# ARTICLE 690

## Solar Photovoltaic (PV) Systems

#### **INTRODUCTION TO ARTICLE 690—SOLAR PHOTOVOLTAIC (PV) SYSTEMS**

You've seen, or maybe own, photocell-powered devices such as night lights, car coolers, and toys. These generally consist of a small solar panel and a small light or motor. Typically, these run on less than 10V dc and draw only a fraction of an ampere. These kinds of devices are very different from a system that can power a house or interconnect with a utility to offset a building's energy consumption.

Consider the sheer size and weight of solar modules for providing electrical power to a building. You're looking at mechanical and site selection issues that may require specialized expertise. The value of these modules also means there are security issues to consider, which may require more than just installing locks. There are also civil and architectural issues to address.

In summary, these installations are complicated and require expertise in several non-electrical areas, which the NEC doesn't address.

Article 690 focuses on reducing the electrical hazards that may arise from installing and operating a solar photovoltaic system, to the point where it can be considered safe for property and people.

This article consists of eight Parts, but the general requirements of Chapters 1 through 4 apply to these installations, except as specifically modified by Article 690.

#### **PART I. GENERAL**

#### 690.1 Scope.

Article 690 applies to photovoltaic (PV) electrical energy systems, array circuit(s), inverter(s), and charge controller(s) for PV systems, which may be interactive with other electrical power sources (electric utility) or stand-alone with or without energy storage (batteries). Figures 690–1 and 690–2

#### 690.2 Definitions.

*Alternating-Current PV Module.* A PV module unit consisting of solar cells, inverter, and components necessary to generate alternating-current (ac) power when exposed to sunlight. Figure 690–3



Figure 690–1

#### 690.4 Installation.

**(A) Solar Photovoltaic System.** A PV system is permitted to supply power to a building/structure in addition to any other electricity supply system(s).

**(B) Identification and Grouping.** PV system conductors, both dc and ac, can be installed in the same raceways, outlet and junction boxes, or similar fittings with each other, but must be kept entirely independent of <u>non-PV system</u> wiring conductors. **Figure 690–22** 



raceways, outlet and junction boxes, or similar fittings, but must be entirely independent of <u>non-PV system</u> wiring.

Figure 690-22

PV system conductors must be identified by separate color coding, marking tape, tagging, or other approved means and grouped as follows:

(1) **PV Source Circuits.** Identified at points of termination, connection, and splices.

(2) PV Output and Inverter Circuits. Identified at points of termination, connection, and splices.

(3) Multiple Systems. Conductors of each system must be identified at termination, connection, and splice points. Figure 690–23

*Ex:* Identification of different systems isn't required where conductor identification is evident by spacing or arrangement.

(4) **Grouping.** Where the conductors of more than one PV system occupy the same junction box or raceway with removable cover, the ac and dc conductors of each system must be grouped together by cable ties and at intervals not to exceed 6 ft. Figure 690–24



Figure 690-23



the same junction box or raceway, the ac and dc conductors of each system must be grouped by cable ties at least once and at intervals not to exceed 6 ft.

#### Figure 690–24

## *Ex:* Grouping isn't required if the PV circuit enters from a cable or raceway unique to the circuit that makes the grouping obvious.

**(C) Module Connection.** Module connections must be arranged so that the removal of a module doesn't interrupt the grounded conductor to other PV source circuits.

**(D) Equipment.** Equipment for PV systems such as inverters, photovoltaic modules, source-circuit combiners, and charge controllers must be identified and listed for the application. Figure 690–25

	PV Installation - Equipment 690.4(D)
Array	PV modules, combiners, and inverters must be identified and listed for the application.
	Figure 1995 Billion Control Co
	Combiner Combiner Disconnect

#### Figure 690-25

**Author's Comment:** Listing means that the equipment is in a list published by a testing laboratory acceptable to the authority having jurisdiction [Article 100].

(E) Qualified Persons. PV systems, associated wiring, and interconnections must be installed by a qualified person. Figure 690–26



Figure 690-26

**Note:** A qualified person has the knowledge related to construction and operation of PV equipment and installations; along with safety training to recognize and avoid hazards to persons and property [Article 100].

**(F) Circuit Routing.** PV source and output conductors must be routed along building structural members (beams, rafters, trusses, and columns) where the location of those structural members can be determined by observation.

The location of PV source and output conductors imbedded in builtup, laminate, or membrane roofing materials in areas not covered by PV modules and associated equipment must be clearly marked.

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

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

**690.5 Ground-Fault Protection.** PV systems must have ground-fault protection to reduce fire hazards. Figure 690–27



#### Figure 690–27

(C) Labels and Markings. A warning label must be on the utilityinteractive inverter stating the following: Figure 690–28

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



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**CAUTION:** The label must resist the environment for 25 to 40 years of system use and be suitable for the environment and be installed so as not to void equipment listing [110.3(B)]. When plastic is used, it should not be placed in direct sunlight, unless specifically manufactured as sunlight resistant; a metallic engraved sign would be best.

#### 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 have no dc output. Figure 690–29





**(B) Inverter Output Circuit.** The output circuit conductors of an ac module are considered an "Inverter Output Circuit" as defined in 690.2. Figure 690–30



Figure 690–30

#### **PART II. CIRCUIT REQUIREMENTS**

#### 690.7 Maximum Voltage

**(A) Maximum PV System Voltage.** Maximum PV system voltage is equal to the sum of the rated open-circuit voltage (Voc) of the series-connected PV modules as corrected for the lowest-expected ambient temperature in accordance with Table 690.7.

