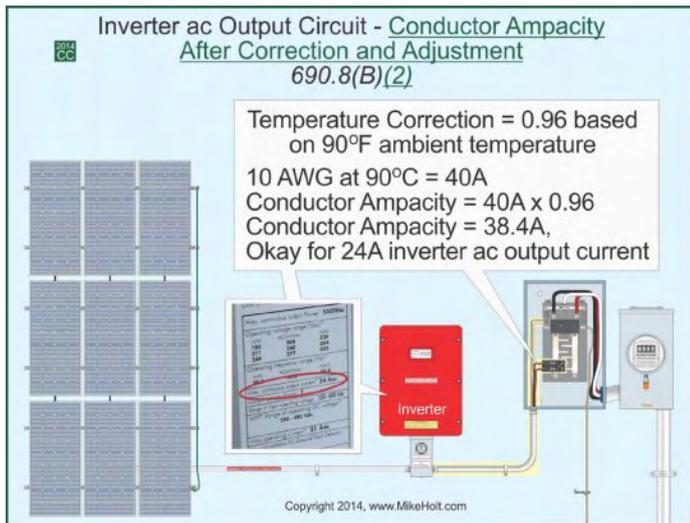


Figure 690-48

690.9 Overcurrent Protection

(A) Circuits and Equipment. PV source circuits, PV output circuits, inverter output circuits, and storage battery circuits and equipment must have overcurrent protection in accordance with Article 240. [Figure 690-49](#)

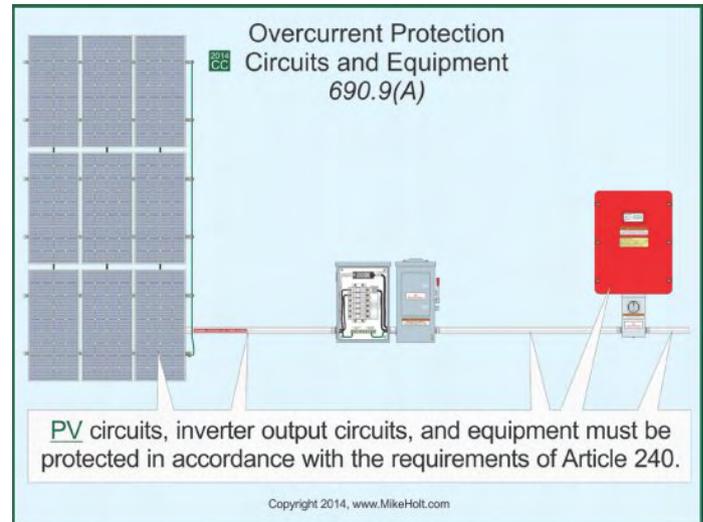


Figure 690-49

Overcurrent devices for PV source circuits (strings) and PV output circuits must comply with (A) through (E). Circuits that are connected to both a power limited supply (such as a PV module) and another supply that has high available fault current (such as an utility) must be protected against overcurrent from both systems.

Author's Comment:

- For an ungrounded system [690.35], both the positive and negative conductor must have overcurrent protection; for grounded systems, only the ungrounded conductor requires overcurrent protection [240.15].

Ex: Overcurrent protection isn't required for PV dc circuits where:

- There are no external sources such as parallel-connected source circuits, batteries, or backfeed from inverters.*
- The short-circuit currents (I_{sc}) from all sources don't exceed the ampacity of the PV circuit conductors or the maximum overcurrent device size specified on the PV module nameplate.* [Figure 690-50](#)

Author's Comment:

- This occurs when the PV source or PV output circuits consist of no more than two circuits and the inverter isn't capable of being backfed to the PV array. When