Open-circuit voltage temperature coefficients supplied in the instructions for PV modules must be used to calculate the maximum PV system voltage instead of Table 690.7. Figure 690–31

**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 http://www.solarabcs.org/permitting/map/.

**Author's Comment:** PV module voltage has an inverse relationship with temperature, which means that at lower temperatures, PV modules' voltage raises and at higher temperatures, PV modules' voltage falls from its nameplate rating.





Table 690.7 Voltage Correction Factors			
Lowest-Expected Ambient Temperature °C °F		Temperature Correction Factor	
0 to 4	32 to 40	1.10	
-1 to -5	23 to 31	1.12	
-6 to -10	14 to 22	1.14	
-11 to -15	5 to 13	1.16	
-16 to -20	4 to -4	1.18	
-21 to -25	-5 to -13	1.20	
-26 to -30	-14 to -22	1.21	
-31 to -35	-23 to -31	1.23	
-36 to -40	-32 to -40	1.25	

**Example:** Using Table 690.7, what's the maximum PV source circuit voltage for twenty-three modules each rated Voc 22.60, at an ambient temperature of -7°C? Figure 690–32

#### PV Voc Table 690.7 = Module Voc × Table 690.7 Correction Factor × # Modules per Series String

 $\begin{array}{l} \textit{PV Voc} = 22.60 \textit{ Voc} \times 1.14 \times 23 \textit{ modules} \\ \textit{PV Voc} = 593 \textit{V} \end{array}$ 



Figure 690-32

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

**Example:** Using the manufacturer's temperature coefficient -0.31%/°C, what's the maximum PV source circuit voltage for twenty-three modules each rated Voc 22.60, at a cell temperature of -7°C? **Figure 690–33** 

#### PV Voc = Rated Voc × {1 + [(Min. Temp. °C - 25°C) × Module Coefficient %/°C]} × # Modules per Series String

PV Voc = 22.60 Voc × {1 + [(-7°C - 25°C) × -0.31%/°C]} × 23 modules PV Voc = 22.60 Voc × {1 + [-32°C × -0.31%/°C]}) × 23 modules PV Voc = 22.60 Voc × {1 + 9.92%} × 23 modules PV Voc = 22.60 Voc × 1.0992 × 23 modules

*PV Voc* = 571*V* 





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

**Example:** Using the manufacturer's temperature coefficient -0.075V/°C, what's the maximum PV source circuit voltage for twenty-three modules each rated Voc 22.60, at an ambient temperature of -7°C? Figure 690–34

PV Voc (V/°C) = {Rated Voc + [(Min. Temp. °C - 25°C) × Module Coefficient V/°C]} × # Modules per Series String

 $\begin{array}{l} \mbox{PV Voc} = \{22.60V + [(-7^{o}C - 25^{o}C) \times -0.075V/^{o}C]\} \times 23 \\ \mbox{PV Voc} = \{22.60V + [-32^{o}C \times -0.075V/^{o}C]) \times 23 \\ \mbox{PV Voc} = (22.60V + 2.40V) \times 23 \\ \mbox{PV Voc} = 25V \times 23 \\ \mbox{PV Voc} = 575V \end{array}$ 

**Author's Comment:** Inverters require a minimum dc voltage to start; therefore PV voltage calculations should be performed to ensure the modules can produce sufficient voltage to start the system [110.3(B)]. **Figure 690–35** 





Installation and Use 110.3(B)		
	SB 5000US	
Recommended Max. PV Power (Module STC)	6250 W	
Max. DC Voltage	600 V	
Peak Power Tracking Voltage	250 - 480 V	
DC Max. Input Current	21 A	
DC Voltage Ripple	< 5%	
Number of Fused String Inputs	3 (inverter), 4 x 15 / (DC disconnect)	
PV Start Voltage	300 V	
AC Nominal Power	5000 W	
AC Maximum Output Power	5000 W	
AC Maximum Output Current (@ 208, 240, 277 V)	24 A, 21 A, 18 A	
AC Nominal Voltage / Range	183 - 229 V @ 208 V	
	211 - 264 V@ 240 V	
	244 - 305 V @ 277 V	

Inverters require a minimum dc voltage to operate in accordance with manufacturer's instructions.

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Figure 690–35

**Example:** Using the manufacturer's temperature coefficient -0.31%/°C, what's the maximum PV source circuit voltage for twenty-three modules each rated Voc 22.60, at a cell temperature of 67.8°C? Figure 690–36

#### PV Voc = Rated Voc × {1 + [(Min. Temp. °C - 25°C) × Module Coefficient %/°C]} × # Modules per Series String

PV Voc = 22.60 Voc × {1+ [(67.8°C - 25°C) × -0.31%/°C]} × 23 modules

PV Voc = 22.60 Voc × {1 + [42.8°C × -0.31%/°C]}) × 23 modules

PV Voc = 22.60 Voc × {1 + (-13.27%)} × 23 modules PV Voc = 22.60 Voc × 0.8673 × 23 modules PV Voc = 451V



Figure 690-37



Figure 690-36

**CAUTION:** Illumination at dawn and dusk is sufficient to produce dangerous voltage, even when the sun isn't shining directly on the PV modules. Although moonlight may not generate lethal voltages, a shock hazard may still exist [690.18 Note]. Figure 690–37

(C) Maximum PV System Voltage. For one- and two-family dwellings, the maximum PV system voltage is limited to 600V, which is the standard voltage of electrical building wiring. Figure 690–38

(D) Accessible. In one- and two-family dwellings, live parts over 150V to ground must only be accessible to qualified persons. Figure 690–39



Figure 690–38

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

 One conductor of each circuit of a bipolar subarray is solidly grounded.

Exception: The operation of ground-fault or arc-fault devices (abnormal operation) shall be permitted to interrupt this connection to ground when the entire bipolar array becomes two distinct arrays isolated from each other and the utilization equipment.

(2) Each circuit is connected to a separate subarray.